Location of geographical objects in crisis situations

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Abstract. This article summarizes the various expressions of object positioning using different coordinate data and different methods, such as use of maps, exploiting the properties of digital Global System for Mobile Communications (GSM) networks, Global Navigational Satellite Systems (GNSS), Inertial Navigation Systems (INS), Inertial Measurement Systems (IMS), hybrid methods and non-contact (remote sensing) methods; all with varying level of accuracy. Furthermore, the article describes some geographical identifiers and verbal means to describe location of geographical objects such as settlements, rivers, forest, roads, etc. All of the location methods have some advantages and disadvantages, especially in emergency situations, when usually the crisis management has a lack of time in a decision process.

1. Object identification using coordinates

The basic requirements for identifying an object or phenomenon located on the Earth’s surface (or near to it) by its coordinates are:

- a unique position, expressed relative to Earth,
- the stability of this position over time (i.e. whether the object moves or not),
- positioning accuracy, to avoid confusion with other objects.

1.1. Unambiguous expression of the position of the object

Assigning coordinate data to an object or phenomenon has to be able to uniquely identify it in space and time. The following different kinds of coordinates are typically used to express position (see also Fig. 1):

- cartesian, rectangular space coordinates (X, Y, Z),
- geodetic (ϕ, λ, h),
- geographical (ϕ, λ),
- rectangular plane (x, y), or
- polar spherical or flat (ρ, θ);
- in specific cases, the convention used may be a combination of several different kinds of coordinates.

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If the coordinates do not already contain information about the position in three-dimensional space (geographic or planar polar coordinates), they must be completed with the altitude or ellipsoid height. Coordinates are expressed using numbers, which represent the linear or angular distance of the object under consideration from the starting point and along the main directions (plan) of the coordinate system. A point location can be expressed using different conventions. Another cause of differences in the numerical expression of the point coordinates is due to the expression of positions using different vertical coordinate systems.

To express the position of any point on Earth, or in close proximity to Earth, one can use a coordinate system which is fixed relative to Earth, and which performs all the same movements as Earth, called a Terrestrial Reference System (TRS). Currently there is a choice between one of two systems – the International Terrestrial Reference System (ITRS) or the World Geodetic System - WGS 84 [6,1]. Both systems are from the mid 1990’s and they have been exchangeable with the uncertainty less than 0.1 meters from that period.

WGS84 (G730) Reference Frame compared with ITRF92 showed an agreement of ~10 cm. Comparisons between the WGS 84 (G873) and ITRF94 reference frames showed their agreement on the order of 2 cm. This shows that the WGS 84 Reference Frame has maintained consistency with ITRF – see also [1].

Unambiguous expression of position can be achieved by using spatial rectangular, geodetic or geographic coordinates, supplemented by elevation. If the coordinate system is defined, it is possible to reciprocally and accurately convert the various different types of coordinates. Geodetic height (h) is completely integrated with these coordinate systems.

The unique value of the height above sea level (according to ISO 19111 Gravity-related height) requires a definition of the height system, and the type of height requires an extra definition in relation to the reference surface - mean sea level (MSL). The relative surface for the expression of elevations on a global scale can be derived from two well-known Earth Gravitational Models (EGM 96 or EGM 2008). The accuracy of the EGM 96 model is approximately 0.5 m to 1 m [6]. The choice of the global coordinate system and the elevation model does not prevent transformation of the position and height into local geodetic systems.

1.2 Positioning Accuracy of Object

Positioning accuracy is very dependent on the method used. Besides accuracy, it is also important when choosing a method to consider how long it takes to take a reading and what technical equipment is required. Another aspect to consider is how easy or difficult it is for consumers to identify their own position. In other words, "user-friendly positioning" methods are an advantage.
The following methods are available:

- a map or image coupled with a grid,
- exploiting the properties of digital Global System for Mobile Communications (GSM) networks,
- Global Navigational Satellite Systems (GNSS), especially Global Positioning System (GPS), see (GPS – SPS, 2008) and (GPS – PPS, 2007),
- Inertial Navigational System (INS), Inertial Measurement System (IMS)),
- hybrid methods based on a combination of GNSS and IMS,
- non-contact (remote sensing) methods of positioning.

Maps or images do not require a source of energy, weight is negligible and the positioning accuracy is about 1 mm in the map scale. The coordinates of objects that are displayed on a map or image must be determined by further measurements.

Use of the GSM network is only possible in areas which receive the GSM signal. Positioning accuracy is within hundreds of meters, ideally 100 m (95%). To achieve maximum accuracy, it is necessary to ensure very precise time synchronization of GSM network transmitters (tens of nanoseconds).

GPS is most widespread among the GNSS systems. To determine the location and exact time it is necessary to receive signals from at least four GPS satellites. GPS signals can be used up to a height of 3 000 km above the Earth [3]. 3D position identification is virtually instantaneous. Positioning accuracy is in place and time is slightly variable. Worldwide it is usually not worse than 10 m (95%) horizontally and 20 m vertically. With additional information (from EGNOS and WAAS systems) an accuracy of 2 – 3 m can be achieved. GPS is often installed in mobile phones or handheld computers (PDA). The coordinates of inaccessible objects have to be identified by additional measurements. GNSS methods are difficult to use in places with objects that prevent the surveying signals being received.

Inertial surveying systems are independent of external signals. They are equipped with sensors for acceleration (accelerometers) and angles or directions (gyroscopes). In low-cost instruments the gyroscope is replaced by a digital compass. The observations of speed and direction are transformed into track gains in the direction of coordinate system axes. Depending on the IMS operation time, localization errors can increase very quickly. After several minutes of operation the position error of a cheap IMS (about $1,000) reaches tens to hundreds of meters. However, IMS is continually developing and improvements to this performance can be expected in time.

Hybrid systems use two or more methods of positioning. The basis is usually the GNSS module, which complements the IMS, a digital compass, altimeter and so on [7]. GNSS ensures that the positioning accuracy is stable over time, and also the continuous correction of IMS. When there is a GNSS signal failure the positioning is determined using the IMU or compass and odometer. The construction of hybrid systems, in particular the use of GNSS / IMS, is still under development.

Non-contact (remote sensing) methods of finding the position of geographical objects include a variety of ways of terrain sensing and evaluation of image data, using a wide range of the electromagnetic spectrum. For example, we have tested laser terrain scanning methods for their possible application in guiding the movement of Unmanned Ground Vehicles (UGV).

2. Thematic and auxiliary methods of positioning

Another way to determine the location of geographic objects is by using different geographical identifiers, gazetteers and descriptive methods that are specific to each class of elements. The starting point for determining the format of these is the standardization agreement [5], which is the basic framework for applying geographical identifiers.

For each class of objects (e.g. topographical relief, bodies of water, vegetation, settlements, roads, etc.) there is a hierarchy of geographic location identifiers, which may supplement or replace coordinate identification. The classes of geographical objects and the methods of using their geographical location identifiers and descriptive characteristics are listed here:
2.1 Relief of Terrain
A point, line or place of terrain relief can be identified using:
- geodetic points (e.g., trigonometric points displayed on the map and marked on the terrain, designated with a class and number),
- elevation points (class, number),
- exposure of the slope,
- contour lines (map available),
- main mountain and valleys in the landscape,
- the edges of distinctive features (embankments, excavations, etc.).

2.2 Hydrography
A point, line or place of hydrography can be identified in the case of flowing water using:
- the catchment area (name, number),
- the identification of rivers in the hierarchy of tributaries in the catchment area,
- the location (or profile) marked on the river over a distance (mileage), measured from the mouth to the source along the central axis of flow,
- bank signification (right, left) in the direction of flow,
- profile signification (name, number);
- local coordinates of a point on the profile of flow,
- other additional information (water level, flow speed, flow rate, changes over time), changing the position of points on the profile of flow.

2.3 Vegetation Cover
According to the system of classification in forests for example, we can identify a location in a forest on the basis of:
- the name and identification number of the forest district,
- the division,
- the section,
- the vegetation group,
- other methods of identification (e.g. the nearest town).

2.4 Administrative areas, settlements and buildings within settlements can be identified by:
- the country (identification by name and the designated international code),
- the hierarchy of administrative areas (identification by names, number codes, the range defined by the perimeter points coordinates, the position of the centre),
- the nearest town or village (identification by names, number codes, the range defined by the perimeter points coordinates, the position of the centre),
- the street (name, code number, coordinate range from beginning to end, position),
- the object’s properties (name, number, range, position, owner).

The example of object location using geographical identifiers is displayed on Figure 2.
2.5 Lines of Communications

The position of a point or place of communication can be illustrated using roads as an example, where one can identify:

- street number,
- distance and direction;
- number, type and name of the section of road,
- number, type and name of the objects on the road (bridge, tunnel, etc.),
- spatial specifications (width, available width, slope, etc.),
- land use (town residential area, rural zone, etc.),
- administrator, owner.

These identification systems for geographical features can be supplemented by other descriptive information, which may help to further specify their location. Examples:

- building identification in towns by reference to adjacent buildings or other local features, such as using the names of shops, restaurants, bus stops or the numbers of the nearest phone boxes, etc.,
- identification of points on the road with the help of road markings.

**Figure 2.** Example of object location using geographical identifiers
Location identification using an intersection with another object class (theme), for example, crossroads, river crossings, etc.

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