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REMOTE SENSING AND GIS FOR CADASTRAL SURVEYING

Manual

2016

Vilnius

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REMOTE SENSING AND GIS FOR CADASTRAL SURVEYING

Manual

Can be used as a teaching material for ***Erasmus program students*** *and for the Vilnius University courses* ***Remoute sensing and Aeromethods.***

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PREFACE

Spatial information is included in many information systems, including the Information System of Geodesy, Cartography and Cadastre.

Cadastral systems usually include a database containing spatially referenced land data, a set of procedures and techniques for systematic collection, updating, processing and distribution of data and a uniform spatial uniform system.

Cadastral data are defined as the geographic extent of the past, current, and future rights and interests in real property including the spatial information necessary to describe that geographic extent. Rights and interests are the benefits or enjoyment in real property that can be conveyed, transferred, or otherwise allocated to another for economic remuneration. Rights and interests are recorded in land record documents. The spatial information necessary to describe rights and interests includes surveys and legal description frameworks such as the Public Land Survey System, as well as parcel-by-parcel surveys and descriptions

This manual is divided into two parts. Both parts are about procedures and techniques for spatial cadastral data collection.

The first part includes a more detailed overview of cadastral plans from a surveying point of view. Also the direct techniques (field surveying and GNSS) and COGO methods are discussed as well.

The second part of the manual is dedicated to the indirect techniques or use of Remote Sensing and LIDAR for cadastral survey.

Each part of the manual ends with the lab assignments for the students. Following the lab assignment 1, students are introduced with the process of measurements of cadastral land plot by using professional GPS and tacheometer instruments, as well as to demonstrate how ArcGIS software can be used to process field survey measurements and draw a cadastral plan. The aime of the lab assignment 2 is to introduce students with the use remote sensing data to compile and update parcel cadastral plans. The scenario of this assignment includes updating procedures of a land parcel by using an aerial digital orthophoto image (or orthoimage) and LiDAR data without fieldwork. Also, natural and infrastructure objects related to the cadastral data will be derived from orthophoto image and LiDAR data. These tasks will be completed in ArcGIS software.

Each lab assignment consists of an introduction, a theoretical justification for the task, task methodological guidance, initial data sets and self-control issues.

The manual is dedicated for Erasmus program students, as well as for the courses related with remote sensing, cadastral survey, GIS methods in field survey and so on.

Authors are very thankful to Andrei Zubanov, who prepared the initial data for lab assignments.

CHAPTER I

1. SPATIAL DATA SOURCES FOR CADASTER: FIELD SURVEY AND GPS

1.1. CADASTRAL MAPS AND CADASTRAL PLANS

A land information system usually includes a database containing spatially referenced cadastral data (objects), and additionally it consists of a set of procedures and techniques for systematic collection, updating, processing and distribution of cadastral data. This manual is about procedures and techniques for spatial cadastral data collection.

1.1.1. Cadastral Plan

This chapter includes a more detailed overview of cadastral plans from a surveying point of view. The cadastral plan (or survey plan) is the foundation block of a cadaster. A registered/licensed surveyor who accurately measures and records the boundaries of each land property and/or cadastral objects should produce it. This occurs whenever a new land parcel is created and each new survey produces a new survey plan. Because of this, each plan is static in time, i.e. it represents the shape and status of the cadaster at the time of survey. However, an existing parcel can be resurveyed and its old survey plan can be updated.

Cadastral plans from different parts of the world will contain different information - this is dependent on local legislation rules/specifications relating to the registering of cadastral plans into the local cadaster system. A properly registered cadastral plan usually is a legal document, which can be used, for example, for the sale of real estate property.

A cadastral plan represents visually or digitally the legal boundaries and dimensions of a surveyed parcel of land and related cadastral objects (e.g., roads, easements etc.), and identifies the type and location of monuments or survey posts (control points) set in the ground to define the boundaries of the parcel (Figure 1).

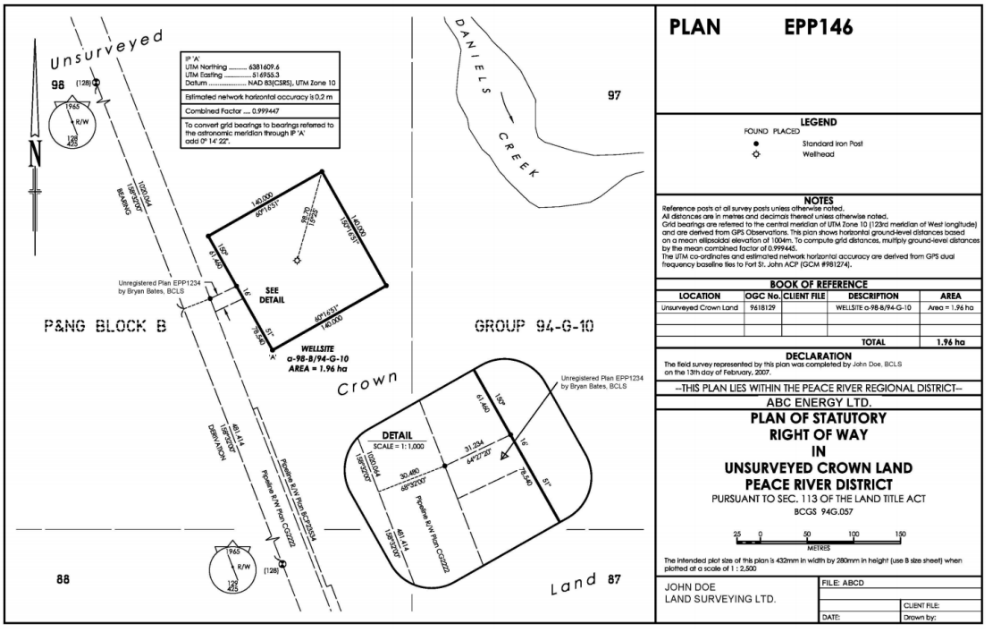


Figure 1: An example of cadastral plan from http://www.ltsa.ca/docs/Example-Plan.pdf

Land records are composed of survey documents (plans) and associated registry records (the rights and interests in land).

When surveying new parcels of land or resurveying existing parcels of land, surveyors must be aware of the legal ownership rights on the land, ownership disputes or conflicts, and historic surveys. Cadastral parcels should be maintained together with both their survey source information (plans) and corresponding registry information (rights).

There are many types of cadastral plans:

- Survey plans or plats (Figure 2);
- Subdivision plans (Figure 3);
- Reference or explanatory plans defining roads, or accompanying right of way, easement, covenant, or lease charges;
- Strata plans;
- Reference plans accompanying municipal bylaws that cancel a highway;
- Posting plans that depict the placement or replacement of the corners of a parcel;
- Air space plans etc.

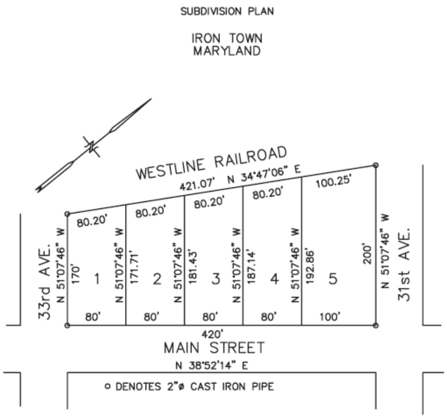


Figure 2: Re-surveyed plat with bearings and distances, the legal description "lot 2 of section 11, T3N, R5W, 6th P.M.Walnut County, Nebraska", descriptions of surveyor etc. (page 186)

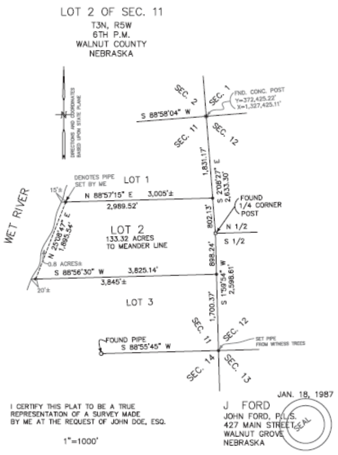


Figure 3: Subdivision plan with bearings and distances (page 230)

In a traditional cadastre, records of rights were supported by paper parcel plans and the traditional term for paper cadaster drawing is a plat. A plat is a report of a survey in the form of a drawing. States, provinces and professional surveying organizations have developed, either through their state board of registration or through their professional societies, a minimum standard or guidelines for preparation of survey plans. Such standards can list elements, which should be shown on plats, and how plats should be designed. One of such examples is the "National Standards for the Survey of Canada Lands" (Canada Lands Survey System, 2015).

One of the examples of successful projects in the establishment of state cadastral survey system is the Swiss Cadastral Reform Project at the beginning of the 1990s (Figure 4). An important feature of this reform was the introduction of free choice of methods for the cadastral survey. In order to guarantee the exchange of geographical data despite the resulting wide variety of hardware and software used, the official cadastral survey interface (AVS) was defined and introduced as a neutral and independent system.

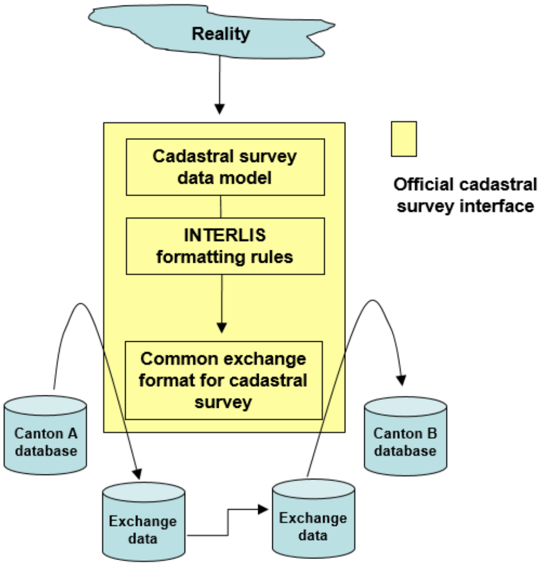


Figure 4: Components of the official cadastral survey interface

AVS is prescribed in the Technical Ordinance on Official Cadastral Surveying and consists of the cadastral survey data model which lays down the structure of the data and the corresponding transfer format constituted by the architecture of the file containing the geographical data to be transferred.

It is also legally specified that the IT systems used within the official cadastral survey must both guarantee the import and export of data to and from the cadastral survey and conform to the description of the data model in the INTERLIS data description language. The official cadastral survey interface was the first application of INTERLIS, which has today become a recognized standard for modelling, integration and exchange cadastral data in the world of geographical information.

The Swiss cadastral surveying data is available in both forms of paper maps and digital datasets and is structured into eleven thematic feature classes/layers (Figure 5), which can be combined among themselves or with other related spatial data such as noise maps, zoning plans etc.

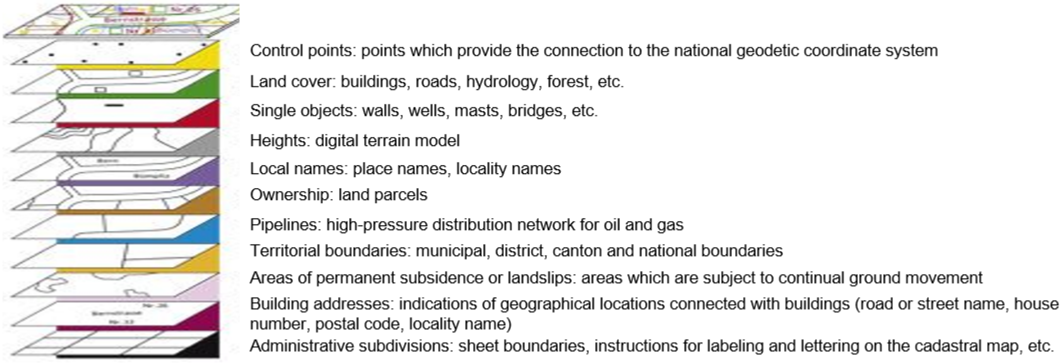


Figure 5: Eleven thematic feature classes of the Swiss cadastral surveying data

The Swiss digital cadastral data can be linked and combined with other related spatial data such as noise and zoning plans spatial data. INTERLIS facilitates the exchange of data between different LIS/GIS.

1.1.2. How is Cadastral Map Different to a Cadastral Plan?

Cadastral maps are produced by joining together individual cadastral plans. A cadastral map also may show the boundaries and ownership of land parcels within administrative units. Some cadastral maps show additional details such as unique identifying numbers for parcels, positions of existing buildings or adjacent street names.

Cadastral mapping is one of the best-known forms of mapping, because it is the mapping that shows all of the land parcels in relation to one another and to the adjoining roads (Figure 6). It is also one of the most ancient forms of mapping – for example ancient Egyptians are known to have developed cadastral records so that land ownership could be re-established after the annual flooding of the Nile River.

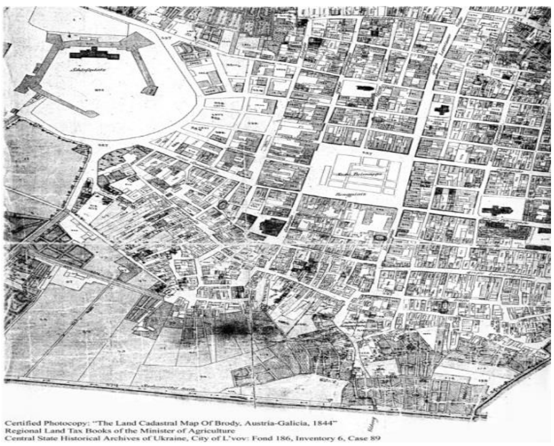


Figure 6. Brody Cadastral Map, 1844

A cadastral map is a general land-administrative tool, which has no real legislative basis (as a cadastral plan does). It is often created on demand and therefore is not necessarily up-to-date. These maps are used by a broad range of people (public and professional) for all manner of things including real estate sales, valuation, planning etc.

1.1.3. Digital Cadaster Database and Survey Data

A digital cadastral geodatabase is a repository where is stored information acquired from the survey process in a form that allows an analysis of the relationship/topology among spatial cadastral objects. A geodatabase may comprise of many feature classes and standalone attribute tables, representing different objects and attributes of land and property boundaries.

There are concerns of survey data entry into a geodatabase. Thus, the database structures should be such that only “valid and clean” data can be entered and stored in the geodatabase. That involves procedures of conversion, cleaning and validation of spatial/attributive data acquired by surveying. For example, parcel boundaries should be closed, without undershoots or overshoots. Correcting data on input is an expensive process.

There are also developed some cadastral geodatabase models (for example ISO-TC211 2012: Land Administration Domain Model (LADM), ESRI Parcel Fabric Model, ILMB Cadastral Fabric Specification and Standard, etc.), which provides schemas in which a progressive creation and improvement of a geodatabase can be done. These schemas can be used in the early stages of a survey to structure the surveying data.

1.2. SPATIAL DATA SOURCES FOR CADASTRE AND SURVEYING TECHNIQUES

Land Information Systems may comprise of spatial and non-spatial/attributive data (survey plans and registry records). Both these spatial data (such as parcel boundary and other cadastral objects) and non-spatial data (such as records of rights, responsibilities or/and restrictions in land and/or attachments to the land) are stored, maintained, and accessed in the database environment. Spatial cadastral data is acquired through cadastral surveying methods which are concerned with geometrical data of each land parcel. The results of cadastral surveys are isolated plans of a parcel or a subdivision. Cadastral mapping goes a step further and produces complete maps, which are based on cadastral surveys.

The cadastral surveying system gives preference to the survey records of parcel boundary positions over physical locations of landmarks on the ground. These records provide information with the coordinates of the landmarks and site plans within a particular national geodetic coordinate reference system in a country. In case of lost or disputed boundary of a land parcel, it is this record or register that takes the precedence over marks on the ground.

Spatial cadastral data can be obtained by several surveying methods. These methods can be divided into the sets of direct and indirect techniques.

In case of direct techniques, the relative or absolute positions of control points (survey marks) is located first on the ground, and then the distance and angles or coordinates of turning points of parcels/plots are measured using surveying instruments. If the distance and angles are measured, then coordinates of turning point’s locations for each land parcel are re-computed from distance-angles measurements using Coordinate Geometry (**COGO**) methods.

On the other hand, in case of indirect techniques, the surveyors use aerial photographs, digital aerial images, satellite images or/and LiDAR point clouds to delineate parcel/plot boundaries and the polygons then are digitized in a second step.

In this module, the direct techniques (field surveying and Global Navigation Satellite System - GNSS) and COGO methods are discussed. It is not a main goal of this course to teach ground surveying techniques in detail, this course is more concerned with how to enter and use survey measurements in GIS/LIS with COGO and other GIS tools.

Usually, country or regional survey standards (guidelines or instructions) define survey methods used for preparation of survey plans. Thus, for example, General Survey Instruction Rules for British Columbia (General Survey Instruction Rules, 2015) defines that

- Cadastral surveys may be conducted using conventional, GNSS, or other methods, providing the survey accuracy standards are met.
- For new surveys consisting of the land surveyor’s own work, the maximum limit of error is 1:5000 ± 2 cm.
- The datum for UTM coordinates must be NAD83 (CSRS).
- A surveyor has a choice what techniques to use: it is the responsibility of the land surveyor to assess which survey method or combination of survey methods must be used for a particular survey.
- However, direct traversing techniques of land boundary lines, which discussed below, should be the preferred method that is placing monuments and determining the length and direction of boundaries is by direct measurement along boundaries.
- The position of natural boundaries may be determined by any survey method that yields an accuracy of 0.5 metres or better. Such methods

also can include indirect photogrammetric methods, e.g., aircraft and satellite images.

Assignment 2 is dedicated to the indirect techniques or use of Remote Sensing and LIDAR for cadastral survey.

1.2.1. Land Boundary Lines

Real property boundaries exist independently of measurements. Boundary lines (also commonly called property lines) define the extent of the legal limits of ownership of any parcel of land.

In initial stages of cadastre's development, land parcels, especially smaller, individual holdings were described according to its relative position to well-known landmarks and by identifying the adjoining landowners, although the large land settlement companies usually claimed land based on latitudinal boundaries. The primary means of distinguishing one parcel from another was the "bounds" system. In many cases of areas of long settlement, the construction of fences, hedgerows, or other obvious physical signs of the parcel limits made the task of marking the boundaries less difficult. This "bounds" system did not require that the size of the parcel be determined in order to define it.

The new cadastre uses the concept of "metes". The parcels' boundaries are defined by the location of corners. The corners or limits of the land parcels were physical marks on the ground. In the past, often, a landowner would simply place set boundary stones to mark a land. Parcel's boundaries ("metes") are defined by measuring the location of the real property corners/marks, along with the plotting of natural landmarks, artificial monuments, and adjacent owners. In real property boundaries, it is the physical location of the corners that is important.

Modern monumentation requirements of corners of parcel's boundaries (technical specifications, marking, planting, re-establishment and restoration of posts) are defined in specifications established by states, provincial and/or professional surveying organizations. Such requirements for example may include (National Standards for the Survey of Canada Lands, 2014):

- Place monuments on all artificial boundaries being surveyed:
    - at each change of direction of straight line boundaries;
    - at intervals not exceeding one kilometre for straight line boundaries;
    - at points of intersection with previously monumented boundaries; and

   - at the beginning and end of curves, at points of changes of curvature, and at points where straight line boundaries intersect curves etc.

- The main purpose of line cutting, blazing, and placement of line markers is to make boundaries identifiable on the ground. Well cut-out boundary lines and markers on boundary lines minimize the risk of boundary encroachments and disputes, support enforcement initiatives …

This record of the distances (metes) and physical limits (bounds) of a land parcel constitutes a "metes and bounds" description. "Metes and bounds" descriptions are used to describe the perimeter of property. Beginning at a point located using the rectangular survey system, "metes and bounds" descriptions are read forwards, traversing from point to point until the entire property has been circumscribed, returning at the point of beginning. In metes and bounds descriptions "commencing," "beginning at," and "point of beginning" are all terms used to describe the starting point for the metes and bounds description.

The "metes and bounds" description is often used to supplement land record system descriptions. Metes and bounds descriptions are, of necessity, redundant. The spatial component of modern cadastre may not include "bounds" description, but includes "meters" description of parcel's boundaries.

Traditionally, surveyors recorded parcel boundaries by the use of bearings and distance dimensions between corners or turning points (Figure 7). With the advent of high-accuracy GNSS technology, it has become significantly easier to measure absolute GNSS coordinates to define the location of parcel's corners. Accurate coordinates give the closest estimate of the true location of a corner on the ground and also have error information indicating the reliability of the coordinates. In a coordinate-based cadaster, parcel boundaries are defined by coordinates at each parcel corner in addition to, or instead of, bearings and distances.

Parcel boundaries have typically, followed a three-part process of coming into being – they are defined by the party who has legal rights in the land; they are demarcated/marked on the ground by a surveyor in the corners (posts, bars, pins, pits, mounds); they are delineated on plans and maps. The use of coordinates is predicated on deleting demarcation from the process – the boundary is defined and then delineated. To be clear: defining boundaries using only coordinates means that monuments (markers, control points) are not placed in the ground to mark the boundaries. Some countries, such as Canada and Australia, permit a surveyor to not plant monuments to mark corners of parcels in subdivisions if some conditions are met.

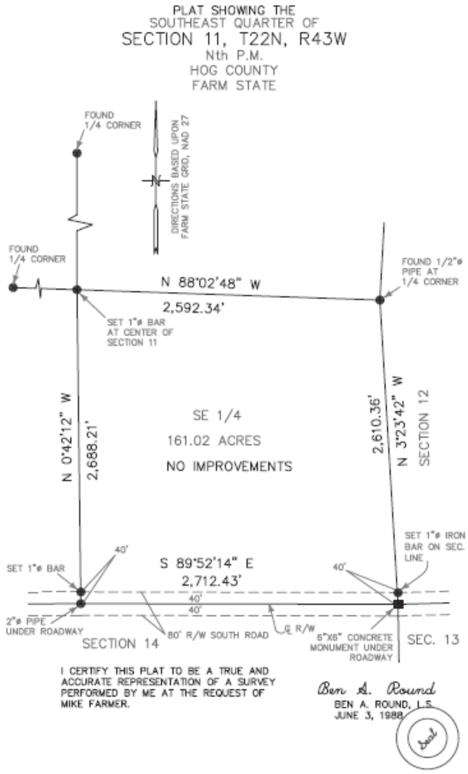


Figure 7: Plat that shows monuments, bearings and distances

Traditional survey methods used for relocating property boundary corners may be interpreted in different ways. When different surveyors use different data to re-establish the location of a boundary, boundary location disputes can arise. A coordinate provides a unique and unambiguous record of a corner and can be quickly and accurately relocated with the use of GPS. To gain maximum benefit from the use of coordinates, a system needs to be in place within the cadaster that provides a measure of the reliability and accuracy of coordinates in a parcel boundary fabric. The more accurate and reliable the coordinate, the higher its weight and influence would be in determining the location of the boundary in the parcel fabric.

Boundary lines are, more often than not, subject to acts of possession or acquiescence. Fences, hedges, tree lines, or other physical obstructions frequently occupy the full length of a real property boundary. These objects, while clearly indicating the general location of the boundary, make the direct measurement of the distance between corners quite difficult. Thus, the majority of boundary dimensions are the result of indirect measurement. As parcel dimensions are almost always the result of computations based on several measurements of angles and distances. The actual distance measured was still between offset points. The relationship of the offset points to the corner monumentation was now more accurately known because of the use of the modern surveying instruments to measure the angle and distance to the actual corner.

The land surveyor must be knowledgeable not only in technical aspects of property boundaries surveying discussed above, but also in legal aspects of cadastre. Thus considerable experience is required to make decisions on the "best evidence" of a boundary location. A cadastral surveyor is usually required to be licenced to cadastral practice by a state, province or professional association. The land surveyor should be aware about legal issues that can affect property conveyance process.

When any piece of land changes ownership it cannot be by word of mouth, but must be done by a written document called a <u>deed</u>. The deed includes a legal description of the property for which some type of survey is usually required. The purchaser normally wants to have a plan of the land(s) described in the offer to purchase. It is also important to see where structures included in the offer are located on the land. Spatial knowledge of any rights-of-way, easements, highway widenings, and the like are essential. Such title <u>encumbrances</u> are important as the owner's rights on the lands are usually severely curtailed. For example, erection of any structure such as even a small construction may be not allowed even though the land is still owned by the owner of the lands adjacent to the encumbrance.

The legal principles of establishing properly boundaries are usually defined by country or province legal documents. These are based on set definitions of legal terms, deed descriptions or title descriptions, riparian rights (for lands bordering on water bodies), adverse possession etc.

Deed descriptions include the directions and distances of all lines along the property boundaries of the parcel of land. The types of corners monumentation and the area of the parcel may or may not be included. The deed description is usually in written form, rather than a survey plan.

Surveys for title records involve the detailed boundaries surveys as well as detailed positioning of the existing buildings on a parcel of land in relation to the boundaries.

Riparian rights refer to those rights of a property owner of land that borders on a water body. The rights include the use of the shore and ownership of land under the water surface and therefore use of the water. The definition of riparian rights and specifications of shoreline boundary’s survey vary somewhat from one country/province to another.

In addition, the survey techniques and their specifications for carrying out rural land surveys and urban land surveys can be different in different countries/provinces (Kavanagh & Mastin, 2012).

Rural land is considered to be land outside the boundaries of cities, towns, villages, and the like. It usually consists of relatively large areas. Rural lands are as not as valuable as urban lands on a per unit basis. Therefore, the property surveys can be done with less accuracy. Control survey networks are not as dense as in urban areas. Most lands were usually classified as agricultural and homestead landuse types. The scale of such survey is 1:1,000 at best.

Spatial descriptions of rural land can be done in several forms, such as written descriptions, “metes and bounds”, and coordinates. Two general types of boundary surveys are carried out in rural lands. One is the original survey whereby new property lines are created. The other is a re-survey, which results in relocating property lines that have been previously surveyed. The principles for both types are similar in that both have to be located with respect to the control point’s survey. However, the procedures (monumentation, survey techniques, accuracy, adjustments etc.) can be somewhat different. Rural land can be subdivided for the purpose of creation of large lots. Certain principles are involved in surveying the irregular boundaries of subdivisions in rural lands, and the surveyor should be aware about these principles.

Urban land surveys differ from rural land surveys. The lands are located within or adjacent to the city or town boundary. The lot sizes are smaller than rural land, but the land value is greater than rural lands. Therefore, the surveys must be carried out with greater accuracy. Re-surveys are simpler and easier than in rural lands because monumentation is more recent and more permanent but the conflict between adjacent property owners can be more intensive because of the higher cost of the land involved.

The boundaries of a land parcel can be described within or adjacent to city or town boundaries in relation to registered plans, blocks, or lots. The original township subdivision boundaries have usually been well established. Consequently, deed descriptions of urban lands usually relate to street locations and lots within a registered plan of subdivision. Land boundaries can coincide and be described with lots on the plan of the subdivision (e.g., "Lot 6, Registered Plan No. 696, Guelph Township, County of Wellington, Province of Ontario"). Or the properties can be described by “metes and\bounds” with the point of commencement referred to a lot or block corner shown on the plan. Either way, boundaries can be related to coordinated monuments/control points.

Original urban boundary surveys fall into two categories. The first is the establishment of the boundary of the area proposed for subdivision. The second is the establishment of the new lot lines by the town or urban planner. Re-surveying of urban lands are seldom done. Re-surveying a urban subdivision is a considerable challenge, requiring perseverance and understanding.

Boundaries and property rights are linked in a cadastral system. Such systems answer the following questions (Canada Lands Survey System, 2015):

1) Who has the right (person, family, corporation, state etc.)?
2) What type of right exists (ownership, lease, licenses, mortgage, easement etc.)?
3) How much is the right worth? What is its value (either monetary or cultural)?
4) Where is the right? This is the role of parcel's boundaries.
5) What is the type of land use? What restrictions are applied? These things require parcel's boundaries to be effectively managed.

1.3. LAND FIELD SURVEYING

Cadastral or land surveying is a general term applied to a number of different types of surveys. Cadastral surveying deals with the establishment of parcel's boundaries of public and private real properties for legal purposes, land ownership, value assessments etc. It also includes the re-establishment of existing parcel's boundaries, measurement of boundaries of new parcels, subdivision of parcels, establishment of positions of cadastral objects (e.g., buildings, drainage features) on ore adjusted to the parcels etc. The legal boundaries of a parcel of land can be rural, urban, or city.

Land field surveying is one of the techniques to obtain initial spatial information according to which cadastral plans are formed. Ground teams of surveyors using surveying methods and instruments undertake field surveys. The primary function of surveying instruments in the field survey is to measure distances, angles, heights and/or coordinates. Field survey method, depending on instruments used, can be extremely accurate, but it involves a lot of time and resources, including a large number of well-trained land field surveyors with assistants for a countrywide implementation.

Conventional techniques for field surveying of distances, angles and heights include the use of plane tabling, sight rule, optical square, levels, the toise, chain or steel measuring tapes. The steel measuring tape, still called a "chain," was state of the art for measuring distances in land boundary surveys almost until the 1970s.

Unlike distances, the measurement of angles developed to a high precision very early in history. In early days, land surveys were carried out using simple instruments that essentially consisted of an aiming sight on top of a plate that had angle readings engraved on it. The surveyor could measure the angle between two sighted points, aided by a survey assistant holding a vertical pole on the point. With the help of compasses, the magnetic bearings of the survey lines are measured. Thus, in chain and compass traversing, the magnetic bearings of the survey lines are measured by a compass and the lengths of the lines are measured either with a chain or with a tape.

The logical development was to have plates with horizontal angle readings enclosed in a metal body, whereby a vertical plate was added in order to also be able to measure the vertical angle, and an optical sight was quickly adopted in favour of the sight lines. The main survey tool was born: the theodolite.

Traditionally, one of the most often used methods for cadaster survey of land plot/parcels boundaries is tachometry or tacheometry (from Greek for "quick or swift measure"). Tacheometry is an optical solution to the measurement of distances and angles. A typical application of tachometry is the measurement of topographic and cadastral objects.

Tachometry is a method(s) of surveying for the determination of distance, direction, and relative elevation of a point with respect to the survey station (a position from which measurements in surveying are made), by a single observation on a rod/staff/prism or other object at the point. The tachometry computation uses a single survey station at a control point with known coordinates.

There are several tacheometry techniques that surveyors can use. These techniques includes traversing, triangulation, trilateration, cross-resections etc. Some of these techniques will be discussed in the next COGO section and associated lab assignment 1.

There are a several methods of tacheometry. The two groups will be covered in these notes.

1. Stadia System:

Traditionally a tachymeter or tacheometer was a type of theodolite. A theodolite was introduced by 1920s into everyday survey work. Theodolite (Figure 8) is a precision instrument that consists of a movable telescope for sighting distant target objects, two measurement wheels that work like protractors for reading horizontal and vertical angles, and bubble levels to ensure that the angles are true. In modern theodolites, some mechanical parts are replaced with electronics.

Figure 8: An optical theodolite, manufactured in the Soviet Union in 1958 and used for topographic surveying

Tacheometric surveys are usually performed to measure the three dimensional location of points on the landscape so as to produce detail land plans including contours, or to collect COGO measurements for a cadastral plan. Observations are usually performed from known survey stations, often established by traversing will be discussed in the next chapter.

When the telescope is pointed at a target object, the angle of horizontal and vertical axes can be measured with great precision - to seconds of an arc.

Instead of observing independent bearings for every line of a boundary, a land surveyor can measure the angles formed at the boundary corners with a theodolite. The angle between two “horizontal” directions can be reported as the angle of a property boundary intersection. Real property boundary angles in corners are measured in the horizontal plane. When surveyors measure angles, the resultant calculations are typically reported as either azimuths or bearings (discussed in the next chapter).

Vertical angles are measurements between geometric lines in a vertical plane. Because real property boundaries are in horizontal plane, vertical angles rarely find their way into property descriptions. Vertical angles are commonly measured in order to compute horizontal and vertical distances.

The land surveyor can measure distances with theodolite combined with a levelling staff to produce a cadastral plan (Figure 9). A levelling staff, also called rod, is a graduated wooden or aluminum rod, used in connection with a surveying instrument for measuring. The theodolite is directed at the levelling staff, held by an assistant surveyor, and the horizontal or vertical distance is calculated based on readings of the top and bottom stadia hairs on the telescope view. A land surveyor makes cross hair intercept readings on a levelling staff manually. As the angle subtended by the crosshairs is known, the distance can be calculated.

Figure 9: Surveyor is taking readings on stuff

For example, vertical and horizontal distances can be calculate by using the following equations with measurements from a fixed hair theodolite (tachometer) in case of when light of sight is inclined but staff is held vertically:

$V = \left(\frac{f}{i}\right) * S * \sin^2(\theta)/2 + (f + c) * \sin(\theta)$ and $D = \left(\frac{f}{i}\right) * S * \sin^2\theta + (f + c) * \cos(\theta)$,

where V and D are the vertical and horizontal distances respectively; S is the staff intercept that is obtained by subtracting the reading given on the staff by the lower stadia hair from the top stadia hair; θ is the angle between horizontal line of sight and middle cross hair; f is the focal length of object lens; c is length of image that is the constant distance between a lens focal point and center of instrument; i – stadia interval that is the distance apart of the stadia lines; values of f, i and c are fixed, known and constant for a particular instrument (Figure 10).

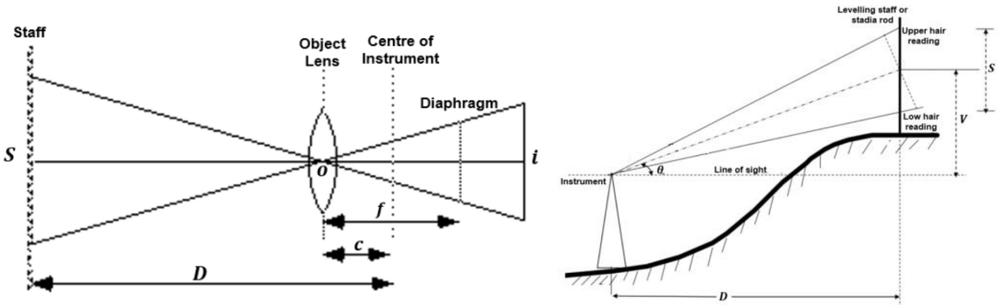


Figure 10: Principles of calculations of a vertical and horizontal distances by using a fixed hair theodolite (tachometer) in case when light of sight is inclined but a staff is held vertically

Conventionally, COGO measurements are recorded in the field-booking sheet/notebooks. Thus, for example, the cross hair intercept readings, horizontal and vertical angles can be observed by theodolite and recorded and later can be used to recalculate horizontal distances and elevation heights by using the formulas. The horizontal distances, heights and bearings parameters are necessary to compute the coordinates of the point on which the staff was placed. Bearings are computed from the horizontal circle reading of theodolite and a known or adopted reference bearing.

Theodolite tacheometry is a quick way of collecting a large amount of information with limited accuracy. Current practice is to replace the staff with an Electronic Distance Measuring (EDM) device for distance measurement, but if you do not have EDM this is a good method for a field object's survey.

2. Electronic Tacheometry:

The stadia procedure is used fewer these days, from the mid-1970s to today more commonly land surveys and geomatics' engineers use a combination theodolite-EDMs (Electronic Distance Measuring devices) known in jargon as a total station (TPS - total station theodolite). A theodolite-EDM is able to measure distance, direction, and relative elevation by reflecting off a reflector's prism on a metal staff, which is moved around the site and placed at the points.

The theodolite part of the total station has a lens rather like a telescopic rifle-sight with cross-hairs which are focused on the prism. The whole instrument swivels horizontally and the lens swivels vertically too. The total station is partly based on a principle used in traditional theodolites, where angles are calculated from vertical and horizontal 360-degree scales. It combines these with an EDM device. This sends out a tiny light signal (often a modulated near-infrared light), which bounces back from the prism giving a time interval that is used to calculate distance. The math behind the operation is very simple, it is in effect the same as the stadia formulas with the term for the distance replaced by the measured slope distance (Figure 11). In this case,

$V = L * sin(\theta)$ and $D = L * cos(\theta)$,

where V and D are the vertical and horizontal distances respectively; L is the measured slope distance measured by EDM, and θ is the angle between horizontal line of sight and prism.

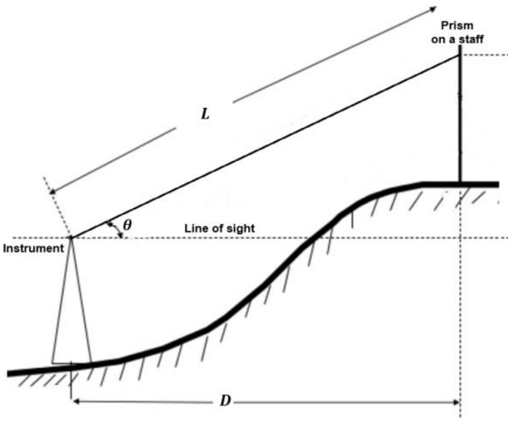


Figure 11: Principles of calculations of a horizontal distances by using a theodolite-EDM in case when light of sight is inclined but a prism is held vertically

EDM instruments include or are connected to a field computer, which stores readings of measurements and facilitates the processing of the data electronically. The computer records the slope and horizontal distances, horizontal and vertical angles from the survey EDM station to the point, and can perform numerous calculations, including absolute coordinates of the point, using operating software that is loaded into the field computer (Figure 12). Coordinates are normally sent directly to a data-logger mounted on the tripod, which can then be downloaded into a computer to produce a plot.

The field computer software is usually includes a number of menus such as Function menu; Survey menu, COGO menu, Road menu, Level menu etc. Some functions of these menus are shown in this chapter lab assignment 1.

Figure 12. Total station (electronic theodolite-EDM and field computer on tripod), prism and prism pole) and electronic measurements of distance and vertical and horizontal angels

Some total stations can work in reflectorless mode. If the visibility in the surveying area is good, the coordinates of a cadastral object can be done with a laser beam without using a reflector with prism. The laser of the tacheometer can be pointed at a parcel object (e.g., poles), parcel terminal points (e.g. fences), and their coordinates can be fixed. Measurements by the laser speed up the work and make it easier, because an assistant to the surveyor does not have to walk and move a reflector. In addition, the measurement with a laser is very convenient when measurements are made in hard to reach or dangerous locations. However, reflectorless survey can be less accurate.

There exists on the market also advanced total station machines. Thus, robotic TPS or self-tracking total stations can be remotely controlled from the prism and programmed to follow the prism automatically, making surveying a one-person job - an assistant surveyor, who holds the reflector, can be eliminated.

Digital photographic imaging TPS contains an integrated metric digital camera that allows a surveyor to take digital photos to each measured point. While photographing, the camera can rotate with the telescope of the total station to take scanning photos whose corresponding orientations are observed from total station. With software, a surveyor can create 3D point clouds and stereoscopic images of surveying site.

Grid scanning TPS can move by itself and does not need a reflector target to measure points by specifying a view window area and setting the horizontal and vertical intervals of the points to be measured/scanned. Rather than surveying each individual point, the surveyor only needs to decide the optimum point interval (grid interval) in order to represent the object with sufficient accuracy. There is, however, still a big gap between grid scanning in total stations and laser scanners.

Integrated GPS TPS combines TPS and GPS. Such a high performance total station with powerful GNSS receiver has no need for control points, long traverses or resections. The GNSS determine the position of instrument station. However, GNSS measurements may require longer occupation periods to do measurements.

Advantages of total station surveying that is the EDM instrumentation has facilitated the development of tacheometry method of cadastral, topographic and contour surveying into a very quick operation. It is now possible to produce plans of large areas that previously would have taken weeks, in a matter of days. In addition, use of EDMs has greatly increased the accuracy of the distance measurements. Total stations are able to measure distances to an accuracy of 2-3 millimeters per kilometer, and angles to 1-

second (1°/3,600°) accuracy. One second in an angle is equivalent to the width of pencil lead at 100 meters.

1.4. COORDINATE GEOMETRY

Coordinate Geometry (COGO) is a method of inputting surveying or engineering data/measurements into GIS, CAD or mapping software. This aspect of cadastral data processing is one of the main interests of working with cadastral data in GIS.

COGO data may be collected in the field using conventional surveying techniques and instrumentation, or may be derived from existing legal survey plans/maps, plats, engineering plans, drawings or records.

Data collected in the field consist typically of coordinates of points, distances and angels (e.g., bearings) between points, and point identifiers (with possibly additional attributes for these points). The data are observed and recorded through standard field surveying procedures, such as a traverse, resections etc. The data may be non-digital (recorded in field notebooks), or digital (recorded on some sort of total station or data logging device). In the latter case the digital data will be transferred to office computers through specialized software. However, non-digital recordings should be manually added to spreadsheets or directly into COGO software in office computers.

The fundamental type of coordinate transformation that COGO software does for the surveyors or topographers is the conversion of surveying measurements (distances, bearings and/or angles) into XY coordinated shapes (points, lines, arcs or polygons features). COGO software, installed in field mobile device and/or office computers, use trigonometry with emphasis on triangle solutions to compute the two or three dimensional coordinates of points based on bearings, angels and distances.

Thus, for example, using COGO, coordinates of parcel's corners are calculated using surveyed bearings, distances, and/or angles from known reference points. The parcel corners and points of deflection defined by these coordinates can then be used to plot the boundaries of the parcel that in turn can be used to define the parcel polygon for incorporation into the cadastral fabric.

Some cadastral state, regional or local authorities provides guidelines on how to work and incorporate COGO inputs into the legal integrated cadastral fabric. For example, COGO output files (e.g., raw and adjusted traverses) must be retained and submitted as project deliverables. When computing parcel corner coordinates to delineate missing or suspect parcels, the incorporation into the fabric should always start with the newest survey plan information in an area, etc.

Ideally, the legal cadastral fabric, which incorporate many spatial datasets, should contain only the parcel geometry was originally created through COGO computational techniques.

1.4.1. COGO Computations Techniques

There exist many COGO computational techniques and associated software tools such as the following:

- Delta X,Y – construction of point or/and line that is based on a change (delta) in x and a change in y from an existing construction point;
- Bearing(Angle)/Distance – construction of point or/and line that is based on a bearing/angle and distance from an existing construction point;
- Curve or Tangent Curve – construction of curve that is based on two of the following parameters: chord distance, angle, arc length, radius; or a radius and arc length, or from an existing construction point;
- Distance-Distance intersection – construction of point at the intersection of two distances from two existing construction points;
- Bearing-Bearing intersection – construction of point at the intersection of two bearings from two existing construction points;
- Parallel, Perpendicular, and Deflection - construction of line by adding a parallel line to an existing line, perpendicular line to an existing line, and deflection off line to an existing line;
- Traverse, that is a series of lines, can be constructed by using the above COGO techniques.
- Triangulation and trilateration etc.

The common COGO computation techniques are discus in more details below.

Delta XY

Coordinates for a new survey point can be computed based on a known differences in X and Y coordinates from a given start point (Figure 13). These coordinate differences are termed delta X, Y. The direction of the computed coordinates from the start point is defined by the sign of the delta values as shown below:

- Northeast: +X, +Y (as shown above)
- Northwest: -X, +Y
- Southeast: +X, -Y

- Southwest: -X, -Y

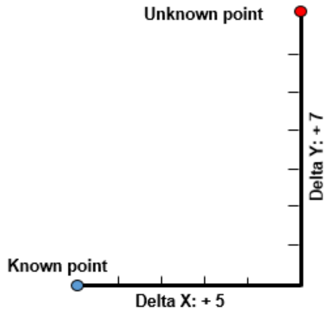


Figure 13: Delta XY computation

Direction-Distance

Coordinates for a new survey point can be computed from an existing coordinate using known distance and direction values Figure 14).

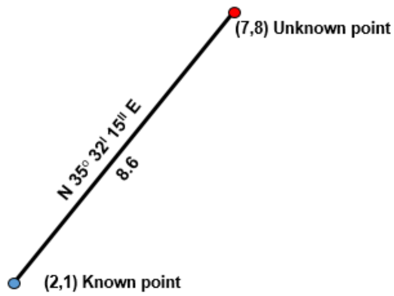


Figure 14: Direction-Distance computation

When surveyors measure angles, the resultant calculations of directions are typically reported as either azimuths or bearings, as seen in Figure 15.

An azimuth is an angle between 0° and 360° which is measured clockwise from the north in most cases. A back-azimuth is the reverse of an azimuth.

Bearings are measured clockwise or counter-clockwise within a quadrant by the cardinal directions from the meridian (directed to the north) and are always less than or equal to 90 degrees. A bearing is an angle from the North or South end of the meridian turned to the East or West. In case of bearings, the surveyor defines lines as being east or west of north (NE or NW), or east or west of south (SE or SW). This method is easily comprehended and widely favored by most users of real property information.

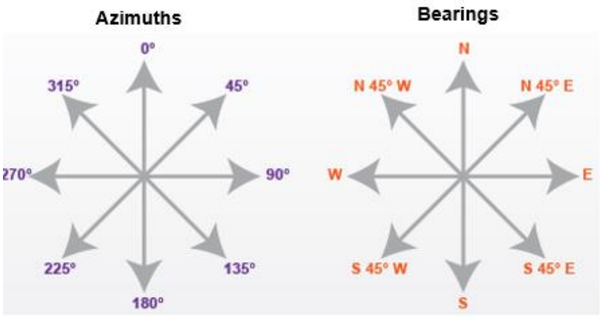


Figure 15: Azimuths and bearings. Note that an azimuth of 360° is the same as 0°.

A bearing notation has three parts:

- Prefix - N or S indicating which end of the meridian is turned from.
- Angle
- Suffix - E or W indicating turning direction from the meridian to the line.

For, example, a bearing notation is N 66°40' E means that from the North end of the meridian, turn 66°40' to the East.

"South 45° East" and "135°" are the same direction expressed as a bearing and as an azimuth.

The most common datum for boundary directions is “north.” However, there are a few definitions of the term “north”: true north, magnetic north, astronomic north, assumed north, geodetic north, north used in a map coordinate system etc. A surveyor may measure angles on the ground relative to a particular definition of north. However, during COGO computation, it is possible to apply corrections between “north” direction used in ground measurements and “north” direction of coordinate reference system used in cadastral fabric dataset. The direction offset is an angle that is added to ground directions to rotate them to used coordinate reference system directions or reverse.

In addition, a surveyor measures distances on the ground relative to the local ground elevation. However, distances in coordinate reference system of spatial data are measured on the ellipsoid. Therefore, the distance factor or a scale factor is used to multiply ground distances to convert them to ellipsoid distances or reverse.

Deflection-Angle-Distance

Coordinates for a new survey point can be computed by defining a deflection angle offset from a reference direction, and a distance from a known point. The deflection angle is an angle between a line and the prolongation of a preceding line; it is a right or left angle depending on whether the new line is right (clockwise) or left (counter-clockwise) of the preceding line (Figure 16).

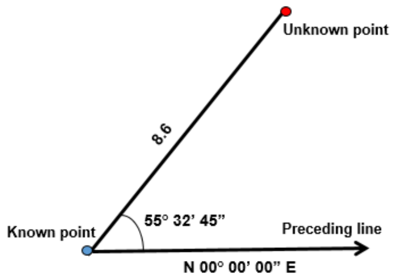


Figure 16: Deflection-Angle-Distance computation

The reference direction is either a bearing or an azimuth, based on a meridian of coordinate reference system.

Intersections and Resection

When the existing survey points are accessible, but the new point is not then the survey needs to employ an intersection technique, e.g., Distance-Distance or Bearing-Bearing intersection (Figure 17). When the existing survey points are not accessible, but the new point is, then the survey needs to employ a resection technique.

COGO intersection is used to create a new point(s) from the intersection of dimensions from two known points. For example, a bearing-bearing intersection creates a point at the intersection point of two bearings from two known points. It also can be a bearing-distance intersection where two possible intersection points are created from the intersection of a distance radiating outward from one known point and a bearing from a another known point. A new parcel point or construction point can be created from the intersection of two line distances from known points.

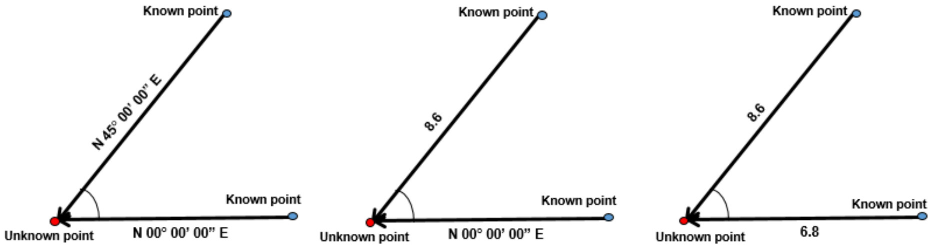


Figure 17: Intersection computations (Bearing-Bearing, Bearing-Distance and Distance-Distance)

GOGO resection is a calculation for the coordinates of an unknown or free station by observing the three established stations or known points from the unknown point. The two angles from the unknown point will be measured by accurate sightings to the three traverse stations in the field (Figure 18). All other angles and distances can be calculated trigonometrically based on the measured two angels and coordinates of known stations. Resection is considered as a technique of plain tabling survey.

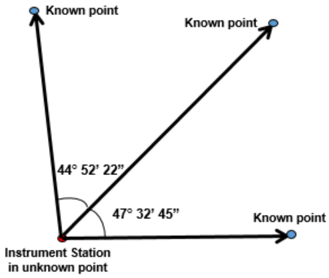


Figure 18 : Resection computation.

1.4.2. COGO Traverse

A traverse consists of a series of lines, whose lengths and directions are measured by surveyors in associated connecting points, called traverse stations (TS) or traverse points, whose X and Y coordinates are to be determined in some reference system of coordinates (Figure 19). A position of a traverse station is computed relatively the preceding TS of traverse and starting from a control point with known coordinates. The route of the traverse line can be adjusted for obstacles such as rough or timbered terrain, swampy land, buildings and areas of heavy traffic.

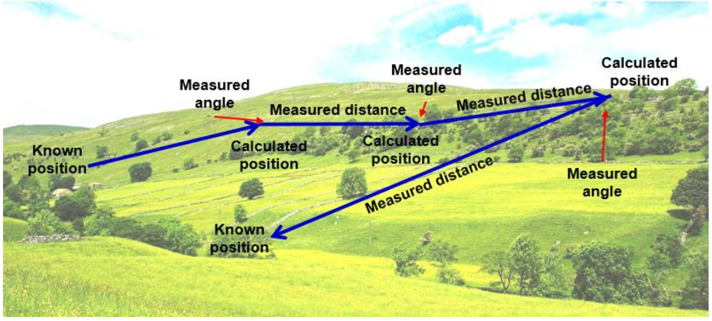


Figure 19. Traverse diagram

Measuring a series of positions in this way is known as "running a traverse." Starting at control points, surveyors measure angles and distances to new locations, and use trigonometry to calculate positions in a plane coordinate system. A traverse that begins and ends at different locations, in which at least one end point is initially unknown, is called an open traverse. A traverse that begins and ends at the same point, or at two different but known points, is called a closed traverse. By "closing" a route between one known location and another known location, the surveyor can determine errors in the traverse.

The angles between the traverse stations can be measured by transit, theodolite, compass, plane table, or sextant. These angles can be interior angles, deflection angles, or angles to the right. The azimuths or bearings can be true, magnetic, assumed, or coordinate reference system. The distances between the traverse stations can be measured by tape, theodolite or EDM. The lengths are horizontal distances. The lengths and azimuths or bearings of each line of the traverse are calculated through field measurements.

Traverse field work consists of the following steps:

1) Select control stations' positions as close as possible to the objects to be surveyed.
2) Mark the stations with monuments in the ground with a precise point marked on the top of it.
3) Make angle and distance measurements.
4) Place signals at each station such as a range pole to be used for taping and angle measurement.
5) A traverse may be either open or closed.

Traverse is a method in the field of surveying to establish control networks, perform tacheometry surveys for topographic and cadastral purposes, etc. Thus, traverses can be used to find accurate positions of a small number of marked control stations. From these stations, less precise measurements can be made to objects to be located without accumulating accidental errors. In this case, traverses can be served as control surveys. When drawing cadastral plans, the stations can be used as beginning points from which to lay out work. When new parcel subdivisions of any kind are to be made, a system of traverse stations in the area must be established and surveyed.

Traverse surveys are made for many purposes which include:

- To establish supplementary ground control points from which cadastral objects may be surveyed for preparing various types of cadastral plans (i.e., establish control);
- To re-establish the positions of exiting parcel's boundary markers;
- To survey the positions of parcel's boundary corners and lines (i.e., a land parcel, recreation site, forest plot, or wildlife habitat area);
- To establish control and surveying railroads, highways, and other objects associated with cadastral surveying and other private and public works;
- Ground control surveys for photogrammetric surveys.

Open Traverse

An open traverse (Figure 20) originates at a starting control station, proceeds to its destination, and terminates at a station whose relative position is not previously known. The open traverse is the least desirable type of traverse because it cannot be checked for accuracy of field measurements as errors or mistakes are not revealed. For this reason, the planning of a traverse should always provide for closure of the traverse. Traverses are closed in all cases where time permits.

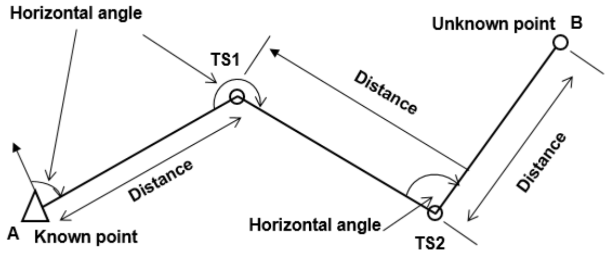


Figure 20. An open traverse

A side-shot course is used to compute a coordinate that is not part of the main traverse course sequence (Figure 21). A side shot is a single measurement to a feature, which is to the side of the main traverse line.

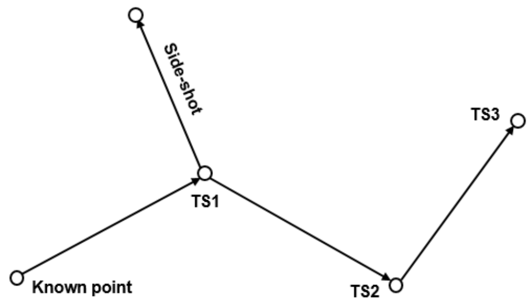


Figure 21. Side-shot in open traverse

The open traverse is suitable for surveying a long narrow strip of land. Thus, open traverses may be run to establish preliminary trail and road locations, canal or the coast line.

Closed Traverse

A closed traverse begins at a point and ends at the same point or at a point whose position is known (Figure 22). Therefore, the position closure gives an indication of the accuracy in measuring distances as well as azimuths. Accidental errors made in the measurements can be adjusted. Large errors can be corrected.

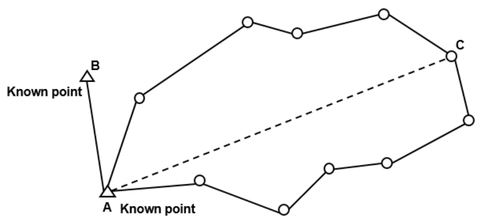


Figure 22. A closed traverse.

The closed traverse is suitable for locating the boundaries of plots, lakes, woods, etc. and for survey of large areas.

A closed loop traverse is a traverse which starts at a given point, proceeds to its destination, and returns to the starting point without crossing itself in the process (Figure 23). The surveyor uses this type of traverse to provide control of a parcel boundary, and measurements for the area computation within the boundary. Angels of a loop traverse inside a closed polygon called interior angles.

A loop traverse is also used if there is little or no existing control in the area and only the relative position of the points is required. A loop traverse starts and ends on a station of assumed coordinates and azimuth without affecting the computations, area, or relative position of the stations. If, however, the coordinates must be tied to an existing coordinate reference system, the traverse starts from a known control station and azimuth on that coordinate reference system. While the loop traverse provides some check upon the fieldwork and computations, it does not provide for a check of starting data or insure detection of all the systematic errors that may occur in the survey.

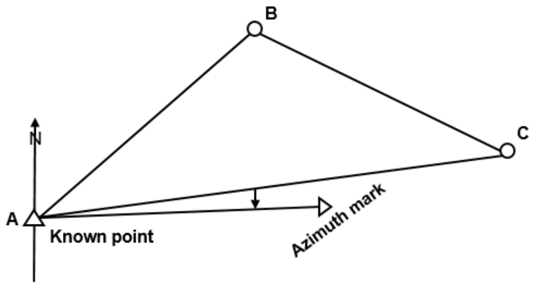


Figure 23. A closed loop traverse

A traverse closed on a second known point (a <u>closed link traverse</u>) begins at a point of known coordinates, moves through the required point(s), and terminates at a second point of known coordinates (Figure 24). The surveyor prefers this type of traverse because it provides a check on the fieldwork, computations, and starting data. It also provides a basis for comparison to determine the overall accuracy of the work.

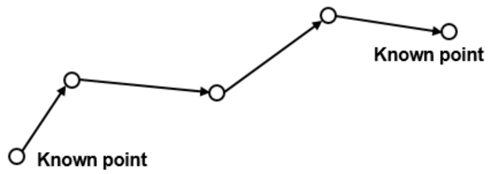


Figure 24. A closed link traverse

In traversing surveying, the following type of angels can be measured: deflection angles, interior-angles, angles to the right, azimuths, and compasses.

1.4.3. Errors in COGO Traversing

Distances and angles can never be determined exactly; measurements are subject to error. The precision and accuracy of the bearings and distances measurements on a survey plan are dependent on a number of factors including, the method of the survey, required levels of accuracy (first order, second order, etc.), density and location of permanent control stations, the type of instrumentation used for the survey, the terrain and topography of the region etc. Modern equipment (including use of GNSS) result in measurements that are more accurate than measurements made with twentieth century equipment. These variations in measurement accuracy must be considered.

A closure error can be determined for a closed link or loop traverses. In a closed traverse, a closure error (or misclosure, discloser error) indicates accuracy of the surveying and potential problems in the original survey data. A closure error is the amount by which a closed traverse fails to match the true and computed position of the same point (Figure 25).

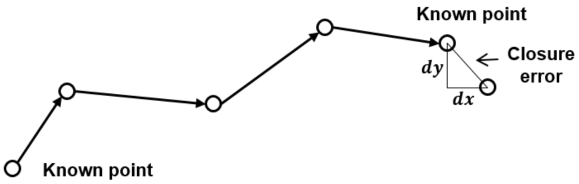


Figure 25. A closure error

X and Y coordinates of the end control point can be calculated through a series of calculations of the coordinates of each station by using the measured horizontal distances and adjusted angles/bearings. The difference between the calculated and known coordinates of the end control point is dx and dy that is the closure error in X and Y coordinates (northing and easting). Closure error of can be calculate as the following:

$$E_{closure} = \sqrt{dx^2 + dy^2}$$

The relative accuracy of distance measurements can be expressed using the following equation. An angular error of one minute is equivalent to a distance measurement error of 3 cm over a distance of 100 m.

$Precision\ or\ relative\ accuracy = \frac{E_{closure}}{l}$, wher l is the total length of the traverse.

The closure of a loop traverse can be computed based on the latitudes and departures of each of its sides. The latitude is the Y-component of the side-line (or its projection on the Y-axes) and the departure is its X-component of the side-line (or its projection on the X-axes). When latitudes are added together, the resulting error is called the error in latitudes (dy). The error resulting from adding departures together is called the error in departures (dx)

The closure error in a COGO traverse could be the result of:

- Measurement precision
- Mistyped values
- Incorrect values in the source
- Measurement error (systematic and random) etc.

Once the measurement data is deemed to be free of human accidental errors and the rough closures are considered to be acceptable, the traverse may be balanced and adjusted. Misclosure caused by numerical precision or measurement error can be solved by applying an adjustment to distribute the error through each of the courses. The most common methods of “balancing a traverse” are the compass rule, the transit rule, Crandall’s rule, and the least squares adjustment. The least squares adjustment is considered a rigorous method, and other three as approximate methods.

All these methods distributes errors according to one of the following adjustment methodologies.

- In the Compass rule assumes that the error of closure is a result of accidental errors affecting angular and linear measurements equally (or that angles and distances are measured with equal accuracy so error is applied to each).

The compass rule, also known as the Bowditch rule, distributes the misclosure in the northings and eastings in proportion to the distance along all the courses from the first point to each of the unadjusted coordinate locations. This method is based on assumptions that the errors in linear measurements are directly proportional to $\sqrt{l}$ and that the errors angular measurements are inversely proportional to $\sqrt{l}$, where l is the length of the traverse. More specifically, a correction factor is computed for each point as the sum of the distances along the traverse from the first point to the point in question, divided by the total length of the traverse. The correction factor at each point is multiplied by the overall closure error to get the amount of error correction distributed to the point's coordinates.

- The Transit rule assumes that the error of closure is a result of accidental errors and that the effects of errors in distance measurement are greater than the effects of errors in angular measurements (or that angles are measured more accurately than distances; distances receive greater adjustment).

The transit rule distributes the closure error by changing the northings and eastings of each traverse point in proportion to the northing and easting differences in each course. More specifically, a correction is computed for each northing coordinate as the difference in the course's northings divided by the sum of all the courses' northing differences. Similarly, a correction is computed for each easting coordinate using the easting coordinate differences. The corrections are applied additively to each successive coordinate pair, until the final coordinate pair is adjusted by the whole closure error amount. After the adjustments are made, revised lengths and bearings for the various traverse lines are computed trigonometrically.

Usually, observed angles are balanced for angular misclosure prior to applying a transit rule adjustment. The angular error of closure (if acceptable for the survey instrumentation used) in the traverse is evenly distributed through each deflection point leaving closing bearings between control points unaltered. The transit rule is used infrequently.

- The Crandall rule assumes that the error of closure is a result of accidental errors and the effects of errors in angular measurements are negligible or have already been adjusted out of the traverse. It further assumes that any adjustment should be applied only to the lengths/distances of the courses (or that angles are held and errors are statistically distributed into the distances).

Crandall's rule was an attempt to apply the concepts of probability to error correction. According to this rule, errors in long distances are more probable than in short distances, and errors in distances in general are more probable than errors in angles. The Crandall rule is most frequently used in a closed traverse that represents a parcel from a subdivision plan to ensure that tangency between courses remains intact as, for example, when applied to a tangent curve. This method uses a least-squares adjustment to distribute the closure error, and applies infinite weight to the angles or direction measurements to ensure that they are not adjusted. In some circumstances the results of this adjustment method may be unexpected, or the adjustment may not be possible, and an alternative method is required.

- The Least Squares adjustment assumes that the error of closure is a result of accidental errors. Least Squares adjustment requires redundant observations.

The Least Squares adjustment theory states that, for any set of measured values, the best set of corrections to apply to the measured values is one such that the sum of the squares of all of the corrections is minimized.

Unlike the above thee rules, in the Least Squares adjustment, the angles of the traverse are not adjusted prior to beginning the least squares procedure. Angles and distances are adjusted simultaneously, based on that the sum of the squares of all of the corrections is minimized. The procedure renders consistent and reliable results in proportion to the quality of the measurements made.

To minimize introduced distortion, least squares adjustment should only be applied against fabric of high positional and relative accuracy. The least squares adjustment is the most commonly used method of adjusting measured values.

These techniques are used only to distribute accidental or random errors of observation. Each assumes that the observations are free of blunder and systematic errors. In general, the Transit rule is not recommended. The Crandall method and the method of Least Squares are computationally complex and are generally not required for simple traverse adjustments. In most cases, a Compass rule adjustment is sufficient for cadastral mapping purposes.

In most cases it should not be necessary to re-balance and re-adjust data from a single plan. However, when a plan should be integrated into a parcel's subdivision or cadastral fabric network, it may be necessary to re-balance and re-adjust traverse surveys. When linking adjacent surveys into cadastral fabric, it may be necessary to re-define parcel's perimeter boundaries by balancing and adjusting data from a number of underlying and adjoining plans to affect a closure and reconcile discrepancies.

1.4.4. Triangulation and Trilateration

The triangulation surveying method is based on the trigonometry that if one side and three angles of a triangle are known, the remaining sides can be computed. Furthermore, if the direction of one side is known, the directions of the remaining sides can be determined. A triangulation system consists of a series of joined or overlapping triangles in which a random side is measured and remaining sides are calculated from angles measured at the corners of the triangles. The corners of the triangles are known as triangulation stations. The side of the triangle whose length is measured, is called the base line. The lines of triangulation system form a network of triangles and triangulation stations (Figure 26). Before survey-grade satellite positioning was available, triangulation was the most common technique for establishment of horizontal control survey network.

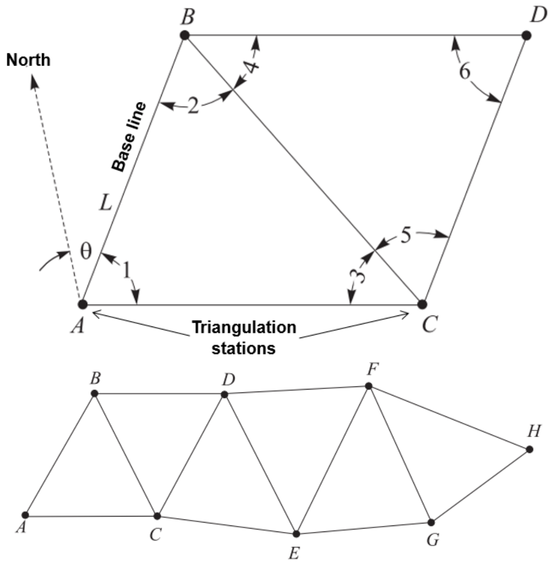


Figure 26. Principle of triangulation network and an example of single chain of triangles

A trilateration network also consists of a series of joined or overlapping triangles. However, for trilateration the lengths of all the sides of the triangle are measured and few directions or angles are measured to establish azimuth. Trilateration has become feasible with the development of EDM devices, which has made possible the measurement of all lengths with high order of accuracy under almost all field conditions.

The main objective of triangulation or trilateration surveys is to provide a number of control stations whose relative and absolute positions, horizontal as well as vertical, are accurately established. More detailed topographic, cadastral or engineering survey are then carried out from these stations.

1.5. GLOBAL NAVIGATION SATELLITE SYSTEM

Global Navigation Satellite System (GNSS) is a term used for the infrastructure that includes a constellation of orbiting satellites stations with worldwide coverage, which are working in conjunction with a network of ground stations and Satellite-Based Augmentation Systems. This infrastructure allows determination of the geographic position, distance, direction, velocity and local time of a user's receiver anywhere in the Earth (on surface or in air) by processing signals from satellites in space. GNSS can be used for civil and military applications.

Currently, the following GNSS systems are operational:

- GPS (United States): the first GNSS, also known as NAVSTAR-GPS: NAVigation System with Timing and Ranging Global Positioning System: fully operational since 1993, is managed by the US Department of Defence (DoD). It now uses a constellation of between 24 and 32 satellites, and provides global coverage.
- GLONASS (Russia): the GNSS is completed in 1995 and fully operational since 2011, is managed by the Russian Aerospace Defence Forces. The full GLONASS constellation consists of 24 satellites, and provides global coverage.

The following GNSS systems are in varying stages of development and planning:

- Galileo (European Union): Europe's GNSS, currently under development as the only civil GNSS, is owned and managed by the European Union. When complete, it will consist of 30 satellites.
- Compass (China): the Chinese GNSS, set to supersede the Compass regional system operating since 2000, is managed by the governmental China Satellite Navigation Office. The system will consist of 35 satellites. A regional service is provided by 2010; the service will be extended to provide global coverage in the years 2015-2020.

The following regional navigation satellite systems are planned and are in varying stages of development:

- IRNSS (India)
- QZSS (Japan)

Satellite-Based Augmentation Systems (SBAS), for example, such as EGNOS (Europe), WAAS (North America), GAGAN (India) and MSAS (Japan), are geostationary satellite systems that provide services for improving the accuracy, integrity, and availability of basic GNSS signals.

1.5.1. The use of GPSS for Cadaster

Surveying for cadastral purposes normally requires an accuracy in absolute position of 10 cm. This accuracy and higher (up to 1 cm) can be easily achieved utilizing GNSS observations of survey grade GNSS receivers. Thus, the high precision of GNSS carrier phase techniques, together with appropriate adjustment algorithms and differential corrections, which are discussed below, provide an adequate accuracy of cadastral surveying with using GNSS.

In current cadastral surveying practice, GNSS is often used in conjunction with traditional surveying methods to provide sufficient information to fix boundaries, marks and occupations which are needed to create or to update a cadastral plan.

GNSS receivers can be used to position survey markers, parcels boundaries and corners, buildings, and other objects related to a cadastral survey. Probably the main use of GNSS in a cadastral survey is an absolute coordinate surveying of control points or tacheometric stations. For example, control points measured by GNSS can be used as start and end points of total station traversing. Or, as is shown in Lab Assignment 1, the GPS point network can be used for the positioning and orientation of a tacheometer at a survey control station from which the plot's boundary are measured by tacheometric techniques.

GNSS instruments can also be used to measure corners and tuning points of a plot's boundary directly. However, GNSS measurements may require longer occupation times to do measurements on a point. An **occupation time** is the amount of time required to allow satellite acquisitions on a station, or point, and to achieve successful processing of GNSS data. Higher precision typically requires a longer occupation time. Occupation times can vary from a couple of seconds (kinematic surveys) to several hours (control surveys). Therefore, for cadastral surveying, it could be more time-effective to establish control points with GNSS, but perform cadastral boundary surveying with a total station. For such a method of surveying an integrated GPS TPS can be used. However, kinematic and rapid-static GNSS surveying techniques do not require excessively long occupation times and can provide accurate cadastral maps in a relatively short period of time and can be reasonably inexpensive.

One advantage of GNSS surveying is that it provides <u>absolute</u> measurements of coordinates in a predefined coordinate reference system. However, for the very accurate GNSS measurements differential or a relative position to base station(s) are required. In addition, GNSS survey techniques can be more accurate than conventional tacheometry.

All GNSS cadastral surveys must be undertaken in accordance with accepted good survey practice such as GNSS observation procedures, and should be designed to detect and eliminate GNSS-related surveying errors.

GNSS data processing and mission planning software are available on the market/Internet or supplied with GNSS devices. The software provides a capability to process GNSS observations captured by receiver(s) and then export data files in a number of different GIS/CAD formats. Then the GNSS data can be represented in a graphical form to draw parcel boundaries with dimensions derived from the GNSS coordinates.

1.5.2. Components of Global Navigation Satellite System

GNSS satellite systems consist of three major segments or components: space segment, control segment and user segment (Figure 27). These segments are quite similar in the three major satellite technologies (GPS, GLONASS and Galileo).

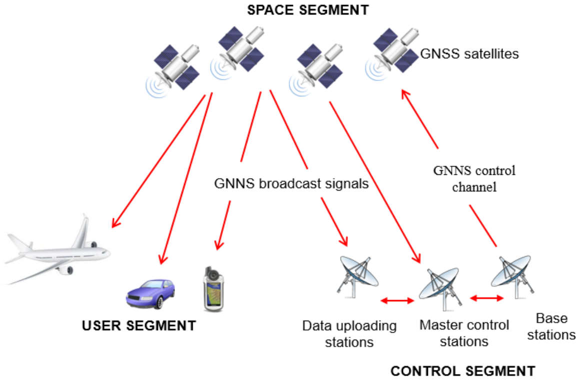


Figure 27. Components of Global Navigation Satellite System.

- The space segment consists of a number of GNSS satellites that are orbiting more than 20,000 km above the Earth. GNSS satellites typically fly in medium Earth orbit. Satellites orbit the earth in an elliptical path. Earth becomes the focal points link.

Each GNSS has its own "constellation" of satellites, arranged in orbits to provide the desired coverage. Each satellite in a GNSS constellation broadcasts a signal that identifies it and provides its time, orbit, and status.

Satellites of SBAS also can be considered as a part of the space segment. SBAS satellites usually use the geostationary orbits. The term geostationary is used to refer to the special case of a geosynchronous orbit that is circular (or nearly circular) and at zero (or nearly zero) inclination, that is, directly above the equator. Satellites in geostationary orbits appear stationary at one location at all times.

- The control segment comprises a ground-based network of master control stations, data uploading stations, and monitor stations.

Monitor stations, usually installed over a broad geographic area, monitor the satellites' signals and status, and relay this information to the master control station. The master control station analyses the signals then transmits orbit and time corrections to the satellites through data uploading stations. The master control station corrects the satellites' orbit parameters and onboard high-precision clocks when necessary to maintain accuracy.

- The user segment of GNSS consists of military and civilian users who use GNSS equipment to process the received signals from the GNSS and/or SBAS satellites to derive and apply location, velocity, direction and time information. The equipment ranges from handheld receivers used for navigation, to sophisticated, specialized receivers used for survey and mapping applications.

Satellite signals require a direct line to GNSS receivers. Trees, buildings, bridges, mountain ranges, and your body can all block the satellite signals. Heavy forest canopy causes interference, making it difficult to compute positions. Signals cannot penetrate water, soil, walls or other obstacles.

1.5.3. Basic Principles of GNSS Measurements

The basic idea behind of satellite-based navigation systems is that they use a version of trilateration to locate a user's receiver, through calculations involving information from a number of satellites. Each satellite transmits coded signals at precise intervals. A GNSS receiver on or near the earth's surface uses these signals to calculate the distance between it and the transmitting satellite (from the transmission time delay). Coordinating current signal data from four or more satellites enables the receiver to determine its position, velocity, and time.

GNSS radio signals are quite complex. Their frequencies are around 1.5 GHz (gigahertz) - 1.5 billion cycles per second – it is a portion of UHF (Ultra High Frequency) radio waves of the electromagnetic spectrum. GNSS operates at frequencies that are higher than FM radio, but lower than a microwave oven. In general, GNSS satellites transmit signals at extremely low power levels. Because of their frequency and low power, the signals have a relatively limited ability to penetrate tree canopy, water, soils, building walls, or other obstacles. GNSS signals will be discussed in detail below.

By knowing exactly where each GNSS satellite is, and how long it has been since the signal was emitted, a GNSS receiver can calculate the distance to the satellite. The receiver calculates how long the tracked satellite signal took to reach it, as follows:

$$T\ (propagation\ time) = Time\ Signal\ Reached\ Receiver - Time\ Signal\ Left\ Satellite$$

Since the speed of light, c, is approximately 300,000 km/s in a vacuum, a receiver can calculate the distance or range D to the satellite by using $Propagation\,Time$. Since $D = c * T$, it can calculate the distance to the satellite. If the propagation time was calculated as 0.07 seconds, the distance or pseudo-range to a satellite from a receiver can be calculated as follows:

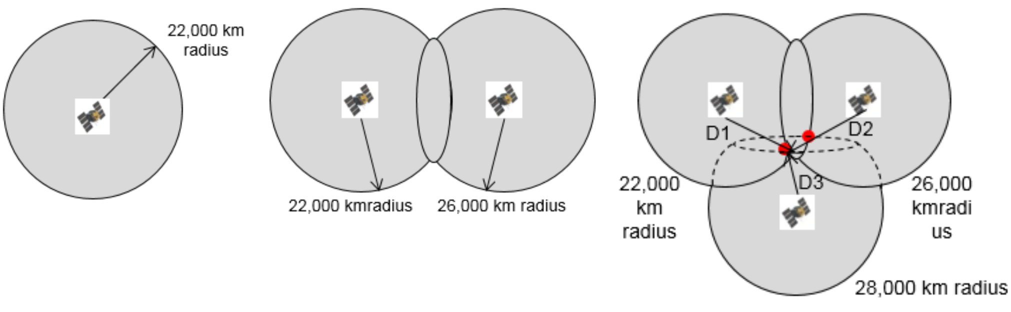
If $D = c * T$, and $D = 300{,}000\ km/s * 0.07\ s$ then $D = 21{,}000\ km$

A pseudo-range is a range estimated from the time rather than a true range.

Of course, this is estimated calculation, since the speed of light slows slightly, and is refracted when it enters a medium such as the Earth's atmosphere. Differing levels of atmospheric pressure cause differing amounts of refraction as the radio signal penetrates more deeply into the Earth's atmosphere.

In order to calculate the position of user's receiver (or coordinates of point on the Earth), the receiver should know the exact position of three satellites and the exact distance to each of them. Therefore, with GNSS, trilateration refers to measuring the distances (ranges) from 3 satellites to establish a position of a receiver on the Earth.

In Figure 28C, the positions of the three satellites are known exactly, and the receiver can calculate D1, D2, and D3 by the time it takes the radio signal to reach the GNSS receiver. Three distance measurements narrow down the receiver position to just two points. Usually the receiver can discard one of the last two points because it is nowhere near the Earth. Three distances plus Earth's surface define one point - the X and Y coordinates of the GNSS receiver on an ellipsoid. Four distances define one point as well, however distances from four 4 satellites can be used for 3D positioning - the X and Y coordinates on an ellipsoid and height above the ellipsoid (h).



A: The GNSS receiver locks on to one satellite and calculates the range to be for example 22,000 km. This fact helps narrow the

B: Now, consider that the receiver picks up a signal from a second satellite and calculates the range between the receiver and the satellite to be 26,000 km. That means the receiver is also

C: When a GNSS receiver is locked onto 3 satellites, its position is somewhere at the intersection of 3 circles which result from the intersection of three spheres. Only two possible points (red) lie at the intersection of these three circles receiver location down, but it only tells us that the receiver are somewhere on a sphere which is centered on the satellite and has a 22,000 km. Many of the locations on that sphere are not on earth, but out in space.

somewhere on a sphere with 26,000 km radius with the second satellite at the center. The receiver must, therefore, be somewhere where these two spheres intersect. When the two spheres intersect, a circle is formed, so the receiver must be somewhere on that circle.1, 2 satellites - no lock, course

3 Satellites - 2D positioning - Earth's surface assumed

Figure 28. Geometry of the GNSS satellites

In order to transmit the exact time as part of the GNSS signal, each satellite must keep very precise time. To do this, GNSS satellites make use of atomic clocks that is very precise but also very expensive ($100,000 and more). All satellite clocks are synchronized and they send their codes at a known time.

However, receivers contain clocks similar to a quartz watch, which is not very accurate. Normally a quartz crystal can lose a second a day, thus there is always an error between satellite and receiver clocks. This error is called timing offset (Δt).

Thus, the first three measurements narrow down a GNSS position. Three ranges are enough if we reject ridiculous answers. The fourth measurement is needed to correct for timing offset (difference in synchronization between satellite and receiver clocks). An extra 4th satellite's range measurement removes timing offset errors. Distances to four satellites enable the receiver to resolve ambiguity in spatial positioning.

There are four unknowns: the receiver coordinates (Latitude, Longitude and Altitude) and the receiver clock offset. Four measurements are needed to solve the equation. In order to solve for these four unknowns, pseudo-range measurements must be taken to a minimum of four satellites to triangulate the position of the receiver.

1.5.4. Global Positioning System (GPS)

As of today, the complete satellite technology is the GPS technology and most of the existing worldwide applications related to the GPS technology. Therefore, this technology will be discussed in more detail in this manual.

The Global Positioning System (GPS or originally known as NAVSTAR) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. The GPS can be used to locate positions anywhere on the earth. Operated by the U.S. Department of Defense (DoD), GPS provides continuous (2 hours/day), real-time, 3-dimensional positioning, navigation and timing worldwide (Figure 29). Any person with a GPS receiver can access the system, and it can be used for any application that requires location coordinates.

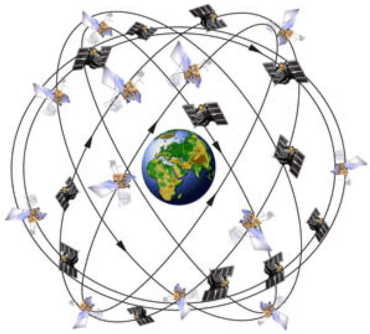


Figure 29. GPS satellite constellation.

GPS Space Segment: The first GPS satellite was launched by the U.S. Air Force in early 1978. The current GPS constellation consists of 24 satellites plus spares, located in 6 orbital planes, which are inclined 55 degrees to the equator. As of August 17, 2015, there were 31 operational satellites in the GPS constellation. The GPS constellation is a mix of old and new satellites (Block's generations). See the official U.S. Government information about GPS page satellites at http://www.gps.gov/systems/gps/space/.

There are four satellites in each of 6 orbital planes. Each orbital plane crosses the equator at 60 degrees from the next plane, so the orbits cross at 17, 77, 137, 197, 257, and 317 degrees. The system is designed to maintain full operational capability even if two of the 24 satellites fail.

Each satellite orbits at 20,200 km altitude. The orbits are very high so that they are stable and predictable. If the orbits were lower, friction from the Earth's atmosphere would eventually alter the orbit of the satellite. Each satellite orbits the Earth every 11 hours 56 minutes, which means that they pass over any point on the earth about twice a day. The satellites rise (and set) about four minutes earlier each day, and are synchronized with the celestial sphere.

Each satellite is about the size of a car, and weighs 860 kg. The satellites are powered by solar panels, which rotate to follow the sun, and are used to charge Nickel-Cadmium batteries for times when the satellite is in the Earth's shadow. The satellites have two important types of equipment on board – atomic clocks and radios/antennae to transmit the signal to Earth. On board each GPS satellite are four atomic clocks, only one of which is in use at a time.

GPS Satellite Signals: GPS satellites broadcast in the UHF portion of the electromagnetic spectrum. The radio waves that they emit are governed by the same rules that affect all other forms of light. Because GPS supports multiple military and civilian applications, each satellite transmits multiple signals on multiple frequencies to support the different services offered. The same is true for the Galileo and GLONASS systems.

Each GPS satellite is sending out signals with the following content: the satellite's ID, position and time stamp. In addition, each satellite sends a navigation message about the position of other satellites (ephemeris and almanac data) used in GPS receivers for later calculations. This content is modulated onto a carrier frequency signal in order to be sent from the satellite to the receiver.

GPS satellites currently emit in five frequencies carrier channels, which are identified as L1 to L5. The frequencies, availability, and applications of these carrier channels are described in Table 1. The carrier signal is controlled by atomic clock. All carrier radiofrequencies and codes are generated from the same 10.23MHz crystal whose long term stability is controlled by Cesium or Rubidium clock (older satellites). 10.23 MHz is fundamental frequency in GPS.

Table 1. Signals used in GPS Satellites, their frequencies, application, and current availability

Channel	Frequency (MHz)	Original usage	Modernized usage	Availability
L1	1575.42 (10.23×154)	Encrypted precision P(Y) code		All Satellites
		Contains 2 positioning codes: C/A (Coarse/Acquisition) and P (Precise) code. Also contains the navigation message, which is contained within the C/A code.	C/A, L1 Civilian (L1C), and Military (M) code	
L2	1227.60 (10.23×120)	Encrypted precision P(Y) code		All Satellites
		Contains P (Precise) Code (redundant transmission of same code as in L1 signal). This channel is also used to measure ionospheric delay in military receivers.	C/A code has been added on this channel in newer satellites (L2 Civilian (L2C) code) and Military (M) code	
L3	1381.60 (10.23×135)	Nuclear weapons monitoring. Used to detect when missile launches, nuclear detonations, and high-energy infrared events are detected	The same	Block IA and above
L4	1379.913 (10.23×1214/9)	(No transmission)	Additional Ionospheric correction signal for improvement of GPS accuracy	Block IIR and above satellites
L5	1176.45 (10.23×115)	(No transmission)	Safety-of-Life signal. Used for aircraft navigation. Within protected band with little radio interference.	Block IIF and Block III GPS Satellites

For example, the L1 carrier signal at 1575.42 MHz (10.23 MHz × 154) frequency, is modulated with C/A code, P(Y) code and navigation message (Figure 30). L1C code will be launched soon as a fourth code of L1 carrier signal and will be used as a common civil signal for GPS, Galileo, QZSS and BeiDou GNSSs. Figure 31 shows how these signals are combined.

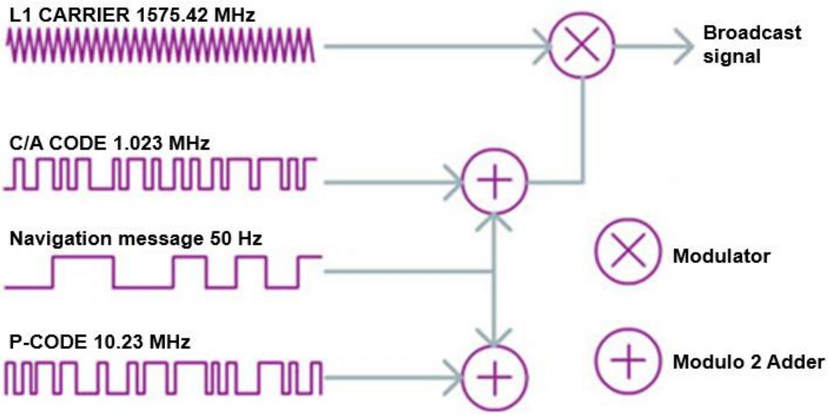


Figure 30. Multiplexing of C/A, Navigation Message, and P code into L1 signal

There are two basic kinds of GPS ranging codes (codes used to determine *propagation time*): these are Coarse Acquisition (C/A) and Precise (P) codes. C/A-code and P-code are used for the satellite clock reading, both are characterized by a pseudorandom noise (PRN) sequence. Current C/A and P(Y) code-signals are broadcast on both the L1 and L2 frequency carriers.

C/A Code is modulated into the L1 signal (and L2 since 2014) and available to civilian users. The course acquisition code chip rate (rate at which the phase might change) is 1.023 MHz. C/A Code provides Standard Positioning Service (SPS). Using the SPS one can achieve 15 meter horizontal accuracy 95% of the time. This means that 95% of the time, the coordinates you read from your GPS receiver display will be within 15 meters of your true position on the earth. Using C/A code on both frequencies (L1 and L2) and additional techniques, a GPS receiver can achieve better accuracy.

C/A Code (as well as P-code) is a repeating Pseudo Random Noise (PRN) code. The codes consist of a sequence with the states +1 or -1, corresponding to the binary values 0 or 1 (Figure 32) information. Each satellite has its own PRN sequence or code. PRN is generated from a "seed" number by algorithm. The algorithm is conveyed in the navigation message from the satellites to a receiver. By using the algorithm received from satellites, a GPS receiver generates the identical C/A code as the satellite. Thus the receiver can separate the signals of each of the satellites by PRN code and plus use the code to determine *propagation time*.

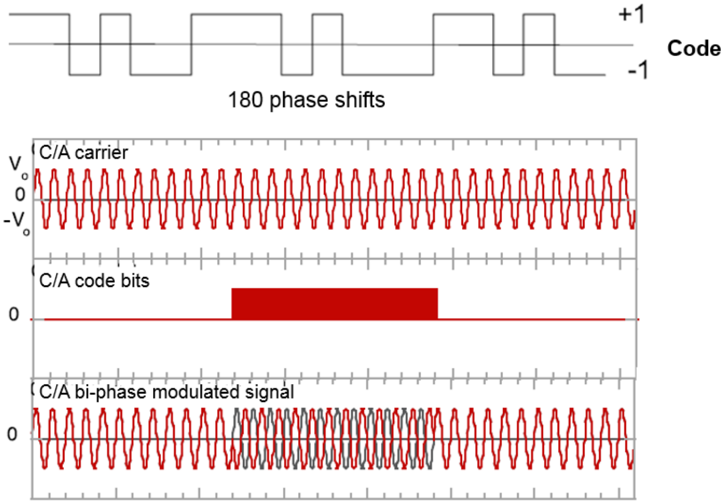


Figure 31: Example of Pseudo Random Noise code and C/A code modulation

In April 2014, the new L2C-code was added to the L2 frequency. L2C is the second civilian GPS signal, which can be combined with L1 C/A in a dual-frequency receiver, to enable ionospheric correction to increase accuracy. Dual-frequency GPS receivers can achieve the same accuracy as the military receivers.

L1C is the fourth civilian GPS signal, designed to enable interoperability between GPS and international satellite navigation systems. L1C is not fully implemented yet.

P (Precise) code, used for the Precise Positioning Service (PPS), is available only to the military and authorized users, the P(Y) code is classified. The P-code rate is 10 times higher than C/A code and is 10.23 PRN code. P-code has the anti-spoofing mode: Virtually anybody can generate a correct C/A code, so it is quite easy to throw off the GPS position. The actual P-code is not directly transmitted by the satellite, but it is modified by a Y anti-spoofing code, which is often referred to as the P(Y) code. A GPS receiver with a cryptographic key can decode Y-Code to produce P-Code. Being able to decode a signal allows a user to be sure that it is a "real" GPS signal. Y-code is also 10.23 MHz derived by multiplying P-code by ~20KHz code.

Using C/A code and P-code on both frequencies, a GPS receiver can achieve better accuracy. Additional techniques can increase the accuracy of both C/A code and P code GPS receivers.

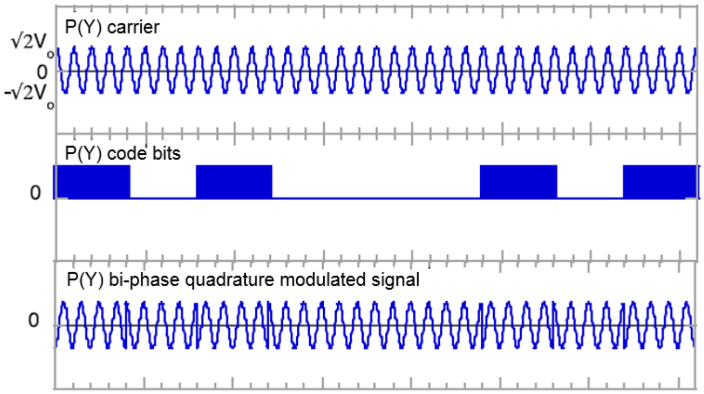


Figure 32: P-code modulation

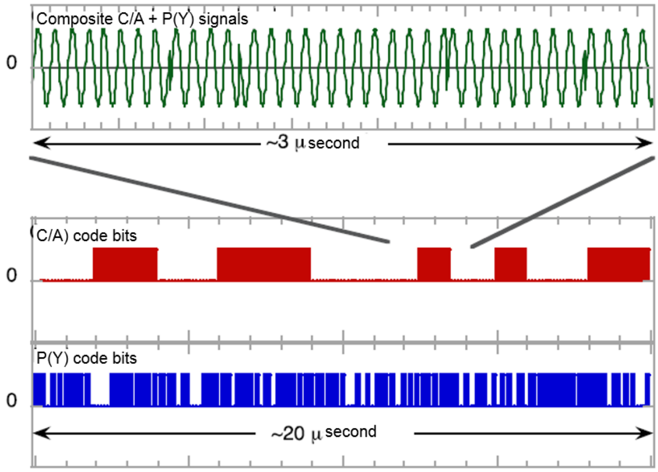


Figure 33: Composite: Sum of C/A and P code

The M-code GPS signal was first broadcast from the GPS Block IIR-14(M) satellite that was launched on September 25, 2005. All new GPS satellites transmit M-code as well as the P(Y)-code signal. M-code is an integral part of GPS modernization and the key enabler for the US Defense Department's Navigation Warfare program.

In addition to the PRN code, the navigational message is modulated into the signal. Navigational message data modulation is implemented by changing the sign of code at a rate of 50 bits/second. The GPS navigational message is used for prediction of orbital parameters and contains two different pieces of information – ephemeris data and almanac data. After turned on, a GPS receiver must update its almanac and ephemeris data and store it in memory.

Ephemeris data tells the GPS receiver where each GPS satellite should be at any time throughout the day. Satellite position (ephemeris) must be known as a reference for range measurements. Ephemeris data is a set of parameters that can be used to accurately calculate the location of a GPS satellite at a particular point in time. This information is accurate to many decimal places.

Satellites are launched into precise and very predictable orbits. US Airforce measures error in ephemeris (satellite position and speed) when they fly over the Colorado Springs control station. Corrected ephemeris information is sent up to the satellite, to be transmitted to users' receivers along with the PRN signals.

To accurately calculate a receiver location, ephemeris data is only usable for a limited time. Ephemeris records are updated every hour. Up-to-date data is needed to minimize error that results from minor variations in a satellite's orbit.

After using all of these parameters, corrections to satellite coordinates at signal transmission time are calculated. Satellite coordinates refer to the WGS 84 system.

Satellite almanac data are used by GPS receivers to predict positions for the satellites (ephemeris). Almanac information is constantly transmitted by each satellite. It has information about the orbits of the entire GPS 24-satellite constellation. It is sent along with position and timing messages. A GPS receiver uses the almanac to establish the availability and position of each satellite it is tracking. Almanac information is less accurate than the ephemeris. It is valid for about 30 days and updated every 6 days or less.

Almanac information includes data about the state (health) of the entire GPS satellite constellation, coarse data (including coordinates) on every satellite's orbit, and satellite clock correction parameters. A complete almanac file in GPS memory helps a ground GPS receiver acquire a signal and determine an initial position more rapidly; used to predict satellite visibility at a particular location; used in mission planning software etc.

GPS Coordinate Systems: The Cartesian coordinate system of reference used in GPS/GLONASS is called Earth-Centered, Earth-Fixed (ECEF). ECEF uses three-dimensional X,Y,Z coordinates (in meters) to describe the location of a GPS receiver or satellite. The origin (0,0,0) of Earth-centered reference is located at the mass center of gravity (determined through years of tracking satellite trajectories). The axes of reference are fixed with respect to the earth (that is, they rotate with the earth). The Z-axis pierces the North Pole, and the XY-axis defines the equatorial plane.

The ECEF coordinates are converted by receiver into reference ellipsoid geodetic coordinates of Latitude, Longitude, and Altitude by using the equation-based method. GPS measurements are calculated by GPS software in the geographic coordinate system of WGS84 datum with Geodetic Reference System 1980 (GRS) ellipsoid (ECEF). Then, a receiver or office GNSS software can transform satellite coordinates to other coordinate systems, NAD83, УСК–2000, etc.

The height determined by GPS measurements relates to the perpendicular distance above the reference ellipsoid and not the elevation above geoid or Mean Sea Level (MSL).

GPS Control Segment: The GPS-System is controlled by the US DoD (Department of Defence). The current operational GPS control segment includes a master control station, an alternate master control station, 12 command and control antennas, and 16 monitoring sites. A master control station is located at Falcon Air Force Base in Colorado Springs, CO.

The GPS control stations measure the satellite orbits precisely. Any discrepancies between predicted orbits (almanac) and actual orbits, and clock (time) information are transmitted back to the satellites. The satellites can then broadcast these corrections, along with the other position and timing data, so that a GPS receiver on the earth can precisely establish the location of each satellite it is tracking.

GPS User Segment: The U.S. military uses GPS for navigation, reconnaissance, and missile guidance systems. Civilian use of GPS developed at the same time as military uses were being established, and has expanded far beyond original expectations. There are civilian applications for GPS in almost every field, from surveying to transportation to natural resource management to agriculture.

1.5.5. GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema)

GLONASS (Globalnaya Navigatsionnay Sputnikovaya Sistema) is the Russian Federation's GNSS. The Ministry of Defense of the Russian Federation operates GLONASS.

The nominal GLONASS **Space Segment** consists of 24 operational satellites and several spares. The satellites are placed into nominally circular orbits with target inclinations of 64.8 degrees and an orbital radius of 19,100 km. This results in an orbital period of 11 hours 15 min 44 sec. Eight evenly spaced satellites are arranged in each of three orbital planes, inclined at 64.8 degrees to the equator and spaced 120 degrees apart (Figure 34). The constellation of 24 satellites provides a continuous and simultaneous visibility of at least five satellites over more than 99% of the earth surface. GLONASS provides three-dimensional position and velocity determinations based upon the measurement of transit time and Doppler shift of radio frequency (RF) signals transmitted by GLONASS satellites.

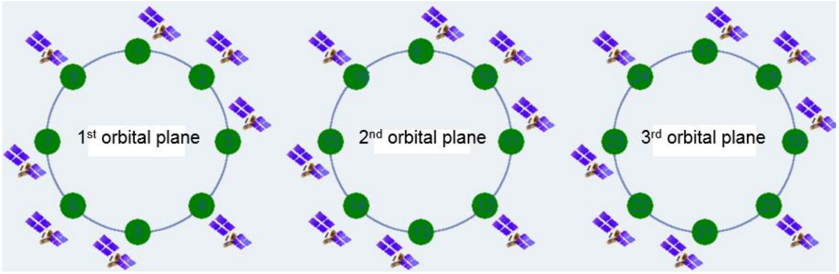


Figure 34. GLONASS satellite constellation

The GLONASS **satellite signal** identifies the satellite and includes: positioning, velocity and acceleration information for computing satellite locations; satellite health information; offset of GLONASS time from UTC (Coordinated Universal Time); almanac of all other GLONASS satellites. GLONASS has its own time scale called GLONASS time, which is synchronized within 1 second of UTC time. The navigation message has the data necessary to convert between GLONASS time and UTC time.

GLONASS satellites each transmit on slightly different L1 and L2 frequencies, with the P-code (HP-code) on both L1 and L2, and the C/A code (SP-code), on L1 (all satellites) and L2 (most satellites).

Table 2 summarizes the GLONASS signals.

Table 2: GLONASS FDMA Signal Characteristics

Designation	Frequency	Description
L1	1598.0625 -1609.3125 MHz	L1 is modulated by the HP (high precision) and the SP (standard precision) signals.
L2	1242.9375 -1251.6875 MHz	L2 is modulated by the HP and SP signals. The SP code is identical to that transmitted on L1.

At peak efficiency, the SP-signal offers horizontal positioning accuracy within 5–10 meters, vertical positioning within 15 metres.

GLONASS is based upon a frequency division multiple access (FDMA) concept: each satellite transmits carrier signals on a different frequency (e.g., L1 carriers are in 1598.0625 -1609.3125 MHz). A GLONASS receiver separates the total incoming signal from all visible satellites by assigning different frequencies to its tracking channels. The use of FDMA permits each GLONASS satellite to transmit an identical SP-code. More exactly, the

GLONASS system is based on 24 satellites using 12 frequencies. It achieves this by having antipodal satellites transmitting on the same frequency. Antipodal satellites are in the same orbital plane but are separated by 180 degrees. The paired satellites can transmit on the same frequency because they will never appear at the same time in view of a receiver on the Earth's surface. Since 2008, new CDMA (Code division multiple access) signals are being researched for use with GLONASS.

A navigation message, which is modulated in carrier, is transmitted from each satellite consisting of satellite coordinates, velocity and acceleration vector components, satellite health information and corrections to GLONASS system time.

The GLONASS **Control Segment** consists of the system control center located in Kranznamensk Space Center about 70 km southwest Moscow. The center is connected with 8 tracking stations distributed across Russia. These stations are responsible for tracking and monitoring the satellite orbit status, determining the ephemerides and satellite clock offsets with respect to GLONASS time, and transmitting this information to the system control center via radio link once per hour.

Additional information concerning GLONASS is available at the website http://www.glonass-ianc.rsa.ru/.

With the availability of combined GPS/GLONASS receivers, users have access to a satellite combined system with over 40 satellites. The use of GLONASS in addition to GPS can reduce signal acquisition time, improve position and time accuracy, reduce problems caused by obstructions such as buildings and foliage and improved spatial distribution of visible satellites, etc.

To determine a position in GPS-only mode, a receiver must track a minimum of four satellites. In combined GPS/GLONASS mode, the GPS/GLONASS enabled receiver must track five satellites, at least one of which must be a GLONASS satellite, so the receiver can determine the GPS/GLONASS time offset.

1.5.6. Galileo

Galileo is the GNSS that is currently being created (not fully operational) by the European Union and the European Space Agency (ESA). The first two operational Galileo satellites were launched from Europe's Spaceport in French Guiana in October 2011. The use of basic (low-precision) Galileo services will be free and open to everyone. The high-precision capabilities will be available for paying commercial users. Galileo will start offering services from 2016.

The Galileo **Space Segment** will consist of 27 operational and three active spare satellites distributed in 3 orbit planes. The satellites are placed into nominally circular orbits with target inclinations of 56 degrees, ascending nodes separated by 120° longitude (9 operational satellites and one active spare per orbital plane), and a medium-Earth orbit radius of 23,222 km. Each satellite will take about 14 hours to orbit the Earth. Currently 9 Galileo satellite are in orbit and healthy. As of 2012, the system was scheduled to reach full operation in 2020.

Once the constellation is operational, Galileo navigation signals will provide coverage at all latitudes. From most locations, six to eight satellites will always be visible. Galileo is intended to provide horizontal and vertical position measurements within 1-metre precision, and better positioning services at high latitudes than other GPS and GLONASS systems.

The Galileo Ground **Control Segment** consists of a network of ground stations. The ground control centre is located in Oberpfaffenhofen; the ground mission centre is located in Fucino; 5 tracking stations are located in Kiruna, Kourou, Noumea, Sainte-Marie, Réunion & Redu; plus there are several uplink stations, sensor stations and a data dissemination network between stations.

The Galileo **User Segment** is composed of Galileo receivers. Their main function is to receive Galileo signals, determine pseudo-ranges (and other observables), and solve the navigation equations in order to obtain their coordinates and provide a very accurate time.

1.5.7. Comparison between GPS, GLONASS and Galileo

Table 3 shows a comparison between GPS, GLONASS and Galileo.

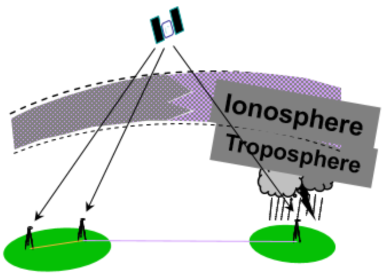
Table 3. Systems comparison: GPS, GLONASS and GALILEO

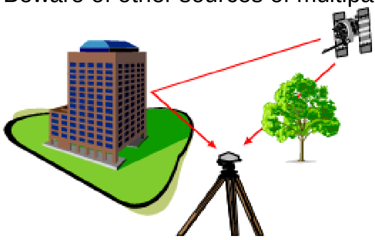
Systems	GPS	GLONASS	Galileo
First launch Full operational capability Launch site	February, 1978 1995 Cape Canaveral	October, 1982 1996 Baikonur/Plesetsk	December, 2011 2020 Kourou (French Guiana)
Nominal number of SV Orbital planes Orbit inclination Orbital altitude Orbit plane separation Revolution period	24 6 55 20,180 km 60 11h 57.96 min	24 3 64.8 19,140 km 120 11h 15.73 min	27 3 56 23,222 km 120 14h 4.75 min
Signal separation	CDMA	FDMA	CDMA
Number of frequencies	5 - L1 -L5	one per two antipodal SV	3(4)-E1,E6,E5(E5a,E5b)
Frequency (MHz)	L1: 1,575.420 L2: 1,227.600 L3: 1,176.450 L4: 1379.913 L5: 1176.45	L1: 1598.0625 - 1609.3125 L2: 1242.9375 - 1251.6875	E1: 1,575.420 E6: 1,278.750 E5: 1,191.795
Number of ranging codes	11	6	10
Geodetic reference system used (Datum)	WGS-84	PZ-90.11 (Earth Parameters 1990)	GTRF (International Terrestrial Reference System at epoch 2011.0)
Time system	GPS time, UTC	GLONASS time, UTC(SU)	Galileo system time

1.6. GNSS ERRORS

There are many sources of possible errors that will degrade the accuracy of positions computed by a GNSS receiver. The errors that can affect the accuracy of standard GNSS pseudo-range determination, that is, the determination of the pseudo-range by single satellite discussed above, are summarised in Table 4.

Table 4: Sources of errors of GNSS pseudo-range determination - Error Budget

Contributing Source	Error Range Potential	Error Range Typical	Explanation
Satellite clocks	1.5 meters	0 meters	Errors in the transmitted clock. Small variations in the atomic clocks (clock drift) on board the satellites can translate to large position errors; a clock error of 1 nanosecond translates to 3 meters user error on the ground.
Orbit errors (ephemeris data)	2.5 meters	0 meters	Errors in the transmitted location of the satellite. Errors in the ephemeris data (the information about satellite orbits) will also cause errors in computed positions, because the satellites were not really where the GNSS receiver "thought" they were (based on the information it received) when it computed the positions.
Ionospheric delays	5 meters	0.4 meters	Atmospheric effects are the largest source of error. Because of free electrons in the ionosphere, GNSS signals do not travel at the vacuum speed of light as they transit this region. The modulation on the signal is delayed in proportion to the number of free electrons encountered and is also (to first order) proportional to the inverse of the carrier frequency squared ($1/f$ squared). With short baselines, less than ten kilometers, the effect are almost equal, and will be canceled out of the solution. Sunspot activity also causes interference with GNSS signals. Delays in ionosphere can be compensated by using dual frequency receivers.
Tropospheric delays	0.2 meters	0.2 meters	Another deviation from the vacuum speed of light is caused by the troposphere. Variations in temperature, pressure, and humidity all contribute to variations in the speed of light of radio waves. Both the code and carrier will have the same delays. Delays in troposphere can be only estimated. 

Receiver noise	0.3 meters	0.3 meters	Distortion of the signal caused by electrical interference or errors inherent in the GNSS receiver itself. Errors in the receiver's measurement of range caused by thermal noise, software accuracy, and inter-channel biases.
Multipath	0.6 meters	0.6 meters	Errors caused by reflected signals entering the receiver antenna. The GNSS signal is a radio wave signal that can easily be blocked. Mountains, trees, towers, and buildings are just a few examples of possible obstructions. Multipath is the error caused by reflected signals entering the front end of the receiver and masking the real correlation peak. These effects tend to be more pronounced in a static receiver near large reflecting surfaces, where 15 m in or more in ranging error can be found in extreme cases. If obstructions are present, it is important to note the azimuth and elevation above the horizon of these structures, and then account for these in GNSS mission planning. Also, some structures that are obstructions in one direction can also be sources of multipath in another direction. Beware of other sources of multipath. 
Total	~ 15 meters	~ 10 meters	
Geometry of satellite positions			Errors are cumulative and increased by PDOP (Positional Dilution of Precision).
Selective Availability	> 50 meters		Selective Availability, or SA, occurred when the DoD intentionally degraded the accuracy of GNSS signals by introducing artificial clock and ephemeris errors. When SA was implemented, it was the largest component of GNSS error, causing error of up to 100 meters. SA is a component of the Standard Positioning Service (SPS), which was formally implemented on March 25, 1990, and was intended to protect national defense. SA was turned off on May 1, 2000.

In the next chapter, techniques for reducing these errors further will be discussed. However, the degree with which the above pseudo-range errors affect positioning accuracy depends largely on the geometry of the satellites' arrangement being used.

The quality of satellite geometry arrangement can be defined by **Dilution of Precision** (DOP) parameters. DOP is a numerical definition of satellite geometry, and it is dependent on the locations of satellites that are visible to the receiver. The smaller the value of DOP, the more precise the result of the time or position calculation. The relationship is shown in the following formula:

$$\begin{aligned} &Inaccuracy\ of\ Position\ Measurement \\ &\qquad = DOP\ x\ Inaccuracy\ of\ Range\ Measurement \end{aligned}$$

So, if DOP is very high, the inaccuracy of the position measurement will be much larger than the inaccuracy of the range measurement.

There are five distinct kinds of DOP:

- GDOP - Geometric Dilution of Precision.
- PDOP - Position Dilution of Precision (most commonly used).
- HDOP - Horizontal Dilution of Precision.
- VDOP - Vertical Dilution of Precision.
- TDOP - Time Dilution of Precision.

GDOP refers to where the satellites are in relation to one another, and is a measure of the quality of the satellite configuration. It can magnify or lessen other GNSS errors. In general, the wider the angle between satellites, the better the measurement. If satellites spaced widely across the sky, a receiver can get a more accurate determination of its position by trilateration than if they are "clumped" together. Most GNSS receivers may select the satellite constellation that will give the least uncertainty, the best satellite geometry.

PDOP refers to horizontal (HDOP) and vertical (VDOP) measurements (latitude, longitude and altitude). The quality of the satellite configuration can be checked on a receiver screen by looking at the PDOP value. A low DOP indicates a higher probability of accuracy, and a high DOP indicates a lower probability of accuracy. PDOP values are:

- 1 - theoretically ideal
- 1-4 - very good
- 5-8 - acceptable
- >9 - poor

Another quality measurement of satellite arrangements is TDOP, or Time Dilution of Precision. TDOP refers to satellite clock offset. A parameter known as the PDOP mask can be set on a GNSS receiver. This will cause the receiver to ignore satellite configurations that have a PDOP higher than the specified limit.

These five DOPS are mathematically related. In some cases, for example when satellites are low in the sky, HDOP is low and it will therefore be possible to get a good to excellent determination of horizontal position (latitude and longitude), but VDOP may only be adequate for a moderate altitude determination. Similarly, when satellites are clustered high in the sky, VDOP is better than HDOP.

In the Figure 35A, the effect of DOP is illustrated. It is difficult to determine where the ranges intersect. Position is "spread" over the area of range intersections, an area which is enlarged by range inaccuracies (which can be viewed as a "thickening" of the range lines). As shown in Figure 35B, the addition of a range measurement to a satellite that is angularly separated from the satellite cluster allows a receiver to determine a position more precisely.

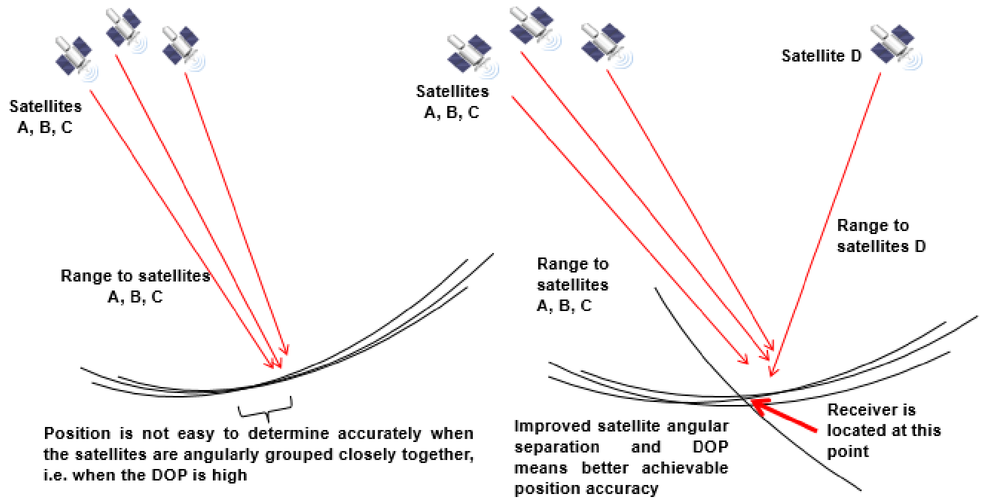


Figure 35. Dilution of precision: poor satellite geometry and improved geometry

DOP can be used as the basis for selecting the satellites on which the position solution will be based to minimize DOP and increase GNSS measurement's accuracy. DOP varies with time of day and geographic location but, for a fixed position, the geometric presentation of the satellites repeats every day, for GNSS. DOP can be calculated without determining the range only the satellite positions and the approximate receiver location are needed. Thus, GNSS mission planning software, which can read the satellite almanac, can be used to plan a date and time for GNSS fieldwork in order to obtain good DOP during the ground surveying.

In Canada and in other countries at high latitude, GNSS satellites are lower in the sky, and achieving optimal DOP for some applications, particularly where good VDOP is required, is sometimes a challenge. This challenge is being reduced with more GNSS constellations and satellites coming on line every year.

1.7. TYPES OF GNSS POSITIONING

The “standard” technique of measurements with GNSS provides positional accuracy of 10-15 meters. However, there are techniques to reduce GNSS errors and get GNSS measurements with accuracy of a few centimetres. Thus, for example, accuracy of GNSS receivers with the use of particular techniques can be classified as:

- Recreational grade GNSS receivers - 10-15 m of horizontal positional accuracy
  - Use of autonomous Code Phase positioning technique
  - Use of C/A code
- Mapping grade GNSS receivers - 1-5 m of horizontal positional accuracy
  - Use of C/A code with Code Phase positioning
  - Use of differential correction in real-time or/and post-processing
- Sub-meter mapping grade GNSS receivers - 10 cm to 1 m of horizontal positional accuracy
  - Use of C/A code and Carrier Phase positioning
  - Use of differential correction in real-time or/and post-processing
- Survey grade GNSS receivers - 1 cm of horizontal positional accuracy
  - Use of P-code or dual frequency positioning
  - Use of Carrier Phase positioning and advanced survey methods

The following discussion describes the listed techniques. The increased accuracy comes at a price of using more expensive equipment, more advanced techniques and more time spent on field work surveying.

1.7.1. Code Phase Positioning

As we have discussed above a GNSS receiver calculates its position by a technique called satellite ranging, which involves measuring the distance between the GNSS receiver and at least three GNSS satellites it is tracking. The range (the range a receiver calculates is actually a pseudo-range, or an estimate of range rather than a true range) or distance, is measured as elapsed transit time.

A range/distance to each satellite can be calculate from the following formula:

$D = c * T + errors$, where c is the speed of light (299,792,458 m / s in a vacuum), T is a propagation time that is a difference between time when signal reached receiver and time when signal left satellite.

In order to measure the travel time T of the satellite signal, the receiver has to know when the signal left the satellite and when the signal reached the receiver. Knowing when the signal reaches the receiver is easy, the GNSS receiver just uses its internal clock to measure when the signal arrives to see what time it is. But how does a receiver "know" when the signal left the satellite? All GNSS receivers are synchronized with the satellites by using ephemeris so they generate the same PRN code at the same time. The amount of delay is the transit time. This principle is demonstrated in Figure 36.

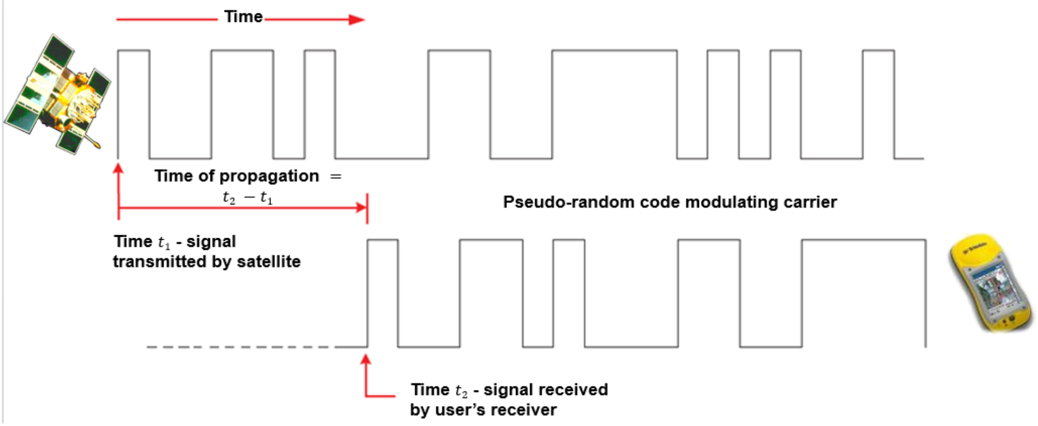


Figure 36: Determining Time of Propagation

Once the receiver has three or more distance measurements, it is basically a problem of trigonometry (trilateration) to determine a receiver coordinates.

1.7.2. Differential corrections and SBAS

Integrating external information into the GNSS-coordinators calculation process can materially improve accuracy. For this purpose networks of augmentation systems are developed. Such augmentation systems are generally named or described based on how the external information arrives to improve accuracy GNSS measurements through differential correction.

Some systems transmit additional error information (such as clock drift, ephemera, or ionospheric delay), others characterize prior errors, while a third group provides additional navigational or vehicle information. Examples of augmentation systems include the International GNSS Service (IGS), US Nationwide Differential GPS System (NDGPS), Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS), OmniSTAR etc. See more at http://www.gps.gov/systems/augmentations/.

Differential correction reduces the effects of some GNSS errors. The main principle of differential correction is to use GNSS receiver "base station" on the ground with known location as a fixed static reference point. The position of a base station is determined to a high degree of accuracy using GPSS and conventional surveying techniques.

In particular point of time, the base station measures ranges to GNSS satellites. Since the base station "knows" where it is with high accuracy, it can compute the errors in its position calculations (or timing errors). Then corrections for the errors can be sent to any number of roving receivers (rovers) in the same general area. These rovers incorporate the corrections into their position calculations (Figure 37). This requires that the base and rover receivers "see" the same set of satellites at the same time.

The incorporation of corrections is based on the following assumption: since GNSS satellites orbit high above the earth, the propagation paths from the satellites to the base stations and rovers pass through similar atmospheric conditions, as long as the base station and rovers are not too far apart.

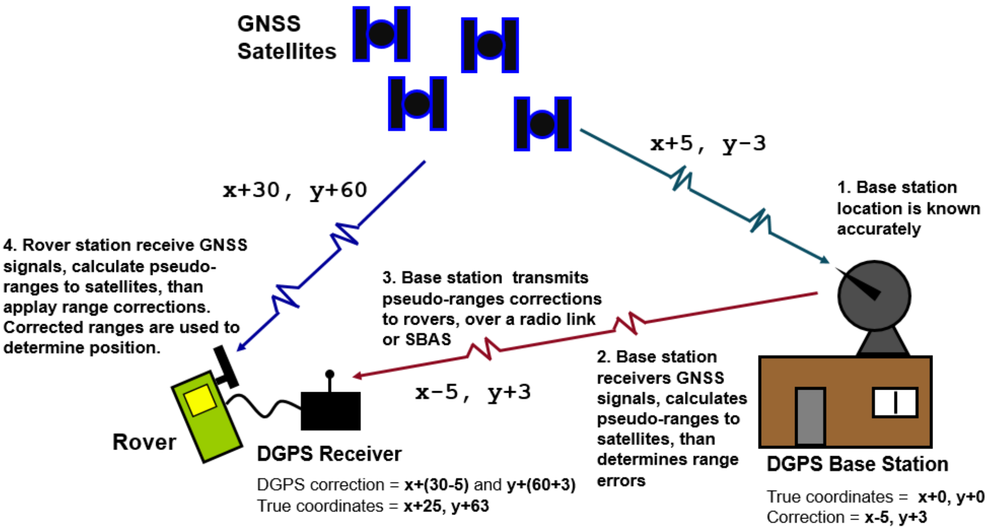


Figure 37. Principle differential corrections with real-time Differential GNSS

Differential real-time positioning requires a data link between base stations and rovers if corrections need to be applied in real-time, and at least four GNSS satellites in view at both the base station and the rovers. The absolute accuracy of the rover's computed position will depend on the absolute accuracy of the base station's position and separation between base station and rover positions (baseline). The base station can usually serve users in an area with up to 500 kilometers radius of baseline. However, differential GNSS works with better accuracy if with base-station-to-rover separations of up to 20 kilometers.

The base station, depending upon how it is configured, can correct roving GNSS receiver data in one (or both) of two ways:

- In **real-time** differential correction or real-time differential GNSS (DGNSS), the base station transmits error correction messages to GNSS receivers located in the field and corrections is performed in real-time by using GNSS differential correction software. Real-time correction can be implemented based on:
  - Local ground-based or terrestrial radio-beacon base stations with BoB (Beacon-on-Belt) receivers. For example, the Nationwide Differential GPS (NDGPS) radio-beacons stations' network is a terrestrial augmentation system, which is used for real-time or post-processed differential corrections.
  - Satellite-based augmentation system (SBAS). For example Wide Area Augmentation System (WAAS) and OmniSTAR communication satellites is used for real-time differential corrections.
- A **post-processed** differential correction is implemented in the office after GNSS data are collected. Thus a file with differential correction errors can be download from a base station via network (e.g., Internet) and applied to the field GNSS measurements on a computer by using differential correction software. The base station file contains information about the timing errors. Since the base station and rover receivers have to "see" the same set of satellites at the same time, the base file has to start before the rover file starts, and end after the rover file ends (a base station is normally set up to track all satellites in view, insuring that it will "see" at least the four satellites that the roving receiver is using to compute positions). Now GNSS differential correction services are available wirelessly through mobile devices.

Differential correction files are disseminated in specific formats. One of most widely used formats is Receiver Independent Exchange (RINEX) format, which supports conversion of position data.

- **Blended mode** – a user uses real-time and post processed techniques.

As it is shown above, there are ground based augmentation systems (GBAS) and satellite based augmentation system (SBAS). For applications where the cost of a ground differential GNSS system is not justified, or if the rover stations are spread over too large an area, a **Satellite-Based Augmentation**

System (SBAS) may be more appropriate for enhancing position accuracy. SBAS systems are geosynchronous satellite systems that provide differential correction services for improving the accuracy, integrity, and availability of basic GNSS signals.

A geosynchronous orbit has an orbital period matching the Earth's sidereal rotation period. This synchronization means that for an observer at a fixed location on Earth, a satellite in a geosynchronous orbit returns to exactly the same place in the sky at exactly the same time each day. The term geostationary is used to refer to the special case of a geosynchronous orbit that is circular (or nearly circular) and at zero (or nearly zero) inclination, that is, directly above the equator. Satellites in geostationary orbits appear stationary at one location at all times.

SBAS systems include reference base stations, master stations, uplink stations and geosynchronous SBAS satellites (Figure 38).

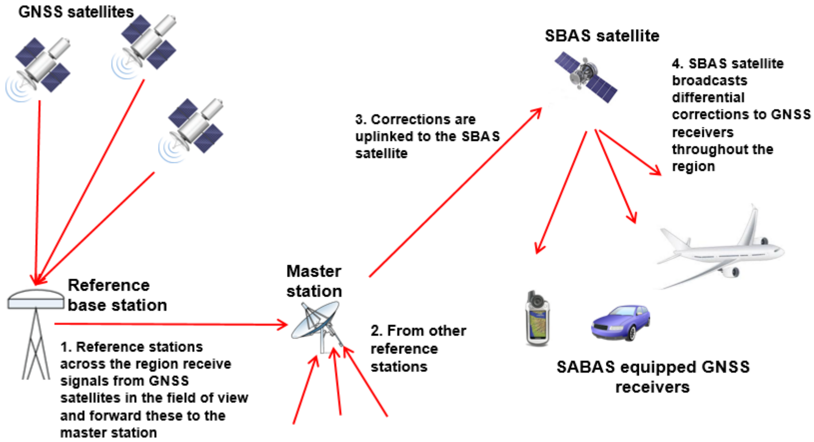


Figure 38. GNSS-SBAS data gathering and correction broadcast

Reference base stations, which are geographically distributed throughout the SBAS service area, receive GNSS signals and forward them to the master station. Since the locations of the reference base stations are accurately known, the master station can accurately calculate wide-area corrections. Corrections are uplinked to the SBAS satellite(s), and then broadcast to GNSS receivers throughout the SBAS coverage area (Figure 38). User equipment receives the corrections and applies them to range calculations.

Several countries have implemented their own satellite-based augmentation systems. Europe has the European Geostationary Navigation Overlay Service (EGNOS) which covers the EU and possibly beyond (http://egnos-portal.gsa.europa.eu/discover-egnos/about-egnos). EGNOS provides both correction and integrity information about the GNSS system, delivering opportunities for Europeans to use the more accurate positioning data for improving existing services or developing a wide range of new services.

The USA has its Wide Area Augmentation System (WAAS). Thus, with Selective Availability set to zero, and under ideal conditions, a GNSS receiver without WAAS can achieve 10-15 meter accuracy most of the time. Under ideal conditions, a WAAS equipped GNSS receiver can achieve less than three-meter accuracy 95% of the time.

CDGPS is currently offered throughout Canada, most of the continental United States, and much of the Arctic. Japan is covered by its Multi-functional Satellite Augmentation System (MSAS). India has launched its own SBAS programme named GNSS and GEO Augmented Navigation (GAGAN) to cover the Indian subcontinent. Both Korea (2013) and China (2014) have announced plans to start their own SBAS implementation.

Some companies, such as OmniSTAR (provide worldwide services including Europe, Middle East, Russia and CIS) and RACAL provide differential corrections in real-time via their own communication satellite systems. A special satellite receiver as well as the payable subscription are necessary to receive their signals.

SBAS services can be free (e.g., WAAS, EGNOS) and commercial (e.g., OmniSTAR, VERIPOS). In general, free government-provided SBAS services use the same frequency as GPS/GLONASS, and commercial SBAS services use a different frequency. In this case, additional equipment may be required to use SBAS differential corrections.

GNSS instruments from some companies offer an integration of GPS/GLONAS receiver with SBAS correction receiver within one rover. For example, in North America, many receivers are now WAAS compatible.

Differential correction can be attributed to satellite ephemeris and clock errors, but mostly to errors associated with atmospheric delay. Differential correction cannot correct for multipath or receiver error; it counteracts only the errors that are common to both base station and roving receivers. For example, GNSS error budget with standard (without differential correction) vs. with differential correction is shown in the following table 5:

Typical Error in Meters (per Satellite)		
	Standard GNSS	**Differential GNSS**
Satellite Clocks	1.5	0
Orbit Errors	2.5	0

Ionosphere	5	0.4
Troposphere	0.5	0.2
Receiver Noise	0.3	0.3
Multipath	0.6	0.6
SA	30	0
Typical Position Accuracy		
Horizontal	50	1.3
Vertical	78	2
3-D	93	2.8

1.7.3. Carrier Phase Positioning

For applications such as cadastral surveying, higher accuracies are required than cannot be achieved from code phase positioning techniques even with differential corrections. Higher accuracies can be achieved by using carrier phase positioning techniques. Carrier phase receivers typically provide up to a few centimeters position accuracy with differential correction. Carrier phase positioning can only be used with a differential system, and only works to about 30 km from the base station.

The carrier phase processing technique gathers data via a carrier phase receiver, which uses the carrier signal to calculate positions. The carrier signal, which has a much higher frequency than the pseudo-random code, is more accurate (typically, about two orders of magnitude) than using the pseudo-random code alone. Thus, carrier wavelengths (19 cm for L1) are much shorter than the C/A code length (293 m modulated in L1) and consequently potentially can be measured more accurately and used to achieve much higher positional accuracies than code measurements. The pseudo-random code with differential correction narrows the reference then the carrier code narrows the reference even more. After differential correction, the carrier phase processing technique results in centimeter accuracy.

Thus, the carrier frequency ν is multiplied by the vacuum speed of light c gives the wavelength λ, e.g., 19 cm for L1. In this case, accuracy detection of pseudo-range D is within 1% of wavelength and error is as little as 2 millimeters. This compares to 3 meters for the C/A code and 0.3 meters for the P code.

$$\lambda = c/\nu$$

However, 2 millimeter accuracy requires measuring the total phase - the number of waves (or full carrier cycles) multiplied by the wavelength plus the fractional wavelength (or cycle). This requires specially equipped receivers. At a very basic conceptual level, carrier phase receivers measure the distance from the receiver to the satellites by counting the number of carrier waves (and even portions of waves) of the L1 and/or the L2 signal between the satellite and the rover station, then multiplying this number by the carrier wavelength.

There is, however, one problem. The carriers are just pure sinusoidal waves: all cycles look the same. A GPS receiver cannot differentiate one cycle of wave from another. The receiver, when it is switched on, cannot directly determine the total number of complete cycles between sattelite and the receiver. It can only measure a fraction of a cycle very accurately (as little as 2 millimeters), while the initial number of complete cycles remains unknown or ambiguous. This is known as the initial cycle ambiguity. Fortunately, the receiver has the capability to keep track of the phase changes after being switch on. This means that the initial cycle ambiguity remains unchanged over time (El-Rabbany, 2002).

A complicated process called "ambiguity" resolution is needed to determine the number of whole waves. If the initail cycle ambiguity paraemters are resolve, accurate range meuremnts can be obtained.

A GNSS receiver which records the carrier phase, measures the fraction of one wavelength (i.e. fraction of 19 cm for the L1 GPS carrier and 24 cm for the L2 GPS carrier) when the receiver first locks onto a satellite and continuously measures the carrier phase from that time. The number of cycles/waves between the satellite and receiver at initial start-up (the ambiguity and the measured carrier phase together represent the satellite-receiver range (i.e. the distance between a satellite and a receiver) and can be represented as

$$D = \Phi - (\lambda * N + e)$$

Where D is the pseudo-range observation, Φ is the carrier phase observation (in length units), λ is the carrier wavelength, N is the integer carrier phase ambiguity, e is errors (range errors due to satellite and receiver clocks' errors, ionospheric and tropospheric refractions) (Wells et al. 1987).

The ambiguity is the unknown integer number of times the carrier wave length at initial start-up. Such ambiguity can be fixed mathematically to get the carrier phase measurements at the accurate level of a few centimetres. Resolution of integer ambiguity requires sophisticated statistical software, access to multiple satellites, and that receivers record the full-wavelength carrier phase and signals of two or more frequencies (e.g., C/A codes from L1 and L2). A rover determines its position using algorithms that incorporate ambiguity resolution and differential correction.

To boosts the GNSS accuracy, dual-frequency techniques should be used. Dual-frequency receivers are capable of providing sub-centimetre GNSS position accuracy with differential correction. Dual-frequency receivers receive signals from the satellites on two frequencies simultaneously. For example, when combined with L1 C/A in a dual-frequency receiver, the new L2C-code enables ionospheric correction, a technique that increases accuracy. Civilians with dual-frequency GNSS receivers enjoy the same accuracy as the military (or better).

Requirements for survey-grade GNSS receivers are that they record the full-wavelength carrier phase and signal strength of the L1 and L2 frequencies, and they track at least eight satellites simultaneously on parallel channels.

The electronics to carry out carrier phase positioning are much more sophisticated and precise than those used for code phase positioning. Unlike code phase positioning, carrier phase positioning must use an analogue radio receiver, which cannot be placed on a chip like inexpensive carrier phase receivers.

The carrier phase receivers are much more accurate than C/A code phase receivers, but require strict data collection requirements and more post-processing. Thus, occupation times on rover stations can be 30 minutes and more. A GNSS receiver has a configuration option to set carrier occupation time, as soon as it is achieved the receiver stores the collected rover file with GNSS data, and then the data can be differentially corrected with carrier phase processing (Figure 39). A new rover file must be created for each subsequent carrier session. Although it is more difficult to gather carrier code data than solely PRN code, accuracy is increased.

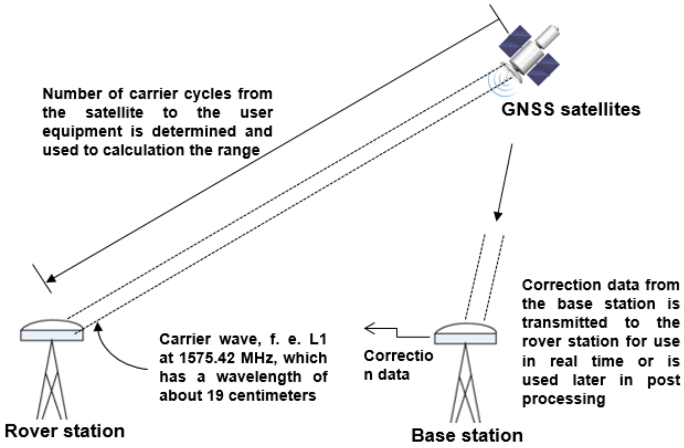


Figure 39: The carrier phase positioning: the range is calculated by determining the number of carrier cycles between the satellite and the rover station, then multiplying this number by the carrier wavelength.

Carrier phase receivers (survey grade) require a clear view to the satellites in order to maintain a constant lock with at least 4 satellites, while C/A code receivers (mapping grade) do not need to maintain a constant lock with the satellites to calculate positions. This makes a C/A code receiver imperative to gathering data in adverse conditions (for example, under trees).

There are several field surveying methods for using carrier phase GNSS observations. Among them are static, rapid static and kinematic techniques. These field positioning methods can use carrier phase signals and PRN signals from GPS or/and GLONAS, and plus differential correction techniques.

Conventional static GNSS surveying was the first method used in the field and it continues to be the primary technique used today. Static GNSS surveying requires collecting data from the same satellites simultaneously between stationary receivers (base stations) for an extended period of time, usually from 1 hour to 4 hours, depending on baseline length. Using this method requires the design of a GNSS network and an observation schedule for the coordination of receivers. The range of accuracy using conventional static GNSS varies depending on the observing and processing procedures followed, the baseline lengths measured and the receivers/antennas used, the accuracy of the differential corrections, among other variables (e.g., site and time selection, the quality of the base station etc.). For very precise applications, specialised software with processing techniques should be employed to handle errors. Using such techniques, accuracies of less than 1 cm can be achieved for baselines of up to 600 km in length depending on satellite geometry.

Fast static is a procedure that uses very short occupation times - minutes instead of hours of observations. Unlike static methods, which sometimes require multiple occupation sessions to build redundancy into the network, rapid-static stations need to be occupied only once. The technique relies on specific processing algorithms and additional information such as P-code observations or redundant satellites (e.g. seven or eight satellites instead of the minimum four). In addition, rapid static surveys should be conducted over short baselines (e.g. less than 10 km) to achieve the few centimetre level accuracy.

The main limitations of carrier code techniques are as follows:

- Need to support limited range with respect to the base location.
- The need of a communication channel for real time applications.
- Some convergence time is needed to fix the phase ambiguities. This time depends on the processing algorithm and the distance between base and rover.
- In order to avoid re-initialization of the processing, the rover has to track the GNSS signals continuously.

1.7.4. Real Time Kinematic

GNSS positioning may also be categorized as static or kinematic. In static positioning, a GNSS receiver is required to be stationary whereas in kinematic positioning a receiver collects GNSS data while continuously moving. Kinematic techniques are sometimes referred to as continuous kinematic or pure kinematic techniques. This differentiates kinematic from semi-kinematic techniques, which require stops at points to be positioned (USGS Global Positioning Application and Practice, 2015).

The Real Time Kinematic (RTK) approach, originated in the mid-1990s, involves using at least one stationary reference receiver (e.g., base station) and at least one moving rover (or several receivers), in addition a communication channel between base station and rover is required. The technique is based on the use of carrier measurements and the transmission of corrections from the base station to the rover, so that the differential errors cancel out. This allows for real-time surveying in the field and allows the surveyor to check the quality of the measurements without having to process the data. If a RTK base station covers a service area spreading about 10 or 20 kilometers, then RTK surveying achieves performances in the range of a few centimeters. A DOP above 6 results in generally unacceptable accuracies for DGPS and RTK operations.

There is also Post-Processed Kinematic (PPK) techniques. PPK surveys are similar to RTK procedures, but the baselines are not processed in real-time.

PPK involves using one or more roving receivers and at least one static base station. GNSS data are simultaneously collected at the reference and rover receivers. The data are downloaded from the receiver, and the baselines processed using GNSS software.

Table 6: Positional accuracies of satanic and kinematic Carrier Phase techniques

Positioning Mode	Typical Horizontal Accuracy (5 Satellite's visibilities, PDOP<4)	Maximum Operating Range
Static	Horizontal: 5mm + 1 ppm (part-per-million) Vertical: 10 mm + 1 ppm	Several 100 km depending on satellite geometry
Real-time Kinematic	Horizontal 1 cm + 2 ppm Vertical: 2 cm + 2 ppm	Recommended: <10 km Maximum: 40 km Usually dependent on communication link

When choosing between a kinematic and a static methodology, the GNSS surveyor basically is making a choice between productivity and accuracy. The kinematic techniques can produce the largest number of GNSS points in the least amount of time; however, because of the shortened occupation times and less data to resolve integer ambiguity, there is a slight degradation in the accuracy of the work.

VOCABULARY

Almanac of GNSS: GNSS data about the state (health) of the entire GPS satellite constellation, coarse data (including coordinates) on every satellite's orbit, and satellite clock correction parameters.

Ambiguity: The number of whole carrier signal wavelengths (cycles) between a GPS satellite and a GPS receiver. This is important in the use of relative carrier phase measurement techniques.

Base station: A stationary reference receiver on the ground (can be on the roof of building) with known location measured with a high degree of accuracy.

Boundary or property line: An imaginary or marked line which define the extent of the legal limits of ownership of any parcel of land.

Cadastral map: A map which is produced by joining together individual cadastral plans.

Cadastral survey plan: A plan of a property boundary survey, which is carried out for legal purposes so as to accurately establish land legal boundaries and land’s ownership, restrictions and usage.

Carrier phase positioning: GNSS measurements based on carrier signal.

Carrier signal or waves: A signal which is modulated in frequency, amplitude, or phase, in order for it to carry information.

Chain traversing: The method in which the whole work is done with chain and tape is called chain traversing.

Closed traverse: A traverse that begins at a point and ends at the same point or at a point whose position is known.

Closure error (or misclosure, discloser error): A traverse error which indicates accuracy of the surveying of closed traverse and potential problems in the original survey data.

Code phase positioning: GNSS measurements based on the pseudo random code (PRN) as opposed to the carrier of that code.

COMPASS (**BeiDou**): The Chinese GNSS, set to supersede the COMPASS regional system operating since 2000, is managed by the governmental China Satellite Navigation Office.

Compass rule: The adjustment method then the error of closure is a result of accidental errors affecting angular and linear measurements equally.

Control GNSS segment: A ground-based network of master control stations, data uploading stations, and monitor stations.

Coordinate geometry (COGO): A method for calculating coordinate points from surveyed bearings, distances, and angles.

Crandall method: The adjustment method then the error of closure is a result of accidental errors and the effects of errors in angular measurements are negligible or have already been adjusted out of the traverse. It assumes that any adjustment should be applied only to the lengths/distances of the courses.

Differential correction: The method of reducing the effects of some GNSS rover errors by applying corrections received from a base station.

Dilution of Precision (DOP): The set of parameters which can be used to measure quality of satellite geometry or a numerical definition of satellite geometry.

Ephemeris of GNSS: A set of parameters that can be used to accurately calculate the location of a GNSS satellite at a particular point in time.

Galileo: Europe’s GNSS, currently under development as the only civil GNSS, is owned and managed by the European Union.

Global Navigation Satellite System (GNSS): A satellite system that is used to pinpoint the geographic location of a user's receiver anywhere in the world.

Global Positioning System (GPS): The first GNSS, fully operational since 1995, is managed by the US Department of Defence

GLONASS: The Russian GNSS, completed in 1995 and fully operational since 2011, is managed by the Russian Aerospace Defence Forces.

Ground based augmentation systems (GBAS): A network of local terrestrial base stations with GNSS receivers (base stations) used for the deferential corrections.

Ionospheric delays: Delays of GNSS signals in ionosphere due to free electrons.

Land surveying: The art and science of measuring, marking, recovering, and mapping the relative positions or locations of terrain features and real property boundaries.

Least Squares adjustment: The adjustment method then the error of closure is a result of accidental errors. The Least Squares adjustment theory states that, for any set of measured values, the best set of corrections to apply to the measured values is one such that the sum of the squares of all of the corrections is minimized.

Loop traverse: A traverse which starts at a given point, proceeds to its destination, and returns to the starting point without crossing itself in the process.

Metes and bounds: the method of descriptions of the perimeter of property.

Monumentation: The process of establishing corners of parcel's boundaries. It is often defined in specifications established by states, provincial and/or professional surveying organizations.

Multipath: Displacement errors of GNSS carrier signals caused by reflections from buildings, walls etc. when signals entering the receiver antenna.

Navigation message: A low frequency signal added to the carrier signal that gives information about the satellite's orbits, their clock corrections and other system status. It contains ephemeris data and almanac data.

Occupation time: the amount of time required to allow satellite acquisitions on a station, or point, and to achieve successful processing of GNSS data.

Open traverse: A traverse that originates at a starting station, proceeds to its destination, and ends at a station whose relative position is not previously known.

Plain table traversing: A method of tacheometry where a plane table is set at every traverse station in the clockwise or anticlockwise direction, and circuit is finally closed.

Plat: A report of a land survey in the form of a cadastral drawing.

Post-processed differential correction: A differential correction techniques which can be implemented in the office after GNSS data are collected.

Propagation time: A difference between a time when signal reached receiver and time when signal left satellite.

Relative positioning: The process of determining the relative difference in position between two locations.

Pseudo random code: A signal with random noise-like properties with repeating pattern of 1's and 0's.

Pseudo-range: A distance measurement between a GNSS satellite and a recovers based on the correlation of a satellite transmitted code and the local receiver's reference code, that has not been corrected for errors in synchronization between the transmitter's clock and the receiver's clock. A pseudo-range is a range estimated from the time rather than a true distance.

Real Time Kinematic (RTK): The GNSS acquisition technique involves using at least one base station and at least one moving rover (or several receivers). The GNSS rover can be mounted on a vehicle or aircraft. The RTK technique provides high positioning performance in the vicinity of a base station.

Real-time differential correction (DGNSS): A differential correction techniques which can be implemented by GNSS receivers in the field during surveying.

Resection: COGO method of calculation for the coordinates of an unknown or free station by observing the three established stations or known points from the unknown point.

Rover: A GNSS receiver used for Real Time Kinematic positioning.

Satellite-Based Augmentation System (SBAS): A geosynchronous satellite systems that provide differential correction services for improving the accuracy, integrity, and availability of basic GNSS signals.

Selective Availability: The capability of GPS. It can be occurred when the DoD intentionally degraded the accuracy of GNSS signals by introducing artificial clock and ephemeris errors.

Side shot: A single measurement to a feature, which is to the side of the main traverse line.

Space GNSS segment: GNSS and SBAS satellites that are orbiting.

Survey post: A control point which is set in the ground to define the boundaries of the parcel.

Tacheometry: An optical solution to the measurement of distances and angles.

Theodolite: A precision instrument that consists of a movable telescope for sighting distant target objects, two measurement wheels that work like protractors for reading horizontal and vertical angles precisely, and bubble levels to ensure that the angles are true.

Theodolite-EDM: An instrument known in jargon as a total station that is able to measure distance, vertical and horizontal angels, and relative elevation by reflecting off a reflector's prism or features.

Timing offset: An error between satellite and receiver clocks.

Total Station: A surveying device which uses electronic transit theodolites in conjunction with an electronic distance meter (EDM) to read any slope distance from the instrument to any particular spot.

Transit rule: The adjustment method then the error of closure is a result of accidentally errors affecting and that the angular errors are less that the linear errors.

Traverse stations (TS): Turning points of a traverse, whose X and Y coordinates are to be determined in some reference system of coordinates.

Traverse: The method of the field surveying. It consists of a series of lines, whose lengths and directions are measured by surveyors in associated connecting points, called traverse stations (TS) or traverse points.

Traversing by fast needle method: The method in which the magnetic bearings of traverse lines are measured by a theodolite fitted with a compass.

Triangulation: The surveying method that is based on the trigonometry that if one side and three angles of a triangle are known, the remaining sides can be computed.

Trilateration of GNSS: the method of measuring the distances from 3 satellites to establish a position of a receiver on the Earth.

Trilateration: The surveying method that is based on the trigonometry that the lengths of all the sides of the triangle are measured and a few directions or angles are measured to establish azimuth, the remaining angles can be computed.

User GNSS segment: Military and civilian users who use GNSS equipment to process the received signals from the GNSS and/or SBAS satellites.

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ASSIGNMENT 1: CADASTRAL GPS AND TACHEOMETRIC SURVEY AND PLAT DRAWING

Description and Objectives

The aim of this lab assignment is to introduce students with the process of measurements of cadastral land plot by using professional GPS and tacheometer instruments, as well as to demonstrate how ArcGIS software can be used to process field survey measurements and draw a cadastral plan.

The students will be introduced to the following cadastral measurements and drawing topics:

- Prepare and configure survey instruments for cadastral plot measurements;
- Survey a plot of land based on adjacent measurements;
- Use a GPS device to build a control point network for cadastral survey;
- Use an electronic tacheometer/total station to survey cadastral plot objects;
- Transfer the measurement data from the survey instruments to ArcGIS;
- Create a GIS database of cadastral measurements in ArcGIS;
- Process cadastral measurements using ArcMap;
- Design a cadastral plot drawing using ArcMap.

Submission Requirements

Once you have finished the exercise, complete the questions, which you can find within the text. Your result of this exercise must be **plot_drawing.pdf** file.

Preparation

GIS data for this exercise you will find: **D:\Data\Lab1_Data**. On your local computer create new directory **Lab1_Result** in **C:\Users\YourUserName\Documents**. This directory must contain all your data and maps for this exercise.

Cadastral GPS and Tacheometric Survey and Plot Drawing

EXERCISE

The aim of the lab assignment is to simulate the field activities of a surveyor, and then a new order is received to measure a cadastral plot and produce a cadastral drawing. These practical tasks are based on the execution of a standard process of field cadastral measurements. Then a land surveyor / geodesist measures a land plot and as a result provides the customer the measurement data and plot drawing.

The first part of this lab demonstrates how to perform field measurements of cadastral plot by using professional GPS and tacheometer instruments. This part will start with a demonstration of technological aspects of instruments (preparation and configuration) as well as the planning of survey activities. The second part of the surveying exercise demonstrates how to build a geodetic ground GPS point network according to the shape of the land plot and its topography. The procedures of GPS surveying are described in detail. Then, how to survey cadastral objects by using an electronic tacheometry based on measured GPS points is demonstrated in step-by-step instructions.

The second part of this lab, instructs how to process field measurements and draw a plot plan in ArcGIS. The first part shows how to transfer measurement data into ArcGIS, and then how to build cadastral feature classes from measurement data. Then demonstrates how to design and layout a cadastral plot plan in ArcMap.

SCENARIO

For this lab, a surveyor carries out cadastral measurements to coordinate a proposed land plot. The plot has an adjoining boundary with seven existing parcels. The information on the neighboring parcels can be found in the public registry/cadastre. The area of the projected plot is larger than 30 hectares – this is a large plot. The task is to compile a plot boundary drawing which also shows metric measures of its segments and other associated cadaster objects. The resulting cadaster data should be stored in a geodatabase.

The field measurements were done using a Leica GPS 1200 instrument and a Leica TPS 1205 tacheometer/total station. The details of presented measurement instructions can vary according to the manufacturer specifications of devices used; however, the principles of measurement methodology remain the same. ArcGIS Desktop version 10.2.2 is used for processing and presentation of measurements. Due to the differences in functionalities of ArcGIS versions, the implementation of some ArcMap steps can slightly vary.

PART A: GPS AND TACHEOMETRIC SURVEY OF CADASTRAL OBJECTS

Surveying, like any profession, has its special terms and slang. The surveying terms and slang can be slightly different, depending on the country. In this lab, the following terms will be in used.

Land parcel is a single area of land under homogeneous real property rights and unique ownership. **Land plot** is a component of a land parcel, normally defined by the way in which the land is used and capable of being plotted on a map. In this lab, the ownership of the proposed plot is unknown; we are only dealing with surveying component of cadaster objects. **Cadastral plan** is a plan that showing land parcel and/or plot boundaries. Cadastral plans may also show buildings and other associated objects.

Land boundary is a line of demarcation between adjoining parcels or lots of land. A land boundary may be marked on the ground by material monuments placed primarily for that purpose; by fences, hedges, ditches, roads, and other service structures along the line; or by coordinates on a survey whose position on the ground is witnessed by material monuments/markers that are established without reference to the boundary line; and by various other methods. A boundary line is a line along which two areas meet. Boundary survey is a survey made to establish or to re-establish a boundary's line on the ground, or to obtain data for constructing a plot showing a boundary line. Another term for cadaster drawing is a **plot**. A plot is a drawing of a parcel of land created by the surveyor that shows the fieldwork, with bearings, distances, etc.

Tachometry (from Greek for "quick measure") is used for cadaster survey of land plot/parcels boundaries. Traditionally, **tachometry** or tacheometry is a method(s) of surveying for the determination of distance, direction, and relative elevation of a point with respect to the survey **station** (a position from which measurements in surveying are made), by a single observation on a rod or other object at the point. The tachometry computation uses a single survey station at a control point with known coordinates. Traditionally a tachymeter or tacheometer was a type of theodolite. A modern electronic tachometry uses a total station (slang), which contains a theodolite and Electronic Distance Measuring (EDM) instruments, to measure distance, direction, and relative elevation by reflecting off a reflector's prism placed at the point. Total station instruments include or are connected a field computer that stores readings and facilitates the processing of the data electronically. The computer records the slope and horizontal distances, horizontal and vertical angles from the survey station to the point, and can perform numerous calculations, including absolute coordinates of the point, using operating software that is loaded into the unit.

The surveying of a proposed cadastral plot plan starts with the establishment of geodetic GPS ground control point network. The GPS point network is necessary for the positioning and orientation of a tacheometer at a survey station from which the plot's boundary will be measured. The orientation of tacheometer is carried out at a survey station, which consists of two GPS points (fixed GPS points). One GPS point can be used as a tacheometer position and second one for the orientation of a tacheometer. At least two GPS points are necessary for orientation a tacheometer on a station. This technique of tachometry survey from two GPS control points is shown below:

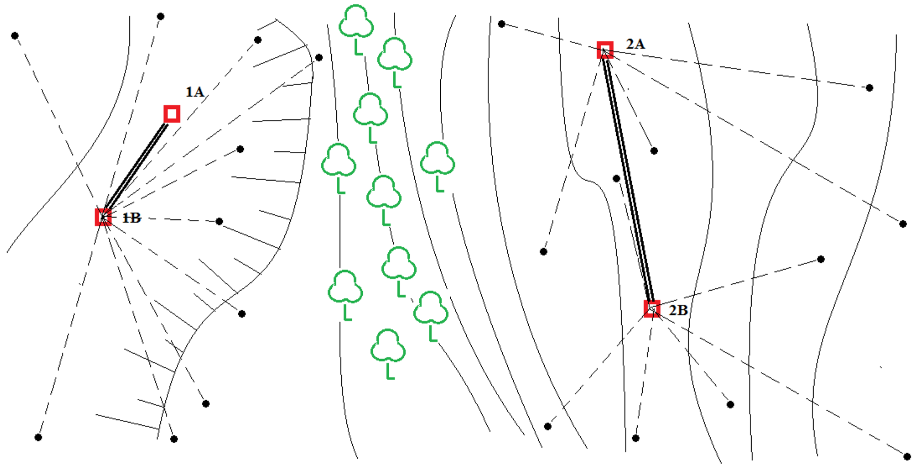


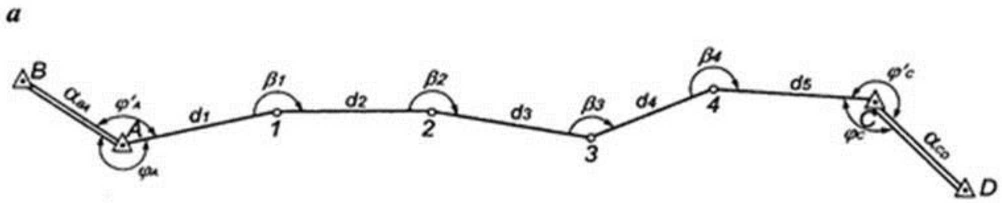
Figure 1: If trees and hills obstruct the views in survey area, it is necessary to set up two stations with two GPS points each. Two measurement stations – station #1 with GPS points 1A and 1B, and station #2 with GPS points 2A and 2B. GPS point 1B is used for a tacheometer positioning, and GPS point 1A is used for the tacheometer orientation. Similarly, GPS point 2B can be used for a tacheometer positioning, and GPS point 2A is used for the tacheometer orientation or vice versa.

If the terrain is relatively flat throughout the surveying area (in the range of up to 3 meters) then it is enough to use only one station with two GPS points to survey whole area. However, if in the area there are objects such as forest, bushes, single trees that can obstruct the view between two GPS points or from a tacheometer position to measured objects, then in the practice, surveyors established a number of two-GPS points' stations that cover the entire surveying area.

As soon as a tacheometer is positioned and oriented at a GPS point, a plot’s boundary and other objects around the positioned station can be measured using a tacheometer and reflector with a prism.

The example implementation of such a survey technique is described in Part A of this lab. In this part of the lab, you will just need to follow the steps and answer the questions found in the text.

Another classical tacheometric survey method is more complex. It is a traverse from two GPS points with known coordinates through the surveying area that also ends with two known GPS points. The example is shown below:



Where A and B, C and D are GPS known points. 1, 2, 3, 4 points are the intermediate traverse points which should be measured and used for tacheometry. To improve the accuracy of measurements, adjustments of the traverse measurements can be done e.g. by software of a total station instrument. To perform the adjustment, the traverse should end with two known GPS points.

Preparation Stage:

At the beginning of survey work, a spatial configuration of the proposed plot should be examined using existing topographic materials, such as ortho-photographs and existing cadastral plots (Figure 2). This is necessary for a surveyor to plan where to set up survey stations with two GPS points that will be using for measuring of the proposed plot’s boundary and associated objects.

Figure 2: The orthophoto plan of survey area – red line shows the boundary of proposed land plot and green lines show the boundaries of existing parcels/plots.

Positions of stations (GPS points) have to be selected according to the natural characteristics of the proposed plot, i.e. the plot shape, terrain and pattern of forest cover. A denser network of GPS points is better according the surveying guidance. GPS points should be fixed in open areas from which the boundary of plot is clearly visible as well as the plot's corner points (buildings, infrastructure objects, etc.). A GPS point network should cover the whole surveying area and allow coordinating of all associated plot's objects. Thus, the number of the GPS points can vary depending on the natural characteristics of survey area, for example:

- If a plot is in an open field and on a plain surface, and all surveying objects are visible from 2 GPS points, then 2 measurement stations are enough to survey a plot. These two stations will have 4 fixed GPS points (two for each GPS station). Two stations with 4 GPS points are necessary to check and adjust the measurements;
- If a plot is located in a hilly or/and wooded area, a GPS point's network should include as many points as necessary, in order to coordinate all objects of plot. For example, if 20 measurement stations are needed, there should be 40 GPS points measured (two for each GPS point) in order to survey whole plot.

In our case, the survey area is a wooded field with a large perimeter; therefore, a several GPS stations should be used to survey the plot using the discussed tacheometry technique. On arrival to the study area, the configuration of the plot should be analyzed and a decision made on how many stations should be set and where the GPS points will be fixed. An optimal configuration of geodetic ground point network should be selected.

As discussed above, a GPS point should be fixed in an open area from which it would be possible to survey the terminal points of plot boundary. Each station, from which a plot will be measured, must consist of at least two GPS points, i.e. the minimum number of the points necessary to carry out this tacheometry technique. A third point can also be fixed in the station to increase the accuracy of the measurements through adjustments, but two points are normally enough for accomplish a cadastral survey with required accuracy.

The position of GPS points should also consider the positions of GPS satellites in the sky. Any surrounding objects, such as buildings, trees, should not disturb satellite signals received by a GPS device. During the measurements, a GPS device should have direct views to at least 6-7 (maximum of 12) satellites, as well as to signals from differential correction satellites or networks (if provided).

Considering all these requirements, 12 stations with 24 GPS fixed points were selected at the surveying area. This configuration covers the entire surveying area, as shown in Figure 3.

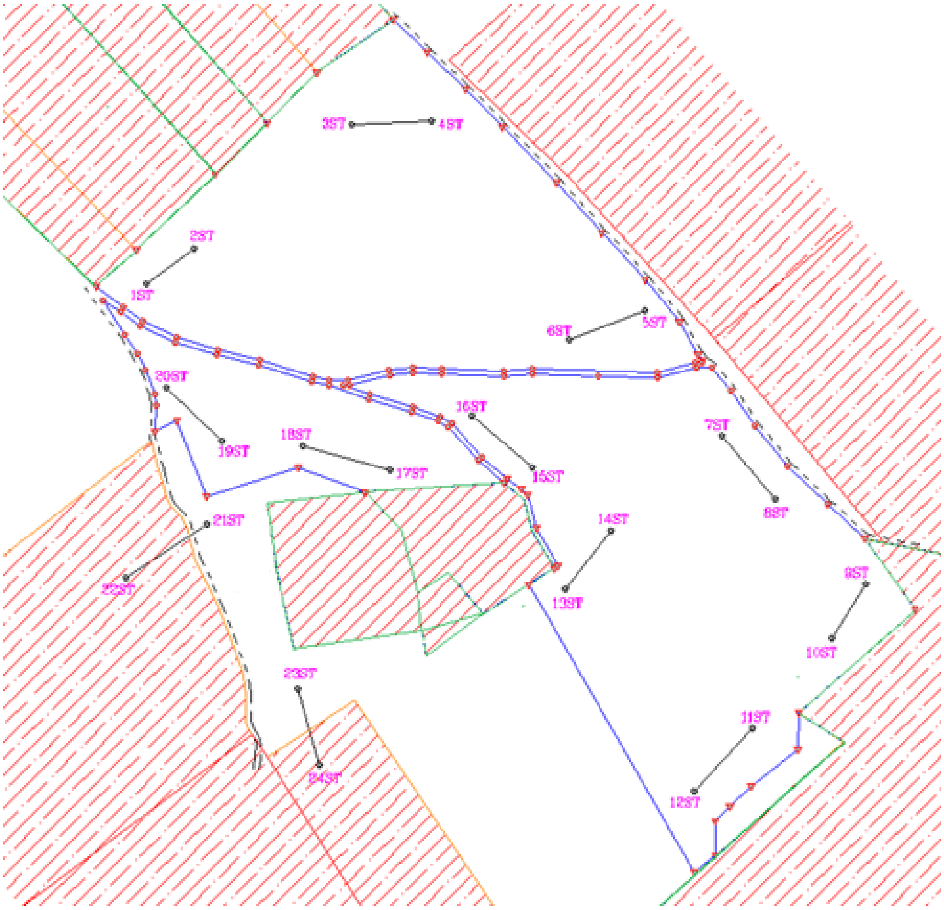
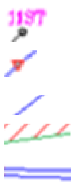


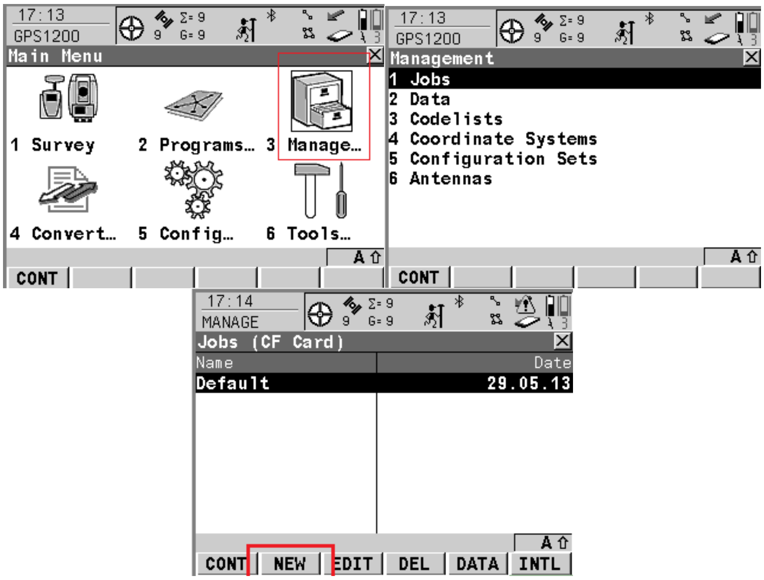
Figure 3: The scheme of tacheometric stations and GPS points



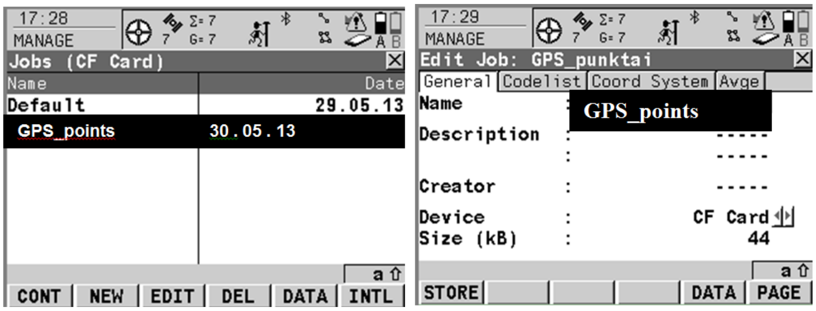
- a fixed GPS point;
- a turning point of the land plot;
- the boundaries of proposed land plot;
- the boundaries of existing land plots;
- the field road.

<u>GPS Measurements Stage:</u>

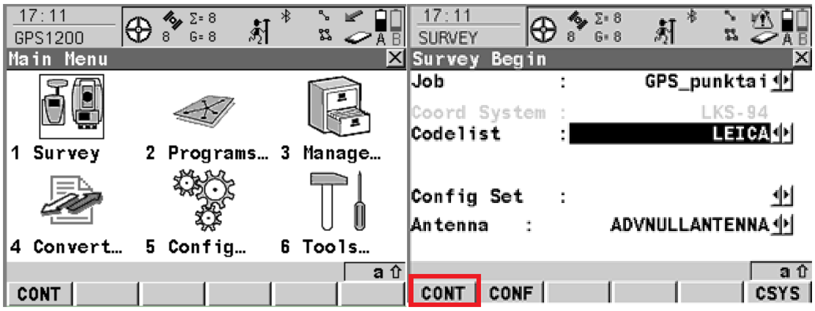
Leica GPS 1200 receiver was used for GPS measurements. To start the measurements at a GPS point, a new job was created by pressing *Management > Jobs > New* (see the sequence of print-screens of GPS receiver below).



When a dialog of the new job was opened, the new job title was entered, for example, *GPS_points*. Then, by pressing *Cont* (Continue) button, metadata for the job can be entered.



Returning to the *Main Menu*, the *Survey* option was selected. Then the *GPS_points* job was selected from the *Job* list and then *Cont* button was pressed.



Now GPS coordinates on the occupied point can be fixed. The dialog shows the parameters of the signal strength and accuracy, which have to be considered before fixing the GPS point coordinates.

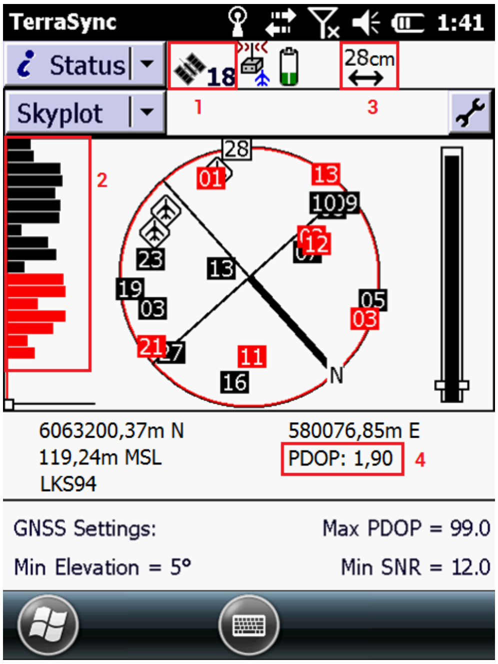
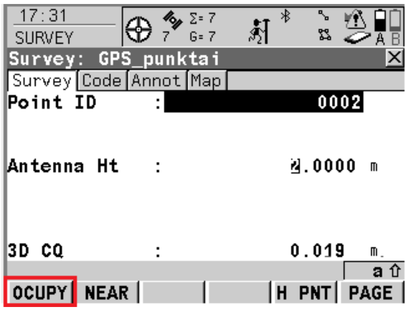


Figure 4: Main screen of signal strength and accuracy parameters of GPS device:

1. **Number of available satellites.**
2. **Satellite signal strength. Black bands indicate GPS signals strengths, red – GLONASS signals strengths.**
3. **Available accuracy.**
4. **PDOP parameter.**

The accuracy of ongoing cadastral measurements of horizontal coordinates must be less than 0.03 m. To achieve such accuracy, a high-quality signal should be awaited for about 1-3 minutes. In addition, the PDOP parameter should be considered. This parameter shows the accuracy of the satellite signals, which should not exceed 4.00 PDOP for cadastral measurements. The smaller the PDOP value, the smaller are the satellite signal errors, and the more accurate are measurements of point coordinates. Therefore, before fixing the point coordinates, the horizontal measurement error of the GPS device should be less than 0.03 m and PDOP less than 4.00. If the values of these parameters correspond to the surveying requirements, then the GPS point coordinates can be fixed.

When the required accuracy is reached, the GPS receiver was set on the station point and *Occupy* option was applied. The point coordinates were set automatically after 20 seconds. It necessary to set the point coordinates 2 times; the second measurement is necessary for confirmation.



Next, the coordinates of other remaining 23 GPS points of selected 12 stations (Figure 3) were measured. Again, each point was measured twice for confirmation. Surveyed GPS points were marked with the temporary markers, such as lath and ribbon, in order to find them later when the tacheometric survey will be carried out.

The coordinates of 24 GPS points were measured by Lithuanian surveyors. They are shown in Table 1. These points are prepared in LKS-94, which is the Lithuanian Coordinate System based on Lithuania 1994 (ETRS89) datum http://georepository.com/crs_4669/LKS94.html.

Table 1: A list of the GPS point coordinates

Coordinate system LKS-94							
Point nr.	Code	X	Y	Point nr.	Code	X	Y

1	ST	6045669.03	543692.30	13	ST	6045346.31	544135.64
2	ST	6045706.28	543743.31	14	ST	6045408.23	544184.59
3	ST	6045837.30	543910.06	15	ST	6045475.01	544100.98
4	ST	6045840.33	543994.32	16	ST	6045529.28	544037.49
5	ST	6045641.10	544220.75	17	ST	6045472.71	543950.29
6	ST	6045610.48	544139.72	18	ST	6045497.94	543857.73
7	ST	6045508.00	544302.37	19	ST	6045503.29	543772.05
8	ST	6045441.50	544358.21	20	ST	6045559.09	543713.92
9	ST	6045351.74	544453.94	21	ST	6045415.43	543756.56
10	ST	6045295.17	544418.75	22	ST	6045358.56	543670.96
11	ST	6045199.38	544334.53	23	ST	6045241.61	543852.25
12	ST	6045132.87	544273.34	24	ST	6045160.58	543875.96

Question 1: What is the minimum number of GPS points that must be measured for cadastral survey of plot? (2 points)

a) 2 GPS points
b) 4 GPS points
c) 6 GPS points
d) 8 GPS points

Question 2. What are the main criteria for choosing right positions for measuring GPS points in tachometry survey? (2 points)

a) Relief

b) Vegetation (trees)
c) Buildings
d) Weather
e) a and b
f) b and c
g) c and d
h) a, b, c, and d
i) a, b and c
j) b, c and d

Question 3: Minimum of 4 satellite readings is necessary to get an accurate 3-D position using a GPS receiver. Explain why. (4 points)

Question 4: What coordinate system is used to define the position of GPS satellites? What coordinate system is used in GPS receivers? (4 points)

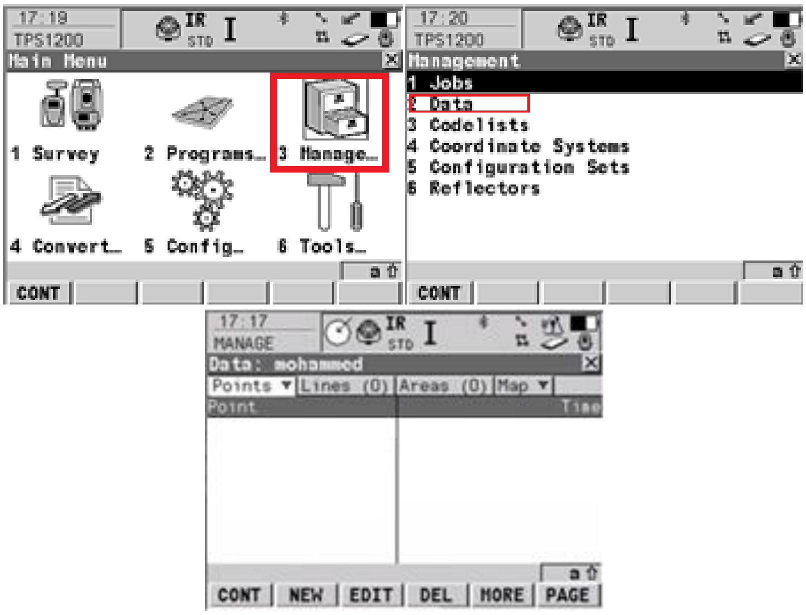
Question 5: PDOP stands for: …. Quantify your answer. (3 points)

Question 6: We mentioned about "differential corrections". What does this term mean and how does DGPS work? (4 points)

<u>Tacheometric Survey Stage:</u>

After fixing the coordinates of 24 GPS points, the points' measurements, which are their LKS-94 coordinates, should be transferred from the GPS data-logger to the electronic tacheometer. Leica TPS 1205 total station was used as the tacheometer for the fieldwork. Since there were not too many fixed GPS points, they can be manually added into the tacheometer, since usually there are no devices for data transfers in the field.

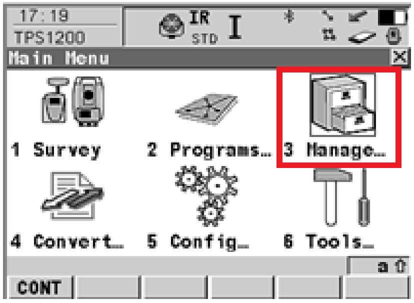
To add a new GPS point into tacheometer, first, the *Management* option was used, and then *Data* > *New* point options were selected (see the sequence of print-screens of GPS receiver below).

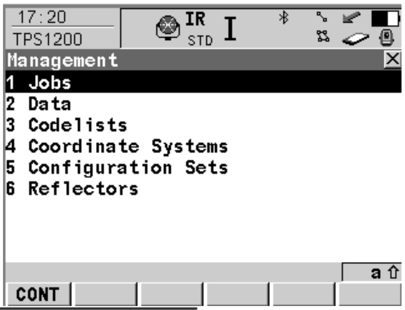


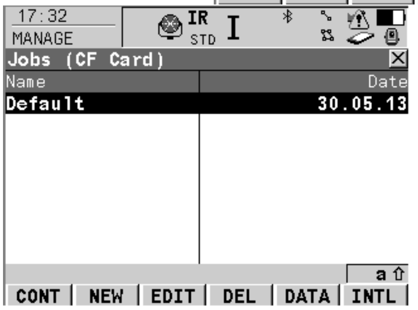
In the *New Point* dialog, a new point was created in the tacheometer by entering its ID, *Easting* (Y) and *Northing* (X) coordinates obtained from the GPS measurements. The *Store* command was applied to create the point, so the point was saved in the device memory.

The same dialog was used to enter ID and coordinates of another GPS point. Sequentially, all points listed in Table 1 with their ID and GPS coordinates were entered in the tacheometer. *ESC* button was used to return to the main menu.

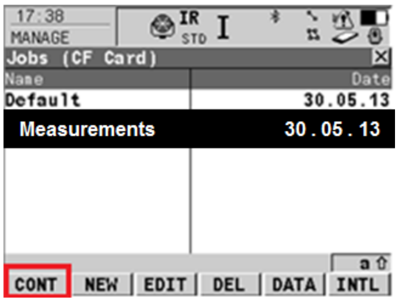
Once the GPS points with coordinates are entered into the tacheometer, the survey of plot boundary can be started. To start, a new job was created by pressing *Management* > *Jobs* > *New*.

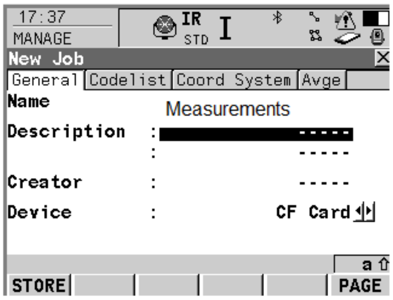






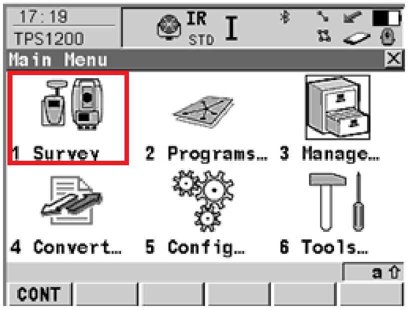
The job title *Measurements* was assigned to the new job. Then, by applying *Cont* button, metadata for the job can be entered.



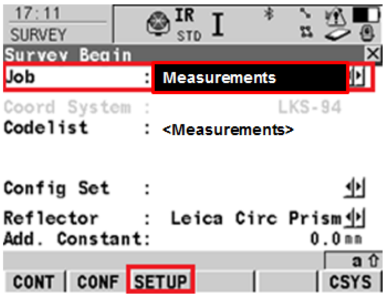


Next, the total station was positioned on one of the measured GPS points, which was found by the temporal marker created on site earlier. Then, the total station was horizontally aligned by using its level.

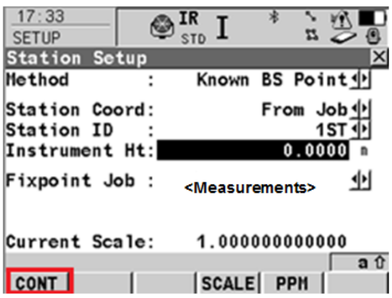
Then the *Survey* option was selected from the *Main Menu*.



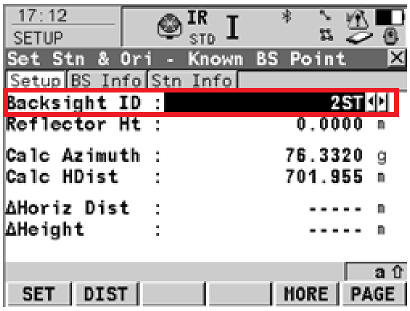
Next, from the job list, the *Measurements* job was selected and the *Setup* button was clicked.



Once the *Setup* dialog window was opened, a function *Known BS Point* was selected from *Method* list. Then the *From Job* option was selected from the *Station Coord* list. In the list *Station ID*, the GPS point on which a device was fixed was selected (one of the 24 measured GPS points). In this case, it was the 1st GPS point. The value of *Instrument Ht* option should be left empty. The heights of the points were not measured because a georeferenced orthoptograph was used as a background for a survey plan. In the list *Fixpoint Job*, the job *Measurements* was selected. These parameters were applied by clicking the *Cont* button. These setting defined the position of the tacheometer.

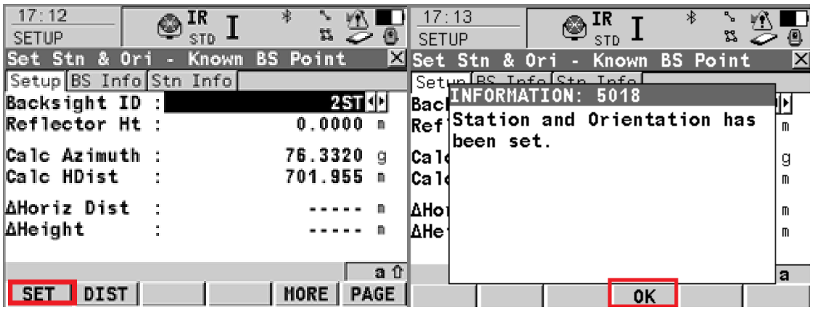


In the next dialog window *Set Stn & Ori - Known BS Point*, the GPS point to which the tacheometer should be oriented was selected from the list *Backsight ID,* e.g., this is the second GPS point. If tacheometric station consists of two GPS points #1 and #2 (see Figure 3), and if the tacheometer was positioned at the point #1, then it should be oriented to the point #2. Thus, the list value of *Backsight ID* was set up to the point #2. These setting defined the orientation of tacheometer.



Next, the telescope of tacheometer was oriented to the prism (Figure 4), which was positioned at the second point, and then *Set*. The orientation of device was confirmed by pressing *OK*.

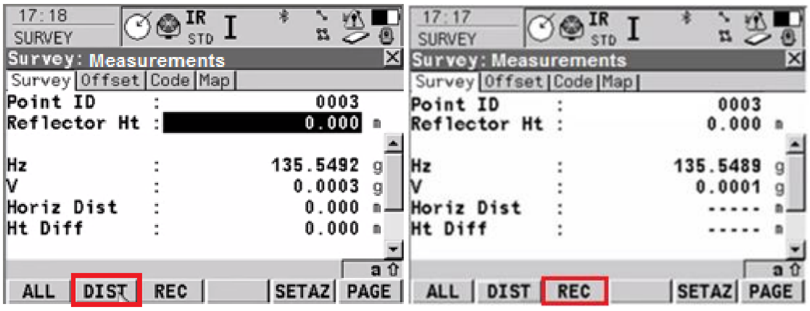
Figure 5: Directing the tacheometer into the prism



Question 7: What is the minimum number of GPS points that must be used for orienting tacheometer? (2 points)

a) 2 GPS points
b) 4 GPS points
c) 6 GPS points
d) 8 GPS points

Once the instrument was oriented, the measuring dialog window opens automatically. To start measuring, the *Survey* button was clicked, the previously created *Job* was chosen and then *DIST* button in the *Job* menu dialog was selected. The prism was positioned on a turning point of the land plot. Then the *REC* button was pressed to save measurement and the next measurement point was chosen. Thus the plot boundary and objects of interest, which should be shown on a cadaster plan, such as roads, power poles, etc., were measured around the GPS point #1.



Road surveying: To survey the roadsides, the reflector with prism was set on the edge of the road. Edges of roads were measured in terminal points from the both sides, then later they can be joined to show road on a plat. The example of a survey of road section is illustrated in Figure 5. The drawing shows where the road terminal points were fixed.

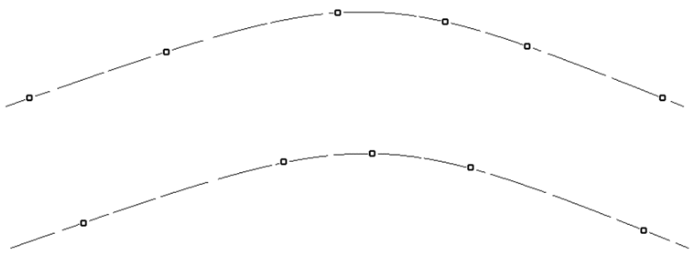


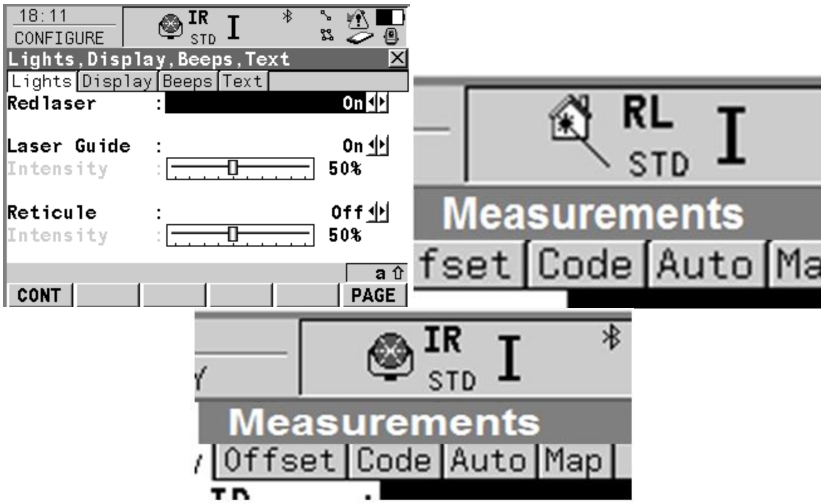
Figure 6: The drawing of road terminal points' survey

The surveying of power poles: To survey the power poles, the prism was positioned near the power pole directly to the tacheometer. Then the exact positions of the power poles were fixed.

Other plot objects, such as fences, forest boundaries, etc., are surveyed in turning points, which are where the objects change in configuration, position or/and direction.

During the tacheometry, each surveying object was coded with the following descriptions: house-1, house-2, house-3 – these points indicate the house corner or wall edge; road-6, road-7, road-8 – these points indicate the road terminal points; fence-7, fence-8, fence-9 - these points indicate a terminal point of the fences, etc.

If the visibility in the surveying area is good, the coordinates of a plot object can be done with a laser beam without using a reflector with prism. By pressing *Shift* and *F11,* the laser is activated. By press *F11* change from the prism mode into the reflectorless mode.



The laser of the tacheometer can be pointed at a plot object (e.g., poles), plot terminal points (e.g. fences), and their coordinates can be fixed. Measurements by the laser speed up the work and make it easier, because an assistant to the surveyor does not have to walk and move a reflector. In addition, the measurement with a laser is very convenient when measurements are made in hard to reach or dangerous locations. However, reflectorless survey can be less accurate.

The cadastral measurements in the surveying area have been completed. Now the measurement data should be transferred into the GIS to prepare the plot drawing.

Question 8. What is the main purpose of using tacheometer in cadastral mapping?(2 points)

a) For measuring GPS points coordinates
b) For coordinating the objects of plot
c) For compiling cadastral plan
d) For editing measurements data

Question 9. In tacheometric survey, when you can use laser to survey objects instead of using reflector? (2 points)

a) When the objects are difficult to reach

b) When raining
c) When good weather
d) When you don't have tachymeter

Question 10. State the principle of tacheometric survey (4 points)

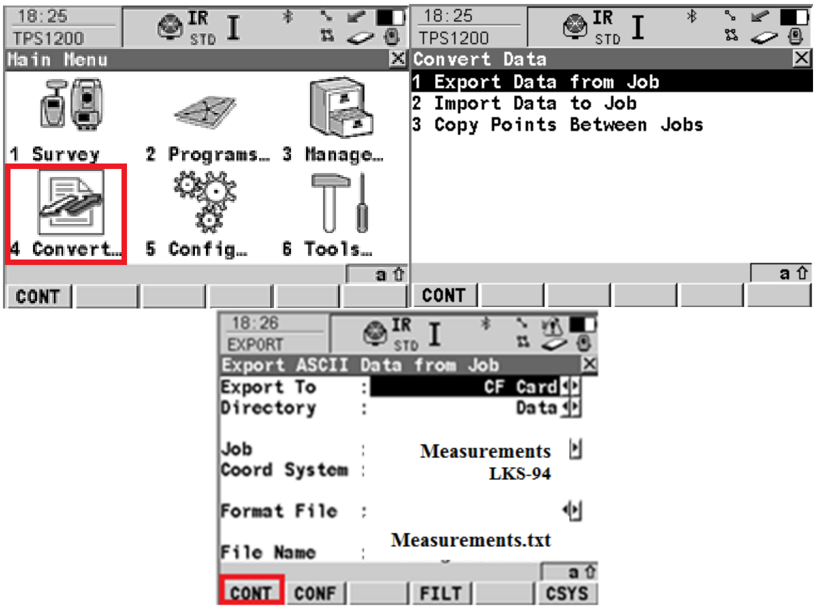
Question 11. A total station contains a ______________ and ________________ instruments (2 points)

Question 12. What for the second GPS point is required to set up an electronic tacheometer at station (2 points)

PART B: TRANSFERING THE CADASTRAL SURVEYED DATA

After making the cadastral measurements of the survey area, preparation for the plot drawing can begin. Before designing a plot, the measurement data should be transferred from the tacheometer into the GIS, where you will do the data processing as well as design a plot drawing. For this task, you will be using ArcGIS for Desktop, where you will transfer the measurement data into a geodatabase.

The software of Leica devices (GPS and tacheometer) includes functions for data conversion and export. Conversion can be done from the *Main Menu* by follow *Main Menu* > *Convert* > *Export Data from Job* > *Cont*. In the *Job* list, the *Measurements* job, which was created and filled in tacheometric survey, was selected.



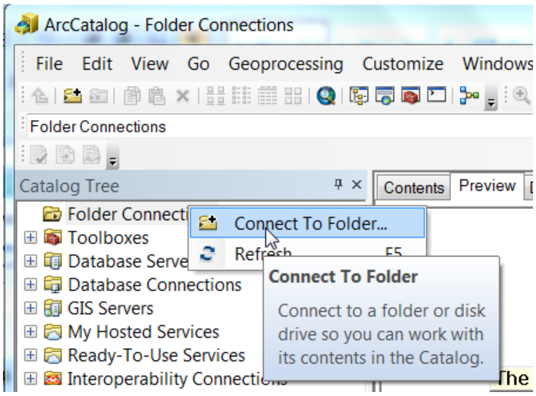
Then by applying *Cont*, the measurement data was saved in TXT format in the memory cards of the tacheometer. Using a memory card reader (usually it is integrated in a computer), the measurement data was transferred into a personal computer, which has the ArcGIS software.

From this point, you should not only answering questions, but also start to work on this assignment task in ArcGIS.

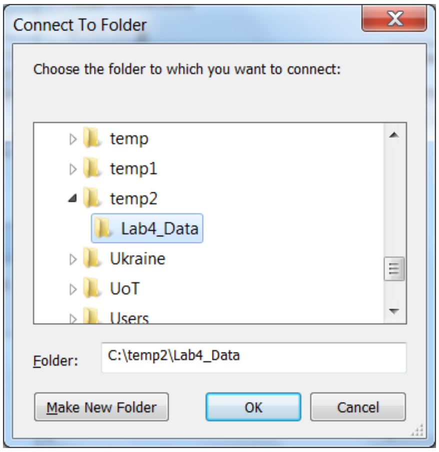
1. You can find **Measurements.txt** file with the measurement data in your working directory, e.g. **Lab1_Data**.

Now you will import the TXT file into ArcGIS.

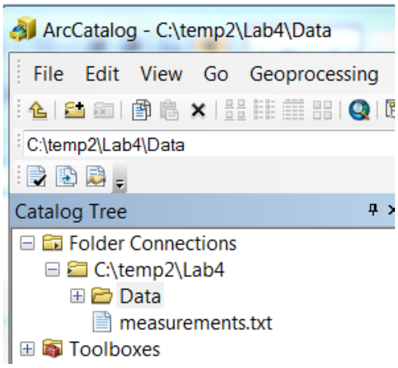
2. Open ArcCatalog. Create a folder connection to your working directory where you copied the TXT file. Right-click the *Folder Connections* entry of ArcCatalog tree and select *Connect to Folder*.



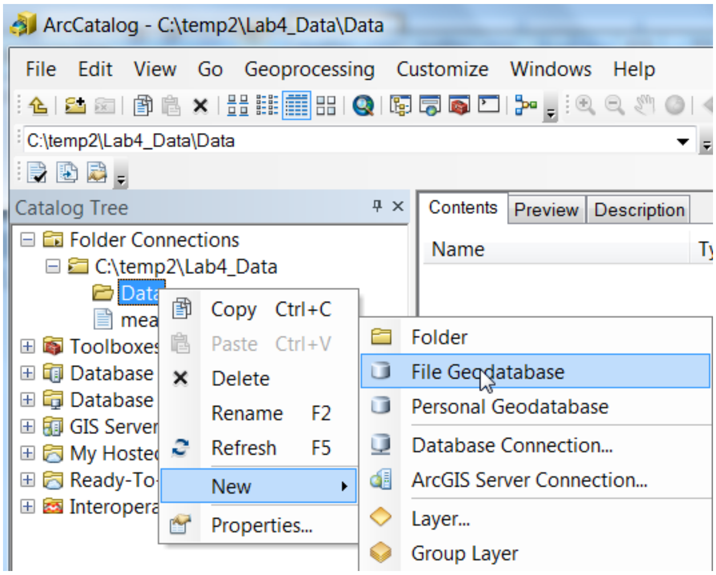
In the opened dialog of *Connect To Folder*, set the path into your working directory (**Lab1_Data**).



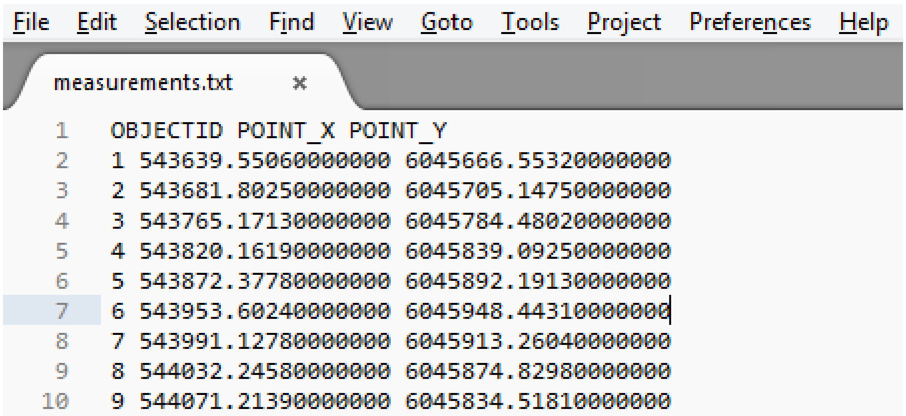
Additionally, create a directory **Data** where you will create databases, and so on.



3. Create a database where you will transfer the tacheometric measurement data. Right-click on the **Data** folder and select *New > File Geodatabase*. Name the new database as **Measurements.gdb**.

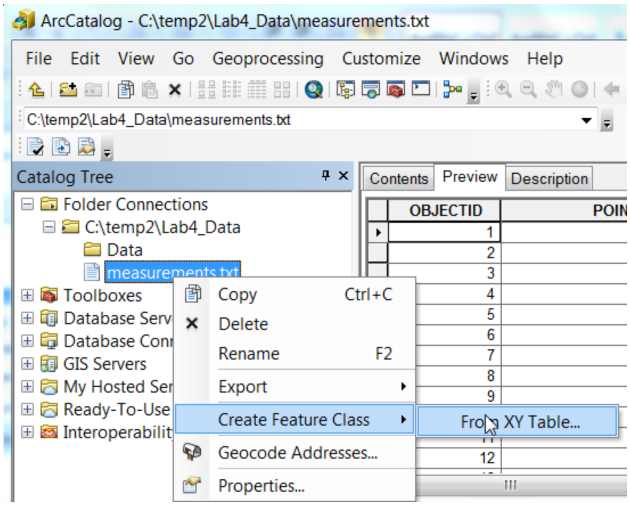


4. Open **Measurements.txt** file in any text editor and check that the measurement data are saved in such form:

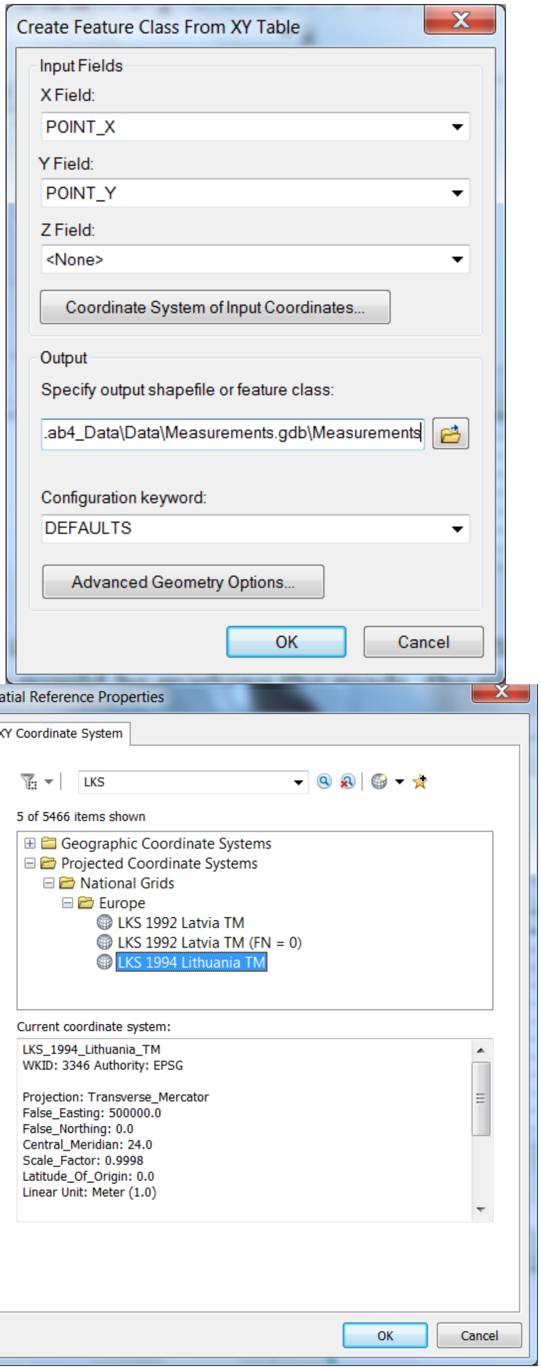


The column names should be specified such as **ObjectID**, **POINT_X**, **POINT_Y** and the measured point data should be listed below. The data values delimited with a space. The measurement data can be edited in a text editor, for example, Notepad, etc.

5. In ArcCatalog, find and select **Measurements.txt** file in your working folder. Right-click on **Measurement.txt** and select *Create Feature Class > From XY Table*.

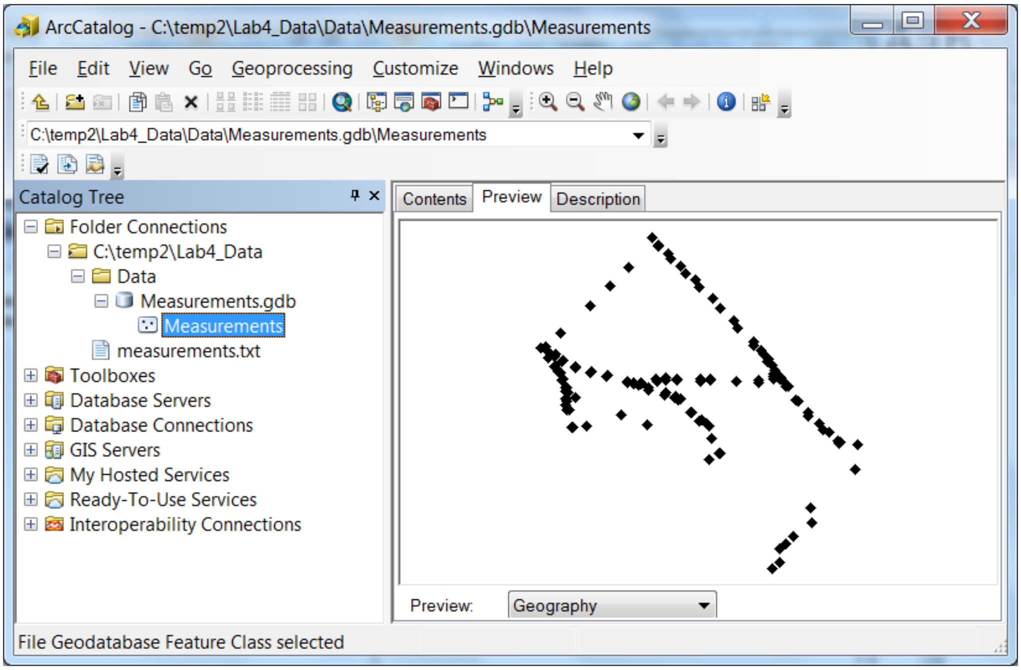


In the opened window, select the file's fields that include the X and Y coordinates (in this case, it is **POINT_X**, **POINT_Y**), then select the *Coordinate System of Input Coordinates* as *LKS_1994_Lithuania_TM*. You can search this coordinate system by the keyword *LKS* in the *Spatial Reference Properties* dialog. Finally, set *Output* into **Measurements.gdb\Measurements** feature class of *File and Personal Geodatabase*. Click *OK*.

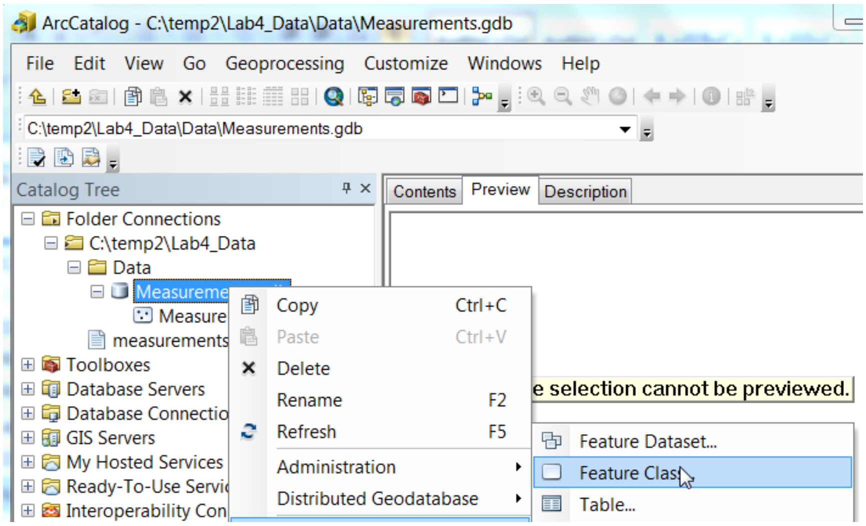


6. Check that the data from TXT files have been transferred to the database **Measurements.gdb** properly. Open the database **Measurements.gdb**, select the feature class **Measurement** and click *Preview* in the right window of ArcCatalog. You should see the measurement points transferred from the TXT

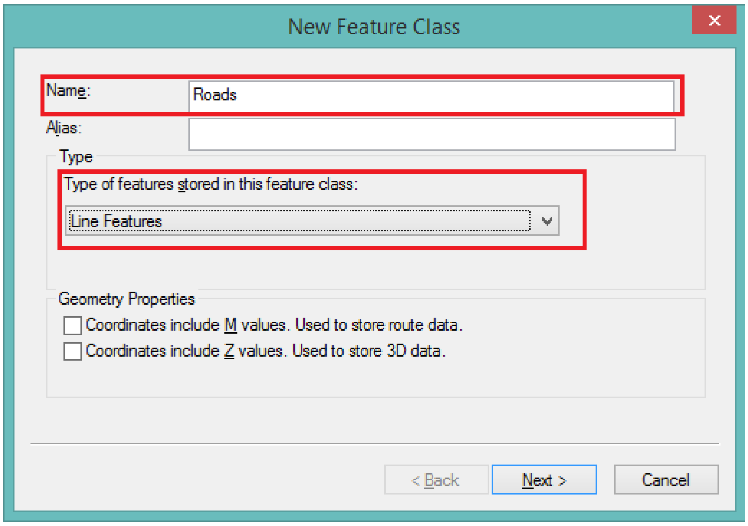
file. If the **Measurement** layer looks like as the following example, it means that you successfully transferred the data into the geodatabase.



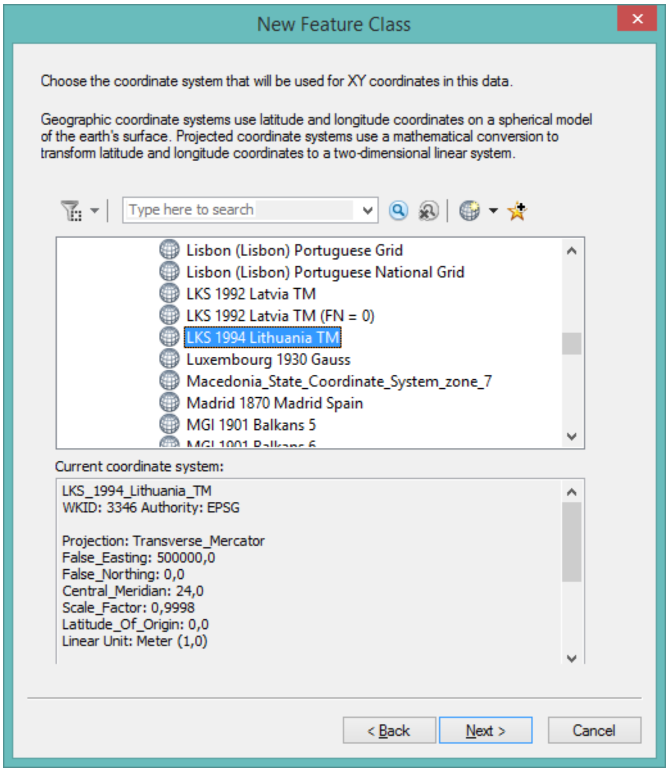
7. To create a drawing of cadastral plot, you need to filter roads, plot boundary and other objects from the tachometry data collection. You will do that by creating feature classes for each respective cadastral object class within **Measurements.gdb**. Open the database **Measurements.gdb**, right-click on it and select *New > Feature Class*.



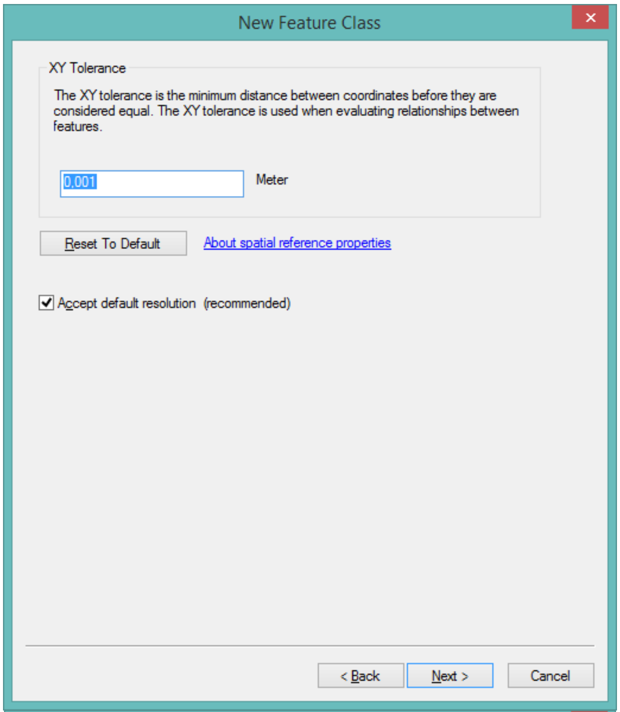
You start with creating a roads feature class by specifying the *Name* as **Roads** and select its *Type* of geometry as *Line Features*. Then click the *Next* button.

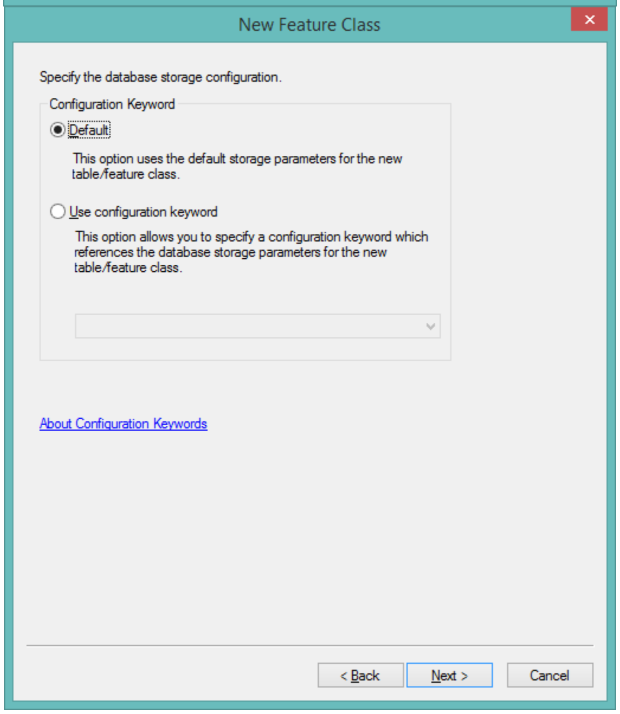


Then you should select the coordinate system of the feature class, which will be again *LKS_1994_Lithuania_TM* and then click the *Next* again.

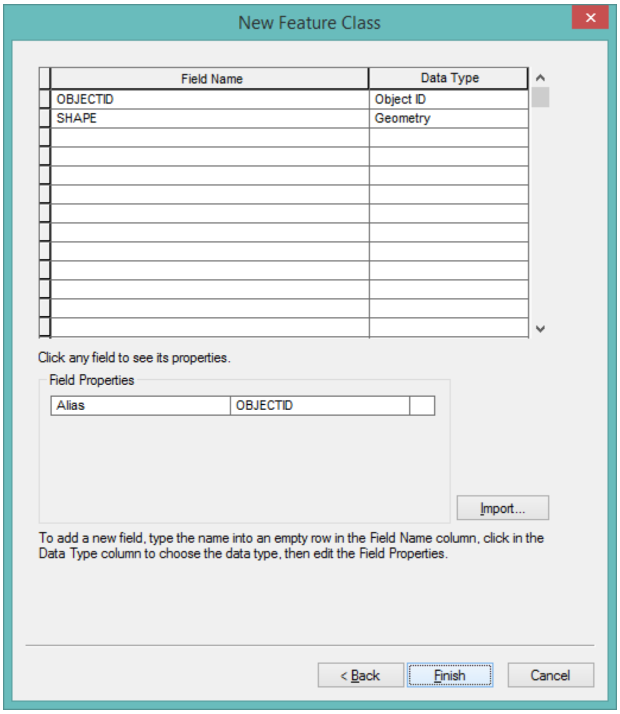


Accept the default settings of XY tolerance and the database configuration in the next two dialogs by clicking the *Next* buttons.





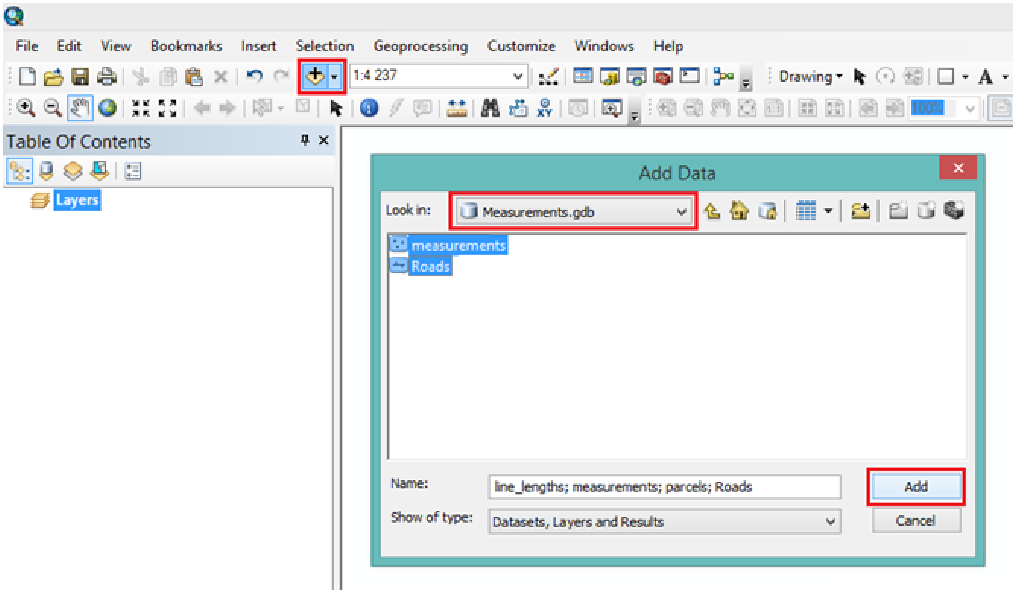
In the last dialog window, you may enter names of the attribute table columns. For example, if you are creating a feature class of buildings, then you may specify the type of the buildings (e.g., made of bricks, wooden, inhabited, uninhabited, abandoned and so on). In our case, creation of fields for additional attribute is not required. Click *Finish*. You have just created a first feature class **Roads** that is still empty.



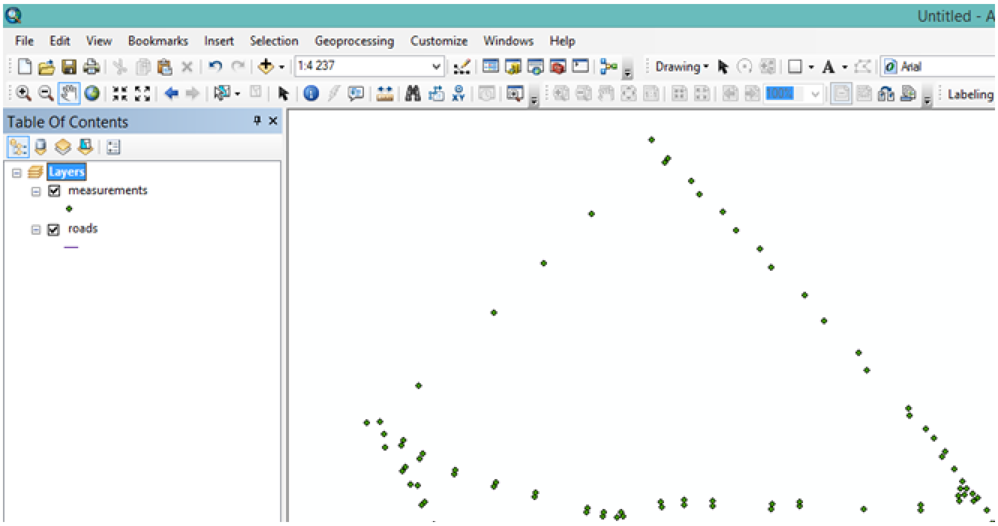
PART C: PROCESSING THE CADASTRAL DATA

In this part of the lab, you will split, update and edit the measurement data, i.e. you will create and/or load feature classes of roads, plot boundary and other surveyed features.

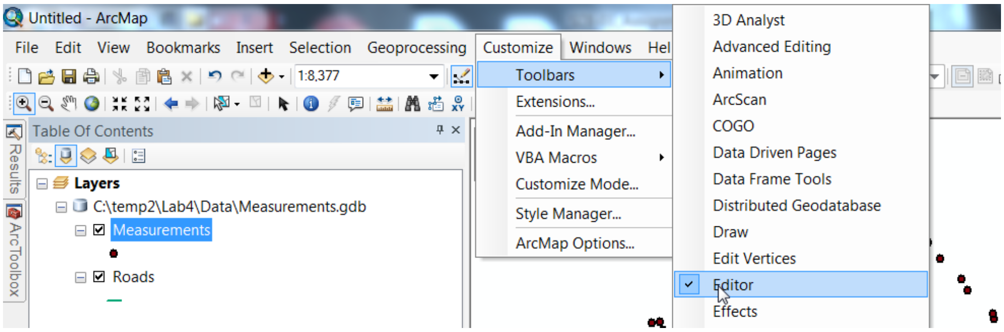
8. Open ArcMap and *Add* the two feature classes from **Measurements.gdb** database. Zoom to **measurements** layer: right click on it > *Zoom To Layer*.



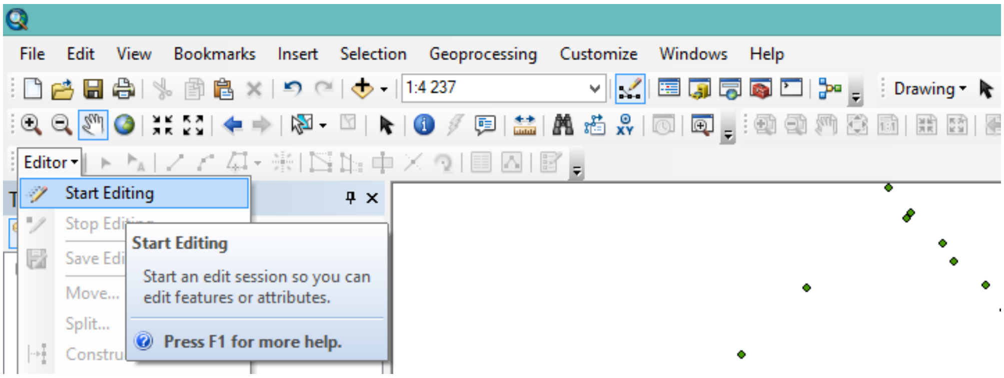
The layers are displayed in the left *Data view* window of ArcMap. You will only see the data of **measurements** layer. **Road** layer is the only feature to display so far.



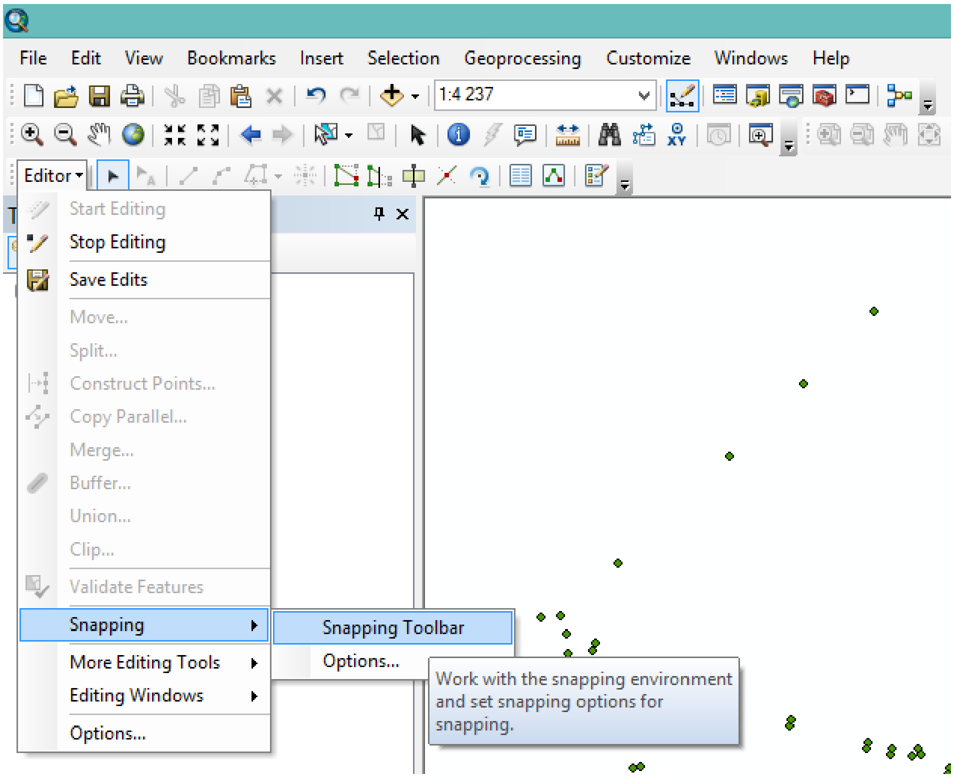
9. To start loading the roads, plot boundary and other objects with features from the tachometric data collection, you have to work in an editing session of ArcMap. Bring *Editor* toolbar on the ArcMap interface: in the main menu of ArcMap, navigate to menu *Customize* > *Toolbars* and check *Editor*.



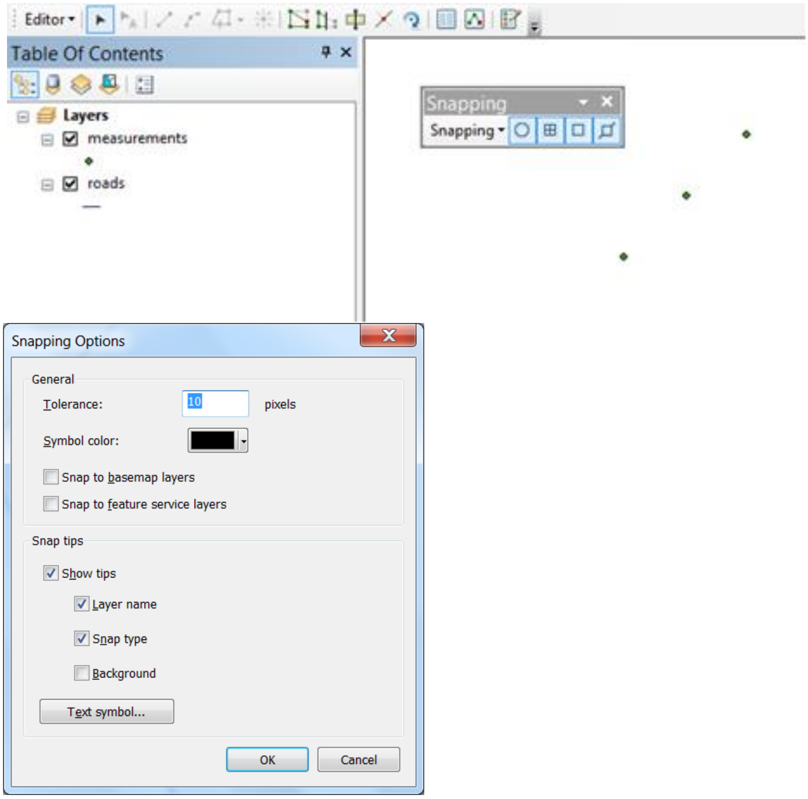
10. Start the data editing session from the *Editor* toolbar dropdown menu by clicking *Start Editing*. Remember that after finishing an editing session, you have always to *Save* edits from *Editor* toolbar dropdown menu.



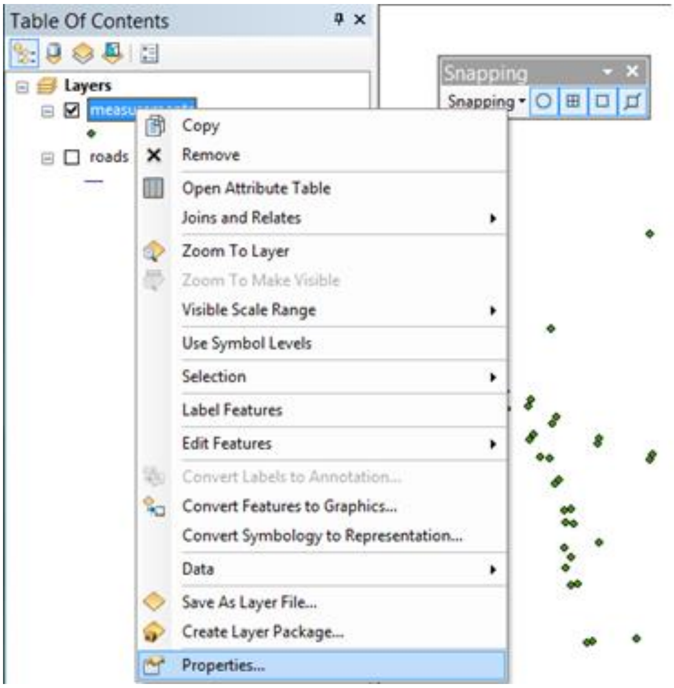
11. To have a perfect matching among edited features, the snapping mode should be turned on. This mode allows snapping to points, ends, vertices or/and edges of coincident features from one layer or multiple layers. For example, if you will build a road by connecting GPS data points, you will need the sidelines of road to be perfectly snapped with those GPS points. You can activate the snapping mode by clicking the dropdown menu of *Editor* > *Snapping* > *Snapping Toolbar*.



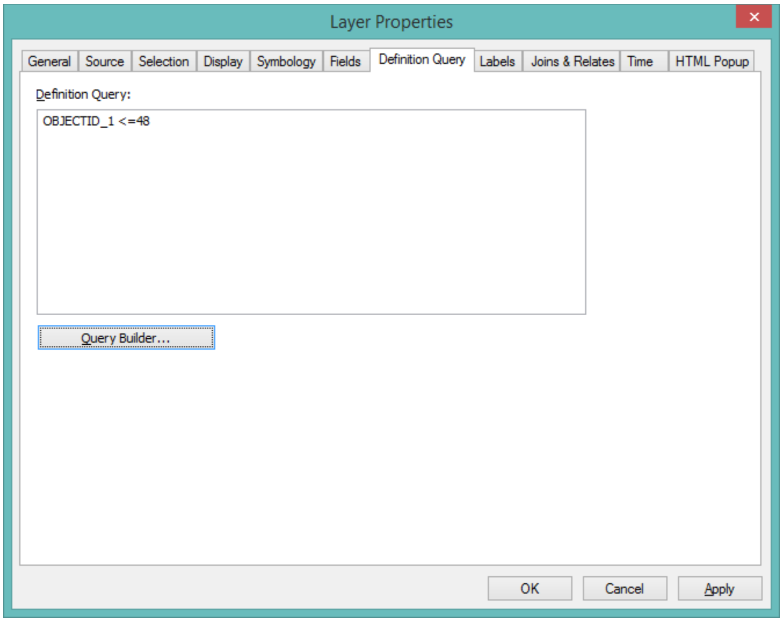
The *Snapping* toolbar will open. You can leave the standard *Snapping* settings, which are activated for the four types of snapping: points, ends, vertices and edges. From the *Option* link of *Snapping* dropdown list, open the *Snapping Options* dialog window and check *Show tips* boxes. It will help during manual edits.



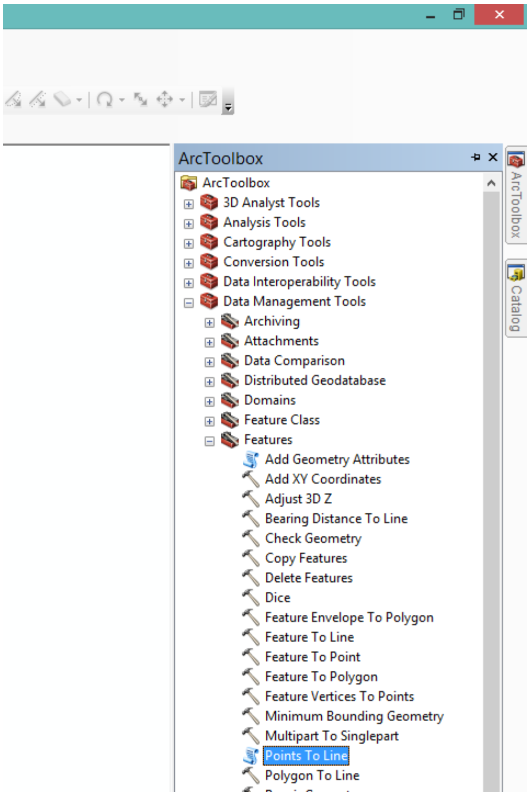
12. First, you will create a **parcel_line** feature class. From the tacheometric survey, we know that our plot boundary line consists of the measurement points with the ID from 1 to 48 (you may have taken notes about this while carrying out the survey, or added associate code as an additional attribute to surveyed points). Thus, you have to select only those points from the **measurements** collection feature class. Double-click the **measurements** layer and select *Properties*.



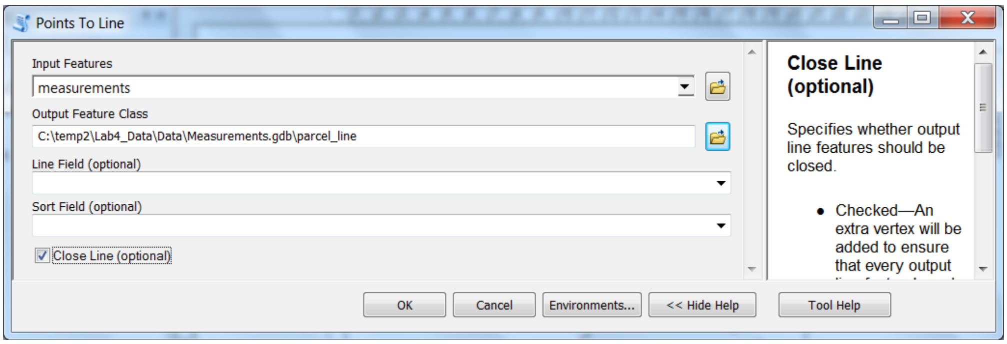
In the dialog window of *Properties*, select the *Definition Query* tab and build a query as *OBJECTID_1 <= 48* and press *OK*. Then the layer **measurements** will display only the points with ID less than or equal to 48.



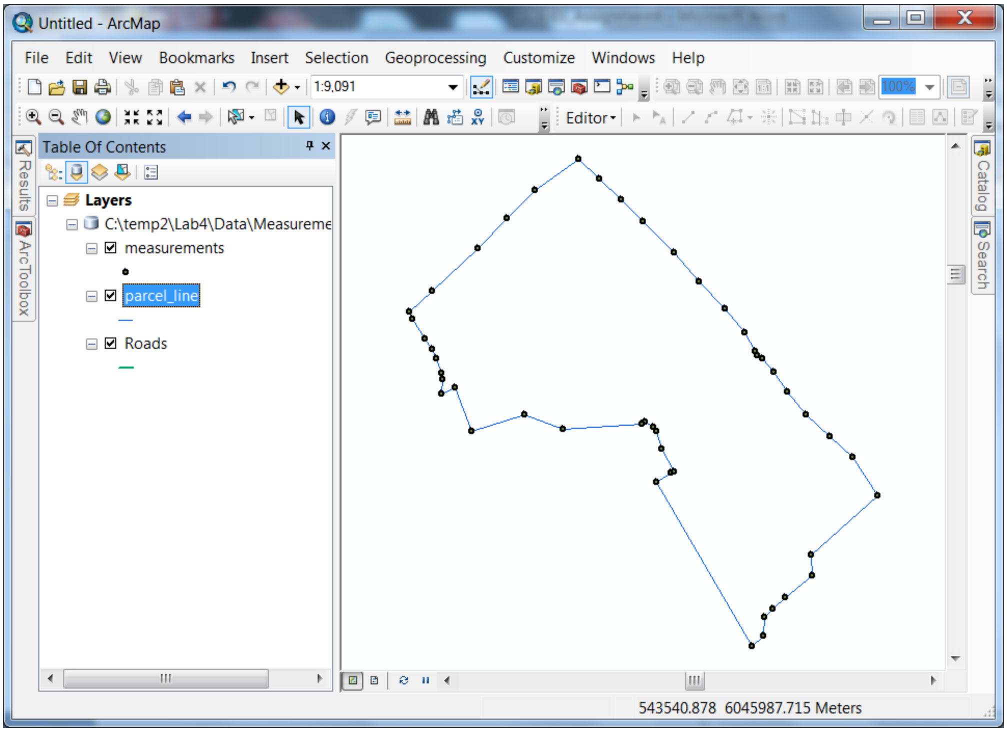
13. In the ArcToolbox , search and find a tool that will convert the selected 48 points into the line, which marks the boundary of land plot. Navigate through the *Data Management Tools* > *Features* and run *Points To Line* tool.



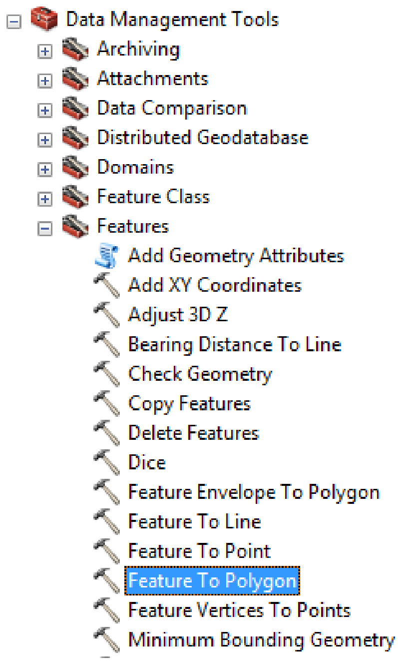
In the *Points To Line* tool dialog, select the **measurements** layer from the dropdown list of the *Input Features* textbox. The tool will only use the selected GPS points from 1 to 48 in processing. In the field *Output Feature Class*, navigate to the **measurements.gdb** database and enter the name of the new feature class, for example **parcel_line**. Check the *Close Line* box. Click *OK*.



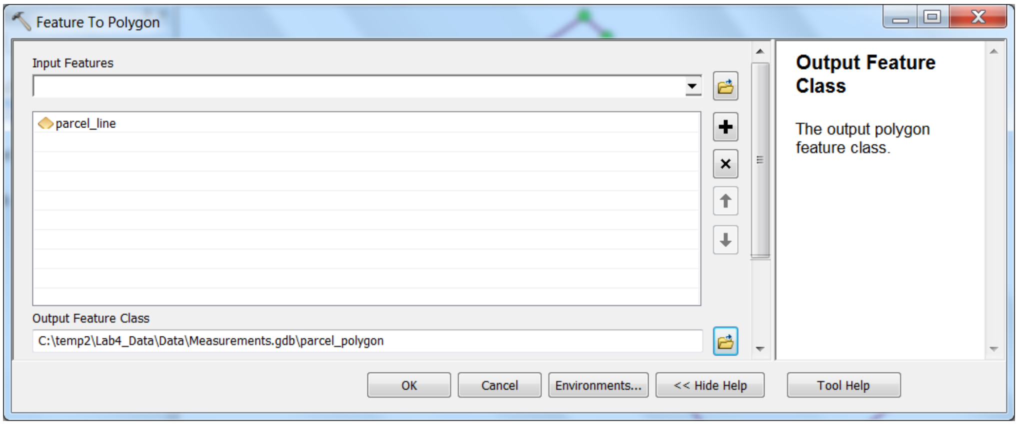
The tool will create a new linear layer, which will outline the boundary of land plot.



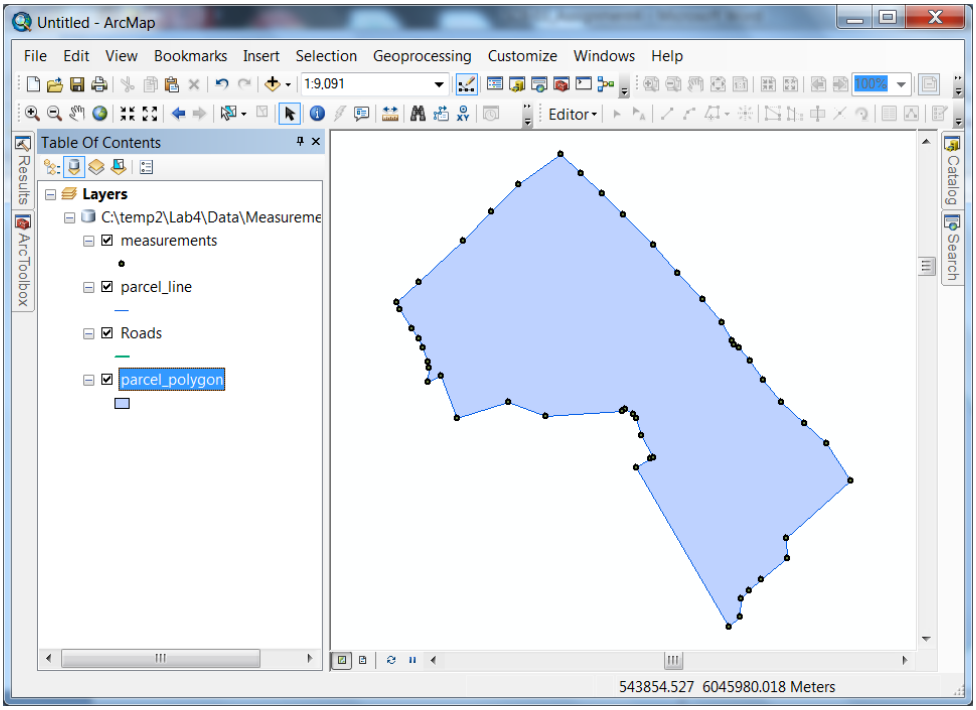
14. Then you will use the **parcel_line** feature class to create a polygonal feature class of the plot. This polygonal feature class can be used to find out the exact length (or perimeter) and area of the land plot. Before creating a polygon, make sure that your **parcel_line** is a closed polyline, i.e. the plot boundary begins and ends at the same point. In ArcToolbox, find the tool which will convert the **parcel_line** feature class into a polygon. Navigate through the *Data Management Tools* > *Features* and run the *Feature to Polygon* tool.



In the dialog of *Feature to Polygon* tool, select the **parcel_line** layer from the *Input Features* dropdown menu. In the *Output Feature Class* box, navigate to **Measurements.gdb** database and enter the name of the new layer, for example, **parcel_polygon**. Click *OK*.

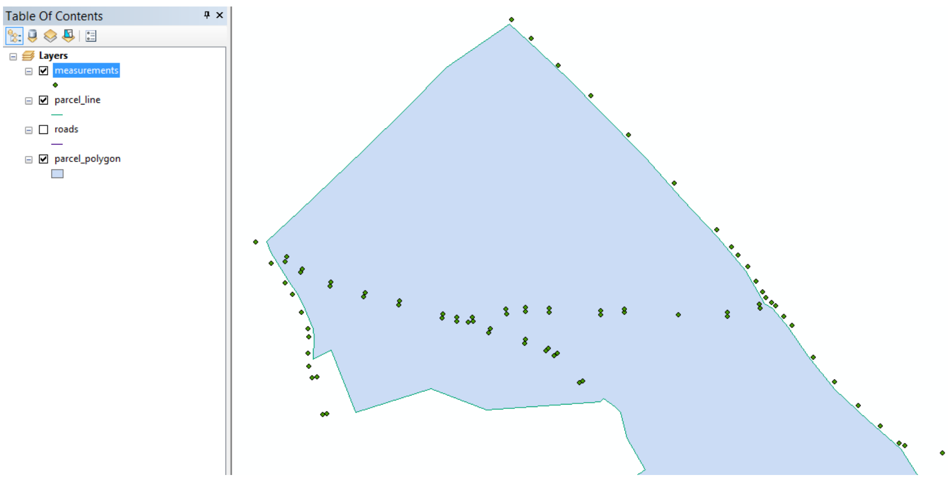


The tool will create a new feature class of the area of land plot.



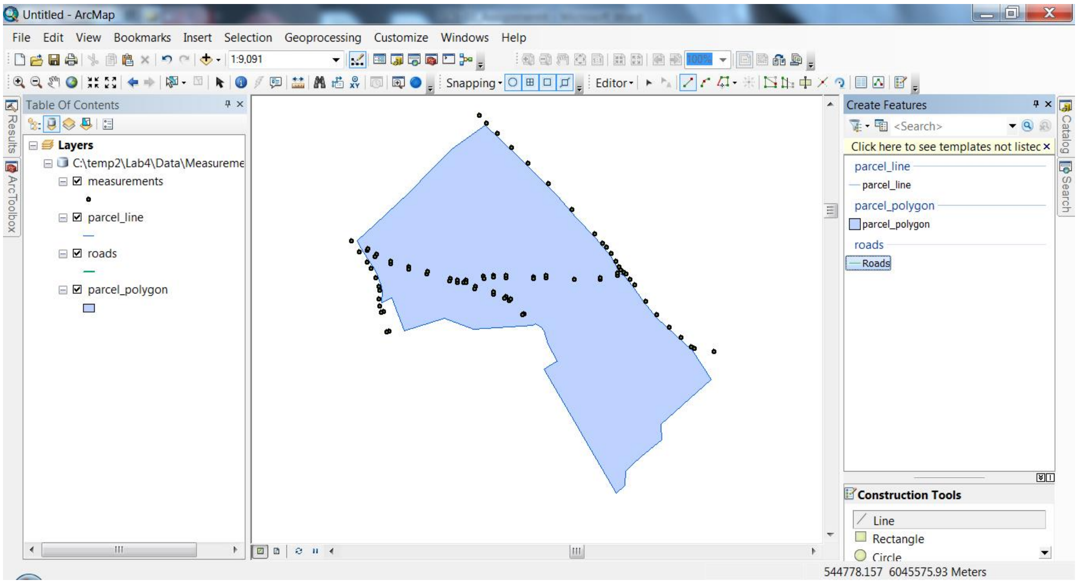
15. *Save* your work as MXD document in your working folder and repeat the *Save* operation from time to time in order does not lose your ongoing work.

16. Next, the roads feature class will be created based from the **measurements** feature class. Repeat step 12, but this time build a *Definition Query* only for those points which ID larger than 48. You will see selected points depicting the roads in the *Data View*.



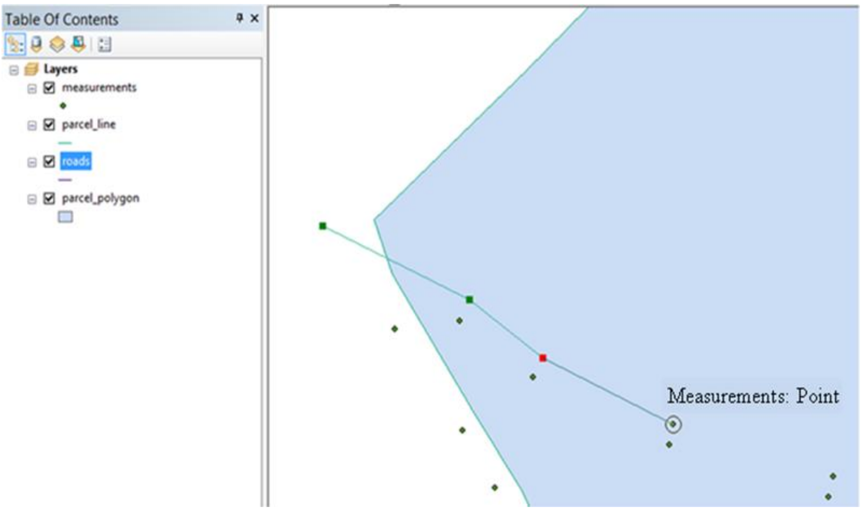
Question 13. How many road's points you selected from the measurements feature class? (2 points)

17. This time you will use the *Straight Segment* tool of *Editor* toolbar to connect the selected measurement points into the road feature class. From the *Editor* toolbar, choose the *Create Feature* option.

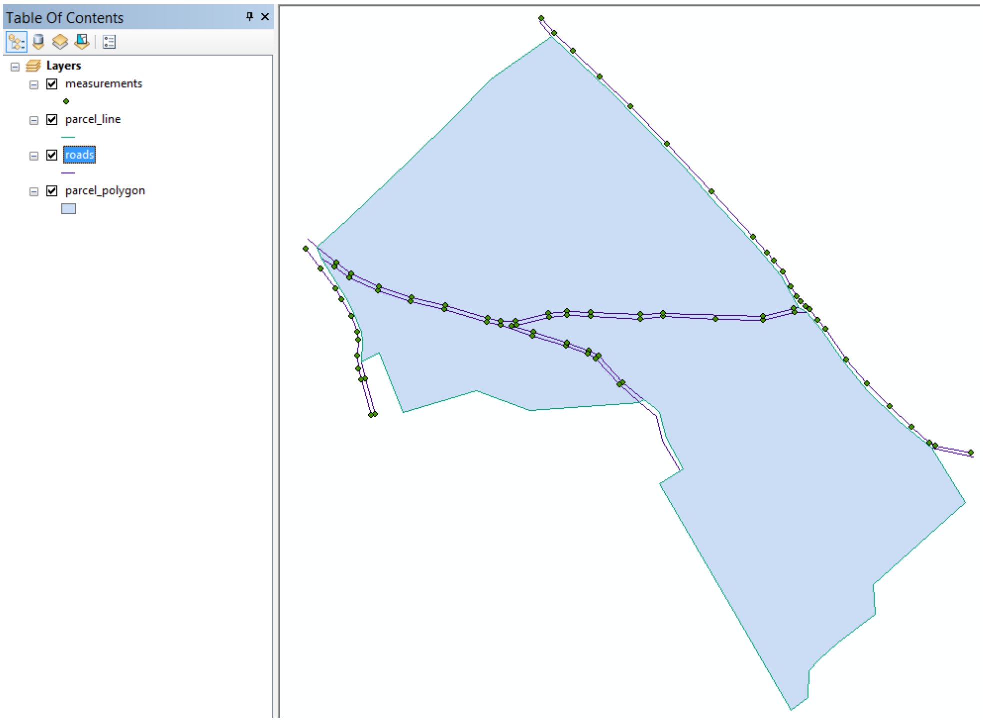


In the *Create Feature* dialog window, select the **road** feature class and *Line Construction* tool below it.

Start drawing the road sideline from the first road point (see the below print-screen) using *Straight Segment* tool. When you move to a point, make sure that the cursor is snapped – it should show snapping tip such as **Measurment.Point,** and only then click on the point to create a polyline vertex. Connect points from the same sideline into a polyline. When you reach the last point of a sideline, double-click on it to complete the polyline.



Create roadside polylines from the remaining points. The road network from all measurement points is shown below.

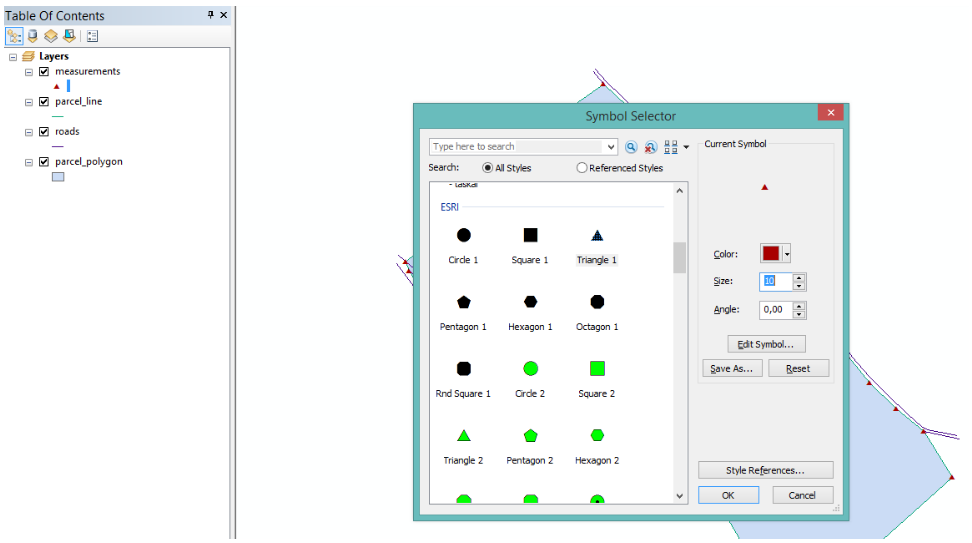


Finish the data editing session by following from the dropdown menu of *Editor > Save Edit > Stop Editing*.

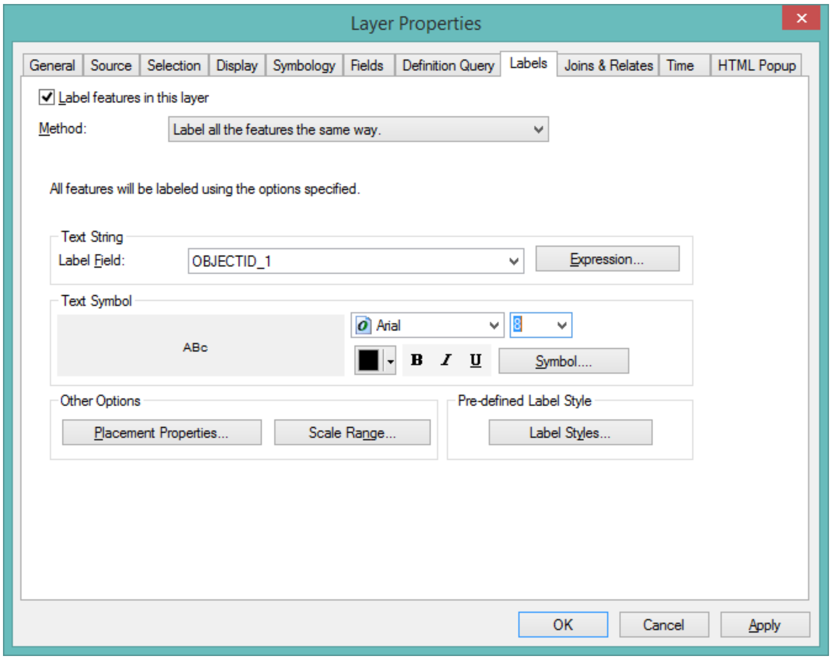
PART D: DRAWING THE PLOT CADASTRAL PLAN

In the last part of lab, you will be using the ArcGIS cartographic functionality to compile a plan drawing of the land plot, which will include cadaster objects and tables, annotations, titles and other associated cartographic elements.

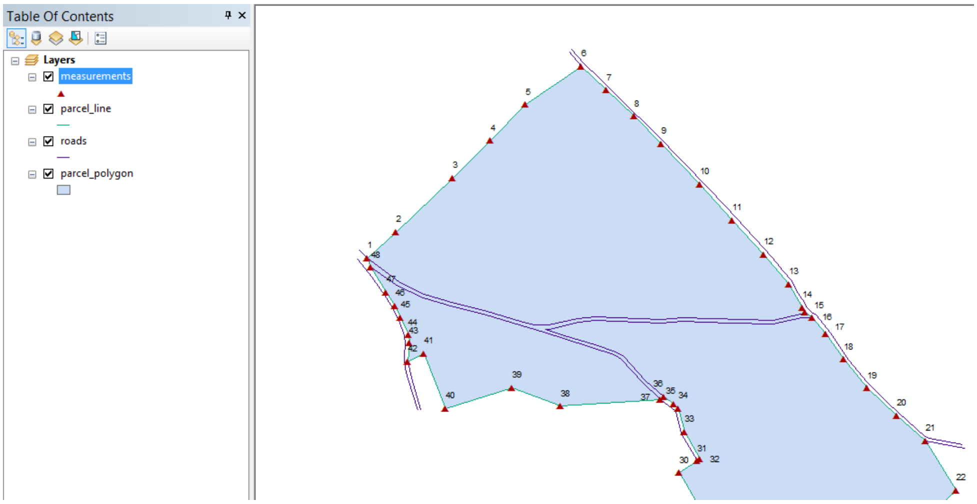
18. You will start with symbolization of the plot boundary. Repeat step 12 to select only the plot boundary points. Then click on the symbol of **measurement** layer to open the *Symbol Selector* dialog. Select a triangle symbol to display the plot terminal points. From the *Color* dropdown palette, select a red color. Choose 10 pixels for the symbol size. Then click *OK*.



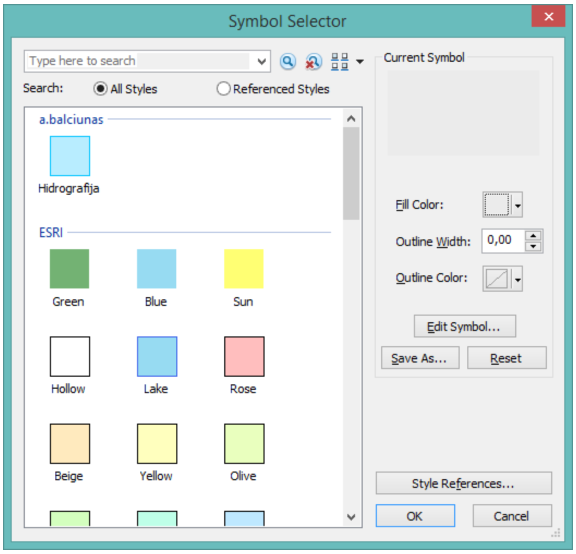
19. Label the plot terminal points by using their points ID. Double-click the **measurements** layer to open the *Properties* window. In the *Properties* window, select the *Labels* tab. Check the option *Label feature in this layer*. In the *Text Spring* section from the *Label Field* list, select the field **OBJECTID_1**. Select the type and the size of the font, e.g., Arial Narrow and 8 pixels, and then click *OK*.



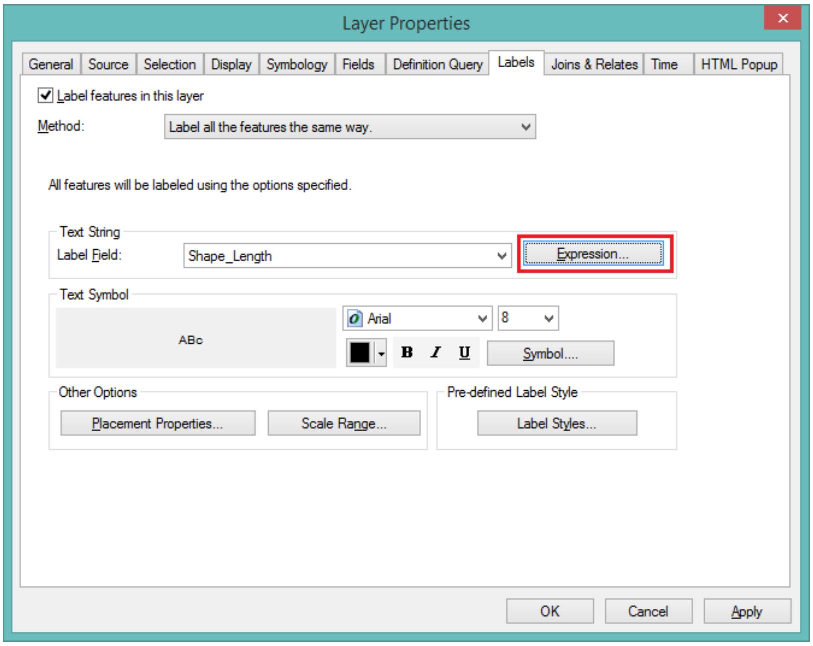
The plot will be symbolized with the chosen symbology and labels.



20. Next, you will design the **parcel_polygon** layer. Click on a symbol of **parcel_polygon** layer to open the *Symbol Selector* dialog. Set a light gray color from the *Fill Color* palette. Do not use outline for this layer. Set the *Outline Width* as 0.00 or/and *Outline Color* as in *No Color*. Click *OK*.



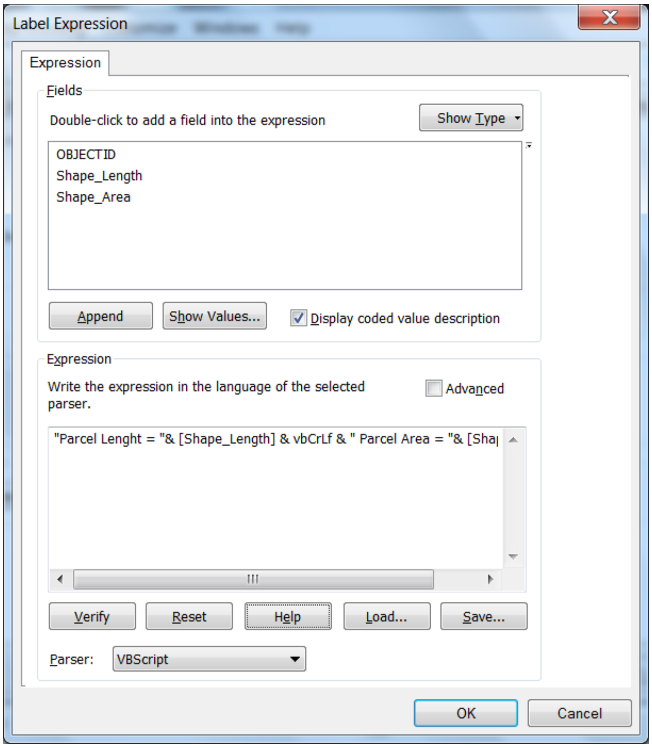
21. Then you will label the plot polygon with its area and perimeter; these plot dimension parameters are often shown on parcel plot. Double-click on the **parcel_polygon** layer to open the *Properties* dialog. In the dialog, select the *Labels* tab, and check the option *Label feature in this layer*. In the *Text String* block, click the *Expression* button.



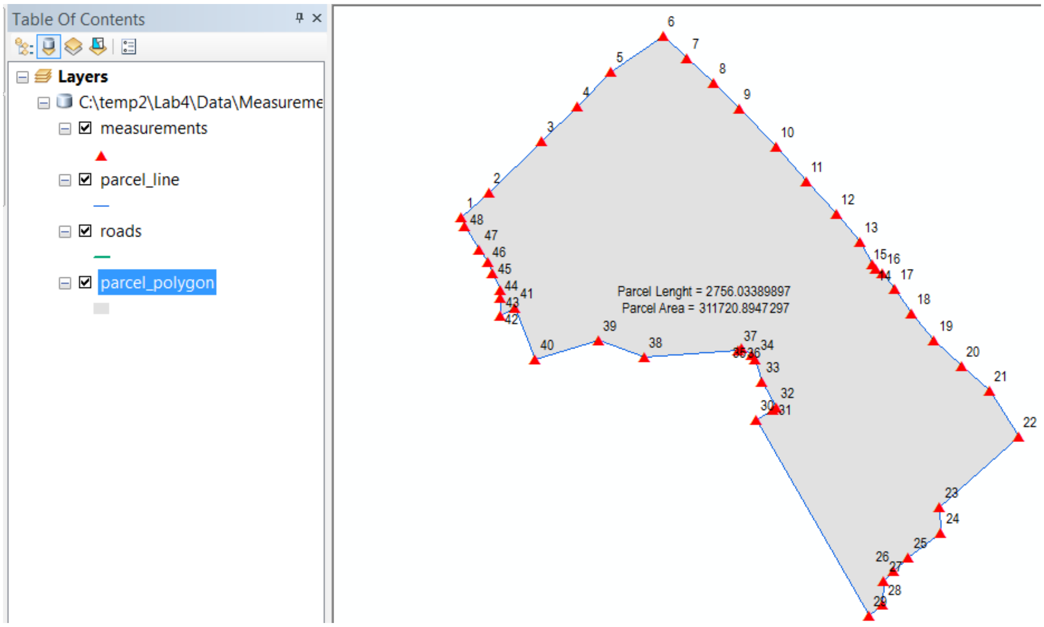
In the *Expression* box, you can enter attribute fields that will be displayed as a part of label, and a static text to annotate a label. Use the following expression:

`"Parcel Lenght = "& [Shape_Length] & vbCrLf & " Parcel Area = "& [Shape_Area].`

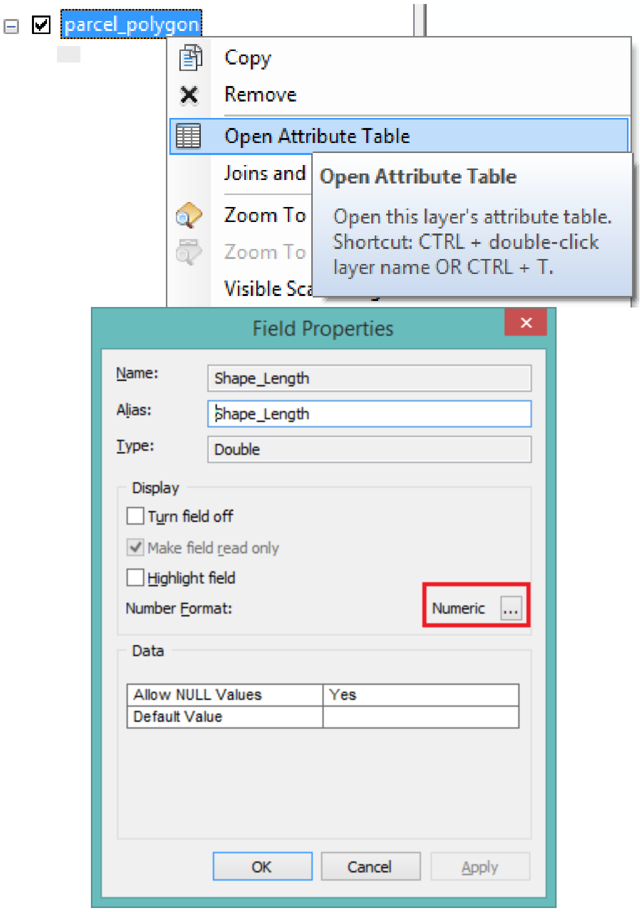
User defines the text in the quotes. The symbol `&` is used to join one text segment with another. The special combination `vbCrLf` is used to create staked text. For example, this expression creates a label with the `Shape_Length` field and the `Shape_Area` field on separate lines. The square brackets enclose field names, whose values will be inserted into the text label. Click *OK*.



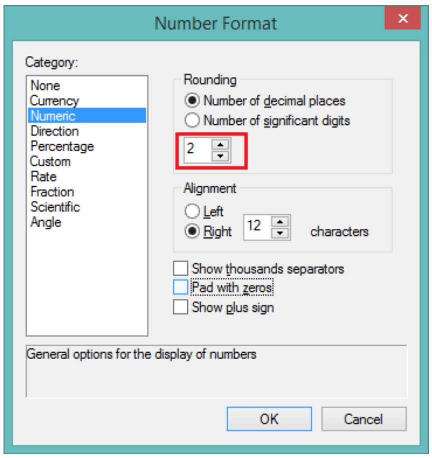
Additionally, you may define the type and size of label font. On a map, you will see a labeled plot with its metric values.



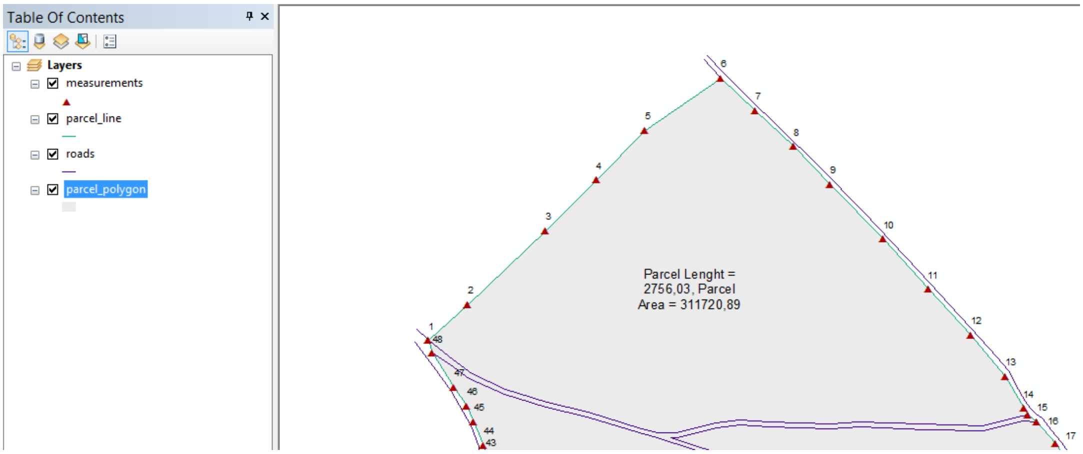
If you are not satisfied with the number of decimal places depicted the parcel length and area, you can change it. Open the *Open Attribute Table* of **parcel_polygon** layer. Then, open the *Properties* dialog of **Shape_Length** column – right click on the column header and choose the *Properties* option. In the *Properties* dialog, click *Numeric* button .



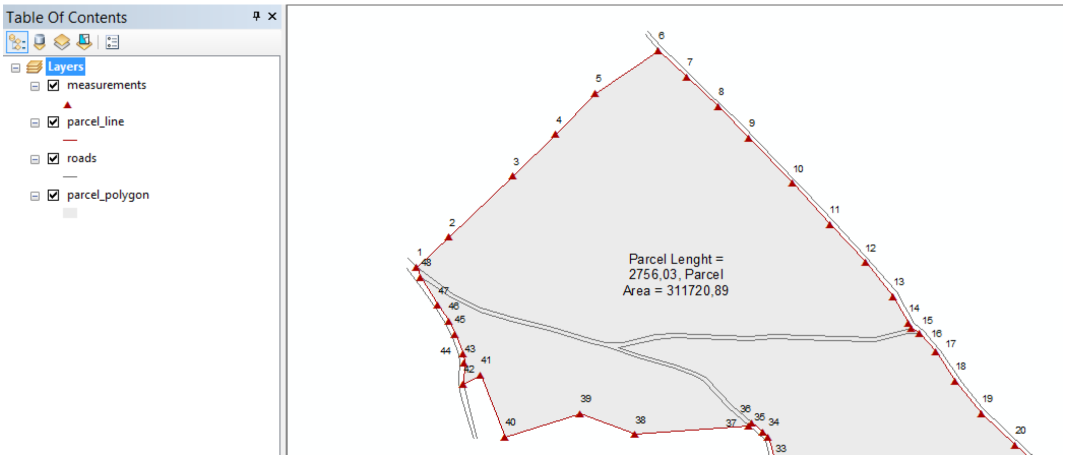
In the *Number Format* dialog, change the value of *Number of decimal places* within the *Rounding* block to 2. Repeat the same for **Shape_Area** column.



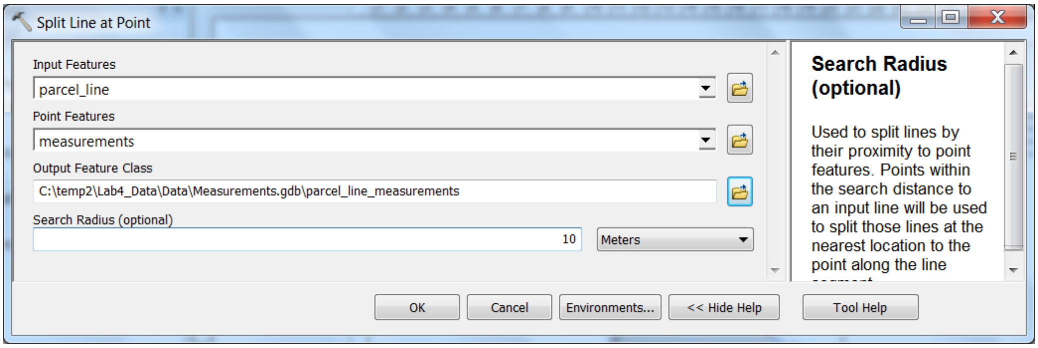
The values of label's attribute will be changed on the map. You may need to *Refresh* the plan to see changes.



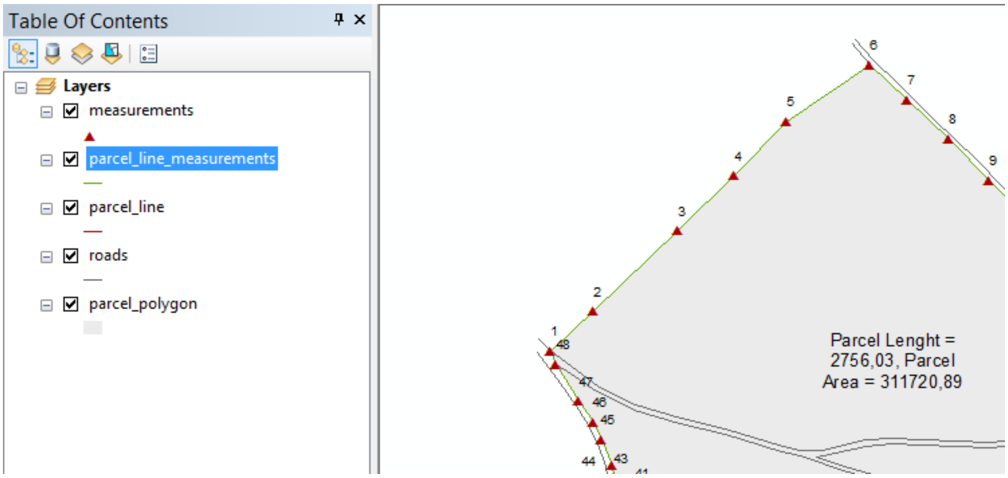
22. Design the **parcel_line** layer.



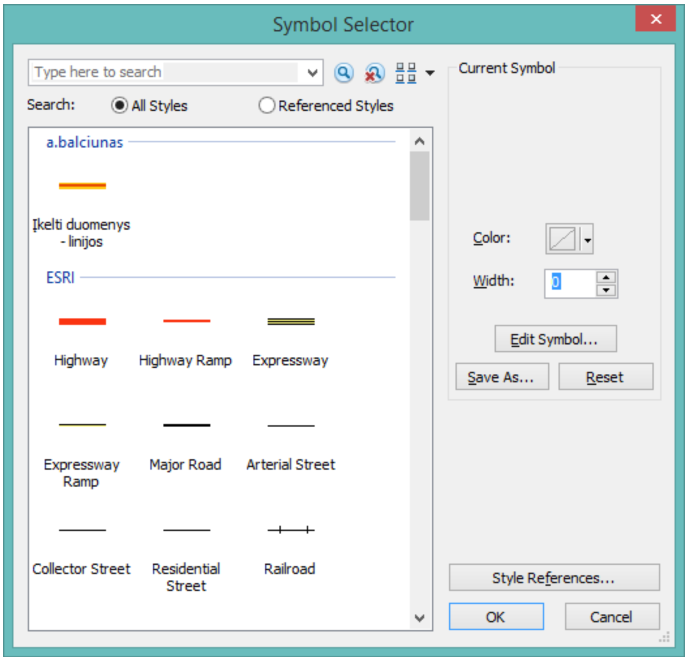
23. Additionally, often the lengths of segments are shown between the plot terminal points. This dimensional information is important for cadastral purposes. First, you will split the **parcel_line** into straight segments. In ArcToolbox, find and run the *Split Line at Point* tool from *Data Management Tools > Features*. In the *Split Line at Point* dialog, pick up the **parcel_line** from the *Input Feature* dropdown list, and the **measurements** layer from the *Point Features* dropdown list. In the *Output Feature Class* box, navigate to the **Measurements.gdb** database and specify a new output feature class as **parcel_line_measurements**. Set the *Search Radius* to 10 m.



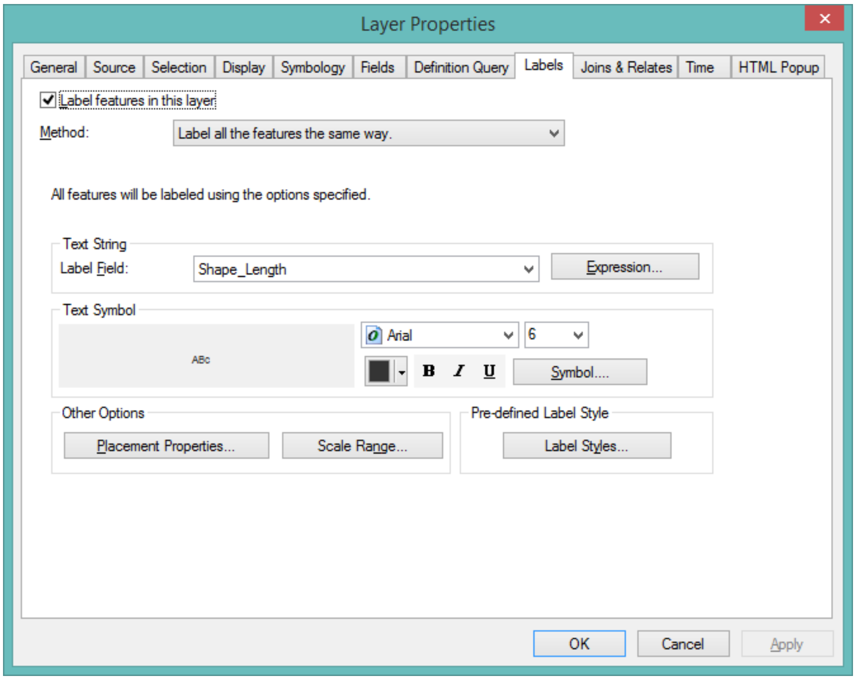
The tool will partition the **parcel_line** polyline into straight-line segments where the polyline touches the points of the **measurement** feature class. As a result, the tool creates a new feature class that matches the **parcel_line**, however, the polyline traverse will be partitioned into straight-line segments and the lengths of segments will be calculated.



24. Now you will design the **parcel_line_measurements** layer. Make the symbol of this layer invisible, because the **parcel_line** layer already shows the plot's boundary. Change the symbology of **parcel_line_measurements** layer to *No Color* or/and zero width.

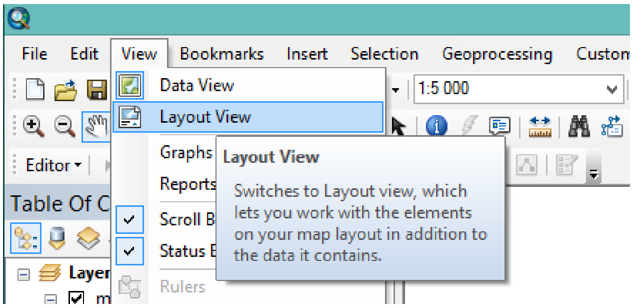


25. Label the segments of **parcel_line_measurements** layer with their attribute values from the **Shape_Length** field. Use the same procedures that you have done above to label the **parcel_polygon** layer.

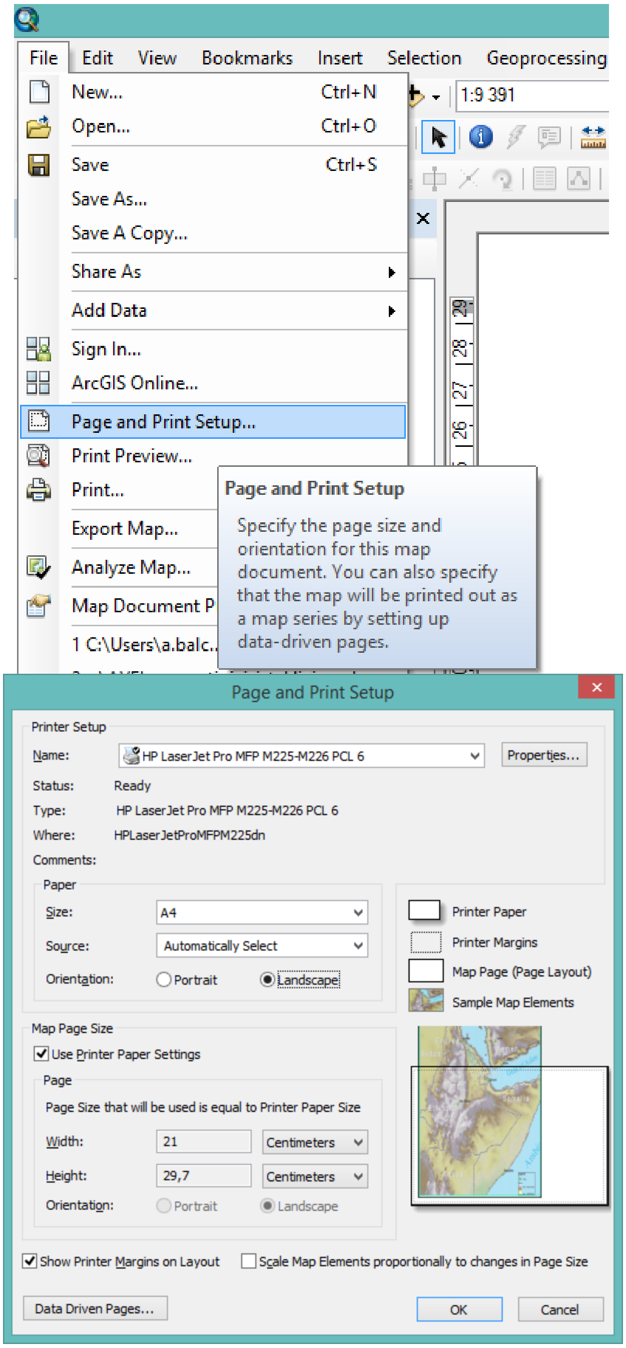


In addition, round **Shape_Length** values to 1 decimal place similar as you have done above for the **parcel_polygon** layer.

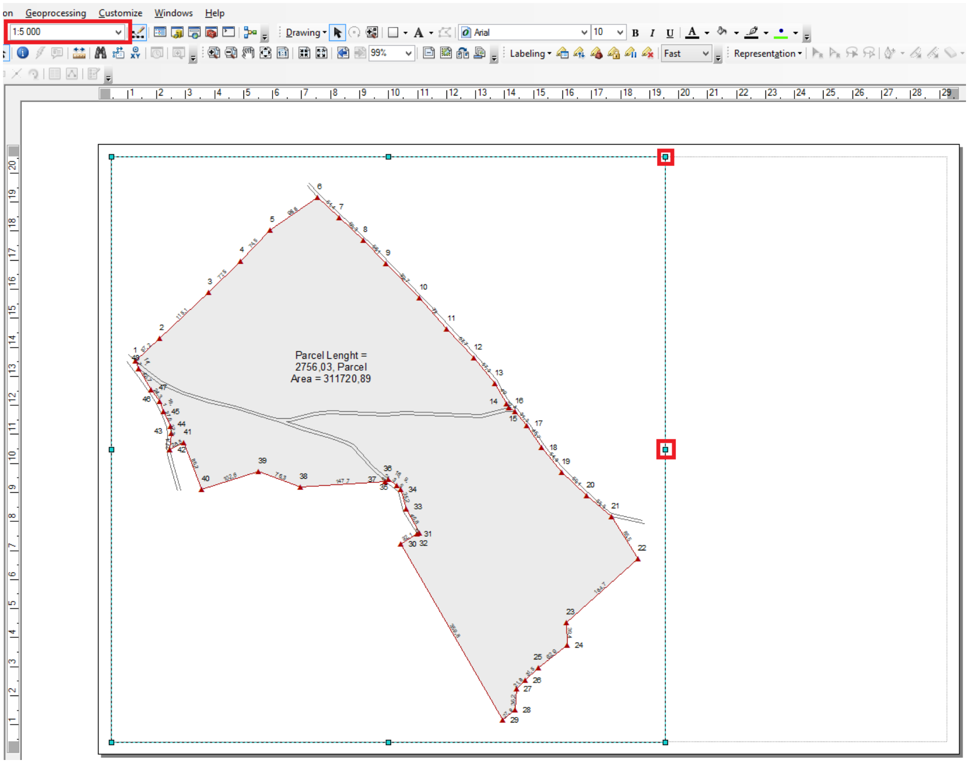
26. Finally, you have to layout the plot. First, switch to the *Layout View* from the ArcMap main menu *View* > *Layout View*.



27. Set the *Page and Print Setup* parameters in the ArcMap main menu *File* > *Page Setup and Print* dialog. Set a page size of the plat to A4 and landscape orientation.

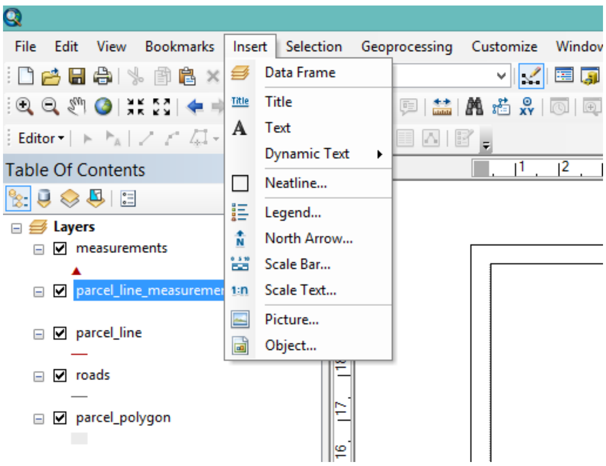


28. Set 1: 5000 scale of the plot. Fit the plat on the right side of layout page by using the zoom tools from *Tools* toolbar and resizing the map frame anchors. Use the *Select Elements* tool  to work with layout frames.

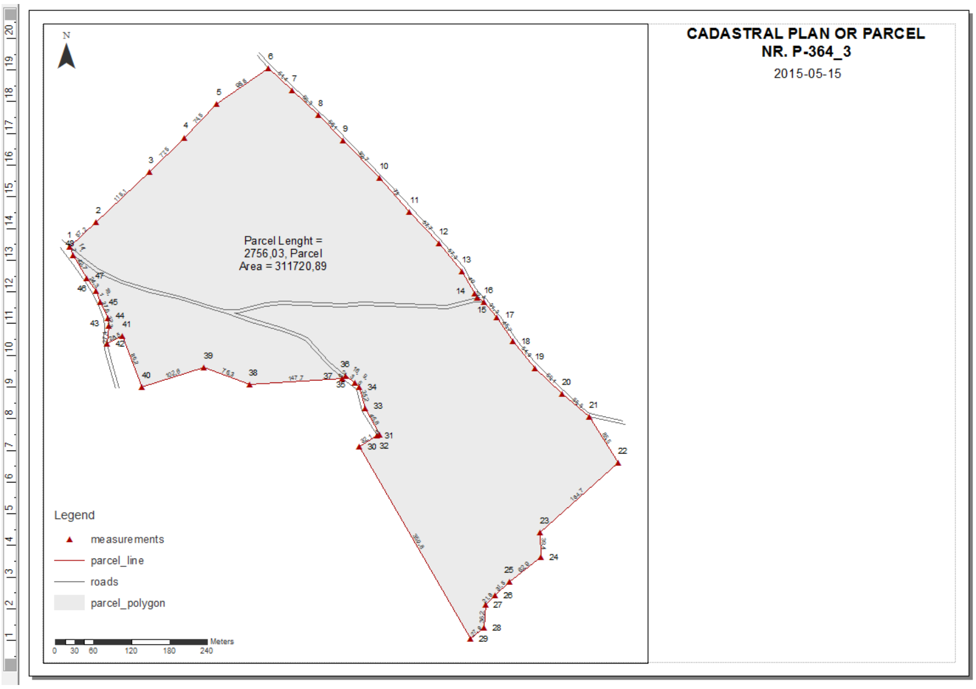


Question 14. What is system of metes and bounds that is used to describe the extent and location of property units? Describe the concept of this western European system. (4 points)

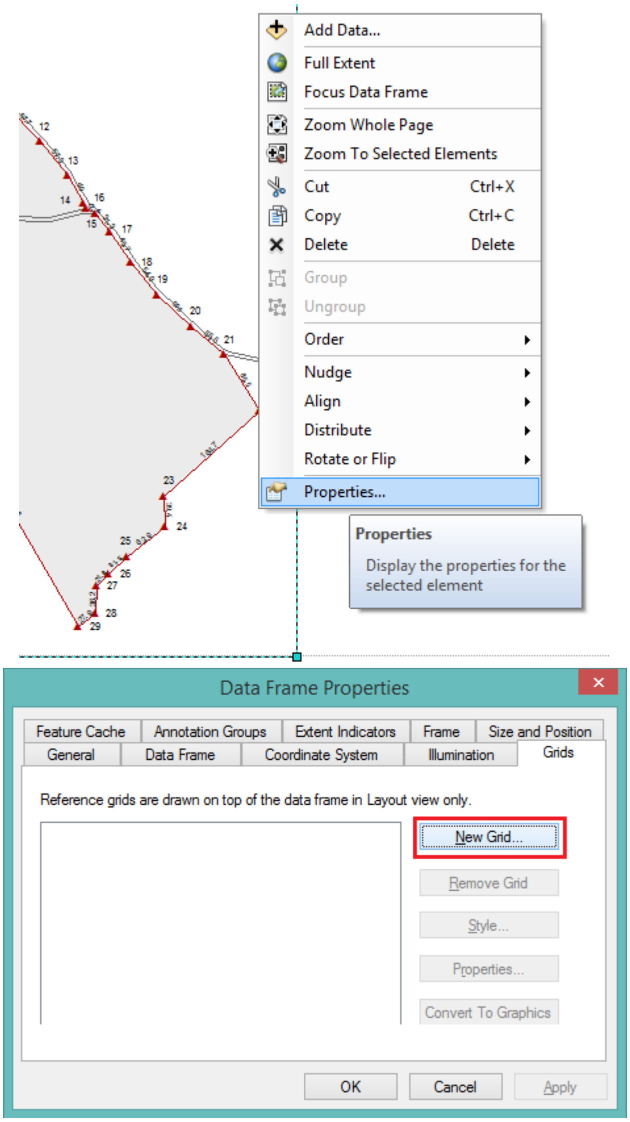
29. Now you will insert other plan elements such as a legend, north arrow, annotation, scale etc. on the layout. All of these plat's elements can be inserted from the ArcMap main menu *Insert*.



You can customize inserted plot elements by changing their *Properties*. In the right top side of drawing layout, insert the title of plot's plan and a date of drawing's complied into a separately text frame such as it is shown below.

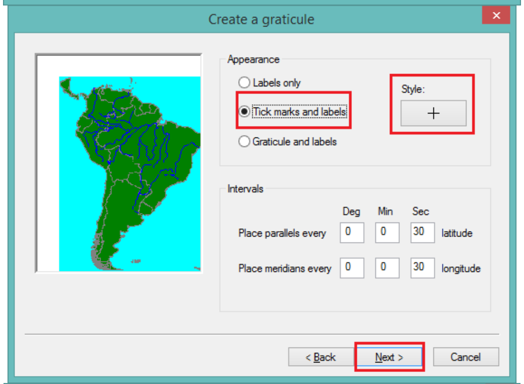


30. Next, insert a geographical grid around the plan. Use the *Select Elements* tool to select the frame with the plan, then right-click on it and open the frame *Properties*. In the dialog, go the tab *Grid* and press the *New Grid* button.



Go through the grids wizard steps and select the main geographical grid settings as shown below. Apply the *Finish* button on the last wizard step and then *OK*.

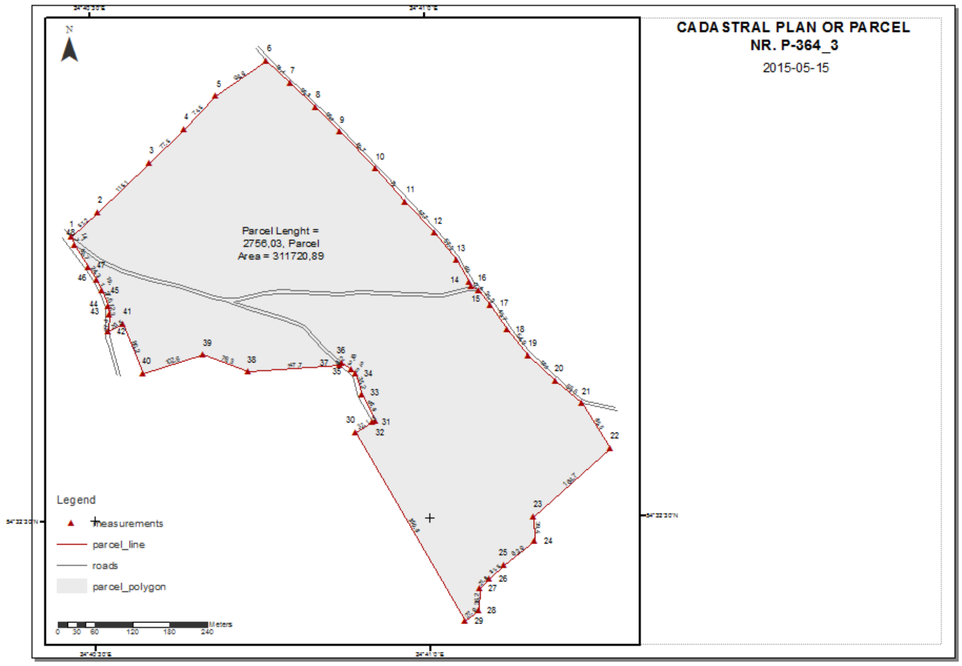

Grids and Graticules Wizard
Which do you want to create?
Graticule: divides map by meridians and parallels
Measured Grid: divides map into a grid of map units
Reference Grid: divides map into a grid for indexing
Grid name: Graticule
< Back
Next >
Cancel


Create a graticule
Appearance
Labels only
Tick marks and labels
Graticule and labels
Style:
Intervals
Deg Min Sec
Place parallels every 0 0 30 latitude
Place meridians every 0 0 30 longitude
< Back
Next >
Cancel

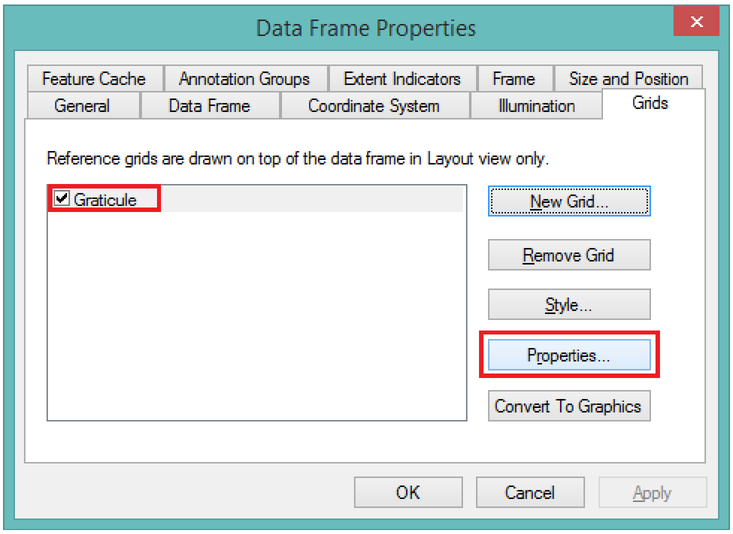

Axes and labels
Axes
Major division ticks
Line style:
Minor division ticks
Line style:
Number of ticks per major division: 0
Labeling
Text style:
< Back
Next >
Cancel


Create a graticule
Graticule Border
Place a simple border at edge of graticule
Place a calibrated border at edge of graticule
Properties...
Neatline
Place a border outside the grid
Graticule Properties
Store as a static graphic that can be edited
Store as a fixed grid that updates with changes to the data frame
< Back
Finish
Cancel

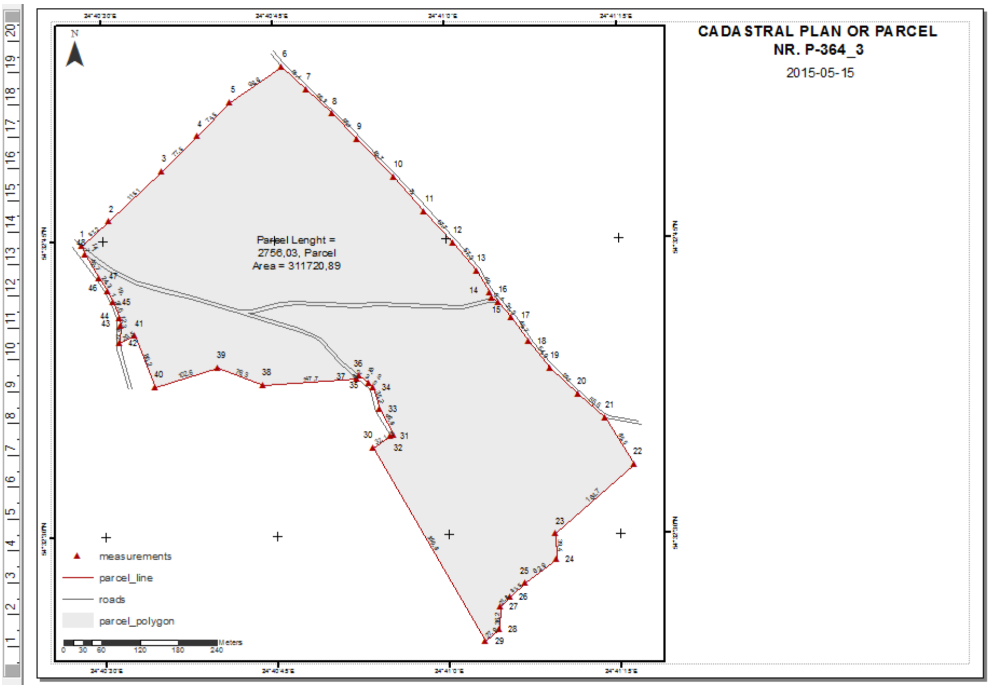
The plot's title should look like as the following:



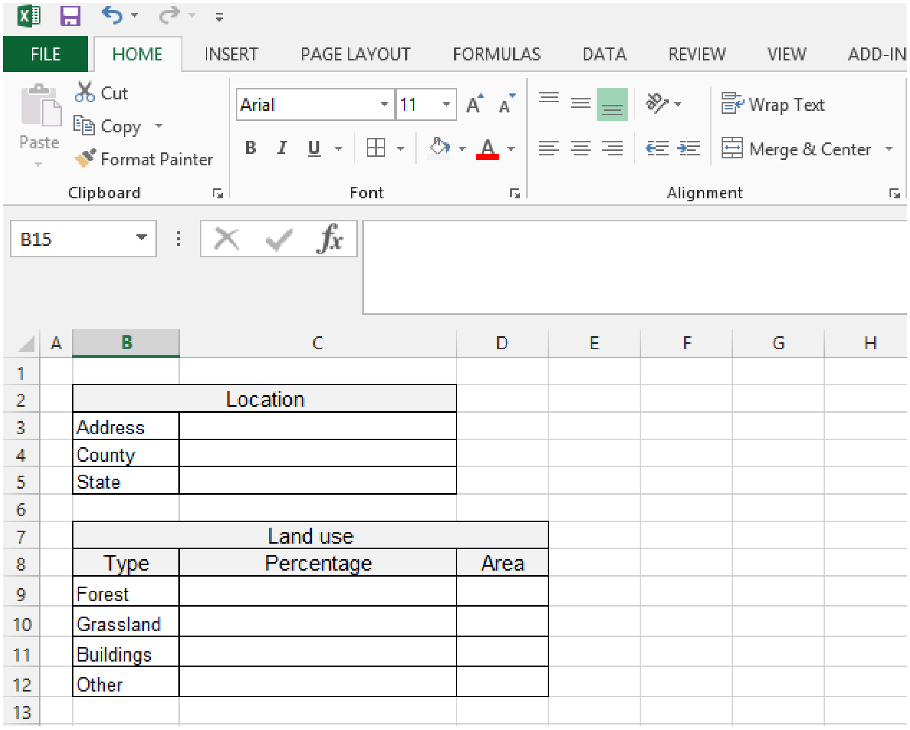
If you would like to change the grid appearance, select it with the *Select Elements* tool, right click it to open its *Properties*. Now you can customize the grid appearance from the tab *Grids* by using the *Properties* of selected grid.



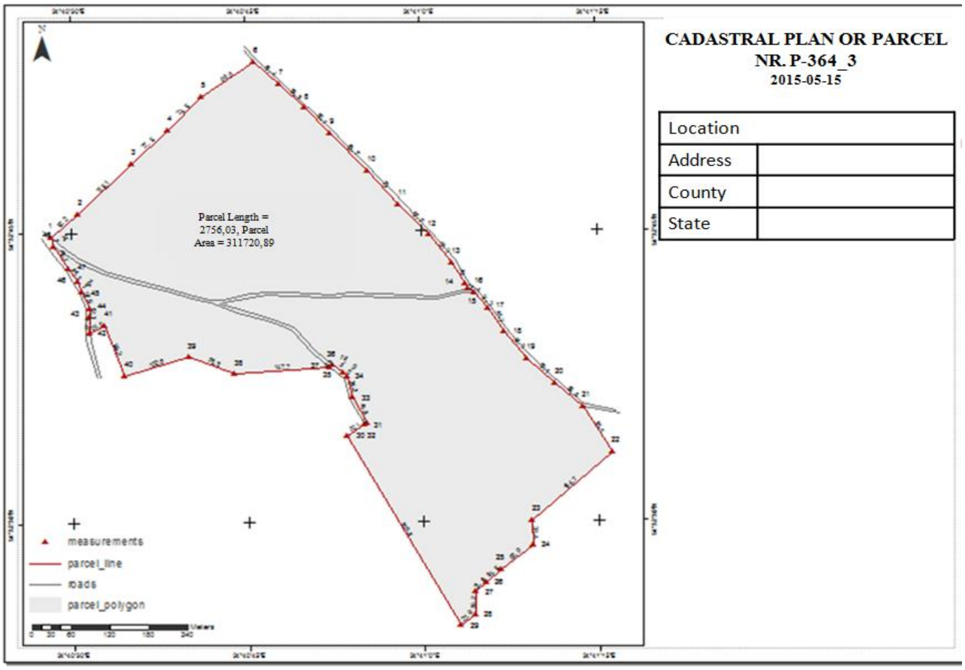
Change the grid so that the side labels of geographic coordinate are aligned properly and make the tics of grid denser, as it shown below.



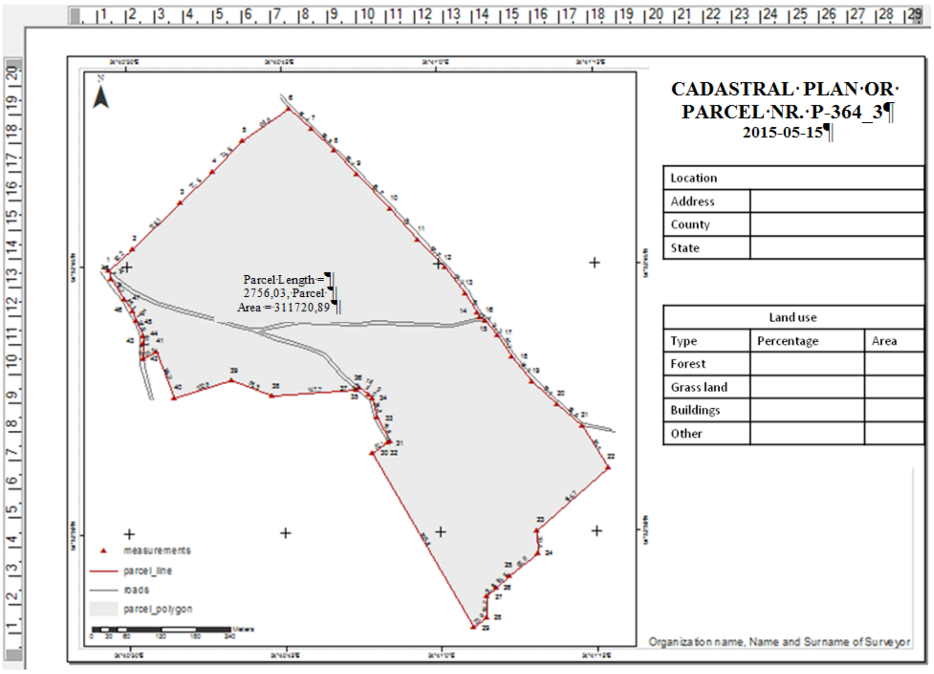
31. Now you will insert tables from the **PlanTable.xlsx** file. These tables were prepared for your use. The tables provide information about the surveyors and other characteristics of plot. There are a few ways to insert tables into an ArcMap layout. If a table prepared in Microsoft Excel, it can be directly inserted into an ArcMap layout. Open the **PlanTable.xlsx** file in Excel from your working folder **Lab1_Data**.



32. Select one table and copy it in the clipboard (you may use keyword combination Ctrl+ C to copy). Insert a copied table in the plat below the title from the ArcMap main menu *Edit* > *Paste*, or use the keyboard combination *Ctrl+V*. Adjust the table into the layout as it shown below by using the *Select Elements* tool.



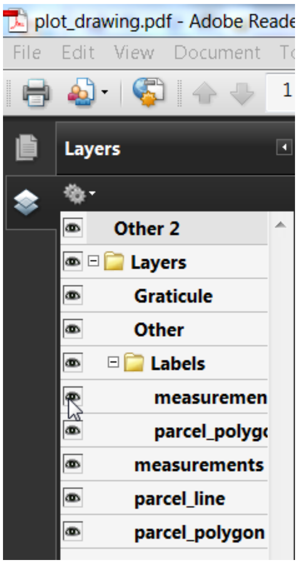
Copy and insert the second table into your plot's layout. These tables can be used to annotate the plot.



Thus, you have compiled a cadastral plot drawing.

33. Print the plot drawing in PDF format: from the ArcMap main menu *File*, use the *Export Map* option. In the dialog, select *PDF* as the *Save As Type*, 300 dpi as the *Resolution* and export the plot's drawing into your working folder with the name **plot_drawing**.

Open your **plot_drawing.pdf** file in Adobe Acrobat Reader. ArcMap creates a dynamic PDF file. In Adobe Acrobat Reader, navigate to the main menu *View > Navigation Panes > Show Navigate Pane > Layers* if you do not see the *Layers* menu in the PDF viewer. You can then turn on and off individual layers by clicking on the "eyeballs" beside each layer.



Question 14: Submit you plot_drawing.pdf with your lab hand-in. (15 points)

CHAPTER II

2. SPATIAL DATA SOURCES FOR CADASTER: REMOTE SENSING

2.1. WHAT IS REMOTE SENSING?

The simplest definition for the term **Remote Sensing** is: "Remote Sensing (RS) is the acquisition of information about an object without touching it." This definition is not very helpful in describing the field of remote sensing.

John Jensen (2007) offers a more descriptive definition:

Remote Sensing is the "noncontact recording of information from the ultraviolet, visible, infrared, and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, scanners, lasers, linear arrays, and/or area arrays located on platform such as aircraft or spacecraft, and the analysis of acquired information by means of visual and digital image processing" (Jensen, Remote Sensing of the Environment: An Earth Resource Perspective, 2nd ed., 2007).

Remote Sensing also can be considered as a discipline of Geomatics or Geo-Information Science, along with GPS and Cartography (Figure 1).

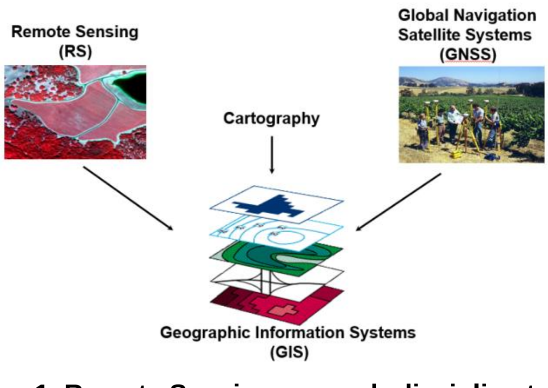
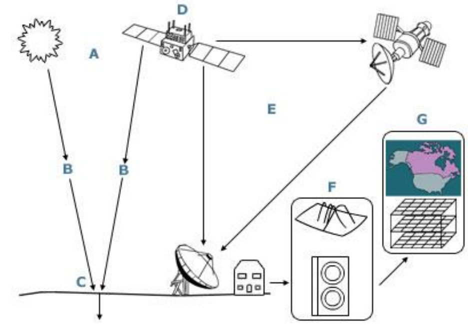


Figure 1. Remote Sensing as a sub-discipline to GIS.

In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved (Figures 2-9). Note, however that remote sensing also involves the sensing of emitted energy (or thermal energy) and the use of non-imaging sensors.



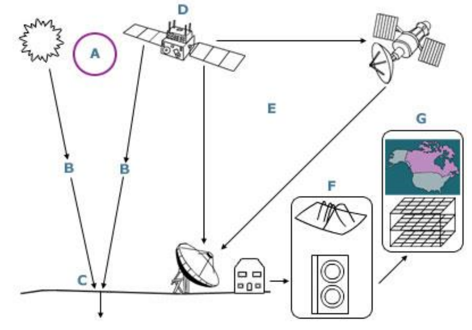
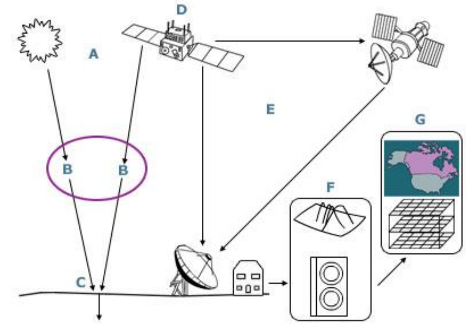


Figure 2. Seven elements comprise the remote sensing process from beginning to end (A to G). (CCRS, 2004).

Figure 2. <u>Energy Source or Illumination (A):</u> The first requirement for remote sensing is to have an energy source, which illuminates or provides electromagnetic energy to the target of interest (CCRS, 2004).



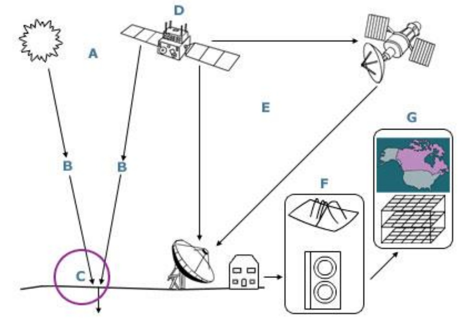
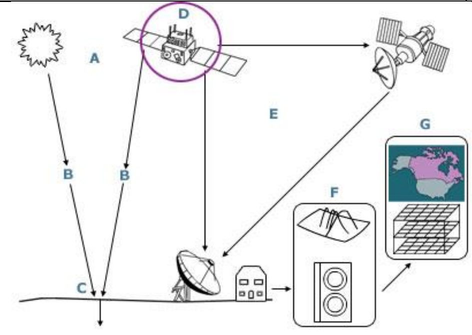


Figure 3. <u>Radiation and the Atmosphere (B):</u> As the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor (CCRS, 2004).

Figure 4. <u>Interaction with the Target (C):</u> Once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation (CCRS, 2004).



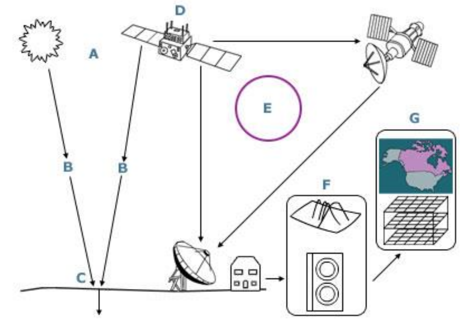


Figure 5. **Recording of Energy by the Sensor (D):** After the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.	**Figure 6.** **Transmission, Reception, and Processing (E):** The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital) (CCRS, 2004).

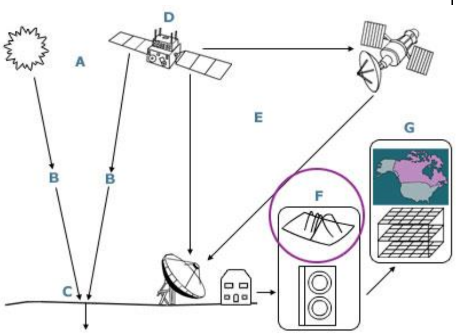
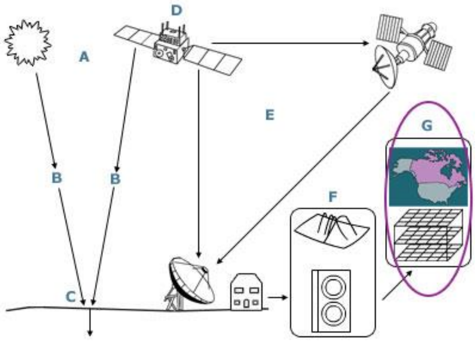

	

Figure 7. **Interpretation and Analysis (F):** The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target that was illuminated (CCRS, 2004).	**Figure 8.** **Application (G):** The final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem (CCRS, 2004).

2.2. USE OF REMOTE SENSING FOR CADASTER

Remote Sensing (**RS**) has become a traditional source of information for a variety of applications such as agriculture, natural resource management, forestry, urban planning etc., because it is relatively inexpensive, provides rapid collection of data for large areas and often offers more current information than maps in vector or paper formats.

Among those Remote Sensing applications is land management. Land management is often based on a cadastre where the landscapes have been structured as land parcels defined by polygons, each polygon being modelled as an object with attributes and relationships with its neighbours.

Remote Sensing sources (aerial photograph and satellite images) are widely used for cadastral purposes. The following practices of Remote Sensing use in cadastral mapping can be identified:

- Remote Sensing images of high-resolution may be used for creating cadastral maps. Large-scale aerial and satellite imaging offers a rapid and cost effective means of extracting topographic and cadastral information for creating maps of parcel fabric. Although aerial and satellite surveys are not the best alternative to field survey with respect to surveying accuracy of parcel boundaries, in many countries it is impossible to do mass rapid cadastral field surveying, and RS techniques can be alternative approach for establishment of a cadastral system in its initial stages. Thus, orthophoto imagery can be used to delineate land parcels with relatively low accuracy for property registration, later updated from field surveying. In addition, orthophoto and LiDAR imagery can be used to delineate cadastral objects on the properties such as buildings or elements of the utility infrastructure (hydrant, power lines etc.)

- Thus according with General Survey Instruction Rules for British Columbia (General Survey Instruction Rules, 2015), the position of natural boundaries may be determined by any survey method that yields an accuracy of 0.5 metres or better. Such methods also can include indirect photogrammetric methods, e.g., aircraft and satellite images.
- Remote Sensing imagery can be used for updating cadastral maps. RS is a rapid technique for monitoring changes of cadastral objects. Illegal use of land and illegal construction on the land can be effectively monitored via RS techniques.
- RS imagery from land resource satellites are traditionally used for land use and land cover (LU/LC) classification. Such LU/LC classifications are then used for urban and rural zoning, definition of protected areas, etc. RS can be an instrument to monitor the evolution of the actual land use using spatial indicators relevant for policy at the political level to support decision-making.
- Remote Sensing imagery can also be used for land and real estate evaluation. For example, RS imageries can be used to classify urban areas based on quality of land and then this zoning can be used for land evaluation and taxation. Real estate agents and potential purchasers can review properties using high-resolution 3D views created from RS imaging sources without needing to visit the site.
- Local municipal organizations are actively using RS sources for their asset infrastructure management. Cadastral related objects such as electricity lines, poles, manholes, etc. can be mapped and monitored using high-resolution imagery.
- Remote sensed imageries provide a historical record of the areas that can be revisited in the future to see what changes have taken place and identify areas in need of updating cadastral records (deeds). In smaller spatial scales, RS sources provide means to describe urban pattern and spatial directions of urban growth.

There are also some disadvantages for using remote sensing for cadastre. Property boundaries frequently do not have visible marks on the ground, so finding the boundaries using RS techniques may be difficult. Aerial and satellite imaging is also highly dependent on weather and climatic conditions.

The implementation of Remote Sensing for land management applications has dramatically changed with digital, web and mobile technologies. In the 1980s, aerial photographs were systematically scanned to be digitally processed and used for land management purposes. In the 1990s, most aerial and satellite imagery was captured in digital formats. In the 2000s, near real-time processing systems began to be used to produce quick-turnaround imagery in digital format within hours of data acquisition through the web or Wi-Fi. More recently, LiDAR (LIght Detection And Ranging) technology appeared in the remote sensing market. LiDAR can be used for creating a 3D cadaster, parcels mapping, identification of rooftops of buildings, etc., but generally speaking as a developing technology LiDAR is still looking for its application in the field of cadastre.

2.3. TYPES OF REMOTE SENSING

How do sensors differ from each other? Most of the Remote Sensing systems can be distinguished between each other based on: platforms for remote sensing sensors; use of energy sources; imaging methods; and image characteristics.

Platforms for Remote Sensing Sensors: In order for a sensor to collect and record energy reflected or emitted from a target or surface, it should reside on a stable platform removed from the target or surface being observed. Platforms for remote sensors can be situated (Figures 10-13):

			
Figure 10. On the ground (up to 50 m) and in situ - invasive technique.	**Figure 11. On an aircraft (up to 50 km) or balloon (or some other platform within the Earth's atmosphere) - non-invasive technique.**	**Figure 12. On an unmanned aerial vehicle (UAV) (up to 20km).**	**Figure 13. On a spacecraft or satellite (from about 100 km to 36000 km) outside of the Earth's atmosphere - non-invasive techniques.**

Use of Energy Sources: Three main energy sources used for Remote Sensing are:

- Solar reflected radiation (from the Sun - reflected energy).
- Long-wave emitted radiation (from the Earth - emitted energy).
    - The sun's energy is also absorbed and then re-emitted in the form of thermal infrared wavelengths.
- Human-made sources (radio and laser wave emission - active energy).

This energy exists in the form of electromagnetic radiation (EMR). The EMR of the electromagnetic spectrum ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). Several regions of the electromagnetic spectrum are useful for Remote Sensing that are ultraviolet (UV), visible (Blue, Green, Red lights), infrared (NearIR, MidIR and FarIR (or thermal)) and microwave (used for RADAR) portions (Figure 14).

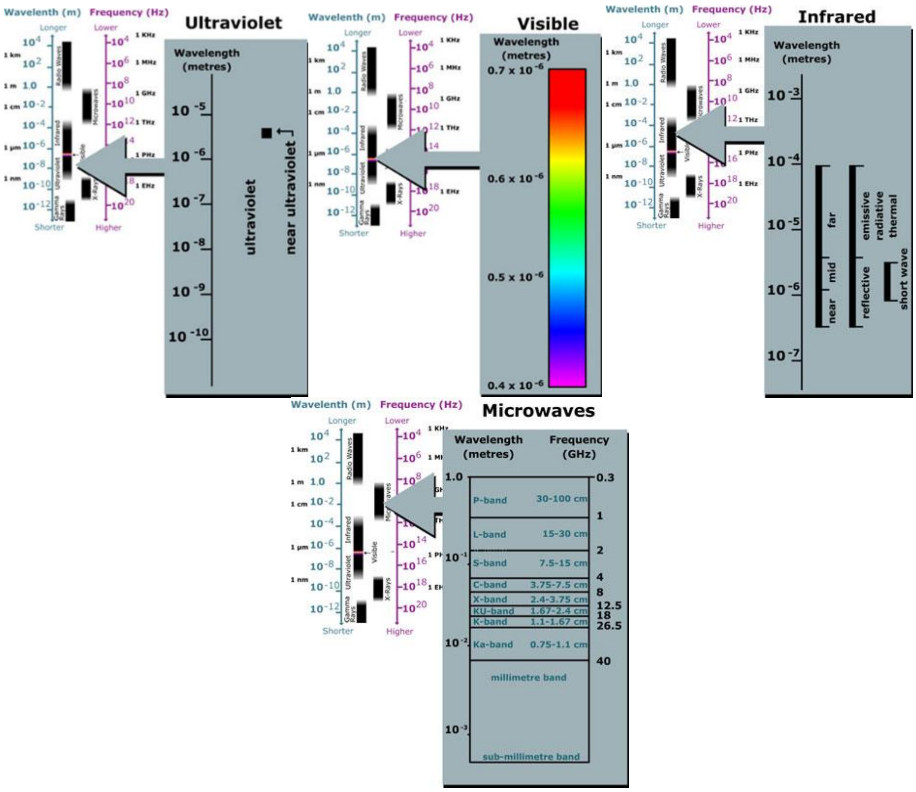


Figure 14: Portions of the electromagnetic spectrum used in Remote Sensing

Remote sensing systems that measure energy, which is naturally available, are called **passive** sensors. Active sensors detect and record energy emitted from the sensor itself.

Passive sensors can record:

- Reflected energy (visible, illuminated by the Sun).
    - For all reflected energy, this can only take place during the time when the Sun is illuminating the Earth. There is no reflected energy available from the Sun at night.
    - Optical RS makes use of visible, near infrared and mid infrared waves' sensors to form images of the earth's surface by detecting the solar radiation reflected from targets on the ground.
- Emitted energy (thermal infrared, emitted by the Earth and objects on it).
    - Energy that is naturally emitted (such as thermal infrared) can be detected day or night, as long as the amount of energy is large enough to be recorded.
    - Thermal RS is operating in the far infrared part of the spectrum: 3.0 to 14 micrometers.

Active sensors, on the other hand, provide their own energy source for illumination. Thus, active sensors actually emit EMR in certain wavelengths toward the target to be investigated, and then detect and measure the returning signal. Active sensors are much more complex than passive sensors, both in their technology and the interpretation of the signal. Some examples of active sensors are a laser fluorosensor and synthetic aperture radar (SAR). Thus, RADARs (RAdio Detection and Ranging) use pulses of long wave EMR in the radio spectrum (~1 mm – 1 m wavelengths) to illuminate the terrain to determine the distance and angular position of objects. In a similar way as RADAR, LiDARs (LIght Detection And Ranging) measure the time for laser pulse (usually visible or near IR wavelengths) to return and generate distance measurement. "**Three Models**" of RS is demonstrated in the following Figure 15.

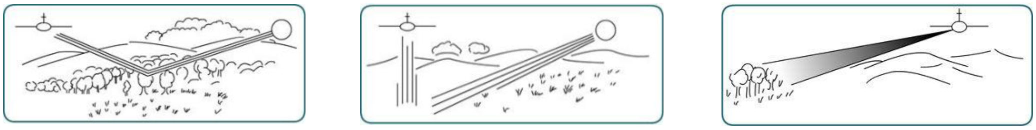


Figure 15a: Passive sensor - reflected solar radiation.

Figure 15b: Passive sensor - emitted terrestrial radiation.

Figure 15c: Active sensor - emitted own energy. (Campbell, 1996).

Imaging methods: A Sensor's systems can be classified by imaging methods:

- Framing systems are instantaneously measure radiation coming from the entire scene at once to form an image, and include:
  - Analogue photographic cameras.
  - Digital array sensors (digital cameras).
- Scanning systems sense the entire scene pixel by pixel (the instantaneous field of view, or IFOV) along or across successive lines over a finite time, and include:
  - Video scanning (vidicons, video sensors).
  - Optical mirror scanning.
  - Line or lines' scanning.

Image Characteristics: There are four types of image resolutions related to image characteristics that can be used to categorized RS images as well as RS sensors:

- Spatial resolution: smallest discernible physical object or detail in an image.

A measure of the spatial resolution of a remote sensing imaging system is the most common measure of resolution and can be defined as that area on the ground that is viewed by the instrument from a given altitude at any given time. The detail distinguishable in an image is dependent on the spatial resolution of the sensor and refers to the size of the smallest possible feature that can be detected.

Spatial resolution of passive sensors depends primarily on their Instantaneous Field of View (IFOV). The IFOV is the angular cone of visibility of the sensor (A) and determines the area on the Earth's surface that is "seen" from a given altitude at one particular moment in time (B). The size of the area viewed is determined by multiplying the IFOV by the distance from the ground to the sensor (C) (CCRS, 2004). This area on the ground is called the resolution cell and it determines a sensor's maximum spatial resolution (Figure 16).

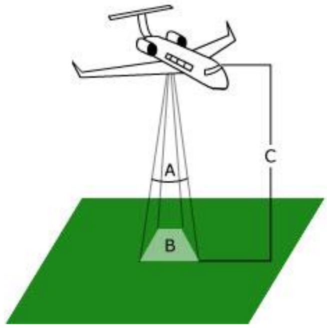


Figure 16: Instantaneous Field of View or sensor's maximum spatial resolution

RS images can be classified by spatial resolution as coarse or low resolution; fine or high resolution, and sub-meter resolution images. Examples images in from course to sun-meter spatial resolutions are shown on the Figure 17:

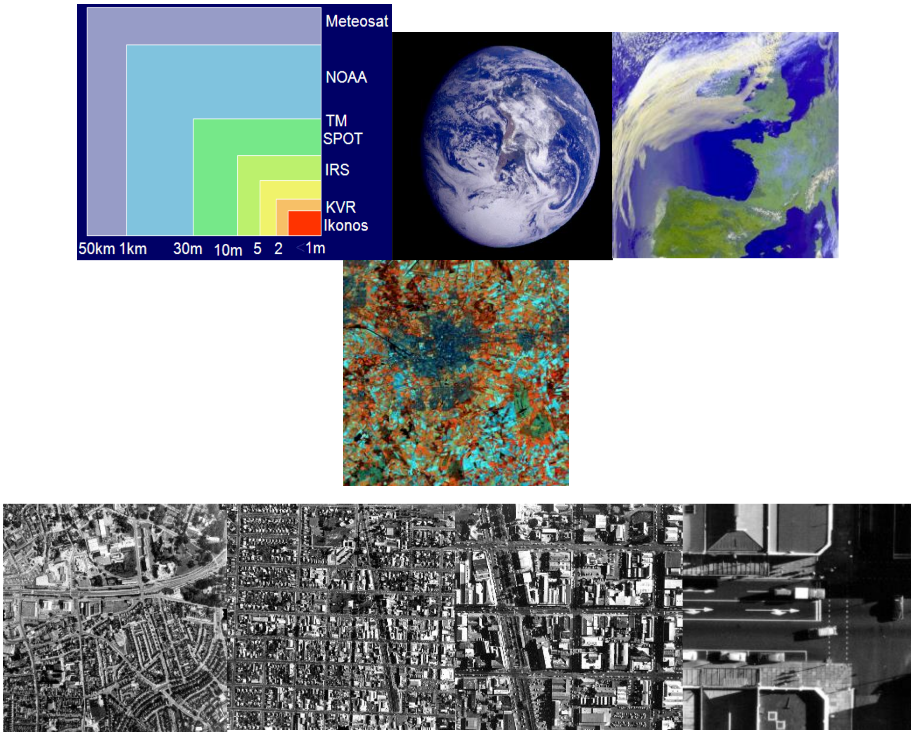


Figure 17: Satellite imageries in different resolutions (ITC, 2006).

- Spectral resolution: "thickness" of bands or channels (min and max wavelength sensed).

A RS sensor gathers and stores information from a particular wavelength range in a band, also sometimes referred to as a channel. A band is a region of the EMR to which a set of detectors are sensitive.

Spectral resolution is the number, wavelength position and width of spectral bands a sensor has. Spectral resolution describes the ability of a sensor to define fine wavelength intervals (bands). The number and distribution of these bands determines the spectral coverage. Multispectral sensors have a few and wide bands. Hyperspectral sensors have many narrow bands.

Images by spectral resolution can be categorized in three types:

- Low (or coarse) spectral resolution images. E.g., panchromatic image.
- Medium spectral resolution images. E.g., multispectral imagery with 2 to 10 spectral bands (Figures 18-19).
- High (or fine) spectral resolution images. E.g., hyperspectral imagery (aka imaging spectrometer) with more than 10 bands.

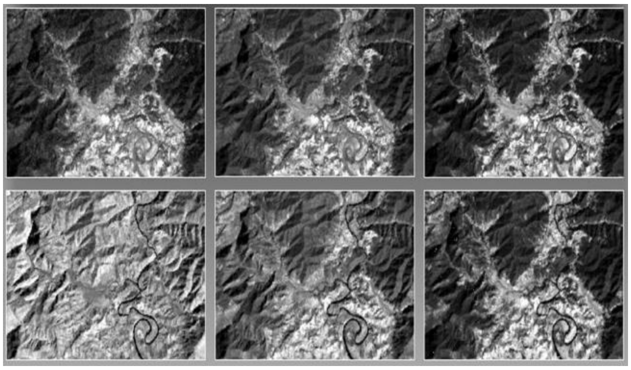


Figure 18: Example of six bands (Blue, Green, Red, Near Infrared, Mid Infrared 1 and Mid Infrared 2) of multispectral imagery

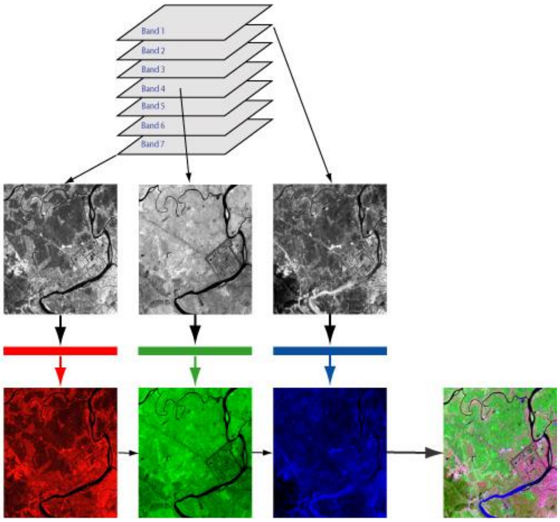


Figure 19: Color composites combinations using multispectral images (The Biodiversity Informatics Facility at the American Museum of Natural History, 2009)

- Radiometric resolution: difference between minimum and maximum reading or measurement, or number of steps between min and max reading or measurement.

While the arrangement of pixels describes the spatial structure of an image, the radiometric characteristics describe the actual information content in an image. Every time an image is acquired on film or by a digital sensor, its sensitivity to the magnitude of the electromagnetic energy determines the radiometric resolution. The finer the radiometric resolution of a sensor the more sensitive it is to detecting small differences in reflected or emitted energy.

A digital image is a matrix of brightness values that are described by Digital Numbers (DN). Brightness values or DN (Figure 20) usually are represented by positive digital numbers which vary from 0 to (one less than) a selected power of 2. This range corresponds to the number of bits used for coding numbers in binary format. Each bit records an exponent of power 2 (e.g., 1 bit equals 2 of power 1 and equals 2 (with the range 0-1), 8 bit equals 2 of power 8 and equals 256 (with the range 0-255)) (Figure 21).

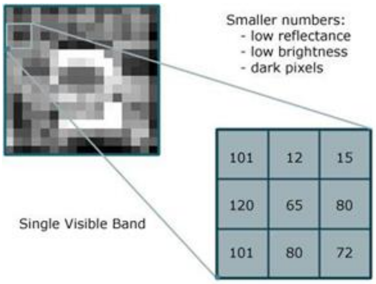


Figure 20: Brightness values of band's pixels and their Digital Number

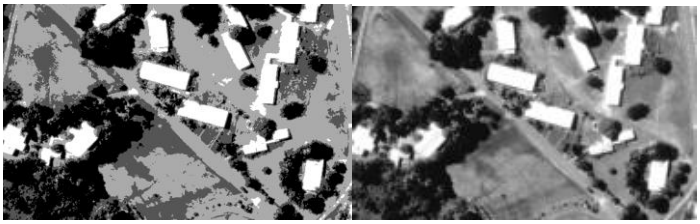


Figure 21: By comparing a 2-bit image representing 4 levels of brightness (left) with an 8-bit image to display 256 levels of brightness (left), we can see that there is a large difference in the level of detail (brightness) discernible depending on their radiometric resolutions.

- Temporal resolution: time between repeated sensing.

The concept of temporal resolution relates to the concept of revisit period of satellite RS, which refers to the length of time it takes for a satellite to return and image the same point on the Earth (CCRS, 2004). The revisit period of a satellite sensor can be several days or even a couple of weeks. However, because of some degree of overlap in the imaging swaths of adjacent orbits for most satellites and the increase in this overlap with increasing latitude, some areas of the Earth tend to be re-imaged more frequently (CCRS, 2004). Some satellite systems are able to point their sensors to image the same area between different satellite passes separated by periods from one to five days. Thus, the actual temporal resolution of a sensor depends on a variety of factors, including the satellite/sensor capabilities of off-nadir view, the swath overlap, and latitude.

A digital Remote Sensing imagery (Figure 22) consists of:

- Multiple bands or channels with a particular spectral resolution.
- Each band is a matrix of pixels in a particular spatial resolution.
- Digital number (DN), which quantifies a magnitude of reflectance, defines value of each pixel in particular radiometric resolution.
-

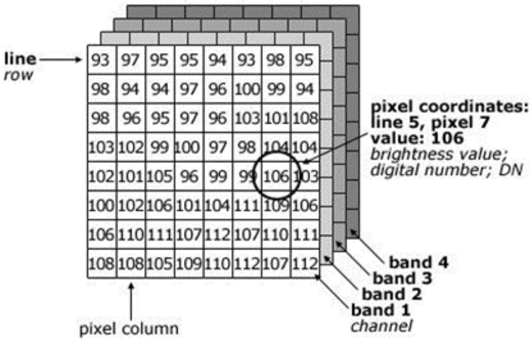


Figure 22: Components of a RS imaginary

2.4. AIRCRAFT OPTICAL IMAGERY

Aerial photography is process of making of images from an aircraft (up to 50 km) or balloon (or some other platform) within the Earth's atmosphere. Aerial photographs and digital aerial imagery has been a primary source of topographic and cadastral mapping in medium and large scales for quite a long time. Aerial photographs started almost as soon as portable cameras were invented and became practical with the invention of the airplane. As the camera was used more and more for aerial photographs, the science and profession of photogrammetry was defined. Digital aerial cameras are replacing film cameras as the sensor of choice in the 1990s.

Aerial photography is a passive method of RS which uses reflected energy from the Sun. Cameras used for aerial photography are mostly frame systems. Two basic types of cameras are used in aerial photography, aerial photographic cameras and digital CCD (charge-coupled device) cameras (Figure 23).

A photograph refers specifically to images that have been detected as well as recorded on photographic film (Figure 24). Photographic films can be sensitive to light from 0.3 micrometers to 0.9 micrometers in wavelength covering the ultraviolet (UV), visible, and near-infrared (NIR). Panchromatic (greyscale), true color and infrared aerial photographs can be printed onto paper or plastic and can be converted into digital formats.

Figure 23: Frame sensors: aerial photographic and digital cameras

Figure 24: A typical aerialphoto is black and white, with image size of 9 inch x 9 inch, and focal length approximately of 6 inch (can be shown in mm)

Digital cameras record electromagnetic radiation electronically, and they differ significantly from their counterparts that use film. Instead of using film, digital cameras use a gridded array of silicon coated CCDs (charge-coupled devices) that individually respond to electromagnetic radiation. The CCD is a rectangular array of pixels that respond to light and record the intensity of the range of the electromagnetic spectrum that it is calibrated to record. It is possible to split multiple CCD's across multiple lenses, or use multiple CCD's with a single lens to simultaneously record different portions of the electromagnetic spectrum (Figure 25).

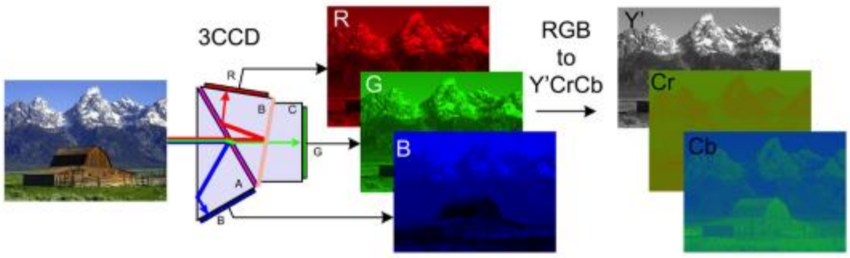


Figure 25. The reflected energy from the visible portion of the electromagnetic spectrum reacts with a three CCD system

Figure 25 shows how reflected energy from the visible portion of the electromagnetic spectrum reacts with a three CCD system. In a three CCD system, there is one CCD for each primary color (Blue, Green and Red). A complex set of mirrors and filters redirect the primary colors onto its respective CCD. This creates three separate images, each reflecting the intensity of returned energy for one of the three primary colors. When those three images are laid on top of each other, they create a true color photograph.

Modern digital imaging systems are capable of collecting data with a spatial resolution up to 1.8 cm at 300 m flying height, and with a spectral resolution of four multispectral bands: Blue, Green, Red and Near Infrared plus a panchromatic band. In general, a panchromatic band refers to black and white imagery exposed by all visible light (but can be exceptions).

The size of the pixel arrays varies between systems, but typically ranges between 512 x 512 to 17,310 x 11,310 pixels. Radiometric resolution can be up to 14 bit.

Most aerial images are classified as either oblique or vertical, depending on the orientation of the camera relative to the ground during acquisition. Vertical images are images that are tilted less than 3° off the vertical are regarded as vertical. For cadastral purposes, vertical images are mostly applicable as they provide high accuracy for delineating parcels and buildings.

When obtaining vertical aerial images, the aircraft normally flies in a series of lines, each called a flight run (A). The distance the camera moves between exposures is called the air base. Aerial images are taken in rapid succession looking straight down at the ground and overlap within and between flight runs. The overlap in these two directions is called forward overlap (or endlap) and sidelap. The forward overlap ensures total coverage along a flight line and also facilitates stereoscopic viewing. Forward overlap within a flight run is from 60 to 70% between sequential images. Sidelap between flight runs is from 25-40% and ensures that no areas are left unphotographed (Figure 26).

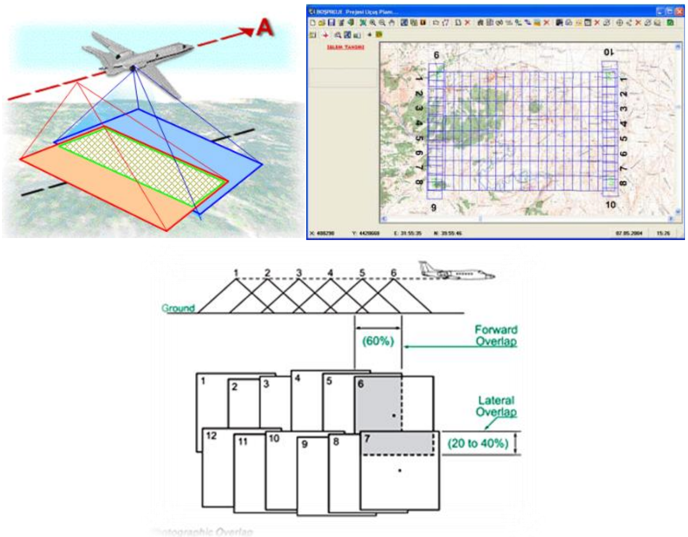


Figure 26: Illustration of flight run, air base and overlaps

There are a few primary uses of aerial imagery: topographical surveying and mapping (including cadastral mapping), Digital Elevation Model extraction, visual and digital image interpretation, and background use.

Where a new cadastral survey of a large area is required to be carried out quickly, an aerial survey is often the most practical method. When time and money allow, the areas can be resurveyed to higher accuracy at a later date.

In the simplest case, aerial images may be used as a base on which to outline the parcels (Figure 27). However, a parcel's boundary delineation could be done only where the boundaries of parcels are visible from the air and/or a ground control network is available to rectify images. Delineation of parcel boundaries can be a laborious if performed by manual screen digitizing or photogrammetry. In some countries, it is sufficient to produce a plan which acts as a signpost to the parcels, the boundaries of which can be determined by inspection on the ground. In such cases there is no need to record the accurate dimensions of any land parcel so long as its boundaries are clearly visible on the aerial images. Such an approach is expedient where large numbers of parcels need to be recorded over a short period of time.

Figure 27: Osama bin Laden compound, http://www.digitalglobe.com/index.php/27/Sample+Imagery+Gallery

In some cases, particularly in urban environments, it is expected that control markers will mark the parcel boundary. Such markers can relate to borderlines, like fences that surround buildings, or break lines between the ground level of buildings and the street. If recognizable, such objects can be used to generate a partitioning that often reflects the actual (or eventual) parcelation of cadastral blocks.

Cadastral surveys of small areas, extensions to existing surveys, and revision work will usually best be done by the ground surveying techniques. In this case, the advantage of speed is much less, and must in any event be weighed against increased costs.

The consideration of aerial images for particular mapping applications depends on the scale of imagery. The accuracy and photo-map scale relationships mainly depend on the resolution of aerial images, the flying height, the base-height ratio and the accuracy of the stereo-plotting. Thus, aerial images with spatial resolution less than 10 cm can be used for cadastral mapping at 1:500 - 1:5,000 scale's range.

2.5. SATELLITE OPTICAL IMAGERIES

Many satellite RS sensors (as opposed to aircraft based system) acquire data using scanning systems, which employ a sensor with a narrow field of view (i.e. IFOV) that sweeps over the terrain to build up and produce a two-dimensional image of the surface. A scanning system used to collect data over a variety of different wavelength ranges is called a multispectral scanner (MSS), and is the most commonly used scanning system.

Modern RS sensors are along-track scanners by design. Along-track scanners use the forward motion of the platform to record successive scan lines and build up a two-dimensional image, perpendicular to the flight direction. They use a linear array of detectors (A) located at the focal plane of the image (B) formed by lens systems (C), which are "pushed" along in the flight track direction (i.e. along track). These systems are also referred to as pushbroom scanners, as the motion of the detector array is analogous to the bristles of a broom being pushed along a floor.

Each individual detector measures the energy for a single ground resolution cell (D) and thus the size and IFOV of the detectors determines the spatial resolution of the system. A separate linear array is required to measure each spectral band or channel. For each scan line, the energy detected by each detector of each linear array is sampled electronically and digitally recorded (Figure 28).

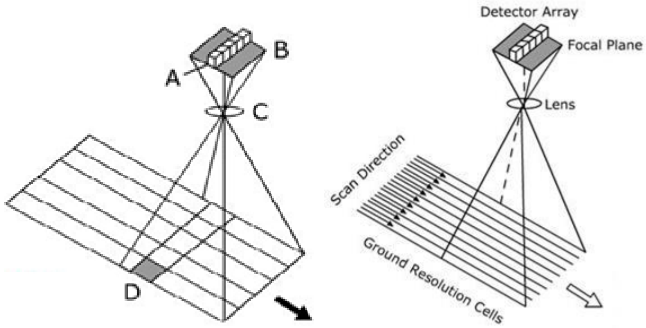
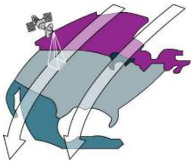
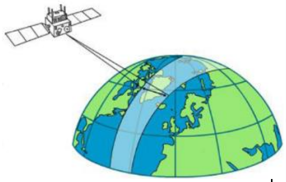
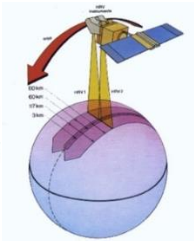
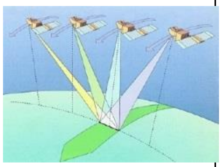


Figure 28: Along-track scanner's components and principles

Most of RS satellite platforms are designed to follow a sun-synchronous orbit (from the north to the south with small inclination) which, in conjunction with the Earth's rotation (west-east), allows them to cover most of the Earth's surface over a certain period of time. These are near-polar orbits, so named for the inclination of the orbit relative to a line running between the North and South poles (Canadian Space Agency, 2009).

Many of these near-polar satellite orbits are also sun-synchronous such that they cover each area of the world at a constant local time of day called local sun time (CCRS, 2004). At any given latitude, the position of the sun in the sky as the satellite passes overhead will be the same within the same season. This ensures consistent illumination conditions when acquiring images in a specific season over successive years, or over a particular area over a series of days. This is an important factor for monitoring changes between images or for mosaicking adjacent images together, as they do not have to be corrected for different illumination conditions (Figure 29).

The near-polar orbit (including sun-synchronous orbit) satellite travels northwards on one side of the Earth and then toward the southern pole on the second half of its orbit. These are called ascending (South-North) and descending passes (North-South), respectively. If the orbit is also sun-synchronous, the ascending pass is most likely on the shadowed side of the Earth while the descending pass is on the sunlit side. Then, sensors recording reflected solar energy only image the surface on a descending pass, when solar illumination is available. Active sensors that provide their own illumination or passive sensors that record emitted (e.g. thermal) radiation can also image the surface on ascending passes. Most of the RS satellite platforms today are in near-polar orbits, which means that the satellite travels northwards on one side of the Earth and then toward the southern pole on the second half of its orbit.

				
Figure 29: Near-polar sun-synchronous satellite orbit	**Figure 30: Satellite swath**	**Figure 31: The satellite swath shifts for each new pass on the orbit**	**Figure 32: Nadir viewing (CRISP, Singapore, 2009)**	**Figure 33: Off-Nadir viewing**

As a satellite revolves around the Earth, the sensor "sees" a certain portion of the Earth's surface called swath (Figure 30). Imaging swaths for space-borne sensors generally vary between tens and hundreds of kilometers wide. The satellite orbits runs the Earth from pole to pole and because of the Earth rotation (from west to east) the satellite swath shifts for each new pass on the orbit, and thus sensor covers different areas on the Earth (CCRS, 2004). Thus, the satellite's orbit and the rotation of the Earth work together to allow complete coverage of the Earth's surface (Figure 31).

Revolution orbital cycle is time taken for platform to complete one orbit of the earth. The exact length of time of the orbital cycle will vary with each satellite. Revisit period is the interval of time required for the satellite to image the same area on the Earth. Revisit period is function of revolution cycle, latitude and off nadir viewing capability. Using steerable sensors, a satellite-borne instrument can view an area (off-nadir) before and after the orbit passes over a target, thus making the revisit time less than the orbit cycle time. Satellites can collect enough endlap that a three-dimensional image can later be created.

Nadir viewing means the sensor images the target directly under the satellite (Figure 32). Nadir imagery poses less distortions and displacements with image geometry. Off-nadir viewing means the sensor can image to the sides of the nadir point (Figure 33). Off-nadir viewing increases revisit time and provides stereo coverage.

Currently, there are tenths of RS satellite programs in operation which satellite imageries can be used for cadastral applications. For the purpose of cadastre, these system can be classified as

- High resolution sensors acquired multispectral and panchromatic imageries with spatial resolution less than 100 meters.

These satellite imageries can be used for land use zoning. Imageries with the spatial resolutions in the range of 20-30 meters are more appropriate to use for analysing land use and land cover patterns than sub-meter spatial resolution imageries. The most popular satellite systems used for land resource management within this resolution level are listed the following table 1.

Table 1: A list of satellite whose imageries can be used to study settlement types and pattern, urban structure, vegetation cover etc. (http://www.satimagingcorp.com/satellite-sensors/)

Sensor Type	Spectral Resolution, Bands, Micrometres	Spatial Resolution Meters	Radiometric Resolution Bits	Temporal Resolution, Days	Swath, Km	Orbit Altitude, Km	Image Example
Landsat 7 ETM+	Band 1 Blue Band 2 Green Band 3 Red Band 4 NIR Band 5 SWIR 1 Band 7 SWIR 2 Band 8 Pan Band 6 TIR	30 30 30 30 30 30 15 60	8	16	185	705	
Landsat 8 OLI	Band 1 Coastal Band 2 Blue Band 3 Green Band 4 Red Band 5 NIR Band 6 SWIR 1 Band 7 SWIR 2 Band 8 Pan Band 9 Cirrus Band 10 TIRS 1 Band 11 TIRS 2	30 30 30 30 30 30 30 15 30 100 100	16	16	185	705	

ASTER	Band 1 0.52-0.60 NIR Band 2 0.63-0.69 NIR Band 3 0.78-0.86 NIR Band 4 1.60-1.70 SWIR Band 5 2.145-2.185 SWIR Band 6 2.185-2.225 SWIR Band 7 2.235-2.285 SWIR Band 8 2.295-2.365 SWIR Band 9 2.360-2.430 SWIR Band 10 8.125-8.475 TIR 11 8.475-8.825 TIR 12 8.925-9.275 TIR 13 10.25-10.95 TIR 14 10.95-11.65 TIR	15 15 15 30 30 30 30 30 30 90 90 90 90 90	8 8 8 8 8 8 8 8 8 12 12 12 12 12	16	60	705	
SPOT-5	Band 1 Green Band 2 Red Band 3 Near IR Band 3 Shortwave IR Band 5 Pan	10 10 10 20 5	8	2-3	60	822	

SPOT-6 and 7	Band 1 Blue Band 2 Green Band 3 Red Band 3 Near IR Band 5 Pan	6 6 6 6 1.5	12	1	30	694	

- Fine resolution sensors acquired multispectral and panchromatic imageries with spatial resolution less than 1 meter.

These satellite imageries can be used for mapping parcel's boundaries, buildings and other cadastral objects.

Table 2: A list of satellite whose imageries can be used to map of individual objects at 1:5,000–1:10,000 scales ([http://www.satimagingcorp.com/satellite-sensors/)](http://www.satimagingcorp.com/satellite-sensors/)

Sensor Type	Spectral Resolution, Bands, Micrometres	Spatial Resolution Meters	Radiometric Resolution Bits	Temporal Resolution, Days	Swath, Km	Orbit Altitude, Km	Image Example
IKONOS	Band 1 Blue Band 2 Green Band 3 Red Band 4 Near IR Band 5 Pan	0.82 3.2	11	3	11.3	680	
Quick Bird	Band 1 Blue Band 2 Green Band 3 Red Band 4 Near IR Band 5 Pan	0.61 2.44	11	1-3.5	16.8	450	

GeoEye 1	Band 1 Blue Band 2 Green Band 3 Red Band 4 Near IR Band 5 Pan	1.84 0.46	11	2.1	15.2	770	
WorldView 3	Band 1 Coastal Band 2 Blue Band 3 Green Band 4 Yellow Band 5 Red Band 6 Red Edge Band 7 Near-IR1 Band 8 Near-IR2 Band 9 Pan	1.24 0.31	11	4.5	13.1	617	

Satellite images are used for creating and updating cadastral maps. The selection and use of different types of satellite images mainly depend upon the requisite level of details, the quality of data required etc. Thus, it is possible to achieve an accuracy of +/- 1 meter by using sub-meter resolution imagery and GNSS controls. In not so mountainous terrain and in planned build up areas it is possible to generate cadastral maps with sub-meter resolution images with up to the map scale of 1:5,000.

The below is one example, where an ortho-rectified QuickBird image was used to digitize land plot boundaries using on-screen digitizing techniques in GIS after confirmation from the land owners in the field (Figure 34).

Figure 34. Digitised cadastral boundaries on high-resolution satellite imagery in Zormandi area (http://geografie.ubbcluj.ro/ccau/jssp/arhiva_2_2012/06JSSP022012.pdf)

2.6. ELEMENTS OF PHOTOGRAMMETRY

All remote sensing imageries (including vertical aerial and digital photographs, satellite imageries) are inherently subject to geometric (positional) distortions and displacements. In order to use RS imageries for topographic and cadastral mapping, the imageries should be corrected. The principles of aerial imagery corrections and the application of aerial surveys for topographic mapping of the Earth's surface come from the use of aerial **photogrammetry**.

Photogrammetry is the science of using aerial photographs and other remote sensing imageries to obtain precise measurements of natural and human-made features on the Earth and produce planimetric (topographic) maps. Photogrammetry forms the baseline of many RS as well as GIS and LIS applications. For RS and GIS applications, aerial photogrammetry often provides the foundation to develop base maps (including topographic and cadastral). This chapter will introduce you with basic principles of photogrammetry related to image correction.

Large-scale topographic maps use an orthographic projection (i.e. using parallel lines of sight) and constant scale to represent features. On the topographic map, objects are located in exactly the same position relative to each other as they are on the surface of the Earth, except with a change in scale. On a map, objects and features are both planimetrically and geometrically accurate (Figure 35).

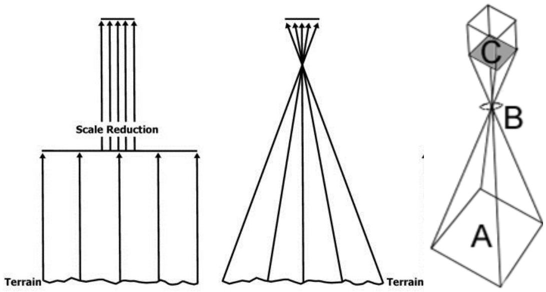


Figure 35: Projections of topographic maps and aerial images (framing cameras)

A photographic image is created in a central perspective where it is assumed that every light ray from the Earth's surface (A) reaching the plane of the film (C) during exposure passes through the camera lens which is mathematically considered a single point, the perspective center of the lens (B). Therefore, the relative position and geometry of the objects depicted depends upon the location from which the photo was taken. This causes certain forms of distortions and displacements in aerial photographs (Figure 36).

The distance between the center of the lens (B) and the principal point of focal plane is termed the focal length f of the camera lens (or principal distance) and it is one of the internal camera geometry parameters. The position of the principal point is defined by fiducial marks mounted on the frame of the camera. Lens distortions describe non-ideal geometry of a real lens.

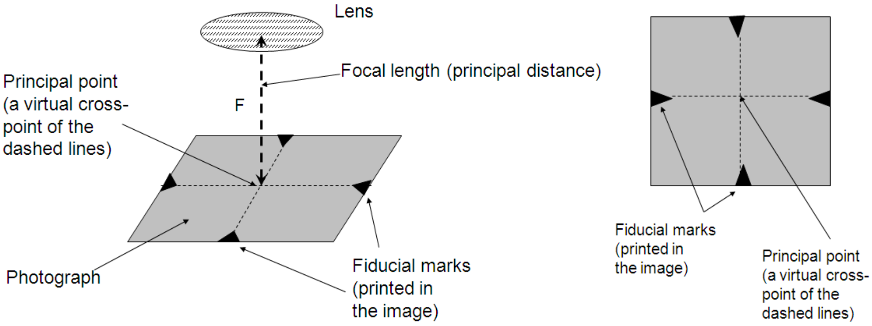


Figure 36: Internal framing camera geometry parameters

One of the important quantitative photogrammetric characteristics of aerial imagery is the scale. In general, image scale is similar to map scale and can be calculated as:

$$Scale = \frac{\text{the relative distance on an image}}{\text{the distance on the ground}}.$$

Alternatively, the scale of a vertical photograph approximately equals to the ratio of the flying height above the ground (H) to the focal length of the camera lens (f). The scale of a vertical photograph can be calculated as $Scale = \frac{f}{H - h}$ (Figure 37).

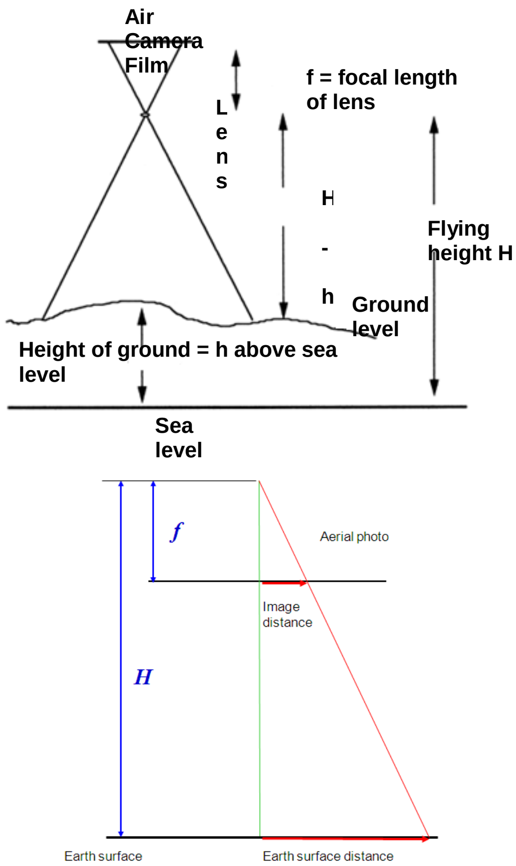


Figure 37: Aerial photo scale calculation

With respect to scale and distance, images contain distortions inherited from a central perspective projection and distortions are different than those found on topographic maps. Since the height of the terrain (h) varies across an area, then so does the the flying height above the ground (H) and thus the scale of the photography. These and other distortions should be corrected.

Geometric distortions are errors on an image between the actual image coordinates and the ideal image coordinates which would be projected theoretically with an ideal sensor and under ideal conditions.

There are many factors affecting the quality of the aerial images and the accuracy of the measurements. However, there are six primary sources of aerial image distortions: terrain, camera tilt, film deformation, camera lens, atmospheric bending, and other camera errors. These types of distortions can occur in satellite images as well.

The terrain and camera tilt sources of error are considered to be the sources that contribute the greatest amount of displacement or geometry error of aerial images. Geometric corrections may be desirable as movement or displacement of the image pixels into correct horizontal positions and geo-referenced space.

Tilt displacement: A tilted image presents a slightly oblique view rather than a true vertical snapshot. All photos have some tilt. Tilt is caused by the rotation of the platform away from the vertical.

Objects on tilted aerial photographs are shifted from their true positions due to a tilt of camera and the respective view of the photograph. As you can see from the slide below, the nadir point on a vertical photograph will coincide with the principal point, but due to tilt, the nadir point is shifted aside from the principal point. The Nadir point (N) is the point where the vertical line projected through the center of the lens (B) intersects the focal image plane (C), and the principal point (O), as you may remember, is defined by fiducial marks, mounted on the frame of camera (Figure 38). When tilt is present, all other points on aerial photographs are shifted due to the platform tilt, as the Nadir point is in Figure 38.

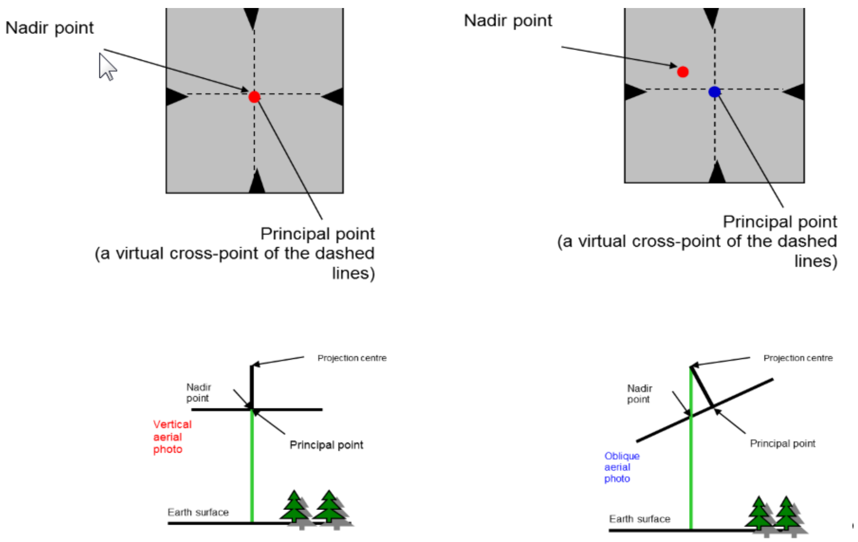


Figure 38. Tilt displacement

The maximum amount of tilt displacement on a tilted photo is given by the formula: $\delta r_{\alpha} = \dfrac{r^2 \sin\alpha}{f - r\sin\alpha}$, where, r - vector in an image from nadir point to depicted object; f - focal length; α - tilt angle.

If the amount and direction of tilt are known then the aerial image may be rectified - transformed to create a complete, corrected vertical image.

Relief displacement: This is typically the most serious type of displacement. These displacements radiate outward from nadir point (N) in an image (Figure 39). For vertical images, the nadir point (N) is very close to the principal point (O). Topographic or relief displacement is caused by the perspective geometry of the camera and the terrain at varying elevations.

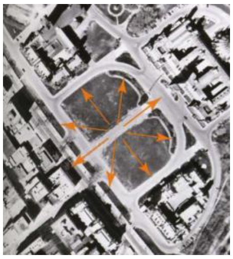


Figure 39: Directions of relief displacements

For example, towers A and B are equally high, but placed at different distances from the nadir point, thus have different relief displacements (blue and red vectors respectively in the photograph). A tower depicted directly beneath the nadir point has no relief displacement.

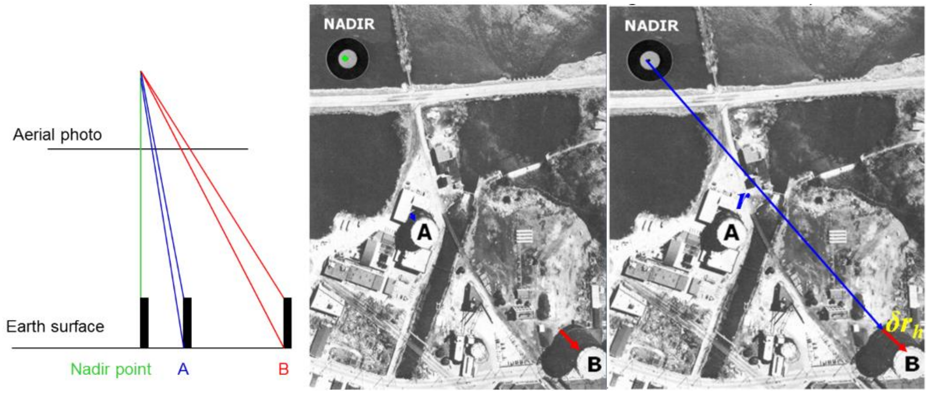


Figure 40: Illustration of relief displacement for towers

Relief displacement δr_h for vertical aerial photography is given by the formula $\delta r_h = \frac{h}{H} r$, where H - flight altitude above ground surface; h - relief elevation on the ground; r - vector (in blue in the photograph) in an image from nadir point to depicted object.

For example if $H = 2000\,m$ (flight altitude above ground surface); $h = 150\,m$ (a mountain's elevation on the ground); and $r = 100\,mm$

(vector in an image from nadir point to depicted object), then relief displacement δr_h for the sample mountain is $\delta r_h = \frac{h}{H} r = \frac{150m}{2000m} 100mm = 7.5mm$

.

What does relief displacement mean with respect to terrain rather than discrete objects such as towers? Point ***A*** on the ground is depicted as point ***a”*** in image, but on a topographic map it should be in a position ***a’,*** that corresponds to point ***A’*** on a Datum plan (a Datum plan should be projected to a map), so we have an error in point position coordinates equal to ***a’a”***. If there is no elevation then there are no displacements. In addition, there is no displacement at or near the nadir point.

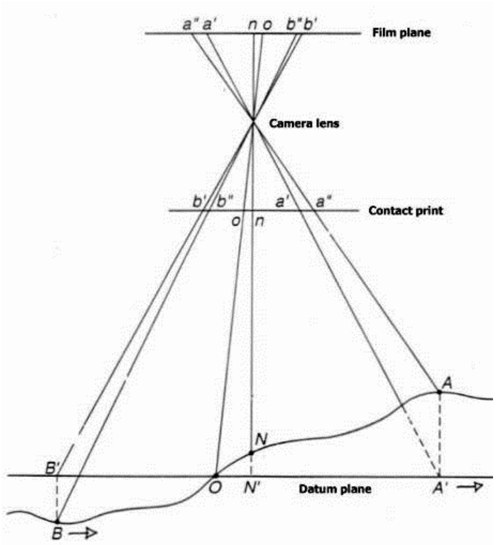


Figure 41: Illustration of relief displacement for topography

The relief correction process is called ortho-rectification, thus δr_h can be applied to each image pixel to remove relief displacement. In order to perform relief displacement, elevations for all pixels depicted in aerial photograph or image are required. These corrections are different for each pixel in image. An orthorectified image appears as though each pixel were acquired from directly overhead.

Elevation values used in the correction process could be acquired from an existing Digital Elevation Model (DEM) or a new DEM can be produced from a stereo model of stereo images. Two consecutive images along a flight run form a stereo-pair that allows to perceive a stereo model within the overlapping area (green rectangle in Figure 42). A single image allows measurement of the planimetric (X,Y) coordinates of an object, however a stereo-pair allows one to retrieve 3D coordinates (X,Y,Z or height) of the object.

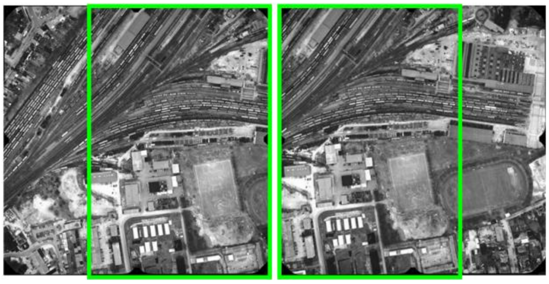


Figure 42: Aerial photograph's stereo pair with 60% overlap

The stereopair parallax method can be employed to determine the height (h) of objects. The parallax method of height determination method requires two overlapping air images (aircraft or satellite) on the same flight line, the height of the aircraft/satellite above the ground (H), and the average image base length (b). The image base length is the distance from the principal point of one air image to the other. The method uses the principle that the radial displacement of a feature varies proportionately with the height of the aircraft/satellite, but takes into account measurements from two air images.

Differential parallax is determined by $dP = P1 - P2$ (Figure 43), photo base length is determined by $b = \frac{b1 - b2}{2}$, and then height of the object is determined by $h = H\frac{dP}{b + dp}$

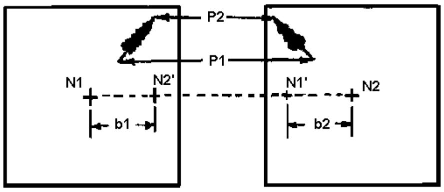


Figure 43: Differential parallax determination principle

Ground control points (GCPs), or accurate geodetic data, is essential for all these geometric corrections. A control point is any station that is identified on a photo and used as an aid to geo-referencing the images.

Non-systematic errors could be corrected through the image registration process. The geometric registration process involves identifying the image coordinates (i.e. row, column) of several clearly discernible points (Figure 44), called ground control points (or GCPs), in the distorted (raw) image (A - A1 to A4), and involves matching them to their true positions in ground coordinates (e.g., latitude and longitude of B - B1 to B4). The true ground coordinates (B - B1 to B4) are typically measured from a map, either in paper or digital format, field surveys (e.g., with GNSS) or from geo-referenced images. Therefore, there are respectively the following types of image registration processes:

- Image-to-map registration;
- Image-to-image registration;
- Coordinate input registration.

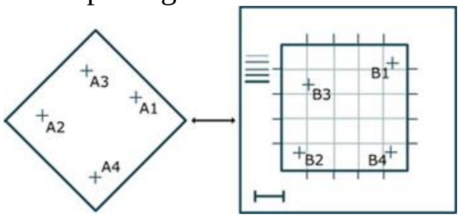


Figure 44: Image registration process principle

If an image is registered to geographic or map coordinate systems, such a registration process also can be termed geo-referencing or rectification. If an image is registered to a coordinate system that has no geographic or map reference, such a process can be just termed image registration.

Lens distortion: Small effects due to the flaws in the optical components (i.e. lens) of camera systems lead to distortions (which are typically more serious at the edges of photos). These effects are radial from the principal point (making objects appear either closer to, or farther from the principal point than they actually are); and can be corrected using calibration curves.

Photogrammetry provides the mathematical foundation needed to remove the distortions and displacements from aerial imagery. In the last decades of the 20th century, aerial photographs were rectified and ortho-rectified by using stereo-plotting equipment. Nowadays, image-processing software (e.g., ERDAS, PCI Geomatica, ENVI, ER Mapper, IDRISI etc.) and GIS (e.g., ArcMap has image processing capabilities) are used to do image correction and DEM extraction from overlapping images.

2.7. LIGHT DETECTION AND RANGING (LIDAR)

LiDAR stands for **L**ight **D**etection **A**nd **R**anging. LiDAR is an RS technique that uses laser light to sample the surface, bathymetric and atmospheric features to producing highly accurate X, Y, Z measurements (Figure 45). The term LiDAR was created as a portmanteau of "light" and "radar”. Thus LiDAR is laser RADAR, or optical RADAR. Both are names used for systems utilizing electromagnetic radiation at optical frequencies/wavelengths.

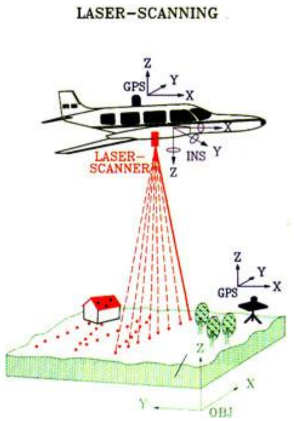


Figure 45: LiDAR system

The acronym “laser” stands for “light amplification by stimulated emission of radiation.” A laser is a device that which generates a stream of high-energy particles (photons) within an extremely narrow range of wavelengths. “High energy” means that enough energy can back scatter to the detector. “Very narrow beam” means that the laser can illuminate and measure small targets with more energy per area. Lasers produce a coherent light source designed for a specific purpose.

LiDAR, laser radar, and optical radar are all names used for "radar" systems utilizing electromagnetic radiation at optical frequencies. The LiDAR beam is very narrow, since it is basically a laser beam of visible or infrared radiation (very short wavelength) - the wavelength for the LiDAR transmitted energy is near/in the visible spectrum, for example, 1.064 μm (Nd:YAG), 0.810 μm (ScaLARS), 0.900 μm (FLI-MAP), 1.540 μm (TopoSys, Riegl) , 1.064 and 0.532 μm (bathymetric lasers).

There are two major categories of LiDAR:

- To detect atmospheric properties - atmospheric LiDARs;
- To detect non-atmosphere objects – target LiDARs.

The second imaging category using a laser range finder instrument can be applicable for cadastral purposes e.g. to delineate parcel boundaries and real properties objects.

A LiDAR instrument principally consists of a laser scanner (transmitter and receiver), a direct georeferencing component (specialized GPS and inertial measurement systems (INS)) and computer processing resources. Satellite, airplanes, helicopters and drones can be used as platforms for acquiring LiDAR data of land areas.

How does conventional (range finding) LiDAR work? A LiDAR instrument uses laser optical light pulses to illuminate the terrain (up to 150,000 times per second) and often LiDAR uses nadir or near-nadir vision of the study area. LiDAR observes only the intensity of the collected radiation and the time delay from transmission to collection. The transmitted laser pulse interacts with and is changed by the target. Some of this light is reflected / scattered back to the instrument where it is analyzed. The change in the properties (strength) of the light enables some properties of the target to be detected. The time interval between when the laser pulse is generated and received back at the antenna after reflecting from a target on the ground is recorded. The time for the light to travel out to the target and back to the LiDAR is used to determine the range to the target. The instrument then calculates the range as:

$Range = c * \Delta t/2$, where $\Delta t = t1 - t0$ is the time delay (Figure 46); c is the light speed.

LiDAR uses the same principle as RADAR (Radio Detection And Ranging) and SODAR (Sound Detection And Ranging), except that RADAR uses microwaves, and SODAR uses sound. In the case of SODAR, c is the speed of sound.

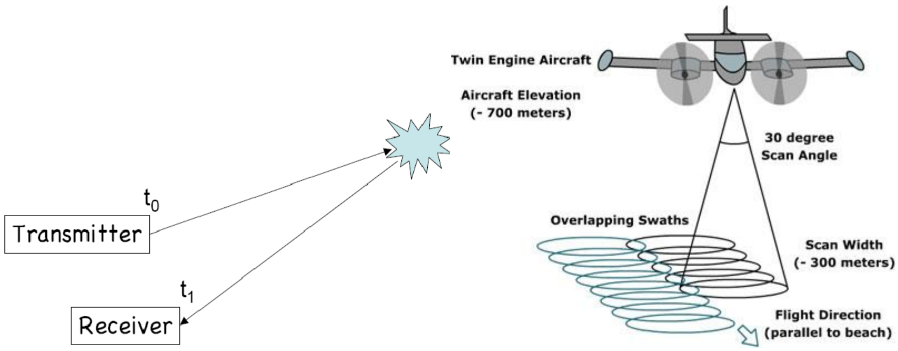


Figure 46: Radiation is transmitted into environment, backscattered by the objects, and then detected and analyzed by receivers (Jensen, 2007)

The main task of target, ranging or profiling LiDAR is to measure a time delay between transmission and reception. Atmosphere or scattering LiDAR, besides time delay, is more interested in signal strength, spectra, etc.

With knowledge of the absolute position (from GPS) of the LiDAR instrument, the range and "pointing angle" of the laser system, the X,Y,Z coordinates of the reflecting object can be calculated. LiDAR geo-references points by using GPS that derives the position of the aircraft, INS that determines the pointing direction of the sensor, and the LiDAR range that is used to extrapolate the coordinates of a target point on the ground.

Heights/altitude of points are calculated by LiDAR by subtracting a $range$ from a precise platform base altitude (D) referenced to an ellipsoid. It gives surface height (h) above the reference ellipsoid as:

$$h = D - Range \pm Interference\ of\ aerosols\ and\ clouds$$

Subtracting the geoid height (N - an approximation of sea level) from the surface height (h) gives a surface elevation (H) with respect to sea level as $H = h - N$

The range measurement process results in the collection of elevation data points (commonly referred to as mass-points) arranged systematically in time across the flight line (Figure 47). The mass-points are reflected from the ground, water bodies, roofs of buildings, power-lines, tree canopy, poles, etc. Thus, point density is inhomogeneous and depends of nature, condition and pattern of all these scanned features, for some patterns more for other less.

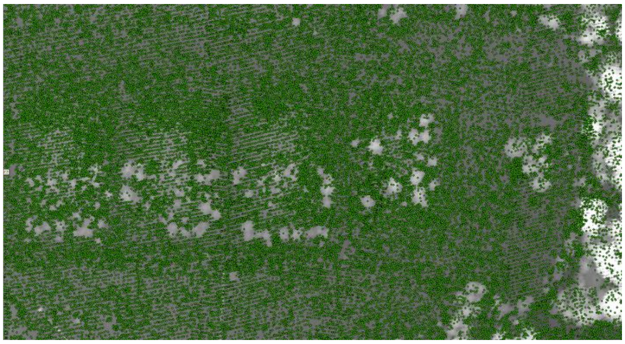
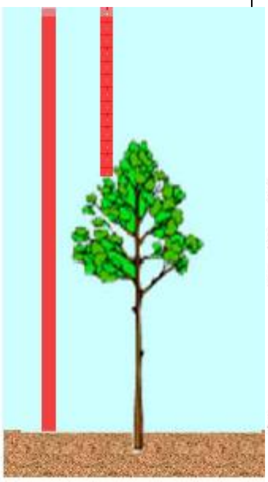
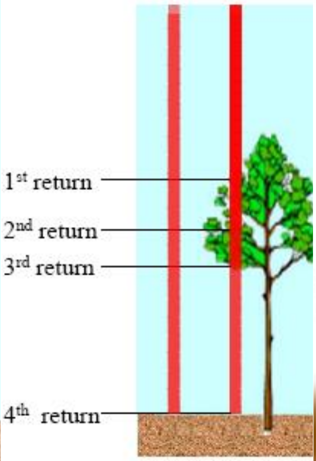


Figure 47: LiDAR mass points is the equivalent of locating 75,000 surveyors in the field per second

The laser pulse is a beam of light comprising a continuous waveform. Early LiDAR systems recorded only one discrete return, either the first peak or the final peak in the reflected wave. A sufficient amount of laser light energy is able to continue on to generate returns from lower portions of the tree, and finally, from the ground (Figure 48A).





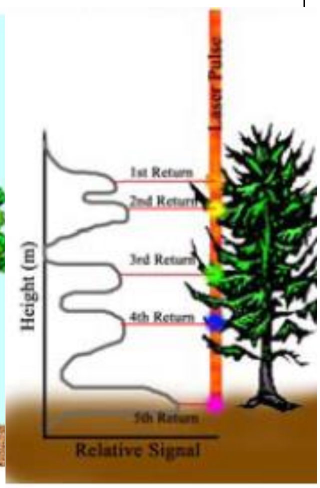


Figure 48A: Discrete Return LiDAR	**Figure 48B: Multiple aveform LiDAR**	**Figure 48C: Full Waveform LiDAR**

In a discrete multiple-return LiDAR, only the peaks would be recorded (Figure 48B). In a waveform LiDAR, the entire return pulse is digitized and recorded (Figure 48C). Capturing and recording this vast amount of data poses some significant challenges and interesting opportunities. Challenges include a need to use mass storage devices and sophisticated software. Opportunities include a possibility to perform more accurate recognitions of scanned features.

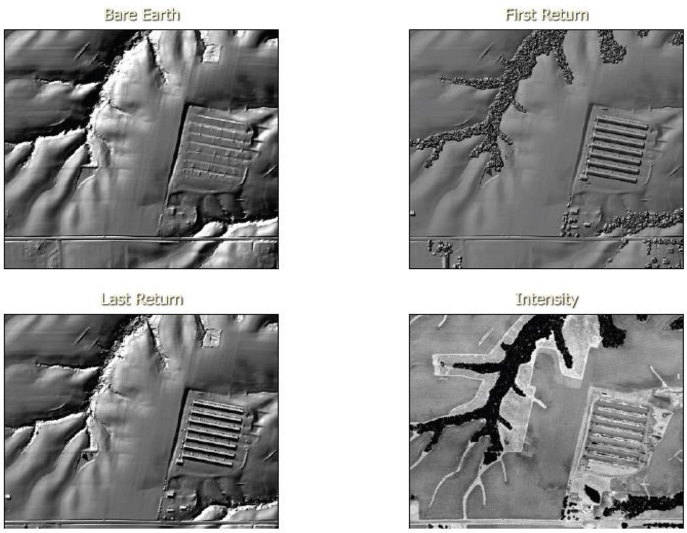


Figure 49: LiDAR returns

In addition, LiDAR systems record the intensity, or the magnitude or strength, of the return pulse (Figure 50). Objects with high reflectivity, such as snow or a metal roof, show a higher intensity return than dark objects, such an asphalt roadway.

Figure 50: LiDAR intensity image

LiDAR data resolution is based on collection density - 1 point/meter to 8 points/meter. The error budget of a LiDAR system is a quantitative evaluation of the random and systematic error sources that contribute to the overall positional (X, Y, Z) accuracy of the post-processed LiDAR point cloud. The majority of commercial organizations that collect LiDAR data state that the horizontal and vertical accuracy of their data is generally on the order of 10-20 centimetres. There are no common accuracy standards for LiDAR used for cadastral purposes.

LiDAR datasets can be disseminated as ASCII X,Y,Z,ID text files, LAS binary files and in other formats. Members of the industry, including LiDAR instrument manufacturers, data acquisition vendors, and RS/GIS software developers, came together under the auspices of ASPRS (American Society for Photogrammetry and Remote Sensing) to establish the LAS binary format. LAS format has rapidly become an internationally accepted standard, and most software packages, including ArcGIS, have become interoperable with this format.

There are numerous applications of LiDAR. The most common application is to use LiDAR point's clouds to generate elevation products (e.g., DEM, DTM and DSM), contour lines for elevation etc. The terms DEM (Digital Elevation Model), DTM (Digital Terrain Model) and DSM (Digital

Surface Model) are all usually used to refer to various types of continuous, three-dimensional spatial data.

In this course, we will consider that Digital Elevation Model (DEM)) is a representation of the continuous surface of the bare earth ground by a large number of selected points with known X, Y, Z coordinates above sea level or ellipsoid. Digital Terrain Model (DTM) is a more complex concept that involves the incorporation of not only elevation (height) measures, but also other terrain features such as rivers, ridgelines, cliffs, height spots etc. into the digital model. A DSM represents the elevations (heights) of the ground and all features on it. For example, if there are buildings or trees in the area, DSM includes those building and tree heights in the elevation values it provides.

In this course, you can consider that points of the first return comprise Digital Surface Model (DSM); that points retune from bare earth and water surface represent Digital Elevation Model (DEM) (no vegetation, building and other non-ground object’s points are included), and difference between DSM and DEM represents heights of buildings, trees etc. (Figure 51).

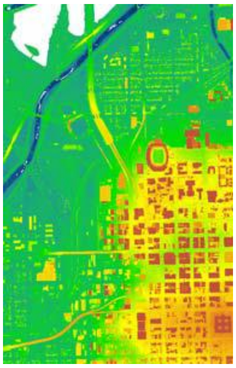


Figure 51a: First return represents Digital Surface Model (DSM)

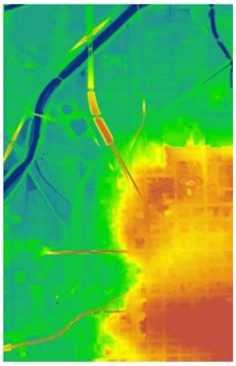


Figure 51b: Bare earth (no vegetation or buildings) represents Digital Elevation Model (DEM)

Figure 51c: Difference image represents (DTM – DEM) (height of buildings and trees)

LIDAR DEM are typically available at raster widths between 0.5 meter and 2 meters.

For cadastral purposes, LiDAR imagery together with high-resolution orthopho

LiDAR imagery together with high-resolution orthophoto images can be used for machine delineation of parcel boundaries and identification of building roofs. Machine-based delineation is an automatic approach and much more time and labour effective compared to manual on-screen digitizing.

Figure 52 (left) shows an orthophoto of a residential neighborhood with two rows of buildings and fences surrounding them (Filin S. et al, 2007). Machine delineation procedures (e.g., edge detection or image segmentation) were applied to determine physical boundaries of cadastral objects. The results, shown on Figure 52 (center), do not reflect the correct cadastral fabric. Sorting out the edges that define objects from the complete edge map is practically impossible by using orthophoto images and machine delineation procedures.

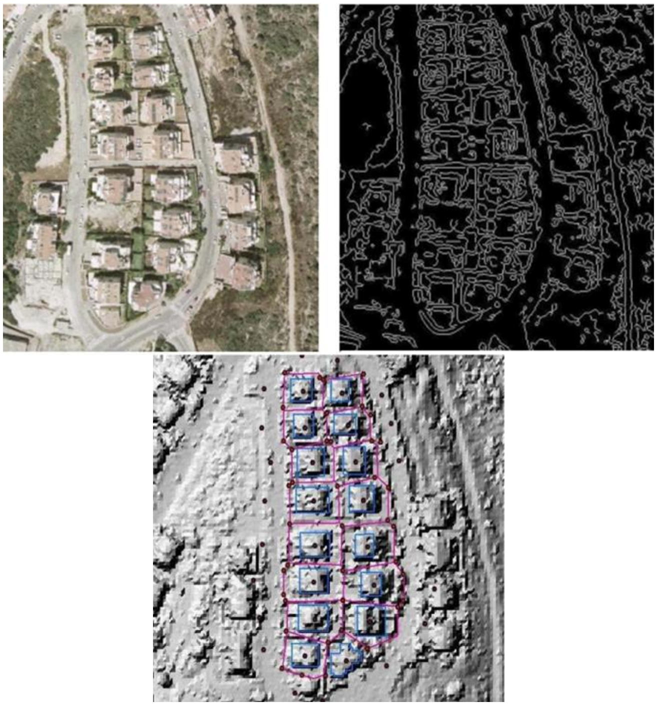


Figure 52. An orthophoto map of a typical residential area (left) and its resulting edge map (center), and the results following the adjustment of the parcels boundaries (Filin S. et al, 2007)

LiDAR images and machine-based parcelation approaches can dramatically improve the results. Application of the multi-step algorithm (Filin S. et al, 2007) on LiDAR mass points imagery produces the parcelation fabric shown on Figure 53 (right). The results show the great potential of LiDAR based interpretation of cadastral objects.

LiDAR imageries also can be used for creating 3D cadastral objects. A major concern in realizing the 3D cadastre vision is the development of efficient methods for the attachment of the third dimension to the existing 2D systems. LiDAR and RS/GIS algorithms and tools provide a means for the extraction of dense and accurate 3D information and integrating the 3rd dimension to 2D objects (Filin S. et al, 2005).

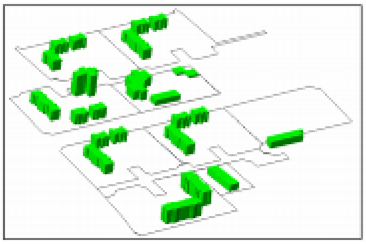


Figure 53. Integrated LiDAR data and 2D cadastre results (Filin S. et al, 2005)

2.8. CONCLUSION

Updating cadastral information is crucial for recording land ownership and property division changes in a timely manner. In many cases, the existing cadastral maps do not provide up-to-date information on land parcel boundaries.

Data collection techniques used in existing cadastre are shown in Figure 54.

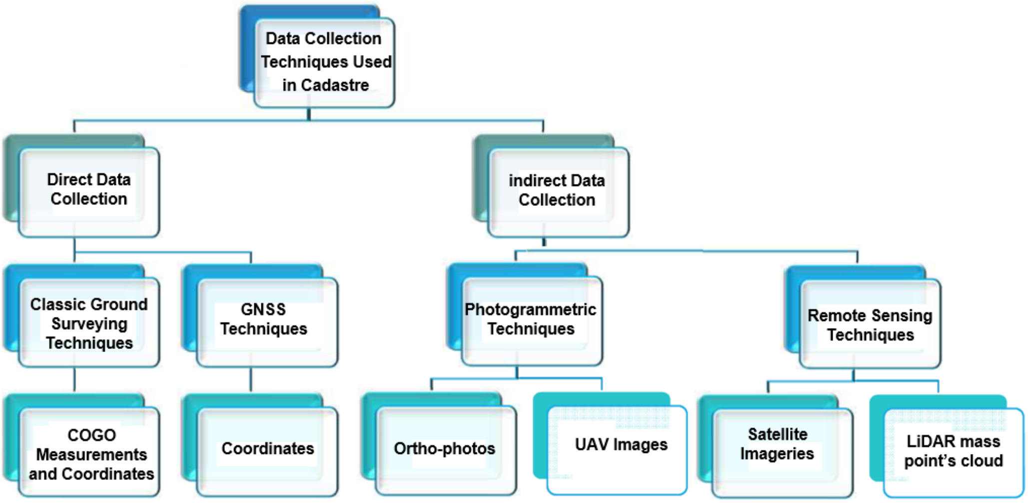


Figure 54: Data collection techniques used in existing cadastre

Remote Sensing (including photogrammetry) is less costly and more efficient (especially in terms of speed) spatial data acquisition technique than modern field surveying. Therefore, RS can help to gain time and speed in compiling and updating of cadastral maps. However, RS still can be not completely applicable for compiling topographic plats as more accurate measurements are required. At the same time, the potential of RS for cadastral applications have not yet been fully explored.

Thus, so far, more accurate cadastral mapping may be achieved by using rectified and ortho-rectified aerial images. An orthographic image with terrain and perspective distortions removed is providing the highest possible accuracy so ground features are displayed in their true planimetrically correct position. Ortho-imagery combines the image characteristics of an aerial image with the geometric qualities of a map.

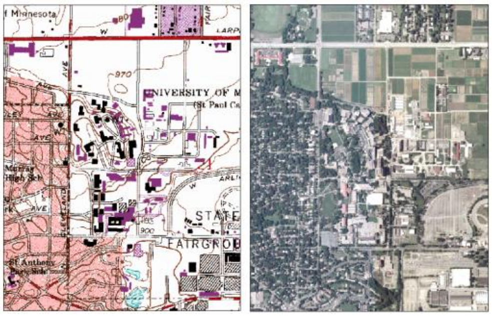


Figure 55: Comparison of topographic map and orthophoto

However, spatial resolution of satellite images has dramatically improved recently (down to 30 cm) and they may play a more important role for cadastral work soon. Object-based extraction algorithms, which use machine learning techniques including neural networks, have improved dramatically in the past two decades. New techniques, such as LiDAR, are becoming more mature and have begun to be used for cadastral purposes.

There is a tendency to integrate direct and indirect techniques for acquiring cadastral information especially for updating the existing cadastral maps in an efficient manner. To reduce the time and cost involved in cadastral data acquisition, surveying and RS techniques can be integrated to use GNSS measurements, photogrammetric products (e.g., DEM, ortho images), sub-meter resolution RS imageries, and existing cadastral maps within one workflow cadastral mapping process (Ali et.al., 2012).

VOCABULARY

Active sensor: The technologies that include transmitters that send out a signal, a light wavelength or electrons to be bounced off the target, with data gathered by the sensor upon their reflection. Active sensors detect and record energy emitted from the sensor itself.

Aerial imagery: Image taken usually from an airplane using either a film or digital camera.

Aerial photography: The process of making of images from an aircraft (up to 50 km) or balloon (or some other platform) within the Earth's atmosphere.

Air base: Ground distance between optical centers of successive overlapping aerial photographs.

Along-track or **pushbroom scanner:** A scanner use the forward motion of the platform to record successive scan lines by a linear array of detectors and build up a two-dimensional image, perpendicular to the flight direction.

Analogue photo: This is the opposite of digital. A photo taken with a film camera.

Antenna: A device that transmits and receives energy in active RS systems.

Atmosphere: Layer of gases that surrounds some planets.

Atmospheric correction: Image-processing procedure that compensates for effects of selectivity scattered light in multispectral images.

Azimuth: Geographic orientation of a line given as an angle measured in degrees clockwise from north.

Backscattering energy: The portion of the EM energy scattered by the targets directly back toward the sensor.

Band (channel): A wavelength interval in the electromagnetic spectrum.

Beam: A focused pulse of energy.

Brightness: Magnitude of the response produced in the eye by light.

CCD: Charge-coupled detector.

Centerpoint: The optical center of an imagery/photograph.

Central perspective projection

Classification: Process of assigning individual pixels of an image to classes, generally on the basis of spectral reflectance characteristics. "Class" can represents the real features or landuse/land cover class on the ground (e.g., forest, building, water etc.).

Color composite image: Color image prepared by projecting any three individual greyscale multispectral bands, each through a different RGB (Red-Green-Blue) color filter.

Detection: A process of detection of EM radiation by a sensor.

Detector: Component of a remote sensing system that converts electromagnetic radiation into a recorded signal.

Digital image processing: Computer manipulation of the Digital Number values of an image.

Digital image: An image where the property being measured has been converted from a continuous range of analogue values to a range expressed by a finite number of integers, usually recorded as binary Digital Number (DN), for example from 0 to 255.

Digital number (DN): Value assigned to a pixel in a digital image. It quantifies a magnitude of reflectance, defines value of each pixel in particular radiometric resolution.

Distortion: On an image, changes in shape, position and DN value of targets with respect to their true shape, position and brightness value.

Dwell time: Time required for a detector IFOV to collect reflected energy from a ground resolution cell.

Earth observation: Process of using various sensors to make images of the Earth's surface from aircrafts and satellites.

Electromagnetic (EM) spectrum: The range of energy which contains bands such as the gamma ray, x-ray, ultraviolet, visible, infrared, microwave (radar), and, radio waves and which travels at the speed of light. Different parts of the electromagnetic spectrum have different wavelengths and frequencies.

Electromagnetic radiation (EMR): Energy propagated in the form of and advancing interaction between electric and magnetic fields. All electromagnetic radiation moves at the speed of light.

Emitted energy: EM energy that radiates from a body or energy source (sun, earth, active sensor etc.). Emission is determined by kinetic temperature and emissivity.

Film: Light-sensitive photographic emulsion and its base.

Filter, digital: Mathematical procedure for modifying values of numerical data.

Flight path or **line**: Line on the ground directly beneath a remote sensing aircraft or satellite.

Flight run: a series of lines, which the aircraft normally flies, to perform aerial photography.

Focal length: In cameras, the distance from the optical center of the lens to the plane at which the image of a very distant object is brought into focus.

Forward overlap or **endlap**: An overlap between images taken along flight run.

Frame imaging system: recording systems that instantaneously measure radiation coming from the entire scene at once.

Ground-control point (GCP): clearly discernible points on the surface of the Earth with known locations and associated points on an imagery, which can be, used to geo-reference the imagery.

Geometric distortion: positional displacement of objects on vertical aerial photograph/imagery due to varying elevation, platform’s tilt and perspective view.

Geo-referencing: Process of aligning geographic data to a known coordinate system.

Grayscale: A sequence of gray tones ranging from black to white.

Ground truthing: The process of fieldwork then image processing results are confirmed with reality on the ground.

Image analysis: The process of studying and processing an image in order to explain, measure, map, count or monitor what is on the Earth's surface.

Image: Pictorial representation of a scene recorded by a remote sensing system.

Incident energy: Electromagnetic radiation impinging on a surface.

Instantaneous field of view (IFOV) or g**round resolution cell**: Area on the terrain from which a detector collects information to form a cell or pixel on an imagery. Or angle through which a detector is sensitive to radiation.

Intensity: The brightness ranging from black to white

Interpretation: The process in which a person extracts information from an image.

Laser range finder: LiDAR instrument that uses lasers to stimulate fluorescence in various compounds and to measure distances to reflecting surfaces.

Laser: Light artificially stimulated electromagnetic radiation: a beam of coherent radiation with a single wavelength.

Lens: One or more pieces of glass or other transparent material shaped to form an image by refraction of light.

Light Detection And Ranging (LiDAR): The remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light.

Mass-points or **point cloud**: Points collected by a LiDAR sensor that show the elevation of the surface of the ground and of objects on the ground.

Microwave: Region of the EM spectrum in the wavelength range of 0.1 to 30 cm.

Multispectral scanner (MSS): A scanning system used to collect data over a variety of different wavelength ranges.

Nadir: Point on the ground directly in line with the remote sensing system and the center of the earth.

Near infrared (NIR): The shorter wavelength range of the infrared region of the EM spectrum, from 0.7 to 2.5 micrometers.

Non-systematic distortion: Geometric irregularities on images that are not constant and cannot be predicted from the characteristics of the imaging system.

Off-nadir: Any point not directly beneath a scanner's detectors, but rather off at an angle.

Orbit: The path followed by a satellite as it passes around a planet.

Orthographic projection: Projection of light using parallel lines of sight and constant scale to represent features.

Orthophotograph or **orthoimage**: A vertical aerial photograph/image from which the distortions due to varying elevation, tilt and perspective view have been removed, so that it represents every object as if viewed directly from above – in orthographic projection.

Ortho-rectification: Process of removing distortions caused by varying elevation and tilt from imageries.

Overlap: Extent to which adjacent images or photographs cover the same terrain, expressed as a percentage.

Panchromatic film: Greyscale film that is sensitive to all visible and NIR wavelengths.

Parallax difference: The difference in the distance on overlapping vertical photographs/images between two points, which represent two locations on the ground with different elevations.

Parallax: Displacement of the position of a target in an image caused by a shift in the observation system.

Passive RS: Remote sensing of energy naturally reflected or radiated from the terrain.

Passive sensor: The technologies gather target data through the detection of vibrations, light, radiation, heat or other phenomena occurring in the subject’s environment. RS sensors that measure energy, which is naturally available.

Photogrammetry: The science of using aerial photographs and other remote sensing imagery to obtain precise measurements of natural and human-made features on the Earth and produce topographic and cadastral maps.

Photograph: Representation of targets on film that results from the action of light on silver halide grains in the film's emulsion.

Pixel: The smallest unit in a raster or digital image.

Planimetrically correct position: the horizontal position of features on the Earths' surface in orthographic projection.

Platform of sensor: A carrier of a sensor. It is usually a satellite or an aircraft, but could also be a hot-air balloon, a tall tower, drones etc.

Polarization: The direction of orientation in which the electrical field vector of electromagnetic radiation vibrates.

Principal point: Optical center of an aerial photograph/imagery.

Pulse length: Duration of a burst of energy transmitted by a radar antenna, measured in microseconds.

Pulse: Short burst of electromagnetic radiation transmitted by a radar antenna.

RADAR: Acronym for radio detection and ranging. Radar is an active form of remote sensing that operates in the microwave and radio wavelength regions.

Radiation: Propagation of energy in the form of EM waves.

Radiometric resolution: Sensor's sensitivity to the magnitude of the electromagnetic energy. It is measured through the range of digital numbers or number of the grey value levels.

Range: In active remote sensing, the distance in the direction of pulse propagation, usually to the side of the platform in an imaging RADAR/LiDAR system. The slant range is the direct distance from the antenna to the object, whereas the distance from the ground track of the platform to the object is termed the ground range.

Real time: images or data made available for inspection simultaneously with their acquisition.

Rectification: The process of applying a mathematical transformation to an image so that the result is a planimetric image.

Reflectance: Ratio of the radiant energy reflected by a body to the energy incident on it. Spectral reflectance is the reflectance measured within a specific wavelength interval.

Reflected energy: EM energy that bounce off a target in opposite direction.

Reflected IR: Electromagnetic energy of wavelengths from 0.7 micrometers to about 3 micrometers that consists primarily of reflected solar radiation.

Registration: Process of superposing two or more images or photographs so that equivalent ground control points coincide.

Relief displacement: Geometric distortion on vertical aerial images. The tops of objects appear in the photograph to be radially displaced from their bases outward from the photograph's centerpoint.

Relief: Vertical irregularities of a surface.

Remote Sensing: The method of obtaining information about objects or areas from a distance.

Return: In active RS systems, a pulse of energy reflected by the target and received at the antenna. The strength of a return is referred to as return intensity.

Revisit period: see temporal resolution

Revolution orbital cycle: A time taken for platform to complete one orbit of the earth.

Satellite images: Images of Earth or other planets captured by satellites.

Satellite: A natural or manmade object continuously orbiting above the Earth or another planet or star.

Scale, principle: Ratio of distance on an image to the equivalent distance on the ground.

Scanner: An imaging system in which the IFOV of one or more detectors is swept across the terrain and produce a two-dimensional image of the surface.

Scattering: Multiple reflections of EM radiation by particles of atmosphere or surfaces.

Scan line: Narrow strip on the ground that is swept by IFOV of a detector in a scanning system.

Scene: Area on the ground that is covered by an image.

Sensitivity: Degree to which a detector responds to EM energy incident on it.

Sensor: Device that receives EM radiation and converts it into a signal that can be recorded.

Sidelap: Extent of lateral overlap between images acquired on adjacent flight lines.

Signal: Data recorded by a remote sensing system.

Stereo model: Three-dimensional visual impression produced by viewing a pair of overlapping images through a stereoscope.

Stereo pair: Two overlapping images or photographs that may be viewed stereoscopically.

Spatial resolution: Ability to separate closely spaced objects on an image or photograph. Spatial resolution is commonly expressed as the most closely spaced line-pairs per unit distance that can be distinguished.

Spectral resolution: A measure of sensor ability to resolve features in the electromagnetic spectrum. It is “thickness” of bands or channels (min and max wavelength sensed).

Stereoscopy: A technique for creating or enhancing the illusion of depth in an image by means of stereopsis for binocular vision.

Sun-synchronous orbit: A polar orbit where the satellite always crosses the Equator at the same local solar time.

Swath: Width of the strip of terrain that is imaged by a scanner system.

Target: Object on the terrain of specific interest in a remote sensing investigation.

Terrain: Surface of the Earth.

Temporal resolution or **revisit period:** It refers to the length of time it takes for a satellite to return and image the same point on the Earth.

Thermal IR energy: IR region from 3 to 14 micrometers that is employed in remote sensing.

Thermal image: Image acquired by a scanner that records radiation within the thermal IR band.

Tilt displacement: A slightly oblique view rather than a true vertical snapshot.

Time delay: the time interval between the generation of a pulse of energy and its return from the targets.

Transmitted energy: Energy that passes through an atmosphere, object or water.

UV: Ultraviolet region of the electromagnetic spectrum ranging in wavelengths from 0.01 to 0.4 micrometers.

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ASSIGNMENT 2: REMOTE SENSING TECHNIQUES FOR CADASTRAL MAPPING

Description and Objectives

The goal of this lab is to introduce the students with the use remote sensing data to compile and update parcel cadastral plans. The scenario of this assignment includes updating procedures of a land parcel by using an aerial digital orthophoto image (or orthoimage) and LiDAR data without fieldwork. Also, natural and infrastructure objects related to the cadastral data will be derived from orthophoto image and LiDAR data. These tasks will be completed in ArcGIS software.

Students will carry out the following procedures to compile the cadastral parcel plan:

- Prepare spatial data to make a parcel plan
- Digitize natural and manmade land objects (landuse classes, hydrography, and roads) using an orthophoto image
- Process LiDAR DEM cloud data to interpolate an elevation surface
- Update a riverbed line using the structural forms derived from the LiDAR DEM
- Subdivide a parcel into land plots by using a riverbed line
- Layout a land parcel plan

Submission Requirements

Once you have finished the exercise, completed the questions, which you can find within the text, submit the file containing your answers to Moodle, as well as the zipped folder with **Hydrography.zip plot_drawing2.pdf** files.

Preparation

GIS data for this exercise you will find: **D:\Data\Lab2_Data**. Data package includes:

Terrain_46_28.txt	LiDAR DEM data
Ortho_4628.sid	orthophoto image
Parcel.shp	parcel boundary

On your local computer create new directory **Lab2_Result** in **C:\Users\YourUserName\Documents**. This directory must contain all your data and maps for this exercise.

Assignment 2

Remote Sensing Techniques for Cadastral Mapping

EXERCISE

The goal of this lab is to introduce students how to compile and update the cadastral plans of land plots without carrying out the accurate ground measurements. Those plans are usually required as foundation material in initial project stages. Later, these plans can be updated with the more accurate cadastral fieldwork measurements. The context of the lab is based on the work of a surveyor when he/she should make a “draft” cadastral plan in a short period of time. This “draft” cadastral plan should show an existing state of land demarcation, and related natural and manmade objects in the study area.

This practical exercise includes three main steps:

1) deriving natural and manmade objects within the existing parcel area from remote sensing material;

2) adjusting the derived riverbed line by using LIDAR DEM data and derived elevation surface, and;

3) subdividing the existing parcel into land plots along the riverbed line, and preparing a layout of plot.

In the first step, a new database will be created, existing cadastral and remote sensing data will be imported into the geodatabase, and then new objects will be digitized based on orthophoto image by using on screen digitizing tools of ArcMap. The second part will use LIDAR data for correction of natural object boundaries, which will be used to subdivide the existing land parcel. The final part will demonstrate how to make a plan’s layout.

SCENARIO

Although initially not given much attention, there is now renewed interest in the application of remote sensing techniques not only for cadastral mapping, but also for updating of the existing cadastral maps. This is due to the development of automated photogrammetric techniques, LiDAR technology and the increase in spatial resolution of remote sensing imagery.

The identification of land parcel boundaries using remote sensing and LiDAR methods is considered as an alternative to ground based surveys and has been adopted in different ways by various countries at different periods of time. The main motivation was to increase the speed of mapping and to reduce costs, particularly where a large number of boundaries had to be registered. Photogrammetric and remote sensing techniques are also used in updating of existing cadastral plans/maps.

The scenario of these practical exercises is to simulate the process of compilation of the land plan ordered by a customer. Some spatial data are provided. You will be using a high resolution orthophoto image and pre-processed LIDAR data to derive additional spatial data. The study area is located in Lithuania; however, the remote sensing and LiDAR data are acquired and prepared by a Ukrainian provider. If you would need to compile a parcel plan on the other areas, you could obtain remote sensing and cadastral materials through web services of respective country's SDI.

The exercises are implemented by using ArcGIS version 10.2.2; however, they can also be done using older versions of ArcGIS software.

PART A: DERIVING OBJECTS RELATED TO THE CADSTRAL PARCEL FROM ORTHOPHOTO IMAGE

You will start by creating a new database for cadastral data. The database will be used to import the exiting data and carry out editing, analysis and layout of derived data. Many operations, which you have executed in the previous lab and described step-by-step, will be required to complete this lab independently. For detailed instructions of how to perform those operations refer to the lab 1 notes.

1. Open the ArcCatalog. *Connect To* your working *Folder* (e.g., **Lab2_data**) where you have stored the lab data and other files.

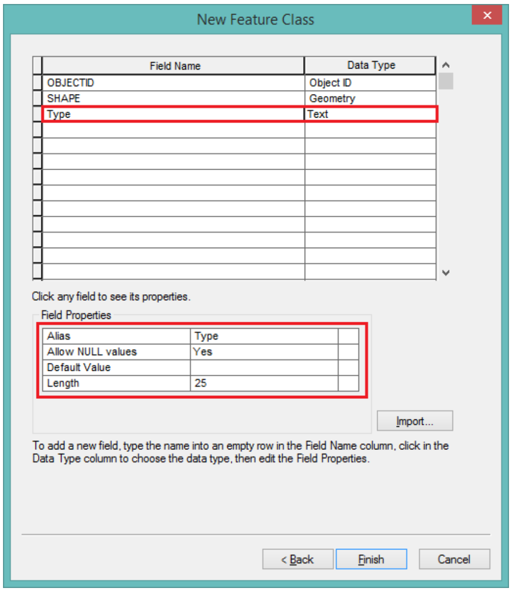
2. Within your working folder, create a database where you will import the existing data. Use the *New > File Geodatabase* operation and name the new geodatabase as **PlanData.gdb**.

3. Transfer the parcel dataset **Parcel.shp** and orthophoto image **Ortho_4628.sid** into the geodatabase. To transfer the **Parcel.shp,** use the *Import -> Feature Class (single)* tool to create a new **Parcel** feature class within the geodatabase. To transfer the orthophoto image into the geodatabase, use the *Import > Raster datasets* tool. This last operation can take a time.

The parcel dataset **Parcel.shp** includes a boundary of a large parcel. In order to create a multipurpose parcel plan, we need to add natural and infrastructure objects, which are present in the study area, into our cadastral database. We can do this by using the orthophoto image. You will start to do that by adding new feature classes for landuse, hydrography and roads of the area within the land parcel.

4. Create three new feature classes **Landuse** (a polygon feature class), **Roads** (a line feature class) and **Hydrography** (a line feature class) within the **PlanData.gdb** database by using *New > Feature Class* command.

a. For the **Landuse** feature class, select the *Polygon Features* as the *Type* of geometry, in the next dialog use the *Add Coordinate System* list  to *Import* the coordinate system definition of the existing **Parcel** feature class (that is *LKS_1994_Lithuania_TM*). In the next two dialogs, accept the default settings. In the following dialog, manually create a new *Text* field **Type** with the *Length* of 25 characters for the **Landuse** feature class: you can type the name of new field and change its settings as it shows in the following screen.



b. Later, you will be using this field to specify the landuse/land cover type (e.g., forests, meadow, etc.). Use the *Finish* button to create the future class.

c. In the same way, create the **Roads** and **Hydrography** feature classes. When creating the feature classes, select the required geometry types. You do not need to add new fields in attribute tables of these feature classes.

5. Now you have five datasets within the **PlanData.gdb.** Close ArcCatalog and start ArcMap. Select and add all five datasets from the **PlanData.gdb** on the map. Zoom to the **Parcel** layer.

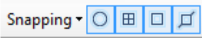
The five layers are displayed in the *Data View* window of ArcMap. You can only see **Parcel** and **Ortho_4628** data because other layers are still empty. Now you will start to create the new objects required to be shown on a parcel plan.

6. Change the symbology of the parcel layer on the map to make the following editing procedures more convenient. Choose the *Hollow* for the fill color of parcel polygon, set the *Outline Width* to 2 and the *Outline Color* to red as 

.

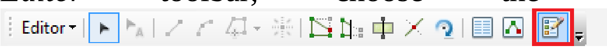
7. *Save* your work as **Plan.mxd** document  in your working folder and repeat the *Save* operation from time to time in order to not lose your ongoing work.

8. Start the data editing session in the *Editor* toolbar. Remember that after finishing editing, you always have to *Save Edits*.

9. To have a perfect match among edited features, the snapping mode should be turned on. This mode allows snapping to points, ends, vertices or/and edges of coincident features from one layer or multiple layers. You can activate the snapping mode by clicking the dropdown menu of *Editor > Snapping > Snapping Toolbar*. The *Snapping* toolbar will open. Activate or check all four types of snapping: points, ends, vertices and edges 

. From the *Option* link of *Snapping* dropdown list, open the *Snapping Options* dialog window and check *Show tips* boxes. It will help during manual edits.

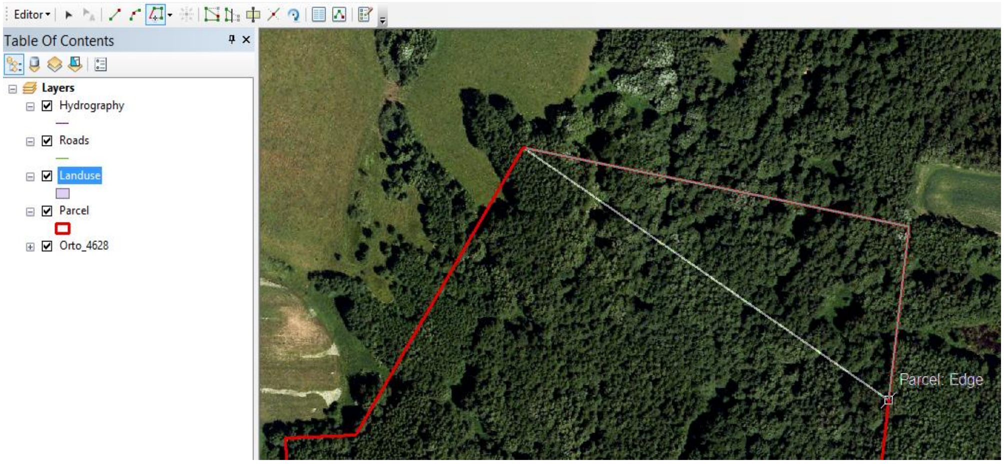
You will be using the *Editor* tool to vectorize forests, meadows, riverbed and roads on the orthophoto image.

10. First you should vectorize landuse types within the parcel polygon. You will be drawing landuse objects within the parcel starting from the forest polygons that are usually best seen in orthophoto images. In the *Editor* toolbar, choose the *Create Features* tool 

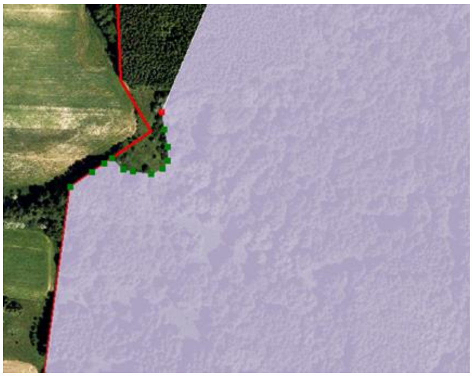
. In the *Create Feature* window select **Landuse** to start digitizing forest polygon.

You will be using the *Trace* tool  to digitize the forest within the parcel. The *Trace* tool allows digitizing of a polygon outline by matching edges of existing features from visible layers on the map. By using this tool, you can preserve topological coincidences among features among the layers.

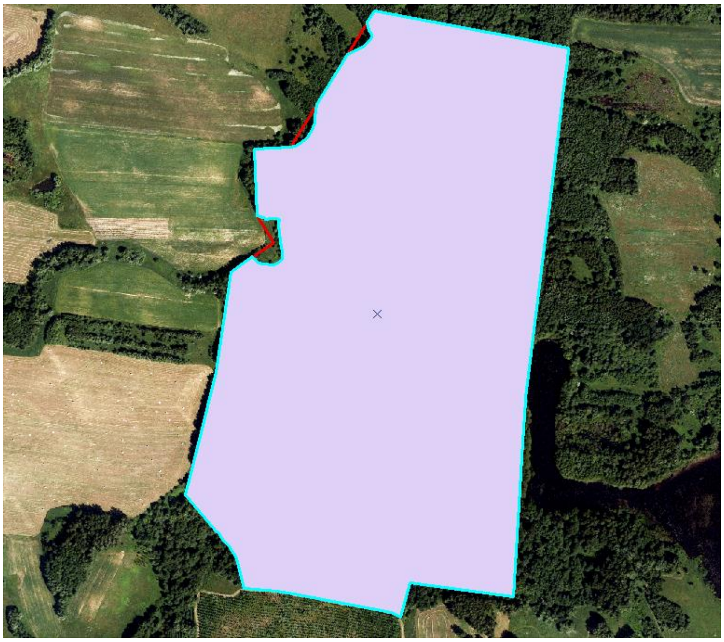
11. Choose the *Trace* tool from the *Editor* toolbar, and start to vectorize the forest by clicking on one of the parcel corners and then follow the parcel outline with the trace tool.



12. However, there are a few places where the parcel is also includes non-forest landuse classes. In these places, you may turn off the *Trace* tool and start manual vectorization the forest boundary. If you need to change a vectorization mode, click on the turning point and select the *Straight Segment* tool . Use this tool to digitize the forest line as it goes, e.g., as you can see in the following print-screen.



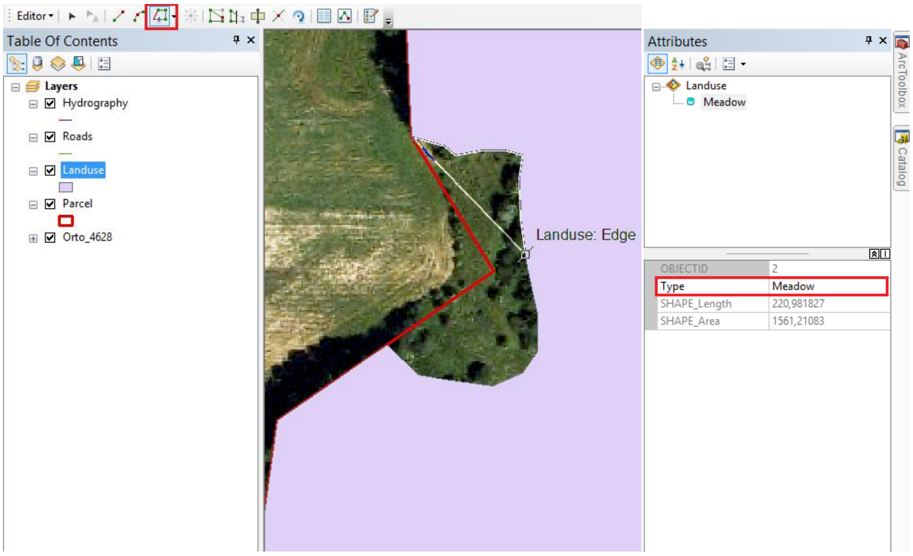
13. When you finish manual digitizing of forest segment, you may again switch to the *Trace* tool and vice versa. The forest polygon may looks as it is shown on the following print-screen.



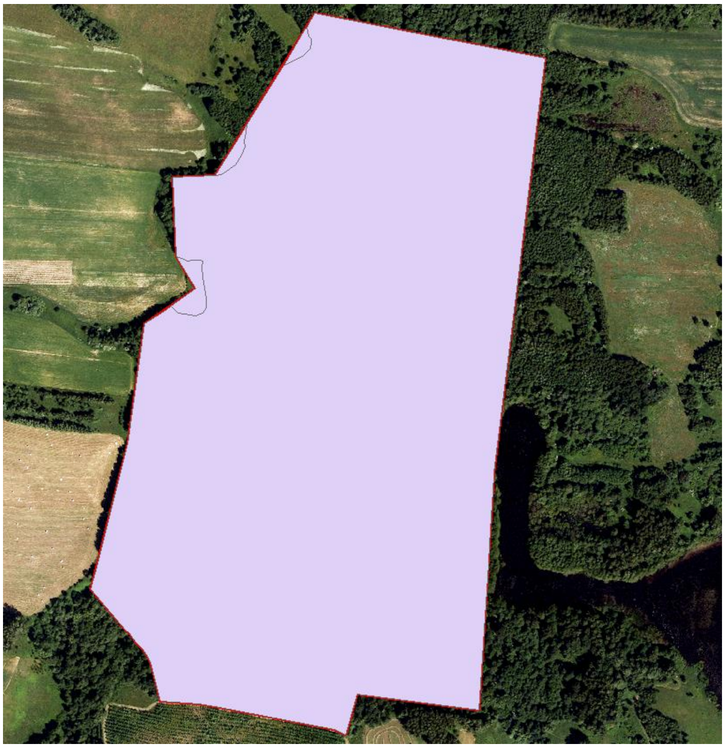
14. Finish the sketch with double click at the starting point.

15. Now you need to specify that this polygon is a forest. Use the *Attributes* button of *Editor* toolbar to open the *Attributes* editing dialog. Enter *Forest* in the *Type* field. If you will add another polygon which you want to associate with *Forest* class, you can use the *Attributes* dialog to enter its *Forest* attribute's value. Do not forget to save your edits.

16. Create the meadow polygons as it shown on the following print-screen. Use the Trace *tool* to traces edges of forest boundary and also parcel outline. Enter *Meadow* as the *Type* value in the attribute editing dialog.



17. You should digitize all landuse polygons within the **Parcel** layer. Your final landuse coverage may be look as it is shown in the print-screen below. If you would like, you may introduce and digitize more land cover classes, e.g., you can divide the *Forest* class to mature forest and regrown forest etc.

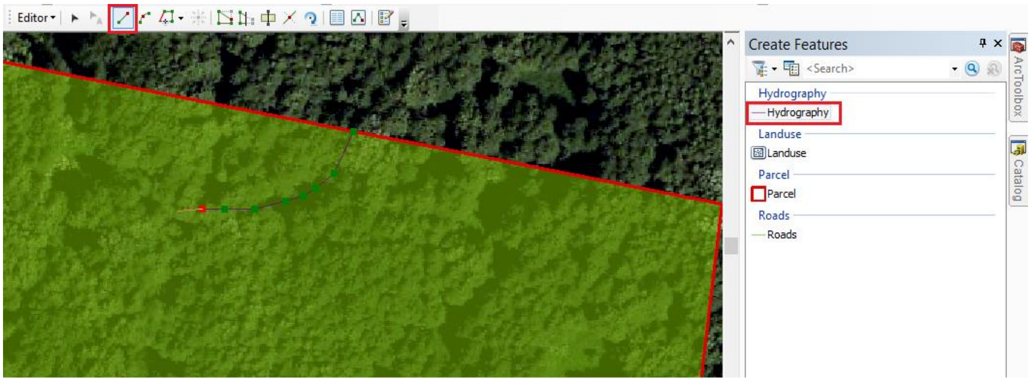


18. Now symbolize your landuse layer based on values from *Type* field. In the *Layer Properties* window, choose *Symbology tab > Categories > Unique values*. Choose *Type* in the *Value Field* list and click *Add All Values* button. Assign appropriate colors to *Forest* and *Meadow* polygons. Uncheck the <*all other values*> symbol category, and then click the *Apply* button.

19. If you would like to digitize other objects by using the orthophoto image and **Landuse** layers, we need to make the **Landuse** layer transparent. Navigate to the *Display* tab of the *Layer Properties* dialog, and set the layer transparency to *30*%. The **Landuse** layer will become transparent on the map, and underneath it the orthophoto image can be seen. These layers can be used for layouting a final plan.

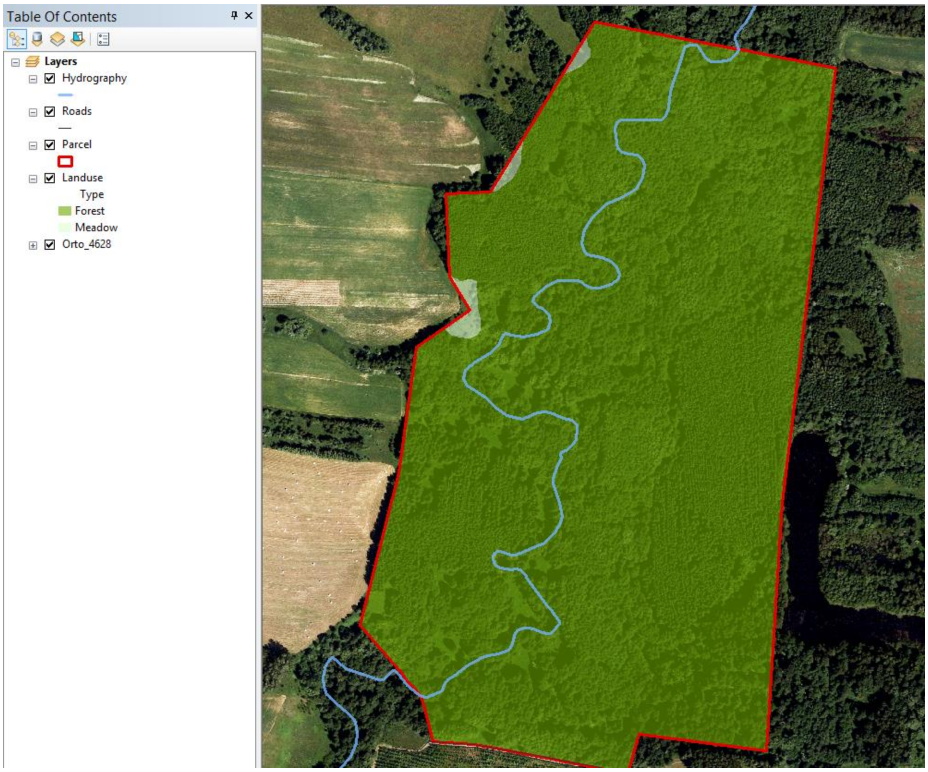
In the next step, a small river crossing the parcel should be digitized and saved in the **Hydrography** feature class. It is not an easy task to derive a riverbed from the orthophoto image as the parcel is covered by forest and we can recognize only the riverbed path approximately by following the changes in the vegetation pattern. Obviously, a result of manual digitizing of the riverbed central line will not be accurate, but we have a LiDAR data to improve the riverbed path.

20. Select the **Hydrography** layer in the *Create Features* window . First try to do a visual interpretation of the orthophoto image within the parcel interior to find the river valley. You may start riverbed digitizing from the top edge of the parcel, as it shown in the print-screen below. You may zoon in more closely to the image. Snap to the top edge approximately at the point where river starts crossing the parcel, as it is shown in the print-screen.



21. Manually digitize the riverbed by sketching its central line by following its valley – the darker tone between the trees. You can use the following print-screen, with the riverbed digitized, to locate the riverbed central line.

In the next part of this lab, you will correct your digitizing by using LiDAR data. Finish the riverbed sketch by snapping its line to the right-bottom edge of parcel boundary as it is shown in the following print-screen.



There is only one road in the study area and this road actually is not inside the parcel, but just shares the bottom boundary with the parcel. This road is shown in black color in the print-screen below. There are no other roads in this study area.

22. Follow the same procedures, which that described above, to digitize the both sides of road of **Roads** feature class. You can use the *Straight Segment* and *Trace* tools to digitize the road's sides.

23. When you finish digitizing, assign the appropriate symbology for the features of **Hydrography** and **Roads** layers.

You have vectorized the natural and manmade objects of study area based on the orthophoto image. Thus, you have just created a database of objects related to the cadastral parcel, which a customer would like to see on the final drawing.

24. Save your **Plan.mxd** and answer the following questions:

Question 1: What is the main purpose of using an orthophoto image in compiling the cadastral plan? Explain your choice. (2 point)

e) To visually present the real estate property
f) To vectorize objects in the land plot
g) To use as a background for mapping of the land plot
h) For geolocation in the study area

Questions 2: What tool you can use to vectorize the matching edges of the features? Explain your choice. (1 point)

a) Start Editing
b) Create Feature
c) Trace
d) Create New Feature Layer

Questions 3: What is the difference between geo-referencing and ortho-rectification of remote sensing images? (3 points)

Questions 4: What is the range of the finest possible spatial resolution of aerial images obtained from the aircrafts and unmanned aerial vehicles (drones)? (2 points)

PART B: USING LIDAR DATA TO ADJUST THE RIVERBED PATH AND SUBDIVIDING THE PARCEL

In this part of the assignment, you will be using LIDAR data to adjust/correct the path of the riverbed and use the riverbed path to subdivide the parcel into two separate plots.

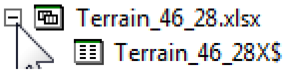
In the wooded area, it is extremely difficult to find a riverbed central line by interpretation of an orthophoto images, because a riverbed is often hidden by foliage, shadows, and so on. LIDAR data, and an elevation surface derived from them, provide the means to locate the riverbed more precisely.

First, you will import the LIDAR data file **Terrain_46_28.xlsx** into the geodatabase and store it in the database.

25. Save your **Plan.mxd** document and close ArcMap and open ArcCatalog.

The **Terrain_46_28.xlsx** file is very large file and can take some time to open it in a Excel editor. The **Terrain_46_28.xlsx** file includes three columns named **Field1, Field2** and **Field3,** in which are stored respectively X, Y and Z coordinates of LiDAR points cloud. There are more than a million points in the cloud. Each point is stored as a separate row. In order to import the data into the ArcGIS, you need to specify which particular columns correspond to the X, Y and Z fields.

26. In ArcCatalog navigate to your working folder and locate the **Terrain_46_28.xlsx.** Expand the file to see its table: click on plus symbol



. Right-click on **Terrain_46_28X$**and choose and run *Create Feature Class > From XY Table* tool.

27. In the *Create Feature Class From XY Table* window, assign the **Field1** of LiDAR file to the *X Field*, **Field2** to the *Y Field* and **Field3** to the *Z Field*.

28. Assign the *Coordinates System of Input Coordinates* to the *Lithuania LKS 1994 TM* coordinate reference system. You can select the *Lithuania LKS 1994 TM* system either by importing it from the existing file with the same coordinate system or navigating to *Projected Coordinate Systems > National Grids > Europe > Lithuania LKS 1994 TM.* Also, you can choose this coordinate system from your *Favorites* list, as you have used it several times.

29. Your *Output* feature class should be saved within the **PlanData.gdb**, use **XYLiDARcloud** as the name for a new points cloud feature class.

30. After filling all the *Add XY Data* fields, run the XY geocoding process. It can take some time, as you are geocoding more than million points. Once the process is finished, *Preview* the **XYLiDARcloud** points cloud and its table in ArcCatalog.

31. Close ArcCatalog and open the **Plan.mxd** in ArcMap. Add the **XYLiDARcloud** feature class in the map display. It also may take some time to display LiDAR points cloud in ArcMap.

Question 5: Why are there such large variations of points cloud density inside the parcel area? (3 points)

The **Terrain_46_28.txt** file is already a preprocessed LiDAR file. This file includes only height points that are reflected from *Ground* (bare earth) and *Water*. All other points (*Vegetation, Building, Noise* etc.) are removed from this file.

Question 6: What is difference between a Digital Elevation Model (DEM) and a Digital Surface Model (DSM)? (3 points)

Millions of cloud's points with heights are not so useful if you do not process them to highlight or extract relief forms and natural boundaries, which can be used to correct the vectorized riverbed line. We are going to use the 3D Analyst tools of ArcGIS to create a DEM interpolated surface from the LiDAR file first and then you will be using the interpolated surface to correct the digitized riverbed line.

32. You may need activate the *3D Analyst* extension of ArcMap from the main menu *Customize > Extensions*.

To create a continuous surface from the elevation points, you will be using the *IDW* (Inverse Distance Weighted) tool. This tool interpolates a raster surface from points using an IDW method. IDW method assumes that the variable being mapped decreases in influence with distance from its sampled location. IDW interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable. You can read more about this method and tool at http://resources.arcgis.com/ru/help/main/10.2/index.html#/na/003000000007000000/.

33. Run the *IDW* tool from *ArcToobox > 3D Analyst Tools > Raster interpolation > IDW*.

- Select the **XYLiDARcloud** dataset in the *Input point features* box of *IDW* tool.
- In the *Z value field* box, select the **Field3**.
- In *Output raster*, navigate into the **PlanData.gdb** database and type a new **IDWsurface** name for an interpolated surface.

Note: In order to run *3D Analysts* extension it should be activated in the menu *Customise > Extensions*.

One of the main parameters of this tool, which a user should define, is the *Output cell size*. This parameter defines the cell size of the output raster. This value is assigned based on the environment setting by default; otherwise, it can be calculated and assigned based on the following rule of thumb: it should be the shorter of the width or height of the extent of the output raster, divided by 250. In our case, the calculated cell size should be around 1. The use of a smaller cell size produces a more detailed DEM, however, at the same time, its file size will be larger and processing time will take longer.

Question 7: Could orthophoto images be used to create DEM? Explain your answer why yes or why not. (4 points)

34. Set the *Output cell size* to 1, use default parameters in the other tool boxes.

35. In the IDW tool window, set the processing extent from the button *Environments* > *Processing Extent* > and set *Extent* to **Orto_4628** and *OK*.

36. Then run the tool. Wait until the **IDWsurface** has been created. Processing can take a time.

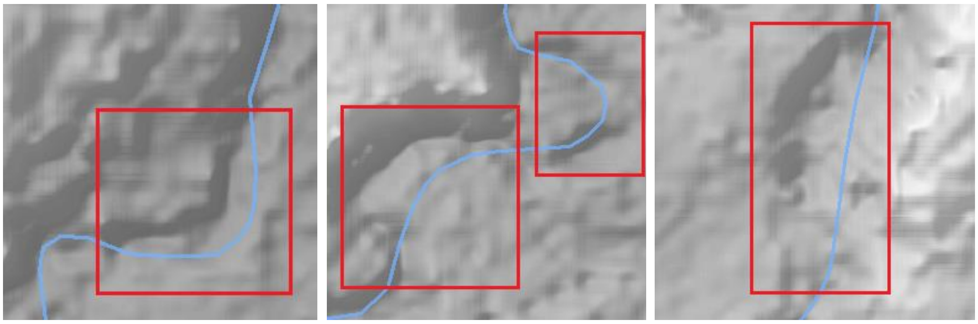
Question 8: What is the linear unit of the chosen cell size? How you know this? (1 point)

37. Turn off all the layers in the ToC and leave only the parcel boundary and **IDWsurface** layer visible. Change the symbology of **IDWsurface** layer: right-click the layer and select *Properties* > *Symbology* tab > *Stretched* > *OK*. Note how well the riverbed and its valley are highlighted in the **IDWsurface** layer, as well as other structural forms of relief: hills, hollows, gullies, etc.

38. We can still stretch the **IDWsurface** surface even more to make these forms more prominent. Come back to the *Symbology* tab of *Layer Properties* window. In the *Stretch Type* field select the *Minimum-Maximum* option. The minimum and maximum values of the calculated statistics will be used as the minimum and maximum values of the color ramp and all values in between will be interpolated linearly. Then check the *Use hillshade* effect box in order to make the relief forms stand out more. Click *Apply*. Now you can see that it is possible to demarcate the riverbed path more accurately.

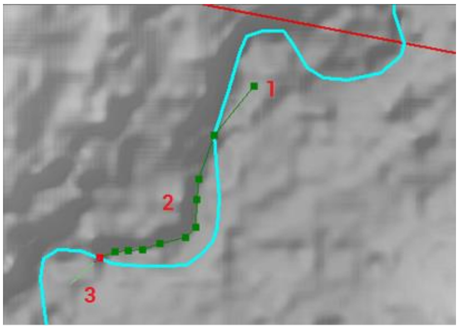
39. Go to the *Display* tab and choose the *Cubic Convolution* from the *Resample during display using* list. Cubic convolution resampling creates a sharper-looking image and can be appropriate for our task of riverbed demarcation. Click *OK*.

40. Next, you should correct the previously digitized riverbed central line by using the stretched surface. In the ToC, turn on visibility of the **Hydrography** layer. You may zoom in closely to the riverbed line. You may find many segments where your vectorized riverbed line does not match well with the actual riverbed. The following print-screen examples demonstrate such miss-digitizing.



41. Start Editing the **Hydrography** feature class. You may use the *Edit Tool*  to double-click on the riverbed line and edit it vertexes (e.g., move, insert or delete). Another tool of *Editor* toolbar, which will be useful, is the *Reshape Feature Tool* . This tool allows correcting the object edges by vectorising them again in a new location.

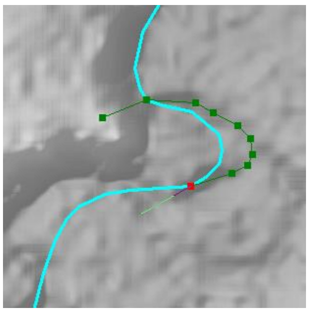
With the *Reshape Feature Tool* you can adjust the riverbed line so that it will match the relief forms. When using the *Reshape Feature Tool*, it is important to know that a newly entered line segment must cross the original line in order to reshape the line. Start the riverbed line adjustment from the other side of the reshaping segment by clicking on the map (1), then vectorize a new segment (2), and again finish editing in the other side of reshaping segment by double-clicking on the map (3).



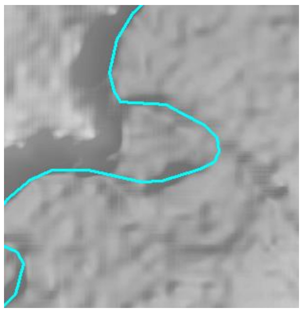
42. Correct the entire riverbed line within the parcel. Do not forget to *Save Edit* when you finish corrections.

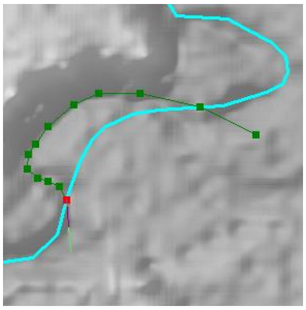
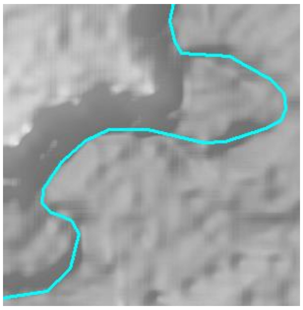
Here are examples of riverbed line before editing and after editing:

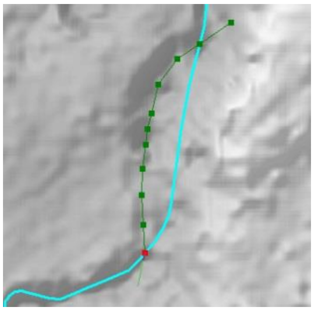
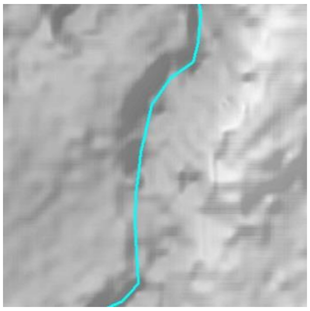
Before



After



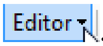
 

43. When you finish and save the edits, preview the adjusted riverbed line on the top of orthophoto image.

Questions 9: Export the Hydrography feature class into a shapefile named Hydrography.shp. Make an archive of Hydrography shapefiles and submit it together with other required files using Moodle for assessment. Your riverbed central line should follow the riverbed as precisely as possible. (8 points)

You may notice that the parcel is transected by the river. The owner would like to divide the parcel by the riverbed line into two separate plots.

44. You will divide the parcel by using ArcMap tools. First, export the **Parcel** feature class to the **Plots** feature class within the **PlanData.gdb**: from the layer drop-down menu use *Data* > *Export Data*. Then, select the **Plots** feature class in the *Create Features* window to start editing it. Turn off the visibility of **Parcel** layer in the ToC.

45. From the *Editing* toolbar select the riverbed line using the *Edit Tool* . Then, run the *Clip* function from the in *Editing* drop-down list 
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46. In the *Clip* dialog, enter the *Buffer Distance*, which defines the buffer width that will be clipped around the selected line. You will need a buffer with a width of 7 meters in total – the river is approximately 7 meters wide. Therefore you should enter a buffer distance of 3.5 meters to make buffers on both sides of the riverbed line that total 7 metres. Run the *Clip* operation.

47. Bring the *Advanced Editing* toolbar on the display, select  the **Plots** polygon (it is multipart feature) and run the *Explode Multipart Feature* tool .

After performing *Clip* and *Explode Multipart Feature* operations, the existing parcel will be divided into large plots separated by the riverbank lines. Area and perimeter values of plots will be calculated by ArcMap within the **Plots** feature attribute table. If you will get additional small polygons, you may leave them as they are, but do not label them when you will design a plan in the next section.

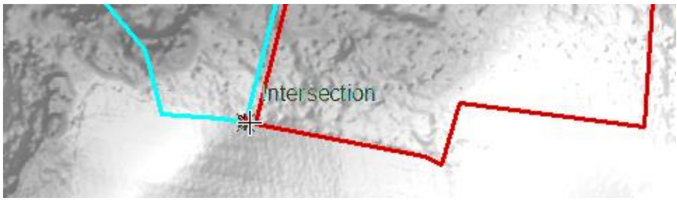
Question 10: What are the total area of the parcel and the total areas of the plots? (3 points)

Usually, a cadastral drafting should include not only annotations of area and perimeter dimensions of the plots, but also lengths/distances of segments of plots boundaries. These dimensions are often required to be shown on cadastral plans/maps.

48. You will derive the lengths dimensions of plots by using a few ArcMap operations. First, the *Feature to Line* tool will be used. Navigate to *ArcToolbox* and then to *Data Management Tools > Features* and run the *Feature to Line* tool. Select the **Plots** layer from the *Input Features* drop-down list and name the *Output feature class* as **Plots_measurements** within the **PlanData.gdb**, and run the tool.

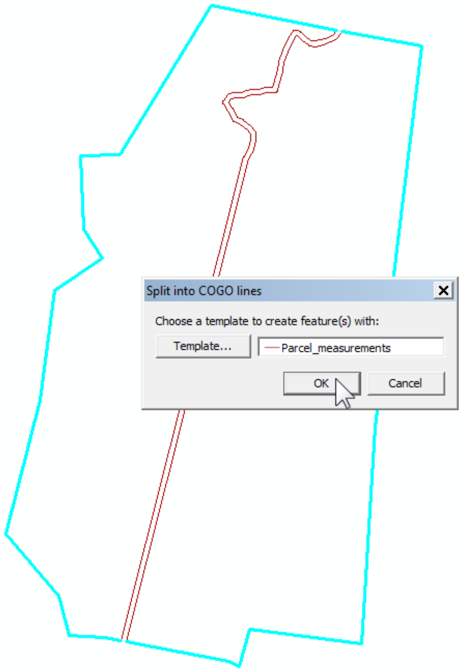
The created **Plots_measurements** feature class will have a few polylines with records, which include **Shape_Lenght** attributes. We would like to annotate with distance labels of only the straight segments of external plots boundaries, but not the riverbank lines. The riverbank lines should be left as solitary segments. Now we need to split the polylines to separate external plot boundaries from the riverbank lines.

49. Select the **Plots_measurements** feature class in the *Create Features* window to start edit it. Use the *Edit Tool* of *Editor* toolbar to select the **Plots_measurements** polyline and then the *Split Tool* to split each polyline in the point where the plot external outline turns to the riverbank line. As the result, you should have 4-5 polylines in the **Plots_measurements** feature attribute table.



Now, we need to divide the polylines of the external plot boundary into straight COGO segments at their turning points.

50. Bring the *COGO* toolbar on the ArcMap display. Use the *Edit Tool* of *Editor* toolbar to select polylines of plot external boundary. Use tool *Split into COGO lines* of *COGO* toolbar to split the external plot boundaries into straight segment lines. Choose the **Plots_measurements** template to create features.



51. Open the **Plots_measurements** feature attribute table and you will see that plot boundaries are comprise of two polylines, which represent the riverbank segments, and the rest of the records are straight lines, which represent the external plot boundary.

52. Symbolize the **Plots_measurements** layer with the same symbology style that you have used to symbolize the **Parcel** layer.

53. Save and stop your editing session as well as save the **Plan.mxd**.

Now, you may answer the following questions and then move to the third part of the lab where you will layout a cadastral plan.

Questions 11: What is the result of the IDW analysis of LiDAR data? Explain your choice. (2 points)

a) Digital elevation model (DEM)
b) 3D model of relief
c) Terrain model

d) Hillshade image

Questions 12: What was the main purpose of using LiDAR data for the compiling of cadastral plan? Explain your choice in this assignment. (1 point)

a) To create digital elevation model
b) To vectorize the cadastral objects
c) To correct the boundaries of the natural objects based on the derived relief forms
d) To create cartographic background for cadastral mapping

Questions 13: Which of the following is a "passive" (as opposed to "active") remote sensor? Explain your choice. (2 points)

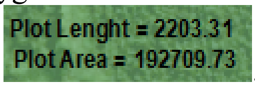
a) Digital aerial camera
b) LiDAR
c) RADAR
d) Sonar

PART C: LAYOUTING THE LAND PLOT PLAN

In this part of assignment, you will compile a cadastral plan drawing that represents the **Plots_measurements**, **Plots, Hydrography**, **Landuse** and **Roads** layers on the top of orthophoto image.

54. Make the **Roads, Hydrography**, **Plots_measurements**, **Plots**, **Landuse** and **Ortho_4628** layers visible on the map. You have already symbolized these layers in the previous steps. You still can adjust symbology and transparency of layers to make all objects readable. *Remove* the **IDWsurface** and **XYLiDARcloud** layers from the ToC.

55. Change the *Fill Color* and *Outline Color* of **Plots** layer to *No Color*. You will use this layer to label area and perimeter dimensions of the plots. The parcel boundaries will be visualized by the **Plots_measurements** layer.

56. Label the invisible **Plots** layer's polygons with values of their area and perimeter. The label should look like as 

. Check the Assignment 1 instructions on how to build the labels.

Question 14: Print-screen and insert an image with your label here. (3 points)

Question 15: Are decimal degrees useful unit for area? Explain your answer. (2 points)

57. Label the **Plots_measurements** segments with their length. The distance labels may look like 

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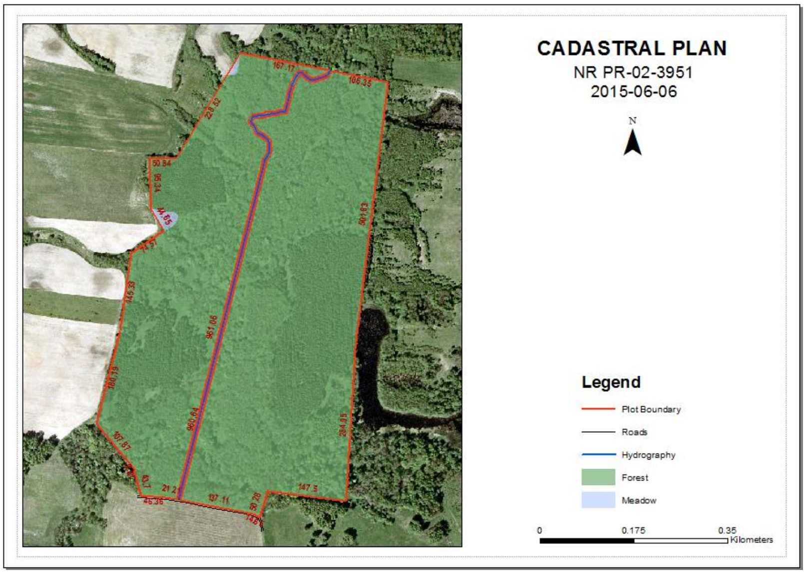
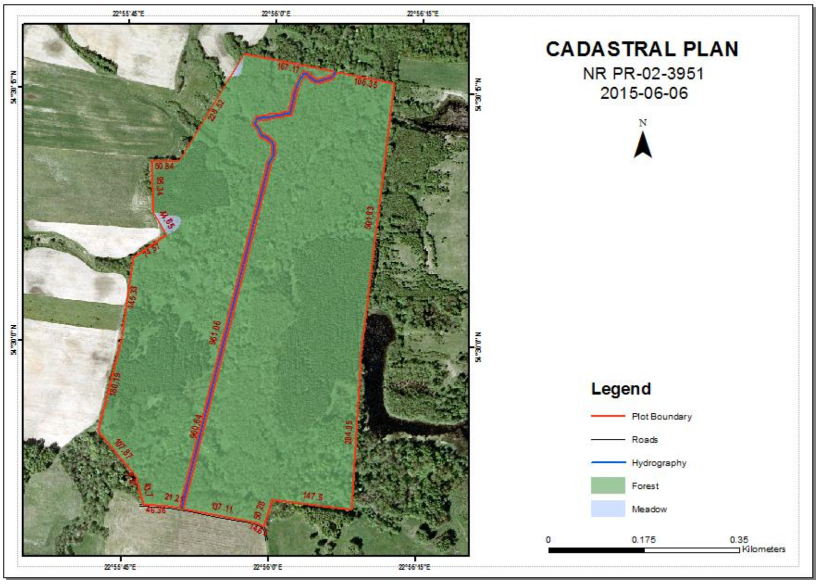
58. Next, layout your map in the *Layout View*. Make a similar layout of main map as you have done in Assignment 1: use the landscape orientation, A4 size page, 1: 5000-scale etc. Your layout may look as the following print-screen.

59. Next use the functionality of *Insert* menu to place the plan title and subtitle, legend, north arrow and scale. You can customize inserted plot elements by changing their *Properties*. Your layout may look as the following print-screen, or you may even find a better design solution of the map elements.



60. Insert and design a geographical coordinate grid around the plan. Your layout may look as the following print-screen.



61. Now you will insert two tables from the **PlanTable.xlsx** file as you did in Assignment 1. Only now, first you should fill this table with *Percentage* and *Area* values of the two landuse classes in Microsoft Excel. You can get the *Area* values from feature attribute table of **Plots** and **Landuse** layer. The *Percentage* values you should calculate yourself in the Excel.

62. Print the plot drawing in PDF format with the name **plot_drawing2**. . And answer the following questions.

Question 16: Submit you plot_drawing2.pdf with your lab hand-in. The assessment of your PDF plot will be based on the completeness of plot elements and plot design. (15 points)

Question 17: Which view mode of ArcMap is used for plan layouting? Explain your choice. (1 point)

a) Edit View
b) Template View
c) Data View
d) Layout View