GEOINFORMATION

Remote sensing, photogrammetry and geographic information systems

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Gottfried Konecny,
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Contents

1 Introduction

Surveying and mapping has recently undergone a transition from discipline oriented technologies, such as geodesy, surveying, photogrammetry and cartography into a methodology oriented integrated discipline of geoinformation based on GPS positioning, remote sensing, digital photography for data acquisition and GIS for data manipulation and data output. This book attempts to present the required basic background for remote sensing, digital photogrammetry and geographic information systems in the new geoinformation concept, in which the different methodologies must be combined depending on efficiency and cost to provide spatial information required for sustainable development. In some countries this concept is referred to as 'geomatics'.

For remote sensing the basic fundamentals are the properties of electromagnetic radiation and their interaction with matter. This radiation is received by sensors on platforms in analogue or digital form to result in images, which are subject to image processing. In photogrammetry the stereo-concept is used for the location of the information in three dimensions. With the advent of high resolution satellite systems in stereo, the theory of analytical photogrammetry, restituting two-dimensional image information into three dimensions, is of increasing importance merging the remote sensing approach with that of photogrammetry.

The result of the restitution is a direct input into geographic information systems in vector or in raster form. The application of these is possible at the global, regional and local levels.

Data integration is made possible by geocoding, in which the GPS satellite positioning system plays an increasing role. Cost considerations allow a judgement on which of the alternate technologies can lead to an efficient provision of the required data.

Surveying and mapping in transition to geoinformation

Geodesy

Geodesy, according to F.R. Helmert (1880), is the science of measurement and mapping of the earth's surface. This involves, first, the determination of a reference surface onto which details of mapping can be fixed.

In ancient Greece (Homer, 800 BC) the earth's surface was believed to be a disk surrounded by the oceans. But, not long after, Pythagoras (550 BC) and Aristotle (350 BC) postulated that the earth was a sphere. The first attempt to measure the dimensions of a spherical earth was made by Erathosthenes, a Greek resident of Alexandria around 200 BC. At Syene (today's Assuan) located at the Tropic of Cancer at a latitude of 23.5° the sun reflected from a deep well on June 21, while it would not do so in Alexandria at a latitude of 31.1°. Erathosthenes measured the distance between the two cities along the meridian by cart-wheel computing the earth's spherical radius as 5909 km. Meridional arcs were later also measured in China (AD 725) and in the caliphate of Baghdad (AD 827).

Until the Renaissance, Christianity insisted on a geocentric concept, and the determination of the earth's shape was not considered important. In the Netherlands Willebrord Snellius resumed the ancient ideas about measuring the dimensions of a spherical earth using a meridional arc, which he measured by the new concept of triangulation, in which long distances were derived by trigonometry from angular measurements in triangles. The scale was derived from one accurately surveyed small triangle side, which was measured as a base by tape.

The astronomers of the Renaissance (Copernicus (1500), Kepler (1600) and Galilei (1600)) along with the gravitational theories of Newton (1700) postulated that the earth's figure must be an ellipsoid, and that its flattening could be determined by two meridional arcs at high and low latitude. While the first verification in France (1683–1718) failed due to measurement errors, the measurement of meridional arcs in Lapland and Peru (1736–1737) verified an ellipsoidal shape of the earth. Distances on the ellipsoid could consequently be determined by the astronomical observations of latitude and longitude at the respective points on the earth's surface.

Laplace (1802), C.F. Gauss (1828) and F.W. Bessel (1837), however, recognized that astronomic observations were influenced by the local gravity field due to mass irregularities of the earth's crust. This was confirmed among others by G. Everest observing huge deflections of the vertical in the Himalayas. This led to the establishment of local best-fitting reference ellipsoids for positional surveys of individual countries.

In the simplest case latitude and longitude was astronomically observed at a fundamental point, and an astronomical azimuth was measured to a second point in the triangulation network spanning a country. Within the triangulation network, at least one side was measured by distance measuring devices on the ground. For the determination of a best-fitting ellipsoid, several astronomic observation stations and several base lines were used. The coordinates of all triangulated and monumented points were calculated and least squares adjusted on the reference ellipsoid with chosen dimensions, e.g. for half axis major a and for half axis major b or the flattening

$$f=\frac{a-b}{a}:$$

Clarke 1880	$a = 6\,378\,249$ m, $b = 6\,356\,515$ m
Bessel	$a = 6\,377\,879$ m, $f = 1/298.61$
Hayford	$a = 6\,378\,388$ m, $f = 1/297$
Krassovskij	$a = 6\,378\,295$ m, $f = 1/298.4$

On the chosen reference ellipsoid, the ellipsoidal latitudes and longitudes were obtained for all points of the first order triangulation network. This network was subsequently densified to second, third and fourth order by lower order triangulation.

The survey accuracy of these triangulation networks of first to fourth order was relatively high, depending on the observational practices, but discrepancies between best fitting ellipsoids of neighbouring countries were in the order of tens of metres.

For the purpose of mapping, the ellipsoidal coordinates were projected into projection coordinates. Due to the nature of mapping in which local angular distortions cannot be tolerated, conformal projections are chosen:

- for circular countries (the Netherlands, the Province of New Brunswick in Canada), the stereographic projection.
- for N–S elongated countries, the 3° Transverse Mercator projection tangent to a meridian, every 3 degrees. Due to its first use by C.F. Gauss and its practical introduction by Krüger, the projection is called the Gauss–Krüger projection. It is applied for meridians 3° apart in longitude in several strips. The projection found wide use for the mapping of Germany, South Africa and many countries worldwide.
- for E–W elongated countries (France) the Lambert Conic Conformal Projection was applied to several parallels.
- the Lambert conic conformal projection may also be obliquely applied, e.g. in Switzerland.
- for worldwide mapping, mainly for military mapping requirements, the UTM projection (a 6° Transverse Mercator Projection) is applied. The formulation is the same as for the Gauss–Krüger projection, with the exception that the principal meridian (here every 6 degrees) has a scale factor of 0.9996 rather than 1 used for the Gauss-Krüger projection.

Since the earth's gravity field influences the flow of water on the earth's surface, ellipsoidal coordinates without appropriate reductions cannot be used for practical height determinations. Height reference systems are therefore separate from position reference systems based on reference ellipsoids.

An ideal reference surface would be the equipotential surface of the resting oceans, called 'the geoid'. Due to earth tides influenced by the moon and planets, due to ocean currents and winds influenced by climate and meteorology, this surface is never resting. For this reason the various countries engaged in mapping systems have created their own vertical reference systems by observing mean sea level tides at tidal benchmarks. Spirit levelling extended the elevations in level loops of first order over the mapping area of a country to monumented benchmarks. These level loop observations, corrected by at least normal gravity, could be densified by lower order levelling to second, third and fourth order. As is the case for positions, differences of several metres in height values may be the result of the different height reference systems of different countries.

The different reference systems for position and height still used for mapping in the countries of the world are in transition, changing into a new reference frame of three- or four-dimensional geodesy. This has become possible through the introduction of the US Navy Navstar Global Positioning Systems (GPS) in the 1980s. It now consists of twenty-four orbiting satellites at an altitude of 20 200 km. These orbit at an inclination of 55° for 12 hours, allowing a view, in a direct line of sight, of at least four of these satellites from any observation point on the earth's surface for 24 hours of the day.

Each of the satellites transmits timed signals on two carrier waves with 19.05 cm and 24.45 cm wavelengths. The carrier waves are modulated with codes containing the particular satellite's ephemeris data with its corrections. The US Defense Department has access to the precise P-code suitable for real-time military operations. Civilian users can utilize the less precise C/A code carried by the 19.05 cm carrier wave.

When three satellites with known orbital positions transmit signals to a ground receiver, the observed distances permit an intersection of 3D-coordinates on the earth's surface. Since the satellite clocks are not synchronized, an additional space distance from a fourth satellite is required for 3D positioning.

The calculations are based on an earth mass centred reference ellipsoid determined by an observation network by the US Department of Defense, the WGS 84 with the following dimensions:

$$a = 6\,378\,137\,\text{m}$$
$$f = 1/298.257\,223\,563$$

Local reference ellipsoids used in the various countries differ in coordinate positions by several 100 m with WGS 84 coordinates.

P-code observations may be used in real time to accuracies in the dm range. C/A codes are capable of determining positions at the 5 m level unless the satellite clock signals are artificially disturbed by the military satellite system operators, as was the case during the 1990 to 2000 period. This disturbance was called the 'selective availability (SSA)'. It deteriorated the C/A code signals to 100 m accuracies in position and to 150 m in height.

To overcome this lack of dependability, more elaborate receivers were developed in the civilian market, which observed the phases of the carrier waves, using the C/A codes only to obtain approximate spatial distances and to eliminate ambiguities when using the phase measurements. The principle of measurement at a mobile rover station thus became that of relative positioning with respect to a permanently operating master reference station.

In static mode (observing over longer duration periods) positional accuracies in the range of several millimetres could be achieved for distances closer than 10 km. For long distances over several hundreds of kilometres, accuracies in the 1 cm to 2 cm range could be obtained by the simultaneous observation of networks.

Relative observations in networks are able to minimize ionospheric and tropospheric transmission effects. Satellite clock errors may be eliminated using double differences.

Multiple effects may be eliminated by the careful choice of observation points. This has encouraged the international civilian community to establish an International Terrestrial Reference Frame (ITRF) of over 500 permanently observing GPS stations worldwide. The absolute position of ITRF is combined with the observation of an International Celestial Reference Frame (ICRF), in which the absolute orientation of ITRF is controlled by stellar observations using radio astronomy (quasars, VLBI).

The existence of an ITRF gives the opportunity to monitor changes of plate tectonic movements of the earth's crust. Thus ITRF is determined at a specified epoch (e.g. ITRF 1993, ITRF 1997, ITRF 2000, etc.), in which local plate deformations can be observed which exceed centimetre accuracies.

The existence of ITRF has encouraged mapping agencies throughout the world to establish new continental control networks and to densify them into national reference systems.

In Europe, thirty-six ITRF stations were selected in 1989 to create the European Reference Frame ETRF 89. This reference frame served to re-observe national networks with differential GPS, such as the DREF 91 in Germany, which permitted the setting up of a network of permanently observing GPS reception stations SAPOS, with points about 50 km apart.

Networking solutions, such as those offered by the companies Geo++ or Terrasat permit the use of transmitted corrections to rover stations observing GPS-phase signals in real time kinematic mode. These enable positioning in ETRF to 1 cm accuracy in latitude and longitude and to 2 cm accuracy in height at any point of the country, where the GPS signals