Overview of Geospatial/Geodetic Engineering

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This article is part of the Systems Engineering and Geospatial/Geodetic Engineering (GGE) Knowledge Area. It provides a broad introduction into the overall topic including related applications in order to make the reader aware where GGE is used in systems.

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Contents

GIS and Geospatial Applications

Perhaps the most comprehensive recent standard textbooks on Geographical Information Systems (GIS) are Longley et al. (2015) and Kresse and Danko (2012). Beyond these two books, there are many others on GIS and respective spatial data capture procedures (surveying, photogrammetry, and remote sensing) and management applications. Tomlinson (2019) and Peters (2012) as well as the online successor to this text book, System Design Strategies, provide valuable insights into aspects of how to set up a GIS system. While Tomlinson (2019) looks more at the management perspective and processes of implementing a GIS, Peters (2012) focuses more on technical aspects.

Domain-specific GIS applications are also documented in numerous textbooks. Domain areas include agriculture and forestry, insurance economics and risk analysis, simulation and environmental impact analysis, hydrology, archaeology, ecology, crime investigation and forensics, disaster management and first responders, marketing, municipalities and cadaster, land administration and urban planning, utility sectors, telecommunications, smart cities and military applications. The latter include Command and Control (C2) systems, or are even extended in Command, Control, Communications, Computers Intelligence, Surveillance and Reconnaissance (C4ISR) systems. Generally speaking, wherever data about events is displayed or portrayed, processed and/or analyzed in a geospatial context, GIS technology is involved. The particular type of user interface doesn't matter. It could be a web interface, a desktop client, or a mobile device such as a smartphone or tablet computer. To provide visualization of this data there must be spatial context for orientation, geographic data such as digital topographic maps, or geographic imagery, Digital Terrain Models (DTM), etc. Beyond such classical geographical data, other types of data are also often used, such as meteorological and other environmental data.

Interoperability is of major concern in geospatial technology. The Open Geospatial Consortium (OGC) is probably the most relevant organization that deals with GIS and sensor systems interoperability. The OGC has published a dedicated set of interface specification standards on their topics.

Positioning, Navigation and Timing

The previous description of geospatial technology focused mostly on stationary objects, i.e. on non-moving geospatial data. This section is mainly concerned with objects in motion, i.e. objects moving in space and with derived applications such as navigation, monitoring, and tracking such objects. The basic operations needed are (geo-)positioning and navigation. Certainly, the majority of people using smartphones are also using various location based services (LBS) that are provided in conjunction with GIS databases and services, such as Google Maps, a well-known online GIS application. As a consequence, positioning and navigation, which are mainly achieved with satellite positioning systems such as Global Navigation Satellite Systems (GNSS), have became ubiquitous and transparent technologies in the last decade. Clearly the most relevant system in common use in the past has been the US Global Positioning System (GPS) since it was the first of its kind. However, it is not the only one of its kind. Russia developed a GNSS called GLONASS; Europe developed the Galileo system which is close to achieving full operating capability; China is working on its Beidhou GNSS. GNSS are used for more than positioning and navigation. Since range measurements conducted by GNSS are based on extremely accurate one-way travel times of signals, these satellites have extremely accurate clocks. GNSS transmit this time for use by other systems, enabling time synchronization of systems and also applications that require frequency normals that can be derived from these time signals. Together, these three GNSS services are called Positioning, Navigation and Timing (PNT). For more on satellite positioning systems and satellite navigation, two excellent sources are Teunissen and Montenbruck (2017) and Hofmann-Wellenhof et al. (2008).

The public does not generally appreciate how many systems used in various domains rely on the availability of GPS/GNSS signals. The majority of national critical infrastructures is now dependent on GNSS (Royal Academy of Engineering 2013; Wallischeck 2016). Thus the availability of open access to GNSS signals is itself considered critical infrastructures. Example infrastructures and applications that depend on GNSS include transport (rail, road, aviation, marine, cycling, walking), agriculture, fisheries, law enforcement, highways management, services for vulnerable people, energy production and management, surveying, dredging, health services, financial services, information services, cartography, safety monitoring, scientific and environmental studies, search and rescue (e.g. as given with the Global Maritime Distress and Safety System, GMDSS), telecommunications, tracking vehicles and valuable or hazardous cargoes, and quantum cryptography (Royal Academy of Engineering 2013).

Geodesy and Geodetic Engineering for Providing the Frameworks for All Spatial Applications

The above sections are application-oriented. However, at a more basic level, all numerical (coordinate-wise) descriptions of natural and man-made stationary and mobile objects, including satellites, need to be referenced to a spatial reference system. It may be a local stationary engineering coordinate reference system, a (moving) internal coordinate reference system that is fixed to an object (in motion), a national spatial reference system, a regional spatial reference system, or even a global spatial reference system, e.g. that given by the World Geodetic System 1984 (WGS84, cf. National Imagery and Mapping Agency 2004), which is the spatial reference system in which GPS works. 2-dimensional ("horizontal") coordinates such as the combination of latitude and longitude in a geodetic coordinate system are fairly straightforward because they are based mainly on mathematical assumptions. The shape of the Earth is approximated by an ellipsoid on whose surface the coordinates are defined, and the ellipsoid is fixed to the Earth via a geodetic datum/geodetic reference frame. Actually also the definition of the ellipsoid itself is part of the geodetic reference frame. Only little input from geophysics is needed (the localization of the rotation axis of the Earth). The third dimension, however, is mostly treated differently. Heights in general are referenced to a reference surface. For ellipsoidal heights this is the ellipsoid, but since ellipsoidal heights can cause confusion as they do not consider the mass characteristics of the Earth with their distribution, it is more common to use heights that are related to a mean sea level (MSL) surface. The latter is mainly dependent on the (irregular!) distribution of masses on Earth and thus on their physical properties. The typical surface used for referencing these gravity-related heights is the so-called geoid which may be approximated by MSL. Beyond these Earth related aspects, however, there are also celestial spatial reference systems and spatial reference systems on other celestial bodies. Torge and Müller (2012) offers more information on these systems. Thus, geodetic engineering with its sub-disciplines of physical and mathematical geodesy together with related engineering disciplines provide fundamental frameworks for various applications in science and technology including systems of systems.

Portrayal of Geographic Data with Map Projections and Cartography

Because people often rely on visual depictions more so than on verbal descriptions, the complicated surface of the Earth typically needs to be “pressed” onto a flat screen, or a map or chart like in traditional cartography, even when it is a 3-dimensional perspective view on a 2D screen. Depending on the display scale, reducing from 3D to 2D cannot be achieved without somewhat or even significantly distorting the shape of the objects. Mathematical geodesy and map projections based on differential geometry provide the basics to achieve these goals (Grafararend et al. 2014). By carefully selecting an appropriate map projection, different characteristics of land masses and applications can be emphasized. One example may be the difference between the classical Mercator projection that is used for nautical charts from the equator up to medium latitudes, and the Stereographic projection that is often used in aeronautics since the shortest distance between two locations there is a straight line. For the Mercator projection, a straight line is a rhumb line, i.e. the line of constant bearing which eases the use of a magnetic compass for steering a vessel (neglecting variations of magnetic declination on Earth). Here, the shortest distance between two points on the Earth’s surface (the geodesic) is a curved line on the chart whose curve is bent towards the pole of the respective hemisphere.

As portrayal of geographic data is a fundamental functionality of GIS, respective map projection modules are generally included in GIS software packages. Beyond these purely projection-related aspects of visualizing geographic data, cartography offers rules and procedures for what to display and how to visualize geographic data. Kraak and Ormeling (2020) show such data may be abstracted by symbols, lines, and areas, including what color and styles to apply to the graphical elements in a map, how to relate these to each other on a screen or paper map, how to generalize them, i.e. how to simplify their shape and depiction or even discard on display, when the scale of display is changed, etc.

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