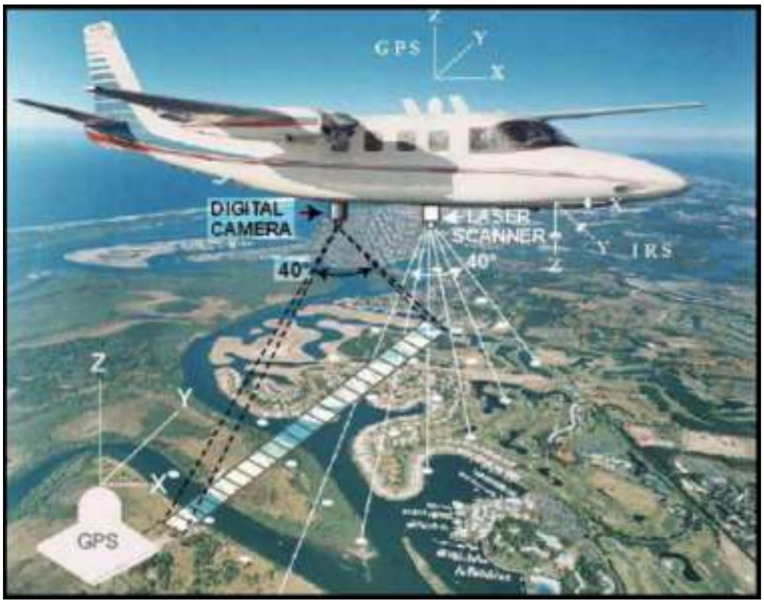
ADVANCED SURVEYING

LECTURE MODULE

Ziwa Ignatius M.

No projection is able to accurately show the correct compass direction, distance, shape and area of all features depicted on it.



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Contents

Preface

This lecture note is prepared for Natural Resources Development College (NRDC) Students who need to understand measurement of distances, angles and other similar activities. It is designed to give the student the basic concepts and skills of surveying for undergraduate level. This material could have paramount importance for the water engineering technologist/ technicians who are involved in engineering activities and projects.

Water Engineering students, as well as Agricultural Engineering and Fisheries students, at NRDC are frequently involved in community diagnosis of water and sanitation facilities, one of the major activities in the Development of Natural Resources. This activity requires, among other things, drawing of sketch maps of the area in question. A basic knowledge of surveying is of great help for planning, designing, layout and construction of different sanitary facilities.

MAPPING

INTRODUCTION TO MAPPING

In general, a map is any concrete or abstract image showing the geographical distributions, provisions and dimensions of features that occur on or near the surface of the earth or other celestial bodies. Humans have been the longest habitat of the earth as a result there has been a need to understand:

1. The earth's physical and environmental patterns at a regional, local as well as global level
2. The need to understand the social and economic patterns and trends; and, hence, solving spatial problems.

Therefore in order to reduce the complex patterns to such proportions that they can be comprehended in a single view, and also be able to solve various spatial problems, mankind inverted a map. Whose field is a dynamic one; i.e. map purpose, map content, size of geographic area to be mapped, use of projections, symbolisations and technology.

A real map is any tangible map product that has a permanent form and can be directly viewed; which can be conventionally drawn of printed using conventional methods. Whereas virtual maps are maps which are either non-permanent, non-physical or non-visible. For ease of describing functionally quite different maps; and to explain what can be confusing differences; we have opted to use a greater number of map types:

General Reference (sometimes called planimetric maps)

These are simple maps showing important physical (natural and man-made) features in an area. They usually have a primary purpose of summarising the landscape to aid discovery of locations. They are usually easy to read and understand. Most of the early mapping of the Earth falls into this group. As a general rule, General Reference Maps would only show relief in a stylised manner. Street and tourist maps are good examples of general reference maps.

Topographic Maps

Like the General Reference Map, Topographic Maps are a summary of the landscape and show important physical (natural and man-made) features in an area. The primary difference is that they show elevation in detail.

Characteristics of topographic maps include:

- they show elevation using contour lines – in simplistic terms a contour line is a line which joins points of equal elevation above sea level
- they have an emphasis on showing human settlement (roads, cities, buildings etc), but may include some thematic information such as vegetation or the boundaries of national parks
- they are typically produced by government agencies – these are often specialist mapping agencies and may have either a civilian or defence purpose
- they have well defined standards (called Specifications) which are strictly adhered to – these vary between mapping agencies and the scale of the map

- they have very good location reference systems – including latitude and longitude, but may also have grid lines
- often have additional information such as an arrow pointing to Magnetic North as well as True North

Understanding Contours

Elevation is usually shown using contour lines. In simplistic terms a contour line is a line which joins points of equal elevation. Where these lines are above sea level they are simply called *contour lines* and where they are below sea level they are called *bathymetric contour lines*. Contour lines can tell an informed reader many things about the shape of the land and its ruggedness. In its simplest terms, the closer contours are together the steeper the land and the further they are away from each other the flatter the land.

Thematic

A map that displays the spatial distribution of an attribute that relates to a single topic, theme, or subject of discourse. Usually, a thematic map displays a single attribute (a "univariate map") such as soil type, vegetation, geology, land use, or landownership. For attributes such as soil type or land use ("nominal" variables), shaded maps that highlight regions ("polygons") by employing different colors or patterns is generally wanted. For other attributes (like population density - a "metric" variable), a shaded map in which each shade corresponds to a range of population densities is generally wanted.

A thematic map is a map that emphasizes a particular theme or special topic such as the average distribution of rainfall in an area. They are different from general reference maps because they do not just show natural features like rivers, cities, political subdivisions and highways. Instead, if these items are on a thematic map, they are simply used as reference points to enhance one's understanding of the map's theme and purpose.

Choropleth Map

A map that uses graded differences in shading or color or the placing of symbols inside defined areas on the map in order to indicate the average values of some property or quantity in those areas. Therefore, a choropleth map is a thematic map in which areas are distinctly colored or shaded to represent classed values of a particular phenomenon.

Cadastral Maps and Plans

The cadastre of a country is its register of property titles and is usually managed by government agencies. The information recorded includes an accurate description of the location of a parcel of land and who owns it. It may also record what the land can be used for (eg residential or not, national park etc) and may also show the location and shape of buildings. In some countries it also records the value of a property, in these cases the cadastre may also be used for land taxation purposes.

The foundation block of a cadastre is the cadastral plan (or survey plan). This is produced by a registered/licensed surveyor who accurately measures and records the boundaries of each property. 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, ie it represents the shape and status of the cadastre at the time of survey. [1]

How is a Cadastral Map different to a Cadastral Plan?

Cadastral maps are produced by joining together individual cadastral plans. 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 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, Land Title Office management of the cadastre, planning etc.

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. 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. [1]

Cadastral survey

Cadastral surveys document the boundaries of land ownership, by the production of documents, diagrams, sketches, plans, charts, and maps. A unit of real estate or immovable property is limited by a legal boundary. The boundary may appear as a discontinuation in the terrain: a ditch, a bank, a hedge, a wall. They were originally used to ensure reliable facts for land valuation and taxation. Cadastral survey information is often a base element in Geographic/Land Information systems used to assess and manage land and built infrastructure. Such systems are also employed on a variety of other tasks, for example, to track long-term changes over time for geological or ecological studies, where land tenure is a significant part of the scenario.

MAP SPECIFICATION

All maps have one thing in common – they have a set of rules which determine how they are made and what they show. This is called a Specification. The specification should also contain information on assumptions, limitations and information sources. This is known as '*metadata*' and is an important aid to the map reader.

Map specifications provide the rules and guidelines for the issues associated with making a map. Specifications are needed for both printed and electronic maps. For simple, one-off, maps these may be very simple, but for complex series maps these can be very complex because it is important that all maps in the series have similar content, as-well-as a consistent 'look and feel'.

GENERALISATION

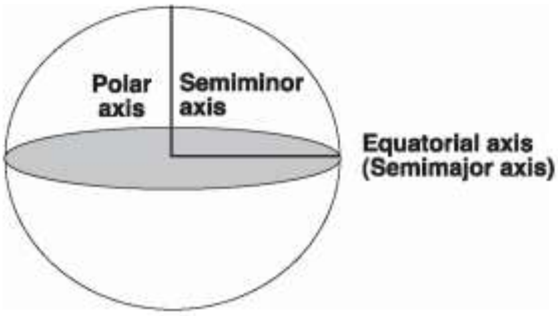
Generalisation is the process of making decisions as to which features are included or not included on a map. As the area of land that is being mapped becomes larger fewer individual features are able to be shown on a map. For example at 1:100 all the individual trees in an area could be depicted, but not at 1:100,000. Decisions need to be made about what is important to retain on the map and what can be dispensed with or shown in another manner. As the scale of a map changes from a smaller number to a larger number the area of the Earth’s surface which can be shown increases, but the amount of detail which can be shown decreases.

This decision is dictated by the map’s purpose and how ‘cluttered’ it can become before it becomes unusable. This process of selecting items for inclusion, exclusion or amalgamation is called generalisation, and all maps do it. Because of the importance of some features, it is sometimes important to show a number of features on a map, regardless of the scale being used.

Consider roads and railways on topographic maps. For this type of map, it is important to show both. However, they are often very close to each other on the ground, on the map their symbols would overlap and be unreadable. Conventions allow for both to be shown on the map by moving one of the features away from the other. This process of deliberately moving features away from their true location is called **cartographic generalisation**, and not all maps use it.

THE FIGURE OF THE EARTH

A spheroid/ellipsoid is defined either by the semi-major axis, a, and the semi-minor axis, b, or by a & the *flattening* – also called ellipticity



MAP PROJECTIONS

Having developed a coordinate system and measurement techniques for the Earth, the next problem map makers faced was how to transfer the information from the surface of a 3 dimensional (3D or spherical), irregularly shaped sphere (the Earth) to a 2-dimensional (2D or flat) 'piece of paper'. Over many centuries a vast number of techniques (often involving very complex mathematical formulae and models) have been developed to do just this. These are called projections.

A projection is a system of mathematics and geometry whereby the information on the surface of a sphere (the Earth) is able to be transferred onto a flat piece of paper (a map). Projections are generally given a name so that they can be easily identified and referenced on a map. They are often named after the person(s) who invented them (eg Mercator); or aspects of the projection (eg Equidistant Conic); or a combination of the two (eg Lambert Conformal Conic).

Distortions

All projections result in some distortion of the relationships between features on the sphere when they are projected onto a flat surface. These distortions include:

- the direction between a feature and surrounding features
- the distance between a feature and surrounding features
- the shape of any feature
- the size of any feature

There is no one perfect projection and a map maker must choose the one which best suits their needs. The only ‘projection’ which has all features with no distortion is a globe. This problem is in part due to the changing relationship between latitude and longitude. Near the Equator a ‘block’ of 1° x1° latitude and longitude is almost a square, while the same ‘block’ near the poles is almost a triangle.

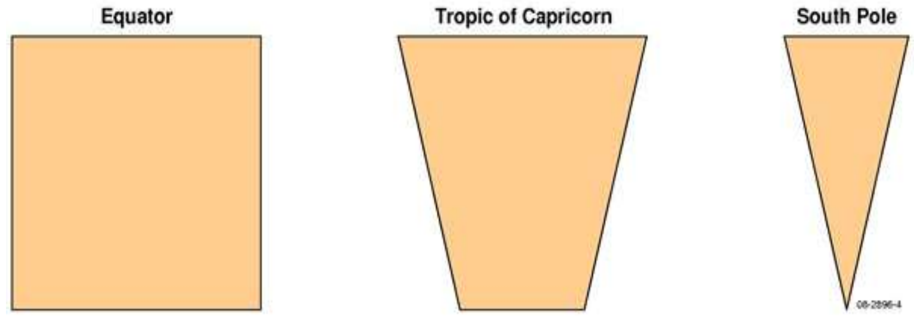


Figure 0-1: A Degree Square at different locations

Describing Projections

There are two ways that projections are classified; Projections are described by referring both of these:

- Basic Type: depends on the characteristic that is preserved
- Basic Technique: depends on the method used to project features onto a flat surface

Basic Projection Types

This describes how a map shows the positional relationship between two features, and their size and shape. Depending on their intended use, projections are chosen to preserve a particular relationship or characteristic. These include:

- Equal-Area; correctly shows the size of a feature
- Conformal; correctly shows the shape of features (A map cannot be both equal-area or conformal – it can only be one; or the other; or neither.)
- Equidistant; correctly shows the distance between two features
- True Direction; correctly shows the direction between two features

Basic Projection Techniques

This describes the way an imaginary piece of paper (which will become the map) is laid on the Earth to obtain the latitude and longitude for the map. Where the imaginary ‘piece of paper’ touches the Earth there is no distortion on the map. As you move away from there however, distortions increase with distance. Because of this, map makers usually choose for the piece of paper to touch the Earth in the middle of a map – thereby minimising the amount of distortion.

Using this concept of an imaginary ‘piece of paper’ touching the Earth there are three basic techniques used to create a projection and therefore a map. These are:

- azimuthal the imaginary ‘piece of paper’ is flat this is usually used over Polar areas
- conical the imaginary ‘piece of paper’ is rolled into a cone this is usually used in mid-latitude areas (approximately 20° – 60° North and South)
- cylindrical the imaginary ‘piece of paper’ is rolled into a cylinder this is usually used over Equatorial areas or for World Maps

Map makers have technical terms to describe the line of latitude or longitude where this imaginary ‘piece of paper’ touches the Earth. These are:

- for a line of latitude – standard parallel
- for a line of longitude – central meridian

Azimuthal Projections

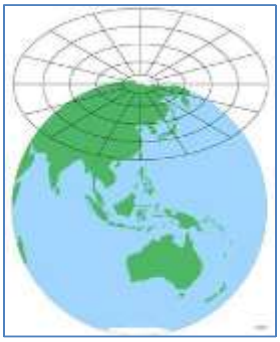
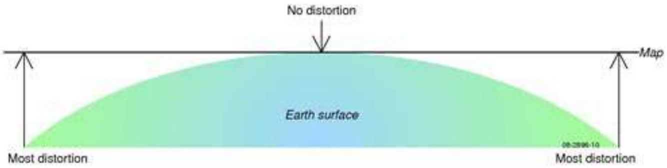


Figure 0-2: Planner Projection

This projection is based on a ‘flat piece of paper’ touching the Earth at a point. The point is usually a Pole, but this is not essential. Azimuth is a mathematical concept with relates to the relationship between a point and the ‘flat piece of paper’ that ’touches‘ the Earth. It is usually measured as an angle. The word itself is believed to have come from an Arabic word mean the way – referring to the way or direction a person faces.

These projections:

- have distortions increasing away from the central point
- have very small distortions near the centre point (the ’touch point of the paper‘)
- compass direction is only correct from the centre point to another feature – not between other features
- are not usually used near the Equator, because other projections better represent the features in this area.



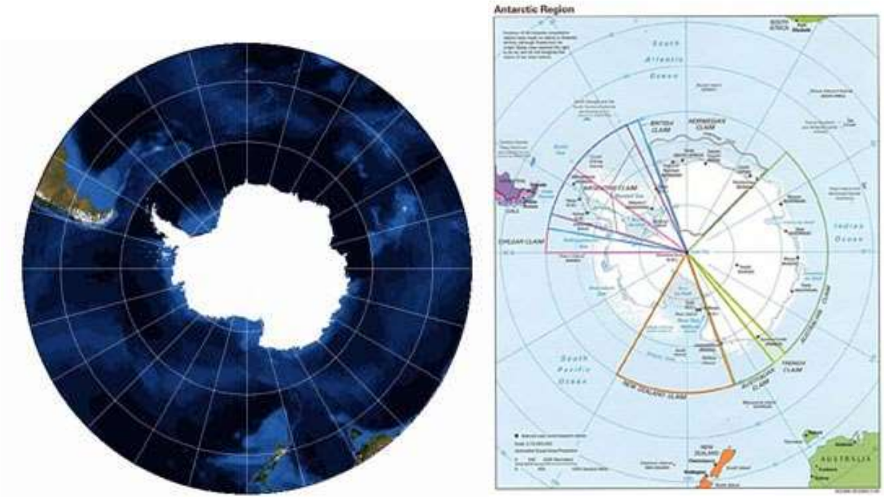


Figure 0-3: Resultant map in Planner Projection

When the centre of the map is the North or South Pole maps produced using Azimuthal Projections techniques have lines of longitude fanning out from the centre and lines of latitude as concentric circles. These projections are often called polar projections.

Conical Projections

This projection is based on the concept of the ‘piece of paper’ being rolled into a cone shape and touching the Earth on a circular line. Most commonly, the tip of the cone is positioned over a Pole and the line where the cone touches the earth is a line of latitude; but this is not essential. The line of latitude where the cone touches the Earth is called a Standard Parallel.

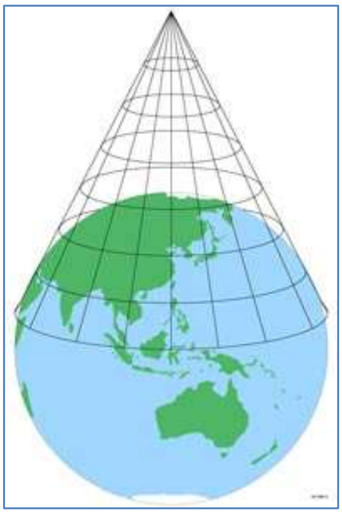


Figure 0-4: Conic Projection

Conic projections are usually used for regional/national maps of mid-latitude areas – such as Australia and the United States of America. These projections:

- are fan shaped when used to map large areas
- have distortions increasing away from the central circular line (the ’touch point of the paper‘)
- have very small distortions along the central circular line (the ’touch point of the paper‘)
- shapes are shown correctly, but size is distorted
- usually have lines of longitude fanning out from each other and have lines of latitude as equally spaced open concentric circles

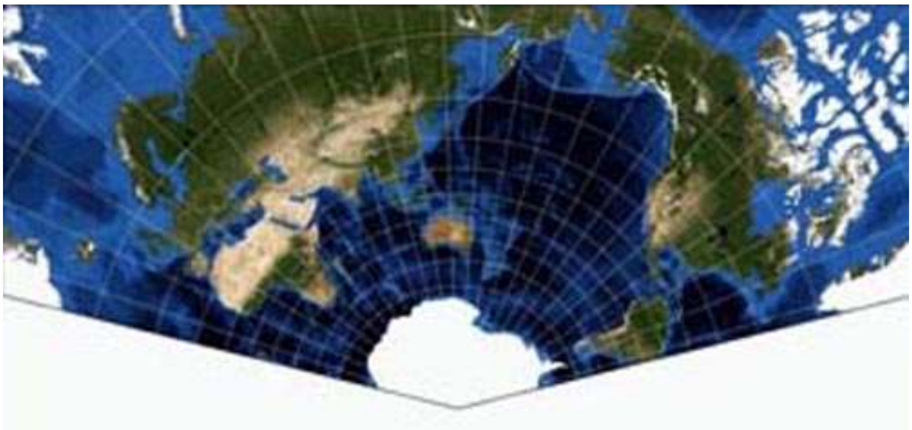


Figure 0-5: Resultant map in conic Projection

This is a typical example of a world map based on the Conic Projection technique. This map is centred on central Australia and the Standard Parallel is 25° South. Note how the shapes of land masses near the Standard Parallel are fairly close to the true shape when viewed from space. Also note how land masses furthest away from the Standard Parallel are very distorted when compared to the views from space. Particularly note how massively large northern Canada and the Arctic icecaps look.

Because of the distortions away from the Standard Parallel, Conic Projections are usually used to map regions of the Earth – particularly in mid-latitude areas. This map uses the same settings as the previous World Map, but it is more typical of a Conic Projection map. Distortions are greatest to the north and south – away from the Standard Parallel. But, because the Standard Parallel runs east-west, distortions are minimal through the middle of the map.

Cylindrical Projections

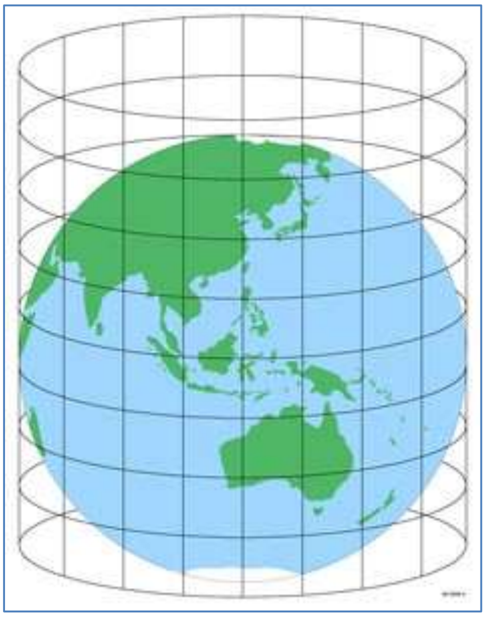


Figure 0-6: Cylindrical Projection

This projection is based on the concept of the ‘piece of paper’ being rolled into a cylinder and touching the Earth on a circular line. The cylinder is usually positioned over the Equator, but this is not essential. Cylindrical projections are usually used for world maps or regional/national maps of Equatorial areas – such as Papua New Guinea.

These projections usually:

- are rectangular or oval shaped – but this projection technique is very variable in its shape
- have lines of longitude and latitude at right-angles to each other
- have distortions increasing away from the central circular line
- have very small distortions along the central circular line (the ‘touch point of the paper’)
- show shapes correctly, but size is distorted.

The first Cylindrical Projections developed had the lines of latitude and lines of longitude shown as straight lines – see the section on the Mercator projection. With advances in computers it became possible to calculate the lines of longitude as curves – thereby reducing distortions near the Poles – see the section on the Robinson projection. To distinguish between these two projections the first continued to be called a Cylindrical Projection, but the second (with the curving lines of longitude) was called Pseudo-Cylindrical Projection.

A projection's name is often a good indicator of some of its properties.

Firstly; Projections are often named after their creator – famous names include Albers, Lambert, Mercator and Robinson. However, without inside knowledge, this gives no indication of the properties of a projection.

Secondly; the projection name may refer to some of its attributes – quite commonly Equal-Area, Conformal and Equidistant are included in a projection's name.

Thirdly; the projection name may refer to its source technique – conic and azimuthal are the one which is most commonly used here. (There is an element of assumption that a projection is cylindrical if not otherwise stated.)

Multiple Standard Parallels or Central Meridians

One very common variation is to have more than one 'touch point of the paper' to the Earth – ie two or more Standard Parallels (or Central Meridians). As we have learnt above the areas near the Standard Parallel have less distortion than those further away from the 'touch point of the paper'. By having two Standard Parallels the distortion levels across the map are kept to a minimum and increase the overall accuracy of the map.

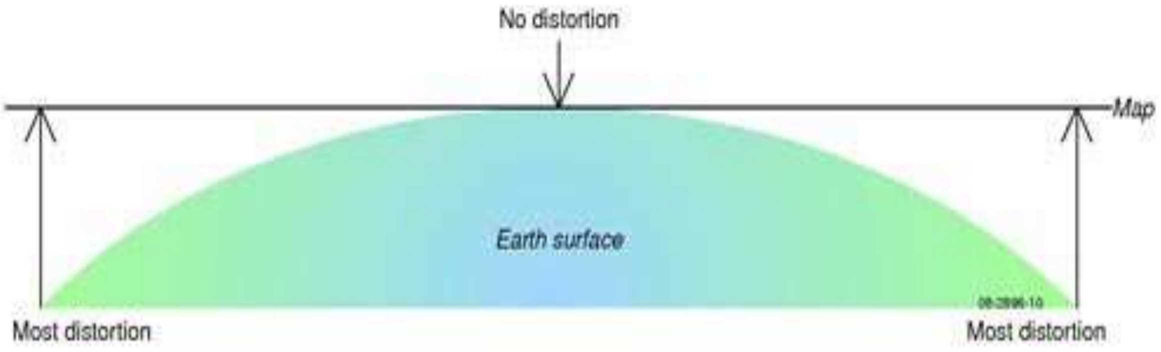


Figure 0-7: Single Parallel

Consider the diagram above which illustrated how distance away from the 'touch point of the paper' results in distortions.

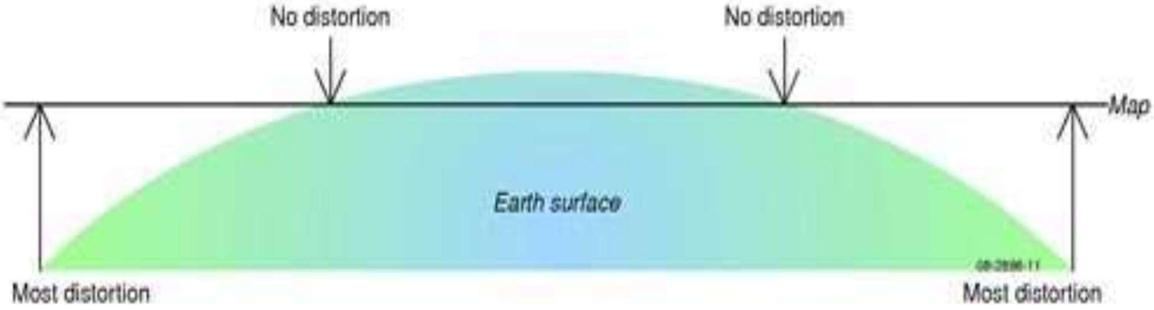


Figure 0-8: Double Parallel

Now note this diagram where the paper doesn't touch the Earth – it slices the Earth. Across the whole piece of paper the distance to the surface of the Earth is much less and therefore distortions are less.

Using this conic projection as an example, the 'piece of paper' appears to 'slice through' the Earth – thereby touching the surface of the Earth in two places and creating two Standard Parallels.

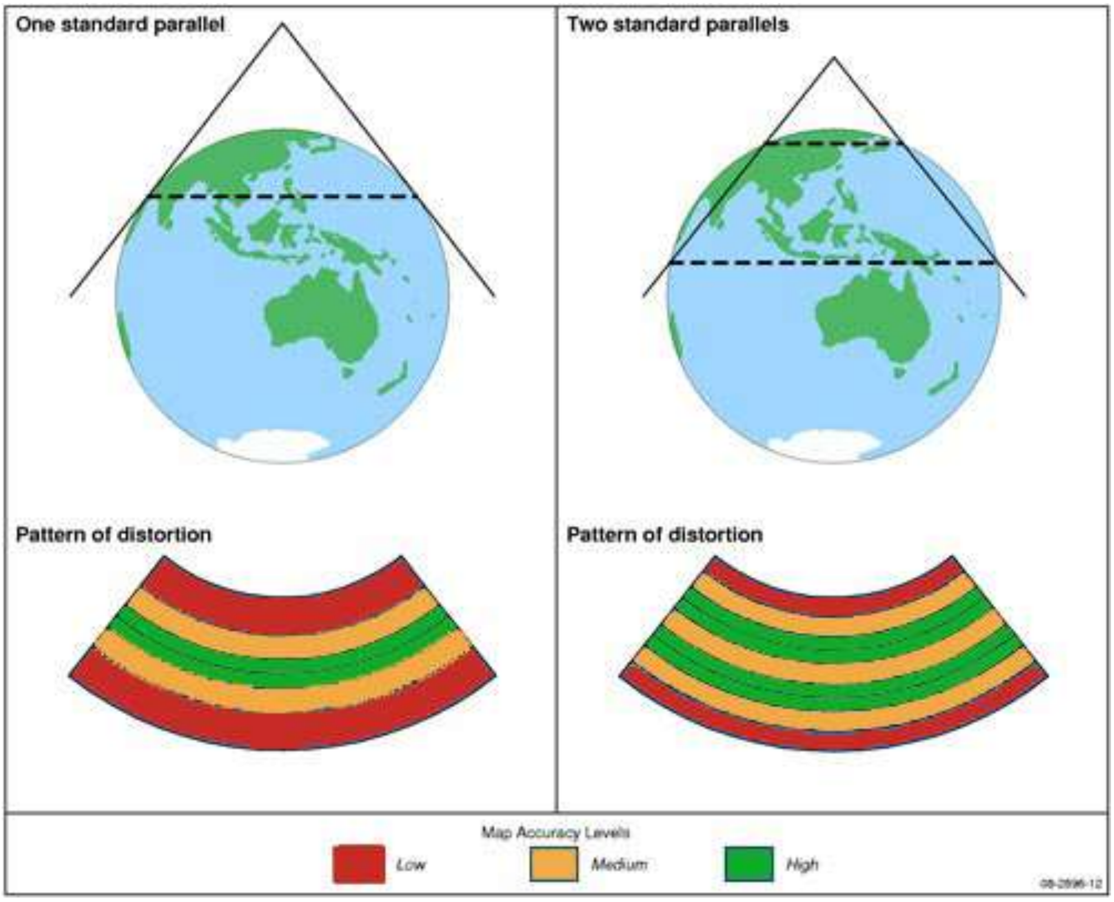


Figure 0-9: Single and Double Parallels in Conic Projection

Merits and Limitations of Projections

No projection is able to accurately show the correct *compass direction, distance, shape* and *area* of all features depicted on it. Because of this, each projection has advantages and disadvantages, as well as serving different purposes and producing different types of distortions. As a general rule maps of local areas have less distortions than those of larger areas or the world.

Many special projections have been developed to specifically overcome some of these distortions. For example:

- 'equal-area' projections preserve true areas
- 'conformal' projections preserve true shape
- 'azimuthal' projections preserve true compass direction from the centre

As a general rule the best projection to use is dictated by the map's:

- location (equatorial, polar, or mid latitudes)
- extent/size (world vs regional vs local)
- Purpose (distortion may not be an issue, but keeping equal-areas or true direction may be important).

Mercator projection

The conformal cylindrical projection tangential to the Equator, possessing the additional valuable property that all rhumb lines are represented by straight lines. Used extensively for hydrographic and aeronautical charts.

Transverse Mercator (TM) projection –

A conformal cylindrical map projection, originally devised by Gauss, also known as the Gauss-Kruger projection. As its name implies, its construction is on the same principle as the Mercator projection, the only difference being that the great circle of tangency is now any nominated meridian. Meridians and parallels are curved lines, except for the central meridian for a specified zone (meridian of tangency), which remains a straight line. Projection zones are established about the central meridian and vary in width from two degrees to six degrees of longitude, with some overlap between zones. The amount of scale distortion may become unacceptable at distances greater than about 1.5 degrees in longitude from the central meridian. In a modified form the projection is in general use for topographic mapping at scales of 1:250 000 and larger.

Universal Transverse Mercator (UTM) –

A worldwide systematic application of the Transverse Mercator Projection applying to the region between 80°S and 84°N latitude. The UTM is a modified TM projection whereby the natural scale of the central meridian is scaled by a factor of 0.9996 to enable a wider area to be mapped with acceptable distortion.

Each Zone is six degrees of longitude in width with a half degree of overlap within the adjoining zone and having a true origin at the intersection of the central meridian of that zone and the Equator.

Universal Transverse Mercator (UTM) Grid Coordinate System

The ***Universal Transverse Mercator*** (UTM) grid coordinate system, divides the earth into a perpendicular grid with constant linear surface distances, in meters, between each of its grid lines in all directions. UTM was developed in order to reduce the complexity of the calculations needed to transfer a location on our spherically-shaped planet to a flat surface.

The Transverse Mercator Projection, which divides the earth like the slices of an orange and flattens the slices, introduces a negligible amount of distortion for map scales typical of most topographic maps. The slight amount of distortion of the geographical features within a zone is negligible and may be ignored by most map users.

The UTM Grid Coordinate System superimposes a perpendicular grid over these earth slices with constant linear surface distance values between each of its grid lines in all directions. Since the pattern of UTM grid lines was superimposed on the grid zones after they were flattened, these grid lines are straight, perpendicular, and they are not distorted. This grid is designed to create a system where each location can be determined from the (0, 0) point in meters or by its grid coordinates. A reference in the UTM system can be converted into a reference in another system, such as latitude and longitude using computer software.

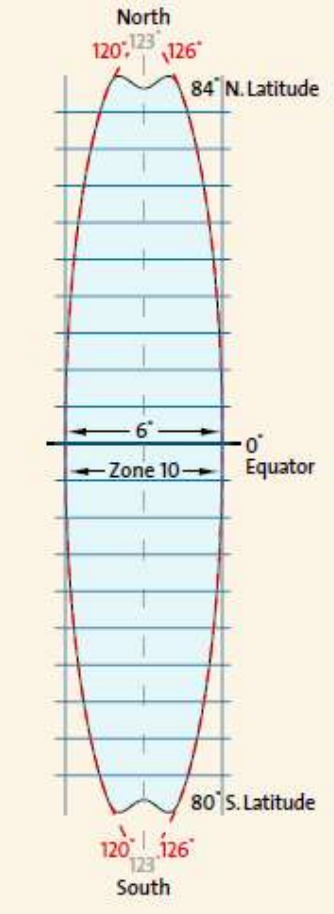


Figure 0-10: UTM zone properties

UTM Measurements & Coordinates: EASTINGS

Each UTM zone is 6° wide, and uses the central meridian as a reference. Zone numbers designate 6 degree longitudinal strips extending from 80 degrees South latitude to 84 degrees North latitude, for a total of 60 zones.

For example, Zone 10 extends from 126° West to 120°West Longitude. The central meridian is 123°, halfway (3°) from the boundary meridians. As another example, Zone 14 has a central meridian of 99° West Longitude.

Eastings, longitudinal measurements within each zone, are measured from the central meridian. The central meridian has a false easting of 500,000m to assure positive coordinates. Thus, a location in Zone 10 that falls directly on the 123° meridian would have an easting of 500,000 meters written: 500000Em.

A location 10,382 meters west of the central meridian (500,000 - 10,382 = 489,618) would be written as 489618Em; likewise, a location 85,640 meters east of the central (123°) meridian would appear as 585640Em… on a GPS unit, this would be 10 Q 585640. (Note that the Q in this example is arbitrary; see Northings which describe Zone characters).

UTM Measurements & Coordinates: NORTHINGS

Northings are measured from the equator (with a 10,000,000km false northing for positions south of the equator). Zone characters designate 8 degree zones extending north and south from the equator.

Zones are divided into sections of latitude that are 8 degrees in height. These sections are lettered C through X, with M and N bracketing the equator. The letter designators give a quick reference as to the latitude of a point indicted by the coordinates.

The letter designator is merely a help, however. While the zone number is critical, as the easting coordinate is referenced to it, the northing coordinate specifies the total number of meters from the equator, regardless of lettered zone section.

Again, eastings indicate the number of meters of longitude within the numbered zone... the same easting coordinate value will repeat for each zone. Eastings are specified as six-digit numbers. Northings, however, are specified regardless of lettered section. Northings specify the absolute number of meters from the equator. Northings are specified as seven-digit numbers.

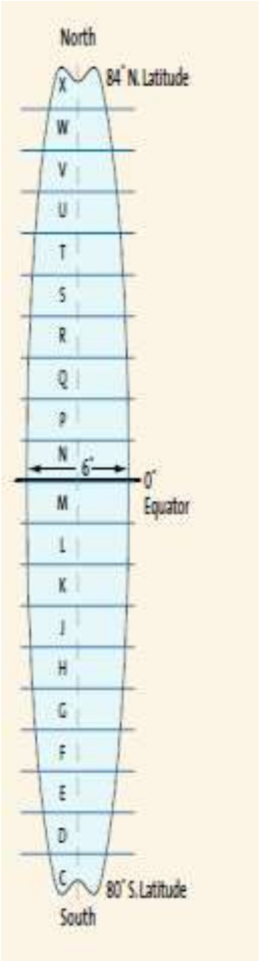


Figure 0-11: UTM zone sections

There are special UTM zones between 0° and 36° longitude above 72° latitude and a special zone (32) between 56° and 64° north latitude.

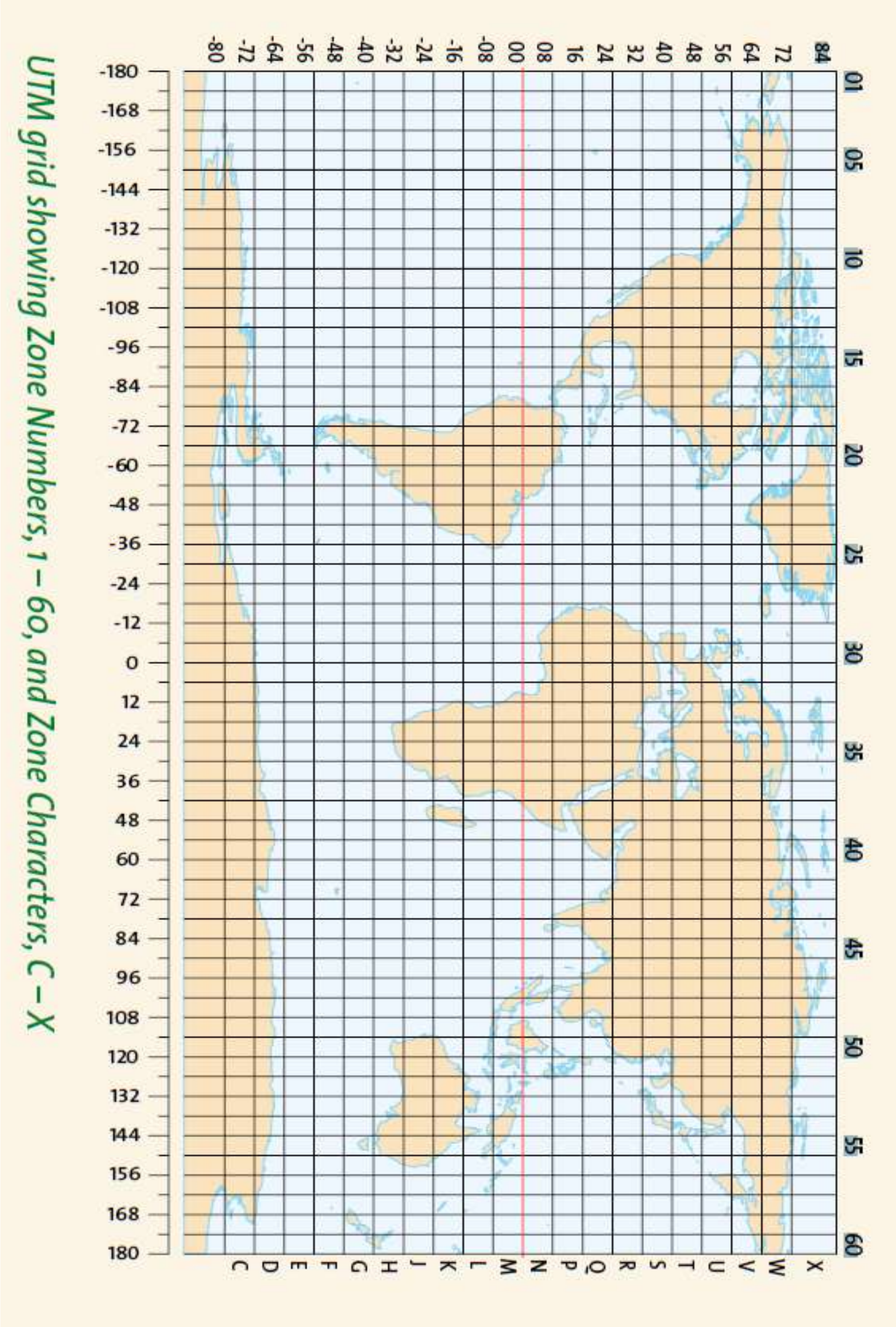


Figure 0-12: UTM Zones

MAP PRODUCTION

Before embarking on the complex task of producing a map, cartographers must first consider two fundamental points:

1. the purpose of the map, and
2. its target audience.

Only after these have been defined should design and production commence. These points are critical to determining what is shown or omitted from the map, how key features will be highlighted while other less important elements are not etc.

Maps have two basic components: the map itself (commonly called the 'face of the map'); and information about the map (commonly called 'marginalia').

Marginalia Information

The term marginalia comes from a convention that all additional information about the map was printed/ drawn outside the edge of the map – i.e. in the margins. This convention has disappeared with time, but the term lives on. There are no hard-and-fast rules as to what marginalia should accompany a map, but there are some well recognized principles which are outlined below. Also, there are no hard-and-fast rules as to how the marginalia should be shown on the map – it is completely up to the map maker's discretion.

The marginalia items which are discussed here are: Graticules and Grids, Legend, Location, North Arrow, Production Information, including authorship, Projection, Scale, Title. These are by no means the only marginalia items – this also is completely up to the map maker's discretion.

Title

It is essential that a map has a title. This is to ensure that the reader knows what is being mapped. This may be very simple or made more complex by including a note outlining the content/purpose and/or limitations of the map. The title is always the largest font size on the sheet, is often in capital letters, and placed in a prominent place. If a note is included it is usually in a smaller sized font to the main title.

Legend

A legend is essentially a decoder for all the symbols used on a map. Remember it is not always intuitive as to what a symbol represents, so give sufficient information to ensure that your map is not misread. For example a tree ***(draw a tree symbol)*** symbol could represent a single tree, a forest, a plant nursery, a city park, a lawn cemetery or even something totally unrelated to plants.

As a general rule a map should always include a comprehensive legend which explains/defines the meaning of the symbols used. This removes the risk of a map being misinterpreted and/or used incorrectly. In cases where space does not permit all symbols to be shown in a map legend, the more obvious ones could be omitted (for example rivers and/or roads are relatively easily interpreted by map users). However, this is best avoided if possible.

Very simple maps (such as an outline map of a country's borders) may not require a legend. Items which can be used instead of a legend include: adding text to describe each feature on the map – this removes ambiguity; and use of well-known symbols / colours etc to identify features (for example continuous thin blue lines usually indicate watercourses and roads are often depicted by red lines)

Scale

This is the mathematical relationship between the size of the map and the size of the piece of earth it is describing. All maps have a scale (maps without scales are essentially diagrams), which may be simple (for single scale maps) or complex (for multi-scale maps). Modern maps have the advantage of using advanced earth measuring techniques and map projections, which results in more accurate mapping, with a reliably consistent scale applied across the face of the map.

A Warning:

In this modern electronic era it is important to remember that a printed map can be easily enlarged or reduced (most photocopiers are able to do) or can be turned into an electronic map (as is typical on the internet). When either of these happen it is important to note that: the Scale Bar will remain correct while the written Statement of Scale will not be correct. The decision as to which of the following alternatives is used is usually based on: the purpose of the map, an assessment of the needs of the map user; and likelihood of being photographically or electronically enlarged or reduced

These are the four alternatives a map maker has to choose from:

- **Showing both**; where the scale is consistent across a map, a Statement of Scale and a Scale Bar are often shown. Also, if a map is to be used for a legal purpose, it is likely that both would be required.
- **Showing a Scale Bar only;** this is emerging as the most common way to show scale on a map – because of the issues associated with photographic/electronic enlargement or reduction of a map.
- **Showing a Statement of Scale only**; this is less preferable to either of the two previous alternatives, because of the issues associated with photographic/electronic enlargement or reduction of a map.
- **Showing neither**; Where the scale is highly variable across a map (such as with some world maps) or the scale is not important as the map is of a well-known/identifiable area it is acceptable that no scale information be shown. This should however be regarded as the 'exception, not the rule'.

Projection

The amount of information supplied regarding the projection used for the map is dependent on the purpose of the map and/or the complexity of the projection.

In simple terms this equates to:

- Simple maps may not require projection information to be shown, but it can be added if desired. A good example is a town/city, holiday resort map where the important factor is that a consistent scale is used and that features stay in their correct position relative to each other.
- Larger area and more complex maps/projections need some projection information to be shown.
- Legal maps and very complex/unusual projections need precise information about the mathematics behind the projection – eg a map of prohibited area.

Note: projection information is often sought by map users, sometimes many years after a map has been published. For this reason a good rule of thumb is to include projection details where possible.

North Arrow

Early maps almost always had an arrow indicating the direction to the Geographic North Pole – called a North Arrow. This convention developed because maps were drawn with no particular reference to the physical reality of the shape of the Earth – rather they were aligned to best suit the subject of the map, for example the route of a trade expedition. However modern convention dictates that north should be at the top of the map and therefore North Arrows are generally not shown on maps

Production Information

Where possible, maps should include production notes (sometimes called 'map credits' but more usually these days: metadata). Important items are:

- a brief statement as to who produced/published the map
- date of publication and/or date of the information shown on the map
- known limitations of the information
- names of organisations and individuals who contributed (information, sponsorship etc) to the map, and/or names of those who compiled, drew, edited or printed the map
- the methodology that was used to produce the map
- edition (this is not usually added to a first edition map)

- a Copyright statement (including the Copyright symbol ©)

Topographic Map Symbols

In cartography, symbols are everything. The very nature of a map as an abstracted representation of the Earth requires symbols to perform the abstraction. To not have symbols is to not have maps.

When we first think of symbols, we tend to think of graphics representing elements that appear at points, like bridges and houses. Symbols can also be linear, representing such features as roads, railways and rivers. However, we also need to include representations of area, in the case of forested land or cleared land; this is done through the use of colour.

Steps in Production a Map

These are the key steps in producing a map:

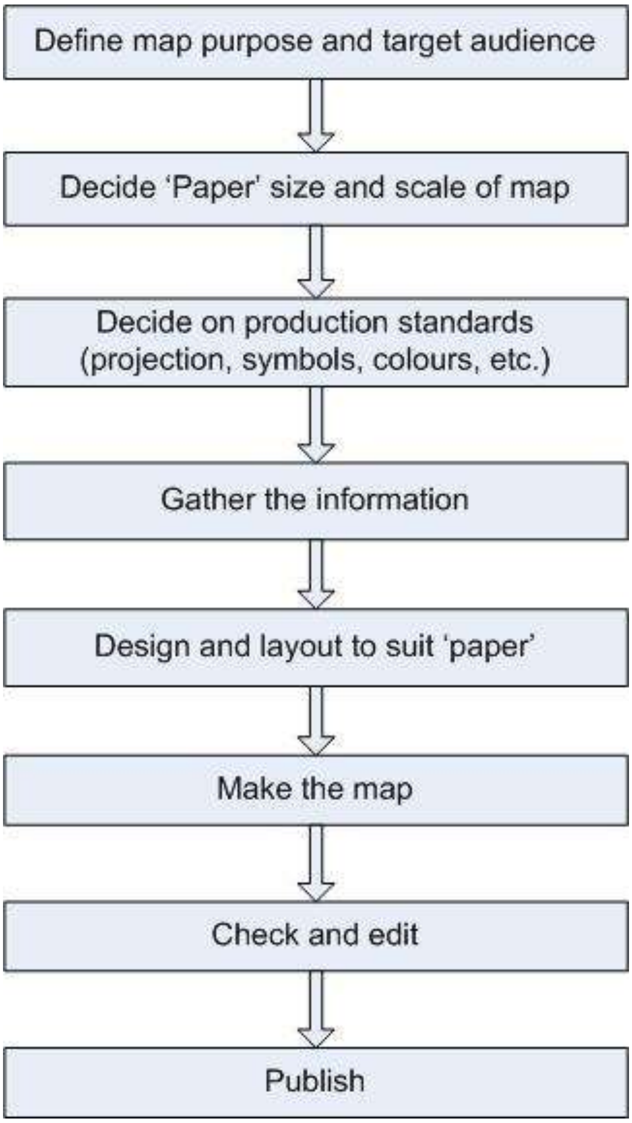


Figure 0-13: Map Production Process

LINEAR MEASUREMENT

Introduction

In plane surveying, the distance between two points means the horizontal distance. If the points are at different elevation, the distance is the horizontal length between vertical lines at the points. In surveying, that under most circumstances, all distance are presumed to be horizontal distances. This dictates that every field measurements taken be either measured horizontally, or if not, reduced to a horizontal distance mathematically. Distance between points can be also be determined using geometric or trigonometric computations working with related distance and angle measurements. [2]

The measurement of distance is one of the fundamental operations in surveying and is carried out by taping, optical or Electromagnetic Distance Measurement (EDM) techniques. Whichever of these is used, the usual requirement in surveying is for horizontal distances. Distances are very important in surveying since they determine the scale of a network. [3]There are several methods used in the determination of distances, the choice of which will depend on:

- Length of the distances involved
- Number of distances involved
- Desired accuracy and precision (Engineering tolerances and legal standards withstanding)
- Available equipment/ personnel/ time
- Type of surveys

Decades ago, especially in Zambia, surveying works were carried out using optical instruments for measuring angles and chains/tapes for measuring distances whilst in advanced countries they already had instruments which were electrically operated for measuring angles and distances.

There are several methods used in surveying to measure distances; these include:

i. **Pacing**

Pacing provides a simple yet useful way to make rough distance measurements. All surveyors and construction technicians should know their own personal unit pace value**.** [4]

ii. **Odometer**
iii. **Measuring Wheel**

DIRECT METHOD USING A TAPE

The most commonly used steel tapes now available are in 20 m, 30 m or 100 m lengths, either encased in plastic or leather boxes with a recessed winding handle, or mounted on an open winding frame with a folding handle.

Various systems are used in the graduation of tapes and it is, therefore, essential to ascertain at which point on a tape the zero point is marked and to inspect the tape markings before fieldwork commences. Tapes are manufactured to measure their nominal length at specific temperature and under a certain pull. These standard conditions (20° C and 50 N), are very often printed somewhere on the first metre of the tape. [3]

Tape Corrections

Tape measurements require certain corrections to be applied to the measured distance depending upon the conditions under which the measurements have been made. These corrections are discussed below.

Correction for Slope

In measuring the distance between two points on a steep slope, rather than break tape every few feet, it may be desirable to tape along the slope and compute the horizontal component. This requires measurement also of either the altitude angle or the difference in elevation *d* (Figure 1.0 below). Breaking tape is more time consuming and generally less accurate due to the accumulation of random errors from marking tape ends and keeping the tape level and aligned for many short sections. In Figure 1.0, if altitude angle is determined, the horizontal distance between points *A* and *B* can be computed from the relation

$$H = L\cos\alpha$$

Where;

- *H is the horizontal distance between points,*
- *L the slope length separating them, and*
- *α the altitude angle from horizontal,*

If the difference in elevation *d* between the ends of the tape is measured, which is done by levelling the horizontal distance can be computed using the following expression derived from the Pythagorean Theorem:

$$H = \sqrt{L^2 - d^2}$$

Another approximate formula, obtained from the first term of a binomial expansion of the Pythagorean Theorem, may be used in lower-order surveys to reduce slope distances to horizontal:

$$H = L - \frac{d^2}{2L}\text{(approx.)}$$

In Equation 2 the term $d^2/2L$ equals C in Figure 1 above and is a correction to be subtracted from the measured slope length to obtain the horizontal distance.

The error in using the approximate formula for a 100 ft length grows with increasing slope. This is useful for making quick estimates, without a calculator, or error sizes produced for varying slope conditions. It should not be used as an alternate method of Equation 1 when reducing slope distances.

Correction for Absolute Length

Due to manufacturing defects the *absolute length* of the tape may be different from its *designated* or *nominal length*. Also with use the tape may stretch causing change in the length and it is imperative that the tape is regularly checked under standard conditions to determine its absolute length. The correction for absolute length or *standardization* is given by

$$c_a = \frac{c}{l} L$$

where

- *c = the correction per tape length,*
- *l = the designated or nominal length of the tape, and*
- *L= the measured length of the line.*

If the absolute length is more than the nominal length the sign of the correction is positive and *vice versa*.

Correction for Temperature

If the tape is used at a field temperature different from the standardization temperature then the temperature correction to the measured length is

$$c_t = \alpha(t_m - t_0)L$$

where

- *α = the coefficient of thermal expansion of the tape material,*
- *tm = the mean field temperature, and*
- *t0 = the standardization temperature.*
- *The sign of the correction takes the sign of (tm-t0)*

Correction for Pull or Tension

If the pull applied to the tape in the field is different from the standardization pull, the pull correction is to be applied to the measured length. This correction is

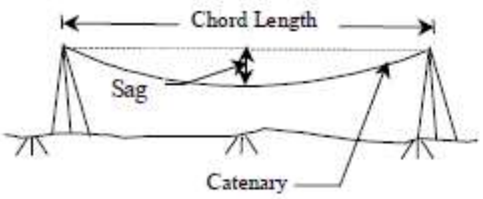
$$c_p = \frac{(P - P_0)}{AE} L$$

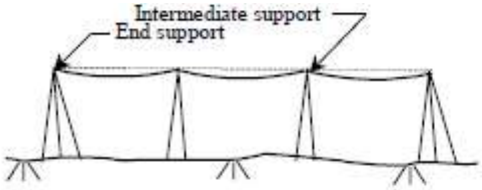
where

P = the pull applied during the measurement,
Po = the standardization pull,
A = the area of cross-section of the tape, and
E = the Young's modulus for the tape material.

Correction for Sag

For very accurate measurements the tape can be allowed to hang in catenary between two supports. In the case of long tape, intermediate supports can be used to reduce the magnitude of correction.





The tape hanging between two supports, free of ground, sags under its own weight, with maximum dip occurring at the middle of the tape. This necessitates a correction for sag if the tape has been standardized on the flat, to reduce the curved length to the chord length. The correction for the sag is

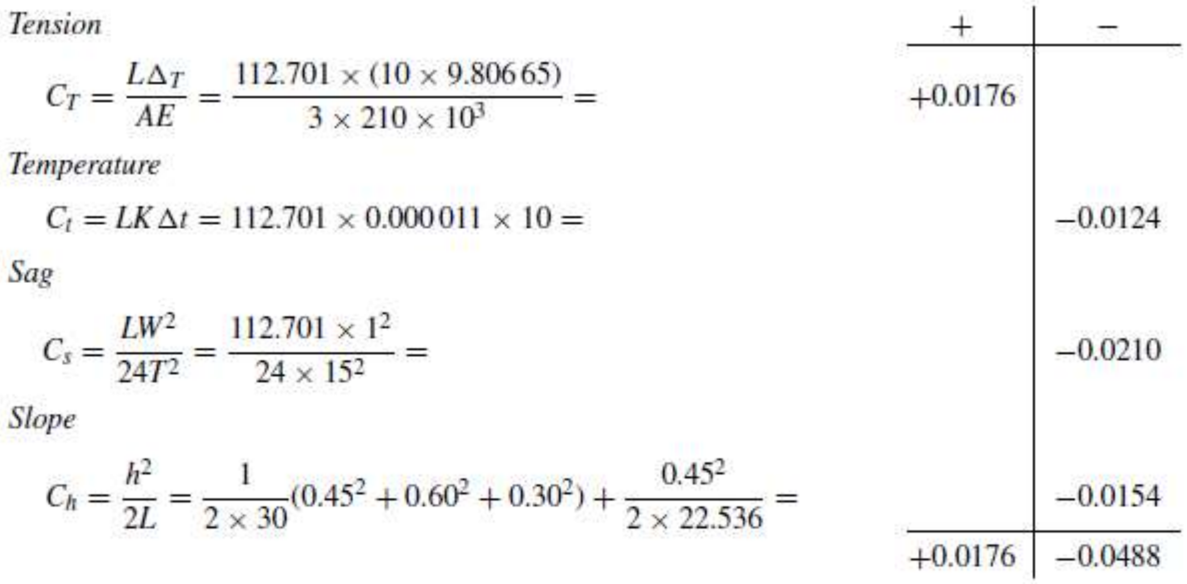
$$C_g = \frac{1}{24}\left(\frac{W}{P}\right)^2 L^3$$

Worked examples

A base line was measured in catenary in four lengths giving 30.126, 29.973, 30.066 and 22.536 m. The differences of level were respectively 0.45, 0.60, 0.30 and 0.45 m. The temperature during observation was 10°C and the tension applied 15 kgf. The tape was standardized as 30 m, at 20°C, on the flat with a tension of 5 kg. The coefficient of expansion was 0.000 011 per °C, the weight of the tape 1 kg, the cross-sectional area 3mm^2, $E = 210 \times 103$ N/mm^2 (210 kN/mm^2), gravitational acceleration $g = 9.806\ 65$ m/s^2.

i. Quote each equation used and calculate the length of the base.

As the field tension and temperature are constant throughout, the first three corrections may be applied to the base as a whole, i.e. $L = 112.701$ m, with negligible error.



	+	−
Tension		
$C_T = \dfrac{L\Delta_T}{AE} = \dfrac{112.701 \times (10 \times 9.80665)}{3 \times 210 \times 10^3} =$	+0.0176	
Temperature		
$C_t = LK\Delta t = 112.701 \times 0.000011 \times 10 =$		−0.0124
Sag		
$C_s = \dfrac{LW^2}{24T^2} = \dfrac{112.701 \times 1^2}{24 \times 15^2} =$		−0.0210
Slope		
$C_h = \dfrac{h^2}{2L} = \dfrac{1}{2 \times 30}(0.45^2 + 0.60^2 + 0.30^2) + \dfrac{0.45^2}{2 \times 22.536} =$		−0.0154
	+0.0176	−0.0488

Horizontal length of base (D) = measured length (M) + sum of corrections (C)

= 112.701m + (−0.031)

= 112.670m

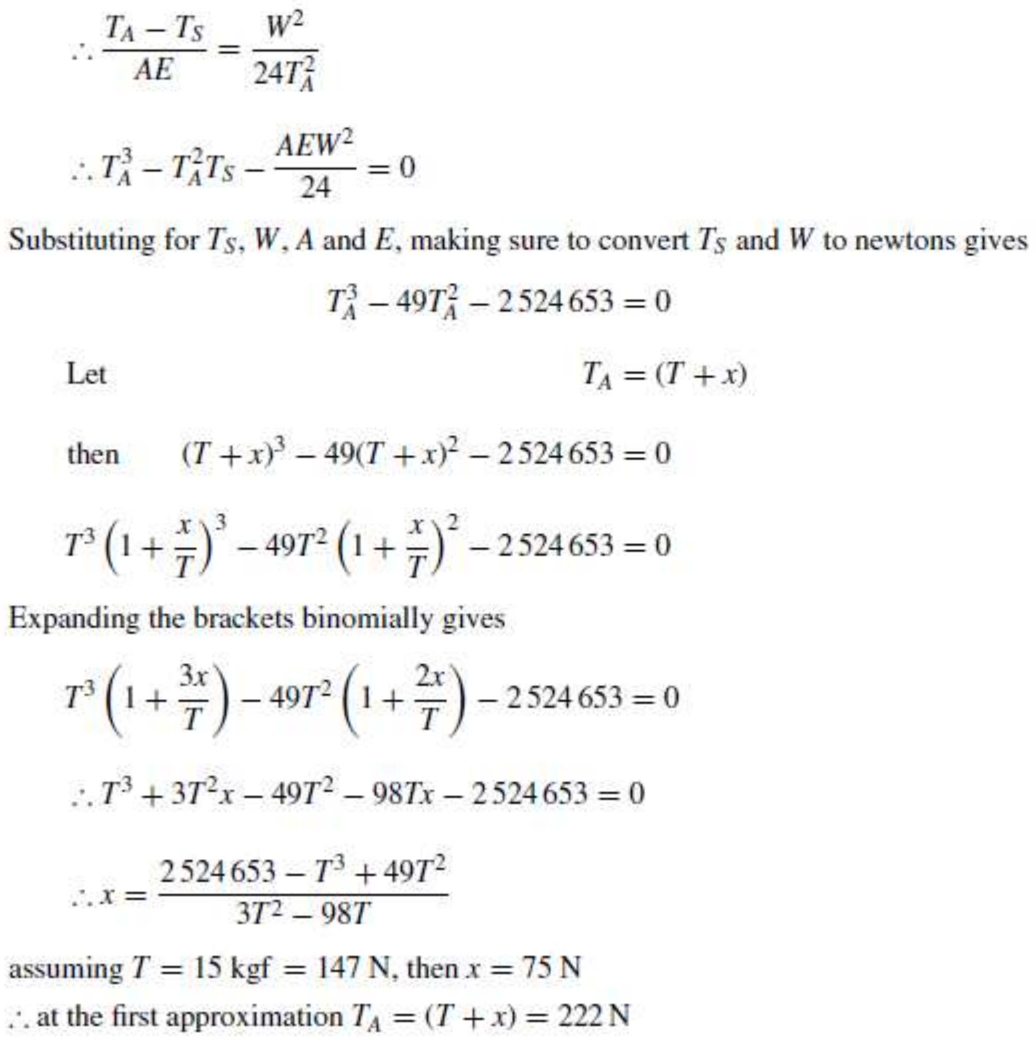
N.B. In the slope correction the first three bays have been rounded off to 30m, the resultant second order error being negligible.

Consider the situation where 112.670m is the horizontal distance to be set out on site. The equivalent measured distance would be:

$$M = D - C$$
$$= 112.670 - (-0.031) = 112.701\text{m}$$

ii. What tension should have been applied to eliminate the sag correction?

To find the applied tension necessary to eliminate the sag correction, equate the two equations:



$$\therefore \frac{T_A - T_S}{AE} = \frac{W^2}{24T_A^2}$$

$$\therefore T_A^3 - T_A^2 T_S - \frac{AEW^2}{24} = 0$$

Substituting for T_S, W, A and E, making sure to convert T_S and W to newtons gives

$$T_A^3 - 49T_A^2 - 2\,524\,653 = 0$$

Let $T_A = (T + x)$

then $(T + x)^3 - 49(T + x)^2 - 2\,524\,653 = 0$

$$T^3\left(1 + \frac{x}{T}\right)^3 - 49T^2\left(1 + \frac{x}{T}\right)^2 - 2\,524\,653 = 0$$

Expanding the brackets binomially gives

$$T^3\left(1 + \frac{3x}{T}\right) - 49T^2\left(1 + \frac{2x}{T}\right) - 2\,524\,653 = 0$$

$$\therefore T^3 + 3T^2x - 49T^2 - 98Tx - 2\,524\,653 = 0$$

$$\therefore x = \frac{2\,524\,653 - T^3 + 49T^2}{3T^2 - 98T}$$

assuming $T = 15$ kgf $= 147$ N, then $x = 75$ N

$\therefore$ at the first approximation $T_A = (T + x) = 222$ N

Reduction to the Mean Sea Level (M.S.L)

In the case of long lines in triangulation surveys the relationship between the length *AB* measured on the ground and the equivalent length *A′B′* at mean sea level has to be considered (Fig. 2.4). Determination of the equivalent mean sea level length of the measured length is known as reduction to mean sea level. The reduced length at mean sea level is given by

$$L' = RL/(R+H)$$

where

R = the mean earth's radius (6372 km), and

H = the average elevation of the line.

When *H* is considered small compared to *R*, the correction to *L* is given as

$$C_{msl} = HL/R$$

The sign of the correction is always negative.

The various tape corrections discussed above, are summarized in the Table [5] below

Correction	Sign	Formula
Absolute length (c_a)	±	$\frac{c}{l}L$
Temperature (c_t)	±	$\alpha(t_m - t_0)L$
Pull (c_p)	±	$\frac{(P - P_0)}{AE}L$
Sag (c_g)	–	$\frac{1}{24}\left(\frac{W}{P}\right)^2 L$
Slope (c_s)	–	$(1 - \cos\theta)L \quad (exact)$
Alignment (c_m)	–	$\frac{h^2}{2L} \quad (approximate)$
Mean sea level (c_{msl})	–	$\frac{d^2}{2L} \quad (approximate)$
		$\frac{HL}{R} \quad (approximate)$

Figure 0-1: Summary of tape corrections

OPTICAL DISTANCE MEASUREMENT

Two disadvantages with taping are, firstly, that the measuring process takes on the ground (if the terrain is undulating this can be very difficult) and, secondly, when a lot of linear measurements are required, taping can be laborious and time consuming. *Optical distance measurement* (ODM) techniques overcome the first problem in that they are undertaken above ground level, and overcome the second problem since they can usually be carried out in a shorter time than that required for surface taping.

The ODM technique, which has the greatest application in engineering surveying, is *stadia tacheometry*. The stadium (Tacheometry) is a rapid and efficient way of indirectly measuring distances and elevation differences. The accuracy attainable with stadia is suitable for lower order trigonometric leveling, locating topographic details for mapping, measuring lengths of back sights and fore sights in differential leveling, and making quick checks of measurements made by higher order methods. The stadia method is based on the principle that in similar triangles, corresponding sides are proportional [6]

Stadia tacheometry

In *stadia tacheometry* the line of sight of the tacheometer may be kept horizontal or inclined depending upon the field conditions. In the case of horizontal line of sight the horizontal distance between the instrument at A and the staff at B is

$$D = ks + c$$

where

k and c = the multiplying and additive constants of the tacheometer, and

s = the staff intercept, = $ST – SB$, where ST and SB are the top hair and bottom hair readings, respectively.

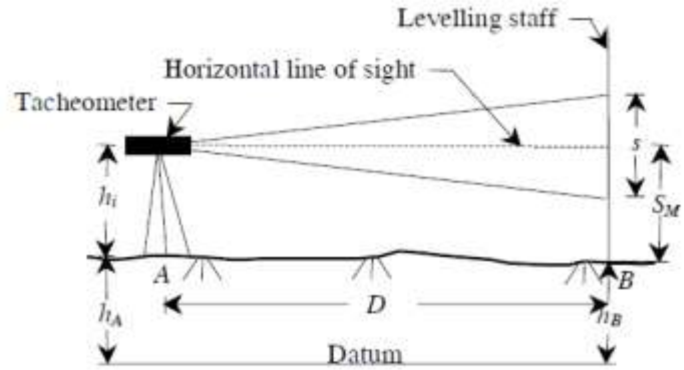


Figure 0-2: Stadia Tacheometry

Generally, the value of k and c are kept equal to 100 and 0 (zero), respectively, for making the computations simpler. Thus

$$D = 100\ s$$

The elevations of the points, in this case, are obtained by determining the height of instrument and taking the middle hair reading. Let

h_i = the height of the instrument axis above the ground at A,

h_A, h_B = the elevations of A and B, and

S_M = the middle hair reading

then the height of instrument is

$$\text{H.I.} = hA + hi$$

and

$$h_B = \text{H.I.} – S_M = h_A + h_i – S_M$$

In the case of inclined line of sight, the vertical angle α is measured, and the horizontal and vertical distances, D and V, respectively, are determined from the following expressions.

$$D = ks\cos^2\alpha$$

$$V = 0.5ks\sin 2\alpha$$

The elevation of *B* is computed as below.

$$h_B = h_A + h_i + V - S_M$$

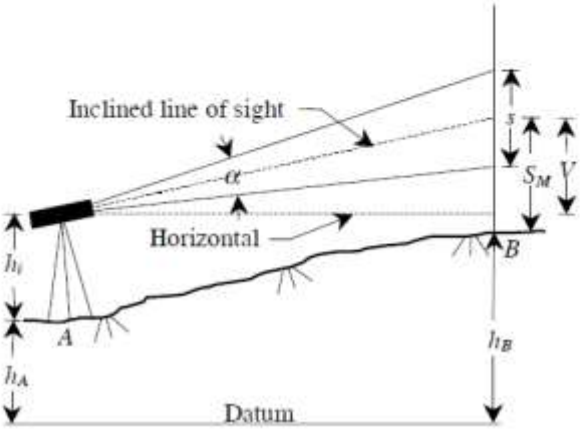


Figure 0-3: Stadia Tacheometry Inclined Sight

SUBTENSE TACHEOMETRY

In *subtense tacheometry* the distance is determined by measuring the horizontal angle subtended by the subtense bar targets and for heighting, a vertical angle is also measured Let

b = the length of the subtense bar *PQ*,

θ = the horizontal angle subtended by the subtense bar targets *P* and *Q* at the station *A*, and

α = the vertical angle of *R* at *O*

then

$$D=b/\,2\tan(\theta/2)$$

When θ is small

$$D = b/\,\theta$$

$$V = D\tan\alpha$$

and

$$h_B = h_A + h + V - h$$

where hs = the height of the subtense bar above the ground.

Electromagnetic Distance Measurements

Introduction

Essentially, this method of distance measurement employs the use of electromagnetic waves. The instrument has a transmitter and it sends out a continuous wave to a reflector which is later received by the receiver in the instrument. This wave is known as the carrier wave which is at some frequency. Therefore, the instruments can be divided into groups, namely: instruments utilizing

a) Radio waves (very low frequencies)
b) Microwaves (medium frequencies)
c) Visible and infra-red light (high frequencies)
d) Laser light (very high frequencies)

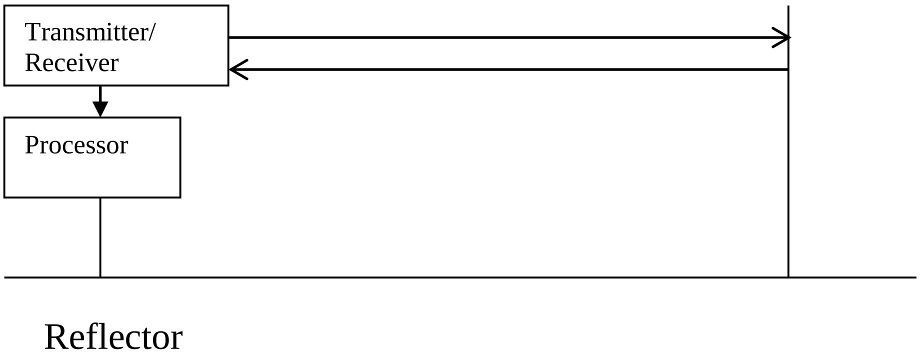
Instruments with low frequencies offer a greater range of distance but require larger transmitters and are more affected by the atmosphere thereby giving less accurate results while instruments that utilise high frequencies are portable and propagation through the atmosphere is stable however because the wavelengths are so small, it is impractical to use directly the waves for the measurements except by modulation. For accurate measurements (say in engineering, surveying, etc.) high frequency carrier wave instruments are used.

Principle

The system has three major components:

- The propagation timer is to determine the travel time of the wave to and from the reflector
- The transmitter transmits the wave at the same time receives it.
- The microprocessor does the computations of the distance.

Now for the system to work there has to be a reflecting surface on the other end of the line. In this respect reflecting prisms are used. Furthermore there has to be a clear line of sight (no blockages in the signal) between the transmitter and the reflector.



Therefore

D = V* t

Where *D = distance between transmitter and reflector*
V = velocity of electromagnetic wave in air
t = half the time taken for the transmitted and the reflected wave.

Errors influencing EDMs

When measurements are taken using an EDM instrument, *human*, *atmospheric* and *instrumental* effects may give rise to errors in the distances displayed and corrections are required to account for these.

Human effects:

the operator must be careful when setting up and operating the instrument in order to eliminate or minimise errors which are human. Due care has to be paid to centring the instrument, pointing to the targets (reflectors) and setting the atmospheric correction values.

Atmospheric effects:

the measuring wave is affected by the atmospheric conditions such as temperature, pressure and humidity. Correction of such errors is done by measuring the temperature and pressure at the time measuring the distance are entered in the instrument either by way of

i. Imputing actual temperature and pressure values so that the carrier wave is generated at particular frequency to compensate for the change in velocity thereby keeping the wavelength constant.
ii. Using atmospheric effects correction pads to determine the correction in mm/km (ppm) to the distance to be measured and entering the value in the EDM.

Instrumental errors:

iii. *Scale error (frequency error) (ρ)*

This is caused by the variations in the modulation frequency of the EDM. The error is proportional to the measured distance. Practically this can also be caused by entering/setting an incorrect atmospheric correction (temperature and pressure).

iv. *Zero error* (*index error*) (ε)

This error occurs if there is a separation between the instrument's electric and the mechanically defined centres. This error is constant in nature i.e. independent of the measured distance. Similarly, an incorrect reflector constant can cause an error in the measured distance. Care has to be taken when interchanging prisms from different manufacturers.

v. *Cyclic error (instrumental nonlinearity)*

This error, which is normally of negligible size, can be caused by internal or external "noise" which affects the accuracy of the phase measurement.

vi. *Pointing errors (applicable to I/R– instruments)*

The errors can result from phase delays caused by imperfect receiver diode and from inaccurate pointing of the EDM to the reflector.

Other corrections

Slope corrections:

Just like we apply slope corrections in distances measured by tapes, we should reduce slope distances measured by EDMs to horizontal distances. The same formulas apply in this case.

$$C_{slope} = l_m(1-\cos\theta)$$

where

l_m = measured distance with tape

θ = the measured vertical angle

$$C_{slope} = \Delta H_{AB}^2 / 2l_m$$

where

l_m = measured distance with tape

ΔH_{AB} = the difference in elevation

Height (MSL) corrections

When a survey has to be based on the national Grid coordinates system (projected coordinates), the line measured must be reduced to its equivalent length at the mean sea level (MSL). The correction is given by

$$\text{Height (MSL) correction} = -\frac{Dh_m}{R}$$

Where h_m = mean height between instrument and reflector above mean sea level and R is the radius of the earth (6375Km).

Scale factor (SF)

The grid distance must be used for the national grid calculations

Grid distance = horizontal (MSL) distance* F

F is calculated differently for L0 and UTM coordinates.

For UTM, F = 0.9996*(1+ $\left(0.01237E_m'^2 \times 10^{-6}\right)$)

Where E'_m = (($E_A + E_B$)/2) - 500) in km

For L0, SF = 1- $\left(\frac{H_m}{R_m} + \frac{Y_m^2}{(2R_m)^2}\right)$

Where Y'_m = (($Y_A + Y_B$)/2) in km

H_m = mean height of the site

Accuracy of measured distances

The accuracy of the distance measured by the EDM is usually quoted as

$$\pm \varepsilon \ (\text{mm}) \pm \rho \ (\text{mm/km})$$

Where e *= Zero error and* ρ *= proportional error.*

Thus the resultant or overall standard deviation of a measurement is given by

$$\text{Standard error} = \sqrt{(\varepsilon^2 + [\,D * \rho * 10\,]^2)}$$

Where D is the distance measured in mm

A Total Station

A total station is an electronic / optical instrument used in modern surveying. It is also used by archaeologists to record excavations as well as by police crime scene investigators, private accident deconstructionists and insurance companies to take measurement of scenes. The total stations is an electronic theodolite (Transit) integrated with an instrument to a particular spatial entity. Some models of total station included. [7]

- Internal Electronic Data Storage (IEDS), to record distance
- Horizontal angle model
- Vertical angle measured model

Data collector Model – which is hand- held computer equipped to write these measurements to an external data collector. Angles and distances are also measured from the total station to points under survey, and the coordinate (X, Y, and Z or northing, easting and elevation) of surveyed points relative to the total station position are calculated using trigonometry and triangulation. Data can be down loaded from the total station to a computer and application software used to compute results and generate a map of the surveyed area.

Some total stations also have a GNSS interface (Global Navigation Satellite System Interface) which combines the advantages of these two technologies (GNSS line of sight not required between measured points, Total station – high precision especially in the vertical axis compared with GNSS) and reduce the consequences of each technology's disadvantages (GNSS – Poor accuracy in the vertical axis and lower accuracy without long occupation period, Total station –

requires line of sight observation and must be set up over a known point or with line of sight to two or more points with known location).

Measurement of distance is accomplished with a modulated microwave or infrared carrier signal generated by a small solid –state emitter within the instrument's optical path, and reflected by a prism reflector or the object under survey. The modulation pattern in the returning signal is read and interpreted by the on board computer in the total station. The distance is determined by emitting and receiving multiple frequencies, and determining the integer number of wave lengths to the target for each frequency. Most total station use purpose built glass porro prism reflectors for the EDM signal, and can measure distances to a few kilometers. A typical total station can measure distances to about 3 milimeters or 1/1000th of a foot. However reflector in a total station can measure distances to any object that is reasonably light in colour, to a few hundred metres. But, robotic total stations allow the operator to control the instrument from a distance via remote control. This eliminates the need for as assistant staff member as the operator holds the reflector and controls the total station from the observed point.

Satellite systems

Satellite-supported Global Navigation Satellite Systems (GNSS) are rapidly replacing all other systems due to many advantages, but most notably because of their range, accuracy, and efficiency. During the 1970s, a new and unique approach to surveying, the *global positioning system* (GPS), emerged. This system, which grew out of the space program, relies upon signals transmitted from satellites for its operation. It has resulted from research and development paid for by the military to produce a system for global navigation and guidance.

More recently other countries are developing their own systems. Thus, the entire scope of satellite systems used in positioning is now referred to as *global navigation satellite systems* (GNSS). Receivers that use GPS satellites and another system such as GLONASS (see Section 13.10) are known as GNSS receivers. These systems provide precise timing and positioning information anywhere on the Earth with high reliability and low cost. The systems can be operated day or night, rain or shine, and do not require cleared lines of sight between survey stations. This represents a revolutionary departure from conventional surveying procedures, which rely on observed angles and distances for determining point positions.

USING A GPS

The Global Positioning System (GPS) is a satellite based navigation system developed by the United States of America's Department of Defense. It is widely used for civilian navigation and positioning, surveying and scientific applications, and although an excellent tool, it is best used with a map.

GPS receivers have many useful features for navigation, such as the ability to store positions and determine speed and direction of travel, (which are beyond the scope of this Guide). Provided it is used correctly, a comparatively inexpensive, hand-held GPS receiver can provide positions with an accuracy better than 15 metres and often at the 5 metre level.

Figure 0-4: Handheld GPS receivers

The GPS satellite system

There are 24 GPS satellites orbiting the Earth. A GPS receiver calculates position by measuring distances to four or more of these satellites. GPS is accessible 24 hours a day, anywhere in the world, in all weather.

AERIAL MAPPING

Introduction

Almost all the survey methods mentioned so far relate to individual survey observations and their subsequent use in survey computations. If a number of points were required the productivity rate would be only a few points per day at best and so to find the coordinates of many points by such a method would be slow and tedious in the extreme. Finding a series of control points with a traverse, or by using the least squares adjustment of a network, would be more productive. The surveyor could then use a total station and data logger to collect a series of detail points more rapidly. Even so the data capture rate would depend upon the speed at which the surveyor could travel from point to point and even in the most favourable environment the data capture rate would not exceed a few hundred points per day. If it is not necessary for the surveyor to physically identify each point on the ground and/or it is not necessary to remain static at each point during data capture then the productivity rate can be improved. [8]

Reflectorless EDM makes it possible to measure to a point without that point being visited, though details of the point still need to be recorded to make the measurement useful. If stringlines of features or ground profiles are followed then data may be captured on the fly, for example with GPS. With ground profiles, such as for DTMs, the data rate may be limited by the speed with which the vehicle mounted GPS receiver can travel over the ground. The density of such data is therefore likely to be variable and will depend on the ability of the vehicle to maintain a constant speed, to cover the area without large or irregular gaps between runs and the ability of the GPS to maintain lock onto the satellites. Although relatively large amounts of data may be collected by a vehicle mounted GPS the overall quality of the data may be variable. With such a method several thousands of points a day could easily be captured. However, higher data capture rates are not really possible where it is necessary for instruments, whether GPS or corner cube prisms, to visit every point of detail. [8]

PHOTOGRAMMETRY

As the word ‘photogrammetry’ implies, it means measurements from photographs, and in the case of aerial photogrammetry it is measurements from aerial photographs. The major use of aerial photogrammetry is in the preparation of contoured plans from the aerial photographs. With the aerial camera in the body of the aircraft, photographs are taken along prearranged flight paths, with the optical axis of the camera pointing vertically down. Such photographs are termed vertical photographs

Aerial surveys are undertaken by using photographs taken with special cameras mounted in an aircraft viewed in pairs. The photographs produce three-dimensional images of ground features from which maps or numerical data can be produced usually with the aid of stereo plotting machines and computers. Aerial Photography is an inter-disciplinary utility that has led to its widespread adoption in many types of landscape/environmental studies. The utilization of aerial photography can be divided between two main activities that in practice are complementary. These are photo-interpretation and Photogrammetry.

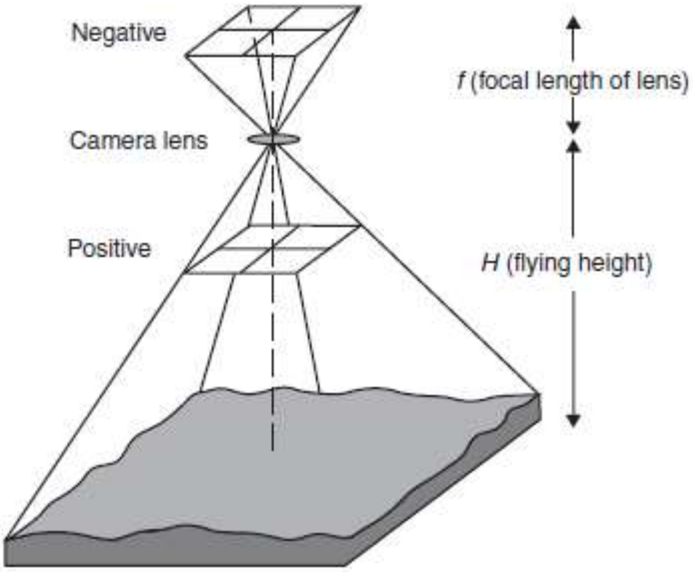


Figure 0-1: The Photo and Ground Relationship

Photo Interpretation is the act of examining aerial photographs/images for the purpose of identifying objects and judging their significance. That is, Photo-interpretation is a qualitative aspect. **Photogrammetry** is the science or art of obtaining reliable measurements by means of photography, for the purpose of determining the position, size and shape of the photographed object [9]. That is, Photogrammetry is a quantitative aspect concerned with the accurate measurement of features recorded by photography, though not necessarily aerial photography.

Although both maps and aerial photos present a "bird's-eye" view of the earth, aerial photographs are NOT maps. Maps are orthogonal representations of the earth's surface, meaning that they are directionally and geometrically accurate (at least within the limitations imposed by projecting a 3-dimensional object onto 2 dimensions). Aerial photos, on the other hand, display a high degree of radial distortion. That is, the topography is distorted, and until corrections are made for the distortion, measurements made from a photograph are not accurate. Nevertheless, aerial photographs are a powerful tool for studying the earth's environment.

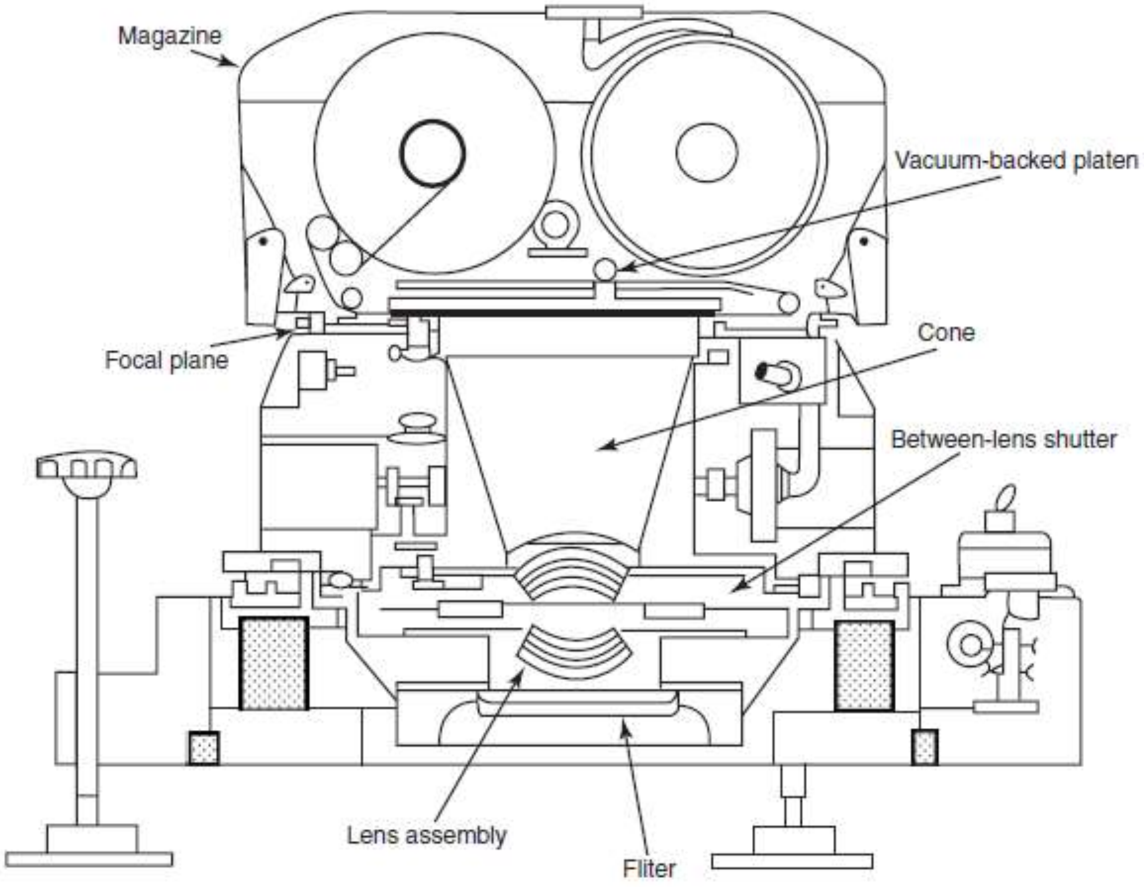


Figure 0-2: An Aerial Camera

Because most GISs can correct for radial distortion, aerial photographs are an excellent data source for many types of projects, especially those that require spatial data from the same location at periodic intervals over a length of time. Typical applications include land-use surveys and habitat analysis.

Based on comparison to ground-based methods

- Aerial photography offers an improved vantage point.
- Aerial photography has the capability to stop action.
- It provides a permanent recording.
- It has broader spectral sensitivity than the human eye.

- It has better spatial resolution and geometric fidelity than many ground-based sensing methods.

SCALE OF AERIAL PHOTOS

The scale of a photograph is the ratio of the distance on the ground to its imaged distance on the photograph. Hence, by similar triangles:

$$\text{Scale} = ab/AB = f/H$$

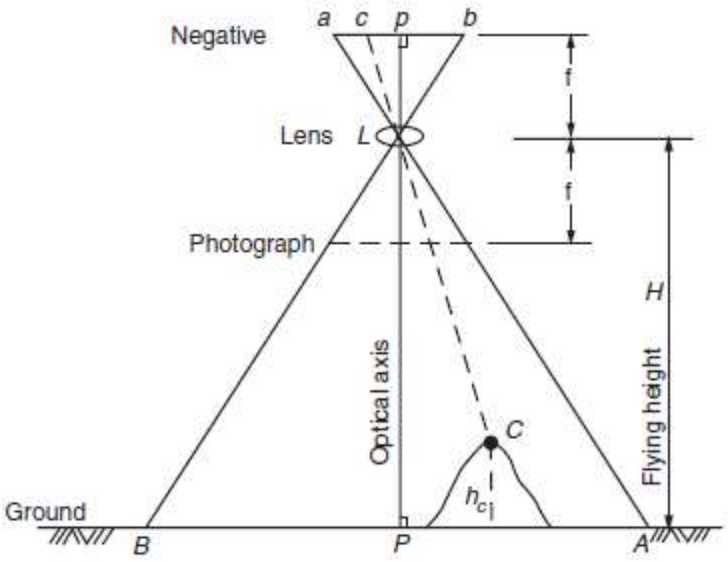


Figure 0-3: Photo Scale

More likely you will have to compute scale using ruler, map, calculator and this formula

$$\mathbf{RF} = \frac{\mathbf{1}}{\mathbf{(MD)(MS)/(PD)}}$$

where:

MD = distance measured on map with ruler (cm or in)
MS = map scale denominator (e.g., 24,000 for USGS Quads)
PD = photo distance measured in same units as map distance

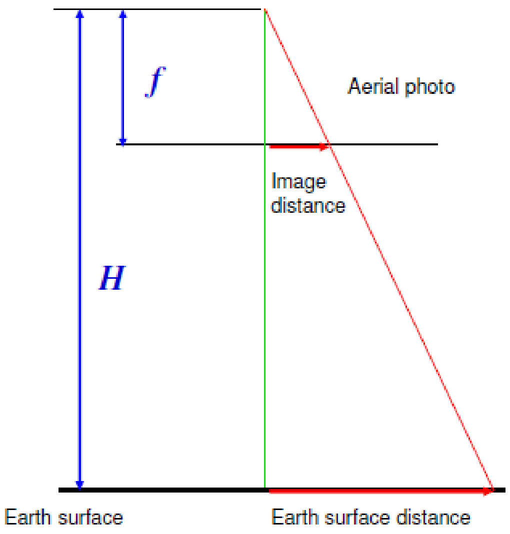


Figure 0-4: Scale of a Photo

Tilt causes variation within a single photograph. Scales are different on either side of the tilt.

GROUND CONTROL

The establishment of ground control points, which are clearly distinguishable on the air photographs, is very important to the photogrammetric process. The minimum number of points required per photograph comprises two plan points to control position, scale and orientation and three height points to control level in the spatial model. Ground control, fixed by normal survey methods, should be more accurate than that attainable by the photogrammetric restitution system used. [8]

Control points must consist of detail already clearly and sharply visible on the photographs and which can be well defined on the ground. Similarly, for height control the points chosen should lie in flat, horizontal ground free from vegetation. Steep slopes or peaks should be avoided to reduce the large height errors that would result from bad positioning within the photogrammetric process. The amount of control required depends largely on the scale and accuracy of the finished plan. [8]

FLIGHT PLANNING

The flight specifications for a particular project will vary with the type of project. For instance, photography required for interpretation purposes will not require the same detailed planning as that required for largescale mapping. The main factors to consider are the directions of the flight lines, the overlaps, scale and flying height.

Some of the factors cannot be obtained until the flight has commenced. For instance, the heading direction and the time interval between exposures can only be calculated when the wind velocity at the time of flight is known. One also needs some idea of the number of photographs required in order to decide on the number of magazines or films to take or the storage requirement for digital photographs. The flying height of the aircraft is dependent on many factors ranging from aircraft capabilities, terrain conditions, and survey requirements. Flight planning is thus a skilled procedure requiring careful planning at all its various stages.

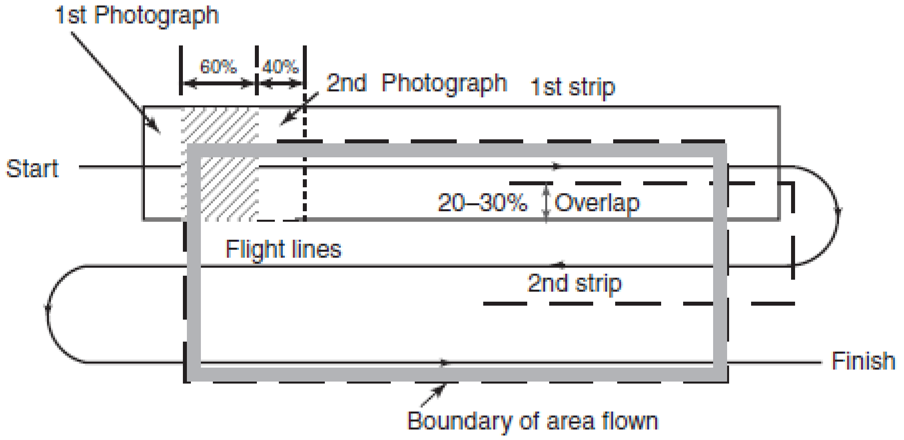


Figure 0-5: Flight Lines

Generally the area is flown parallel to the longest side to give the minimum number of strips. In this way the number of turns and run-ins, which are non-productive, are reduced to a minimum. If large areas having different levels exist, such as mountain ranges or plateaus, the area may be flown parallel to these in order to avoid rapid variation in scale.

Each photograph in a strip normally overlaps the previous one by 60%, thus the new ground covered on each photograph is 40%. The purpose of the overlap is to permit stereoscopic viewing of the area. Each strip overlaps the previous one by 20 to 30%, thus complete coverage of the area is obtained. The overlapping, which is automatically controlled on the air camera, is illustrated more clearly in *Figure 6 below*. The distance *B* between each photograph in the air is called the air base, while its equivalent on the photograph, *b*, is called the photo base. Due to the overlap, both of the principal points of the adjacent photographs will appear on the central photograph. The photo bases are in fact the direction of flight of the aircraft. [8]

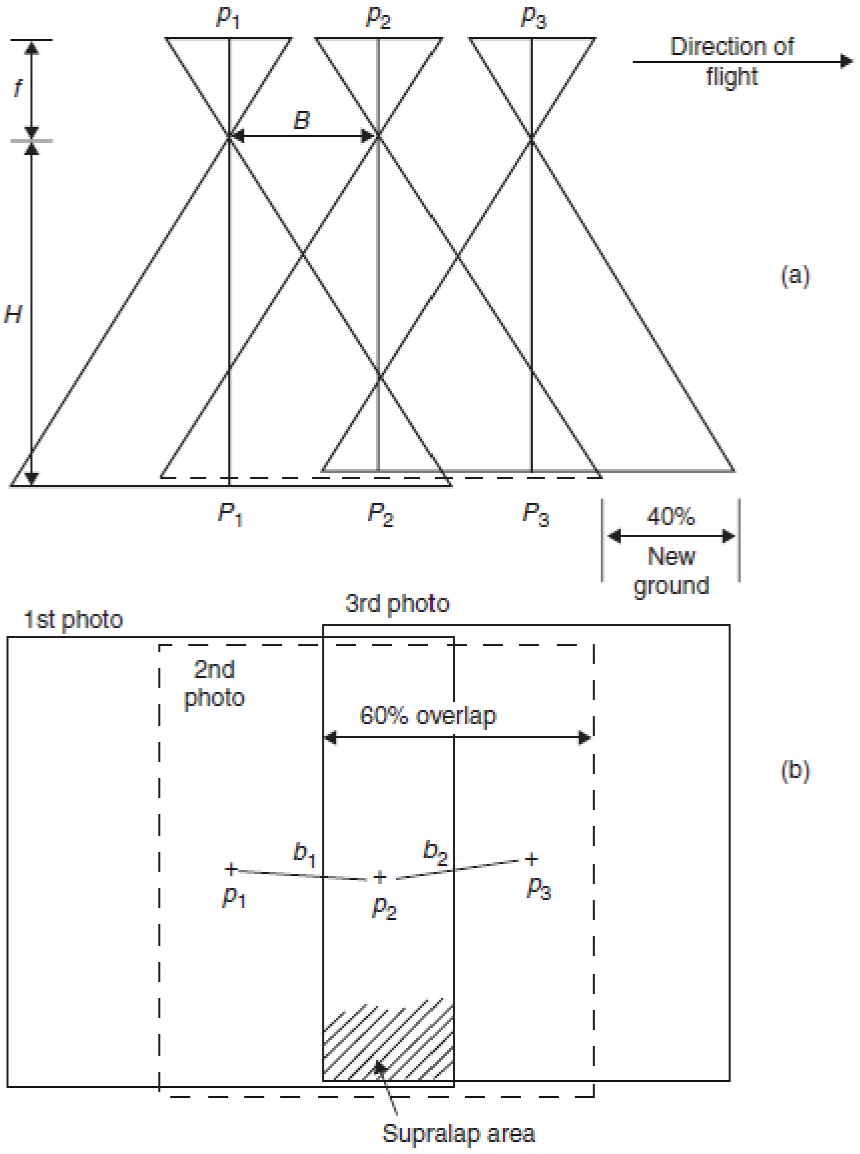


Figure 0-6: Overlapping Photos

THE USES OF AERIAL PHOTOGRAPHS.

Aerial photographs are now being used in a number of fields which include the field of archaeology, construction, natural resource management, urban and region planning, engineering ,land resource surveys, transport studies, forestry inventory, agriculture-crop or soil mapping, and topographic mapping among others(Wolf, 1983). These will looked at in details below.

DETECTION OF ARCHAEOLOGICAL SITES.

To begin with aerial photographs are used for detecting archaeological sites that are difficult to see from the ground. Archaeologists use airborne technologies such as Sideways-looking airborne radar (SLAR), an advanced aerial technology that sends and receives pulses of radiation. These pulses are used to form a detailed picture of the terrain below and around an aircraft's flight path

.It records information about the earth’s surface and subsurface. Aerial photographs of infrared radiation can also detect minute differences in ground temperatures. Using infrared photography, archaeologists identify soils that have been disturbed or manipulated in the past, as well as other ground features that are normally invisible. Infrared photographs and thermal scanners also detect the presence of subsurface stone and variations in soil moisture. Subsurface stone may indicate the presence of buried buildings, and soil moisture differences can reveal ancient crop fields.

TOPOGRAPHIC MAPPING.

Aerial photographs are also used in topographic mapping. This is done by means of aerial photogrammetry, which uses stereoscopic pairs of photographs taken from an aircraft and, more recently, from artificial earth satellites. Horizontal and vertical ground surveys must appear in the photographs. These photos are then reconstituted into stereo models for drafting true-scale maps. Precise cameras are required; and precision-mapping equipment is used to depict natural and artificial objects in true position and to show true elevations for all points in the mapped area. Elevations on topographic maps are shown chiefly by use of superimposed contour lines, connecting points of equal evaluation, to give a readable picture of the terrain.

GEOLOGICAL STUDIES OF ROCKS AND MINERALS.

Aerial photographs are used in the geological studies of rocks and minerals .They can be interpreted to give information on the structure and the lithology of rocks. In the study of structural geology, features such as bedding, dip, foliation, folding faulting and jointing can be observed. Aerial photos provide evidence of bedding through the occurrence of ridges in the stereo model and differences in tonal response where beds differ in their mineral constituents (Barrett, 1976).Moreover according to Lo (1986; 186) in case of geological, geomorphologic and hydrological application, the role of aerial photography remains dominant in providing information on the distribution, structure, and types of vegetation, crops and soils. This is because they enable stereoscopic coverage, the distinctiveness of the tonal and textural variations of the photographic image and the superior spatial resolution.

ENGINEERING AND CONSTRUCTON FIELD.

Furthermore aerial photographs are used in the field of construction as they assist engineers in planning construction projects. For example aerial photos have been successfully used in the development of water distribution systems since they can provide most of the necessary data such as the number of homes to be served, the distance between homes, vacant land, and the types of land usage(residential, commercial, or industrial).In a similar manner it has been demonstrated that aerial photographs can aid in the planning of sewage collection systems and treatment plants as they provide information on gradient, an important factor in sewage collection systems. Moreover the use of aerial photos is perhaps the most practical and economical method for designing the layout of pipelines or pumping stations (warnick, 1954).

TRANSPORT STUDIES.

Aerial photographs are also used in areas of transport studies. The application of this is in transport studies falls broadly into four categories thus highway planning, traffic studies, parking assessment and highway inspection.(Macleod,1966).This is so because the aerial photographs provide qualitative and quantitative data about the ground surface required for route location, preliminary survey and design as well as construction locations of urban highway projects. In traffic studies aerial photos are used to pin point areas of congestion and to provide data on traffic flow in the areas (Estes and senger, 1974).

LAND RESOURCE SURVEYS AND MAPPINGS.

In the field of land resource survey and mapping purposes, aerial photos are used to produce tourist maps of for instance the Victoria Falls (Pullan, 1976).Aerial photos are used extensively in land surveys such as inventory making, catchment conservation planning, farm and project plan and settlement planning. Land surveys are made to establish boundaries of land areas by setting corner markers or monuments, to ascertain coordinates of these corners, and to obtain boundary and area information required for record-deed descriptions and for plotting parcels of real property. Land surveys are accomplished with a degree of precision depending on the value of the land involved, and permanent visible and recoverable monuments set at the corners.

AGRICULTURAL PURPOSES AND SOIL MAPPING.

Aerial photographs are also be used in agricultural purposes in order to get information and associated statistics on crops, rangeland, livestocks and other agricultural resources

FORESTRY INVENTORY

Aerial photos are also used in forestry inventory to determine the volume of the timber resources for economical and management purposes. The success of this approach is largely determined by the large scale of photography because morphological characteristics of the trees become progressively less distinct as the scale is decreased until they are inseparable from photographic tone, texture and shadow pattern. The most useful morphological characteristics from the vertical aerial photographic point of view are crown shapes, texture and branching habit. The stereomodel of the aerial photographs facilitate recognition of the crown shape which includes Oval, dome, cylindrical, conical, rounded, flat bottom etc (Lo, 1986).

Photo Interpretation Elements

Photo Interpretation is the act of examining aerial photographs/images for the purpose of identifying objects and judging their significance. It can also be referred to as feature extraction for the purposes of gathering information about earth surface features. Because air photo interpretation often involves a considerable amount of subjective judgment, it is commonly referred to as an art rather than a science. Actually it is both.

Photo interpretation is premised on **experience and imagination.** This is because:

- It is relatively easy to recognize features or conditions in oblique photographs, but a vertical or near vertical view can be quite confusing.
- Recognition elements are often used to arrive at a logical conclusion, i.e. characteristics of image features that can be used to identify the feature.

Purpose of Photo Interpretation

[a] Detection/Identification

The primary task of the interpreter is first the qualitative approach of: Detection, Identification, and classification of objects, features, phenomena and processes. The interpreter conveys his or her response by labeling or adding aspatial attributes. Detection and identification of geographic features represented in air photos is based on image characteristics, and then relating image characteristics to known ground conditions in order to obtain information about things you can't see in the airphoto.

For example, an experienced interpreter can distinguish between high and low income areas on an airphoto based on looking at lot and building size and on associations between features such as presence of swimming pools, lots backing onto a golf course, etc.

[b] Measurement

As opposed to detection and identification, the making of measurements is primarily quantitative.

[c] Problem Solving

Interpreters are often required to identify objects from a study of associated objects that they can identify; or to identify object complexes from an analysis of their component objects. Analysts may also be asked to examine an image, which depicts the effect ofsome process and suggest a possible or probable cause.

Recognition Elements of Image Interpretation

First-order Primitive Element

(i) Tone

Tone refers to the distinguishable gray variation from white to black, or the color characteristics in the image. Tone or color relates to the reflective characteristics of objects within the photographic spectrum. Tonal contrasts provide important clues for object identification. For example, healthy vegetation reflects much of the incident near-infrared energy, appearing light tone in black-and-white near IR photography and red in color near IR aerial photography.

(ii) Resolution

Resolution is defined as the ability of the entire photographic system, including lens, exposure, processing, and other factors, to render a sharply defined image. An object or feature must be resolved to be detected and/or identified. Resolution is one of the most difficult concepts to address in image analysis. Resolution can be described for systems in terms of modulation transfer (or point spread) functions; or it can be discussed for camera lenses in terms of being able to resolve so many line pairs per millimeter. There are resolution targets that help to determine this when testing camera lenses for metric quality. Photo interpreters often talk about resolution in terms of ground resolved distance, the smallest normal contrast object that can be detected and identified on a photo.

Second order elements

Geometric Arrangements of Primitive elements

(i) Size

The size of an object is one of its most distinguishing characteristics. The most commonly measured parameters are length, width, perimeter, area and occasionally volume. Measuring the size of an unknown object allows the interpreter to rule out many possible alternatives. Measuring the size of a few well-known objects in an image such as car length, road and railroad width, size of typical single-family house in the area allows you to understand the size of unknown features in the image and eventually to identify them. It is risky to measure the precise length, perimeter, and area of objects on unrectified aerial photography. The absolute and relative size of objects can be important in discrimination of objects and features (cars vs. trucks or buses; single family vs. multi-family residences, brush vs. trees, etc.).

In the use of size as a diagnostic characteristic; both the relative and absolute sizes of objects can be important. Size can also be used in judging the significance of objects and features (size of trees related to board feet which may be cut; size of agricultural fields related to water use in arid areas, or amount of fertilizers used; size of runways gives an indication of the types of aircraft that can be accommodated).

(ii) Shape

Shape describes the external form or configuration of an image object. Cultural objects tend to have straight edges and geometrical shapes and distinct boundaries, whereas natural features tend to toward irregular shapes with irregular boundaries. The shape of objects/features can provide diagnostic clues that aid identification. Cultural features with distinct shapes: Pentagon building in Washington DC, airport runways, shopping malls, cloverleaf interchanges, center-pivot irrigation systems. Natural features with distinctive shapes: sand dunes, volcanic cinder cones, alluvial fans, meander floodplain.

Man-made features have straight edges while natural features tend not to. Roads can have right angle turns, railroads do not. Numerous shapes: linear, curvilinear, circular, elliptical, radial, square, rectangle, riangular, hexagonal, star, elongated, and amorphous.

Spatial Arrangement of Tone

(i) Texture

The visual impression of coarseness (roughness) or smoothness caused by the variability or uniformity of image tone or color is known as texture. It represents the frequency of change and arrangement of tones. This is a micro structure of image pixels. It is produced by an aggregate of characteristics too small to be detected individually, such as tree leaves and leaf shadows. Smooth (fine) textures are associated with cropland (plants at about the same height), bare fields, and calm bodies of water; Coarse (rough) textures are associated with forestland (mature tree crowns) and young lava flows, while grass is medium.

It is often possible to distinguish between features with similar reflectance characteristics based upon their textural differences. Texture, just like object size, is directly correlated with photo scale. Thus, a given feature may have a coarse texture in a low-altitude photograph, and smooth texture in a high-altitude photograph.

(ii) Pattern

Pattern is the overall spatial arrangement of related image objects. The repetition of certain forms is characteristics of many human objects and some natural features. In comparison with texture, pattern is a macro image characteristic. It is the regular arrangement of objects that can be diagnostic of features on the landscape. The orderly arrangement of trees in an orchard or grove usually a grid pattern versus the random distribution of trees in a forest.

Likewise, the network or grid of streets in a subdivision or urban area can aid identification and aid in problem solving such as the growth patterns of a city. Pattern can also be very important in geologic or geomorphologic analysis. Drainage pattern can tell the trained observer a great deal about the lithology and structural patterns in an area. Dendritic drainage patterns develop on flat-bedded sediments; radial on/over domes; linear or trellis in areas with faults or other structural controls. Patterns can be described as random, systematic, circular, centripetal, oval, curvilinear, linear, radiating, rectangular, hexagonal, pentagonal, octagonal, etc.

Third-order Elements

Locational or Positional

(i) Site

The location of object in relation to its environment is called the site factor and is important for recognizing many cultural and natural features. How objects are distributed with respect to geographical locations and associated human and natural environment. The physical characteristics of a site might include elevation, slope, aspect, and type of surface vegetation cover and associated soil type. Socioeconomic site characteristics might include the value of the land, the land-tenure system, zoning codes, etc.

For example, many types of natural vegetation are characteristically confined to specific locations such as swamps, marshes, and stream banks, or to sites differing in elevation and aspect. Thermal and nuclear plants are often found near major sources of surface water. Aspect, topography, geology, soil, vegetation and cultural features on the landscape are distinctive factors that the interpreter should use when examining a site. Just as some vegetation grows in swamps others grow on sandy ridges. Agricultural crops may like certain conditions. Man-made features may also be found on rivers (e.g. power plant) or on a hill top (observatory or radar facility).

(ii) Association

Some objects are so commonly associated with one another so that identification of one tends to indicate or confirm the existence of another. Association is one of the most helpful clues for identifying cultural features that comprise aggregate components. Association is one of the most helpful clues in identifying man made installations. Schools at different levels typically have characteristic playing fields, parking lots, and clusters of buildings in urban areas. Large farm silos typically indicate the presence of livestock.

Interpreted from lower order elements

(i) Height

The ability to visually appreciate and measure the height (elevation) or depth (bathymetry) of an object or landform is one of the most diagnostic elements of image interpretation. Height can add significant information in many types of interpretation tasks; particularly those that deal with the analysis of man-made features. Stereoscopic parallax is measurable when the same object is viewed from two different vantage points along a flightline. Stereoscopic method is the optimum approach to visually appreciating the three dimensionality of the terrain and for extracting accurate x,y,and z values of image objects. In monoscopic images, there are visual cues that we can use to appreciate the height or depth of an object. Any objects such as a building or utility pole that protrudes above the local datum will exhibit radial relief displacement outward from the principal point of a typical aerial photograph. In addition, all objects protruding above the local datum also cast a shadow that provides diagnostic height information.

(ii) Shadow

Shadow cast by oblique illumination are important in photo interpretation because their shapes provide profile views of certain features that can facilitate their identification. Features often recognizable by the shadows include water towers, electrical-transmittion towers, oil-storage tanks, bridges, and various species of trees. Shadows are particularly helpful if the objects are small or lack tonal or color contrasts with their surroundings. Low sun-angle (early morning or late afternoon) photographs accentuate minor surface irregularities. Shadows can provide clues about the height of an object when the image interpreter does not have stereoscopic imagery in hands. When interpreting imagery with substantial shadows, it is a good practice to orient the imagery so that the shadows fall toward the interpreter. Shadows can also inhibit interpretation.

Aids to Image Interpretation/ Methods of Image Interpretation

Field Observation/Ground Truthing

Field observations as an approach to image interpretation are required when the image object/feature and its relationship to the ground objects/features are not clearly understood. Then the interpreter has to go into the field to verify and identify the feature. Field observations are necessary for accuracy and familiarization with the environmental conditions/features in reality. The amount and type of field work required for a given project may vary greatly and is generally dependent upon the,

- Type of analysis involved.
- Image quality, including scale resolution and information to be interpreted.
- Accuracy requirements for both classification, and boundary delineation.
- Experience of the interpreter and the knowledge of the sensor, area, and subject.
- Terrain conditions and the accessibility of the study area.
- Personnel availability, access to ancillary material.
- Cost considerations.

Direct Recognition

Is the application of an interpreter's experience, skill and judgment to associate the image patterns with informational classes or attribute data; This is a qualitative and or subjective analysis of an image using the elements of image interpretation as visual and logical clues.

Interpretation by Inference

Is the use of a visible distribution to map one that is not itself visible on the image; the visible distribution acts as a surrogate, or proxy, for the mapped distribution. For example, soil mapping from aerial photos is mapped using closely related patterns of landform and vegetation. Thus, landforms and vegetation patterns act as proxies for the soil pattern. Use of this approach requires a complete knowledge of the link between the proxy and the mapped distribution.

[D] Probabilistic Interpretation

- Are efforts to narrow the range of possible interpretations by formally integrating non-image information into the classification process.
- For example knowledge of cropping patterns can be used to identify a particular crop likely existing in the image.

[E] Deterministic Interpretation

- Are based on quantitatively expressed relationships that tie image characteristics to knowledge of ground conditions.

- E.g., photogrammetric analysis of stereo pairs for landform information, where a topographic model of the landform can be reconstructed.

[F] Collateral Material

- Collateral material or information refers to non-image information used to assist in the interpretation of an image.
- This may include, census data, a map of flora of a given area, a land use map of an area, meteorological statistics, or agricultural crop reports can all be used in support of a given interpretation.
- Basically, collateral material represents data/information that an interpreter may use to aid in his/her accomplishment of a given analysis task. Two classes of collateral data deserve special mention here. These are photo/image interpretation keys and field verification.

[G] Image Interpretation Keys

Also referred to as image analysis keys or convergence of evidence

- A photo/image interpretation key is a set of guidelines used to assist interpreters in rapidly identifying photo/image features.
- As a general rule, keys are more easily constructed and used for the identification of man-made objects and features than for natural vegetation and landforms.
- For analysis of natural features, training and field experience are often essential to achieve consistent results. Basically, an interpretation key helps the interpreter organize the information present in image form and guides him/her to the correct identification of unknown objects.

In short, determination of the type of key and the method of presentation to be employed will depend upon:

- The number of objects or conditions to be identified; and
- The variability typically encountered within each class of features or objects within the key.

Two types of keys are generally recognized.

- **Selective keys** are arranged in such a way that an interpreter simply selects that example that most closely corresponds to the object he/she is trying to identify, e.g. industries, landforms, etc.
- **Elimination keys** are arranged so that the interpreter follows a precise step-wise process that leads to the elimination of all items except the one (ones) that he/she is trying to identify.
- **Dichotomous keys** are essentially a class of elimination key that divide features into two sharply distinguished parts or classifications. Most interpreters prefer to use elimination keys in their analyses, although studies have revealed no significant difference between

the results achieved from the use of the two types of keys as long as the material within each key is well organized.

References

[1] A. C. o. S. a. Mapping, “Fundamentals of Mapping,” Commonwealth of Australia 2016, 25 January 2016. [Online]. Available: http://www.icsm.gov.au/mapping/maps_cadastral.html. [Accessed 10 February 2016].

[2] E. TARI and H. KALAMAN, *Surveying 1*, Istanbul Technical University, 2010.

[3] R. Zimba, *GE 212 LECTURE NOTES: Introduction to Geomatics*, Lusaka: University of Zambia, 2010.

[4] A. Abdel-Rahim, *CE 211 – SURVEYING ENGINEERING*, 2011.

[5] A. Chandra, Surveying: Problem Solving Theory and Objective Type Questions, New Delhi: New Age International Publishers, 2005.

[6] W. Tafesse and T. Gobena, *SURVEYING*, Haramaya University in collaboration with the Ethiopia Public Health Training Initiative, The Carter Center, the Ethiopia Ministry of Health, and the Ethiopia Ministry of Education, 2005.

[7] Civil Engg, “Distance Measuring Equipment in Survey,” 2014. [Online]. Available: http://www.aboutcivil.org/distance-measuring-equipment-surveying-levelling.html. [Accessed 31 january 2016].

[8] W. Schofield and M. Breach, Engineering Surveying, Sixth, Ed., Jordan Hills, Oxford: Elsevier Ltd., 2007.

[9] D. E.E., “Photogrammetry for Civil and Forest Engineers,” in *Lecture Notes No. 55*, Fredericton, N.B., 1982.