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USAGE OF THE GLOBAL NAVIGATION SATELLITE SYSTEMS IN SAFETY AND PROTECTION ISSUES

Summary. Currently, global navigation satellite systems (GNSS) play a key role in the broad field of security and human life. In principle, almost every area of human activity (for example, mining, energy or construction) systems related to saving human life are introduced. Generally, satellite navigation is an indispensable element of this type of systems. In this paper, authors present basic principles of the GNSS operation and the current state of knowledge about usage of the global navigation satellite systems in the area of safety, protection and rescue issues.
Keywords: GNSS, GPS, protection, safety, satellite systems

1. INTRODUCTION

One of the ways to achieve safety in the broadest sense is to guarantee a certain level of emergency detection, assistance, and rescue. There are many definitions of SAR (Search and Rescue) depending on the country, approach and agency involved. The Canadian Forces describe it as '*Search and Rescue comprises of the search for, and provision of aid to persons, ships or other vehicles which are, or are feared to be, in distress or imminent danger'* (http://www.towarf.com/sarsystem.html*)*, while the United States Coast Guard '*The use of*

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available resources to assist persons or property in potential or actual distress' (https://enacademic.com/dic.nsf/enwiki/116405), they are also other definitions. All of them connect the necessity of providing help to people who are in actual or potential danger or distress. Currently, an inseparable element of SAR is Global Navigation Satellite Systems (GNSS), without which SAR would be significantly impeded, and slowed down. GNSS has been used in navigation and positioning since the 80s. Among the first of them: GPS (Global Positioning System) and GLONASS (Global Navigation Satellite System); there are other providers: Beidou, Galileo and QZSS (Quasi-Zenith Satellite System). Our focus is on the use of GNSS in emergency and security issues. The first section (Introduction) contains a summary of the literature research on the use of GNSS in SAR. Second, the basic of GNSS positioning describes the principles of GNSS positioning. Third and fourth describe the current state of knowledge regarding search and rescue applications, respectively.

GIS (Geographic Information System) is among the other sources of gathering positions from GNSS. Emergency command and rescue strongly relies on spatial information: first, are positioning of the emergency events, the search of surroundings environments or GPS tracking, these GIS applications in emergency rescue are described by (Yao et al., 2011). Nowadays, a lost phone is a serious problem due to its use as a personal ID or as a credit card. The loss occurs because of two major reasons: user's own fault (destruction or loss) or due to theft (Kristian et al., 2012). Appropriate applications allow determining the phone's last known position through the use of a GNSS receiver. Mobile phones are also used in 112 emergency calls and determining the receiver location (Ptolemus, 2014). On the other hand, GPS might be used for national security improvement (Akinode, 2011). We describe such applications as a tracking system for monitoring employees who travel long distances. It allows to improve company productivity, ensure drivers do not exceed the speed limit and meet their delivery schedule. Another application in this field is parole by using a small tamper-proof receiver worn as a bracelet or anklet. We describe the use of GPS positioning to track suspected terrorists, demented persons or stolen cars. The use of GPS and the GIS in road accident mapping and emergency response management have been the subject of many studies (Muthoni Njeru and Imwati, 2016). We propose a new system for car accident reporting mechanisms to get more accurate geographical localisations as the data is not being used by police departments. Wadhe et al. 2016 proposed the use of the application for tracking ambulance. We described a model to track the nearest free ambulance using a global positioning system and bring it to the person in distress. A similar idea was conducted by Wadhe et al. (2016), proposing the algorithms for ambulance tracking by the hospital management using GPS. Furthermore, we propose the use of GSM-trackers on fire service units in action along with database support on duplex transmission via the GIS portal. The GSM technology is used to transmit the signal to the off-site monitoring centre, while the GPS technology is used to determine the precise location of the tracking device. We propose developing a system for women protection by using GPS and GSM (Global System for Mobile Communications) as suggested (Devi and Nayak, 2017). Location based services (LBS) using mobile phones are described (Wankhede, 2018), who proposed an application that would provide information regarding services such as the nearest hospital, police station or a blood bank. Similar to the above, GPS/GNSS applications in an emergency and security issues were also submitted by other authors (Akinode, 2011; Anon, 1994; Devi and Nayak, 2017; Lee et al., 2019).

2. BASIC OF GNSS POSITIONING

Each GNSS system consists of three parts (segments): space, ground and user segment. Space segment are satellites on the orbit, control segment is a ground-based network of master control, data upload and monitor stations. The user segment is the equipment that processes the signals received by the GNSS satellites (Akinode, 2011). GNSS positioning is generally based on the precise time measurement on the satellite-receiver distance. Fig. 1 presents a general schema of steps involved in GNSS positioning. GNSS satellites positions are assumed to be known and are transmitted via broadcast message together with satellite clock correction. Control segments, when necessary, adjust satellites' ephemeris and time. GNSS signal passes through the atmosphere to the user equipment.

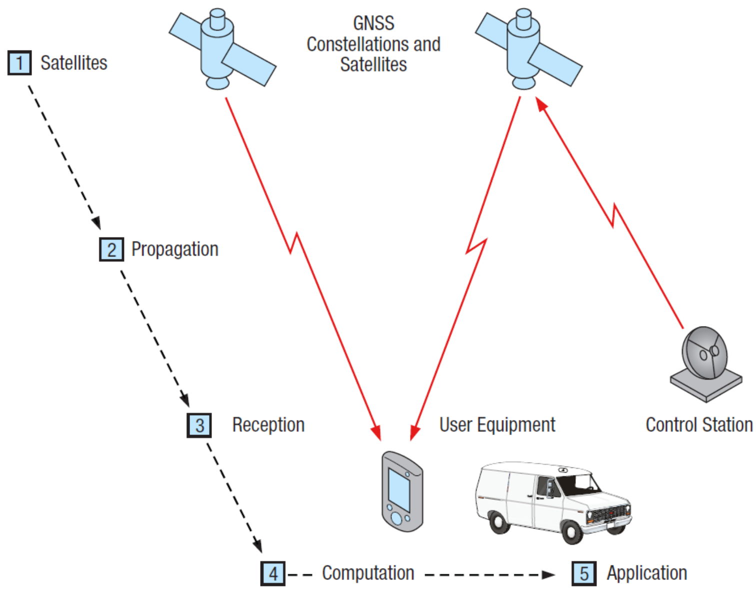

Fig. 1. GNSS principle of the operation (Charles, 2010)

Single receivers position is determined on the basis of trilateration based on the knowledge of at least 4 satellites' positions and each distances receiver-satellite (Ogaja, 2011). The unknowns are 3 components of receiver position and a receiver clock correction (Fig. 2).

Each GNSS satellite transmits both code and phase signals on two (older blocks) or more frequencies together with navigational data containing the satellite's position, time, health and other information. Phase observations are used for more demanding and precise applications as geodesy or engineering. In case of emergency and security issues, code-only receivers are used, the same as in touristic or mobile phone receivers. It provides a couple of metres accuracy level which is sufficient for this kind of applications.

Determining the user's position (x, y, z) and the receiver clock offset (t_r) requires at least four visible satellites (Montenbruck et al., 2018). Based on the pseudoranges ρ recorded by the receiver, a set of equations is determined as:

$$\rho_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} + c \cdot t_r \qquad (1)$$

where ρ_i are pseudorange of ith satellites (i = 1, 2, …, n), x, y, z are receiver's coordinates which are unknown, x_i, y_i, z_i are ith satellite coordinates, ith satellite, c is a speed of light in vacuum and t_r is a receiver clock error. Based on the least squares estimation technique, in a matrix form:

$$L = AX \tag{2}$$

where L is a vector of observations, A is a matrix of linear functions of unknowns and X is a vector of unknowns(Ogaja, 2011). The least square solution of (2) leads to:

$$X = (A^T PA)^{-1} A^T PL \tag{3}$$

where P is the weight matrix, assumption of the weight matrix equal I leads to Equation 3 without matrix P. Pseudorange measurements are also appropriately modelled based on the receiver class and the accuracy assumed to receive. Currently, the number of GNSS applications is very wide, among everyday life, from engineering to scientific (Konopka et al., 2013; Skorupa, 2019).

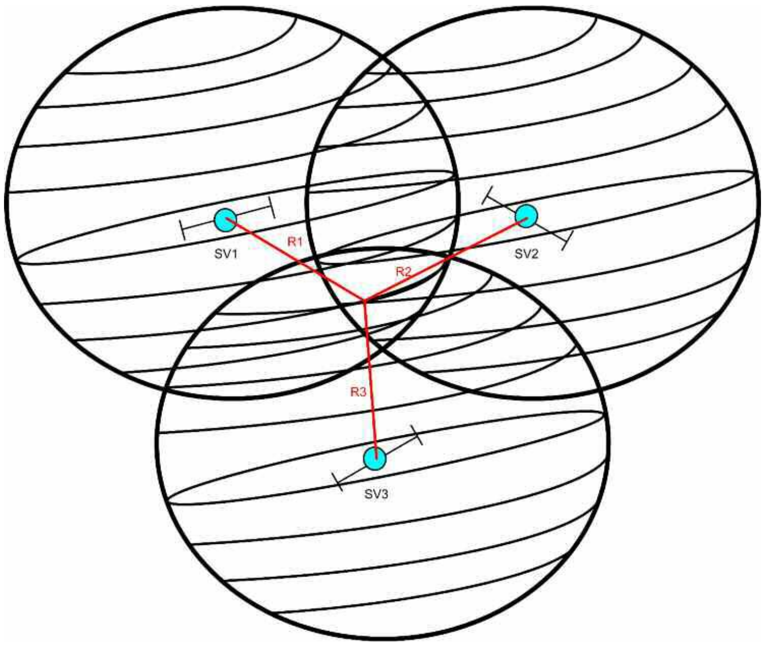

Fig. 2. Trilateration rule using signals from three satellites (Assir, 2011)

3. SEARCH APPLICATIONS

Search and Rescue (SAR) as a part of emergency operations involve locating and helping people in distress. The Galileo Initial Services was the first GNSS constellation offering global SAR capability (Fontanier et al., 2019; Ilčev, 2018). The SAR/Galileo service is Europe's contribution to the upgrade of COSPAS-SARSAT, an international satellite-based SAR distress alert detection and information distribution system (Barnes and Clapp, 1995; Lee et al., 2019). Established in 1979, it is used to detect and locate emergency beacons activated by aircraft, ships and individuals. It provides accurate, reliable and timely alert and location data from distress beacons in the 406-406.1 MHz band and broadcast this information to dedicated ground stations (MEOLUTs) in the L-band at 1544.1 MHz (Wang and Wang, 2019). Currently, over 40 countries and organisations participate in the operation and management of the COSPAS-SARSAT system, which also cooperates with the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO) and the International Telecommunication Union (ITU) (Barnes and Clapp, 1995). The time to detect a person at sea or in the mountains ranges from one hour to just 10 minutes after the distress beacon is activated; localisation of the distress beacon from 10 km to less than 5 km; location accuracy after 1 transmitted burst within 5 km >70%, - 12 bursts and 10 min - >95% (https://www.gsa.europa.eu/european-gnss/galileo/services/search-and-rescue-sargalileo-service).

State-of-the-art software, database access, and instant cross-communication capability make it possible to collect publicly available electronic maps online with any geospatial information updated in real-time. This algorithm was effective in preventing and eliminating the consequences of emergencies and humanitarian disasters, which led to the emergence and rapid increase of the crisis mapping segment. As the core idea of crisis web mapping is the mass participation of users in the collection of necessary data (crowdsourcing), the "locomotive" of its development at the current stage is non-state, usually volunteer, online communities and organisations. Similarly, the use of the innovative potential of crisis cartography by official bodies; international organisations, governments, and rescue bodies, is becoming quite extensive. To increase the informativeness of electronic project maps, crowdsourcing data is increasingly being complemented by high-tech professional information (for example, satellite data). The central principle of the architecture of this system is dynamic, synchronised in time and space, complex, multi-level visualisation of the entire array of data obtained from different sources (Lu et al., 2015), on a platform of special mapping web resources. Presently, the global system (infrastructure) of mass web mapping is in its infancy and has a decentralised, multi-layered architecture that combines both global Google Maps (https://www.google.com/maps), Open Street Map (https://www.openstreetmap.org), Bing Maps (https://www.bing.com/maps) and local Sudan Satellite Sentinel Project (http://www.satsentinel.org/), CERA (http://cera.govt.nz/), Yandex Maps (https://yandex.com/maps/) and wide-ranging and crisis-driven services like Development Seed (https://developmentseed.org) or Tomnod (http://www.tomnod.com) that can be proprietary and non-profit, research centres, for example, Crisis Mapping and Early Warning Program within the Harvard Humanitarian Initiative (https://hhi.harvard.edu/resources/crisis-mapping-and-early-warning), are diverse online communities, blogs, forums Green Map System (https://www.greenmap.org), iRevolution (https://www.irevolution.com), and more. Meanwhile, network organisations that play the role of global focal points and discussion venues have already emerged, in the crisis web mapping segment, for example, the International Network of Crisis Mappers (https://crisismapping.ning.com/), which at present, brings together more than 1,700 organisations and about 2,000 web mappers in 157 countries. The organisation has been hosting the Annual International Conference of Crisis Mappers (ICCM) since 2009. One of the main technological problems in the development of modern web-cartography is that there are currently no reliable proven technologies for verifying crowdsourcing data. This gives a small percentage of errors and inaccuracies, however, it is still unknown about cases of deliberate third-party misrepresentation or targeted large-scale misinformation in the context of these projects.

An unmanned aerial vehicle (UAV) is an aircraft that is unoccupied but under human control, whether radio-controlled or automatically guided by a GNSS-based application. UAVs can be used to scout territory in unsecured airspace and in contaminated areas. Mission coordinates may be predefined and corrections may be sent to keep the UAV on a specific task. In modern warfare theory, widely implicated "survivability onion" (Woolley et al., 2016), which implied technological development ensuring that attackers and defenders avoid successively being: seen, targeted, hit, penetrated or killed. The first three position partly use GNSS geopositioning data: radar signature reduction; radar and laser jammer.

4. RESCUE APPLICATIONS

In armed conflicts and local wars of the late nineteenth and early twentieth centuries, the one with reliable information about the terrain won and is able to quickly collect multifaceted, variable data in the course of the battle, analyse them, make the right decisions and prove it in a timely manner to the subordinates. According to the concept of a "network-centred war", fully endorsed by the US Defence Ministry, a guaranteed victory must be achieved over the enemy's information advantage, which will allow him to advance in intelligence, in the assessment of the rapidly changing battlefield, in the planning of the operation (combat) and making the right decision. Currently, the United States provides more than 300 types of geoinformation documents not only for its Armed Forces but also for military contingents of countries participating in joint operations. Currently, there is intensive work on the elements of the new model of civil protection, where the emphasis is on early warning and immediate response to emergencies based on permanent multichannel monitoring and mapping data online. Nowadays, this model is widely used in the context of individual emergencies and humanitarian disasters, which is, in fact, a process of refining and testing it. Considering the positive results of these tests, as well as the continued and intense interest in crisis web-mapping by international organisations, governments and reputable research circles, in the medium-term, there will continue to be processes of refinement of this model and its implementation as an important resource of government and international civil protection systems in different countries of the world (Aven and Renn, 2019). Furthermore, experts acknowledge that, in the global dimension, this interaction is not systematic, regular and legitimate enough, and therefore remains an open question. For Ukraine, in terms of the readiness of the community and public authorities, joining this process will be further complicated by the following factors: today there are virtually no purely Ukrainian online communities on web mapping and crisis crowdsourcing; participation of Ukrainian users in global projects of this kind is minimal, accordingly, there are no regulatory mechanisms for potential cooperation between the state and non-governmental profile organisations and projects. On the other hand, Ukraine has a sufficient degree of technological readiness to deploy full-fledged mass web-based mapping resources, in particular:

a) relatively high level and good prospects of internet penetration (including mobile, which is the main hardware platform for mass web-mapping);
b) own scientific and technological resources for the development and improvement of GIS;
c) availability of its own Sich-2 orbiting spacecraft, of which one of the regular functions is emergency monitoring.

There is also a wealth of global experience, a wide range of open-source software, international online networks and non-profit organisations open to collaboration at various levels.

5. DISCUSSION

Two ways of the GNSS use have emerged: on prevention application purpose, and on action operational. In each of them are joint base elements as described above, and specific elements with different attributes. The joint elements must include (Fig. 3): basic GPS-positioning equipment and systems which are equivalent for any purpose and developed on measurable principles and standardised exchanging protocols. The specific elements must focus on navigation positioning accuracy and map layers, which is illustrated and operated with algorithms for safety, security and protection application.

Based on the goals of the article, we have selected the three most common functional features. Including:

- availability of target map layers with a set of adaptive tools (map layers);
- processing of input variables, commands with a certain amount of time (delay time);
- the degree of correspondence of positioning accuracy and position coordinates to the scale of the map and layer objects with destination agreement (navigation positioning accuracy);
- availability or development, algorithmization and verification of mathematical models for analysis and forecasting of risks, threats, changes in map data (industry hazards, meteorological quick changes, social disturbances, etc.) – (adequacy of mathematical models).

Fig. 3 presents a diagram of the GNSS usage process in safety applications depending on the destination. The criterion for establishing the priority of functional features (1, 2, and 3) is the time of use of the application. For operational needs in emergencies, rescuing people from threats, search and other escort needs, the time on average scales from several to hundreds of minutes.

For analytical evaluation of prospects of different (short/long) term, forecasting the development or elimination of the consequences of an emergency, the appropriate time is determined from several to hundreds of days (in the future, years).

Improving the accuracy of positioning coordinates in practical applications of emergency and security activities and tools remains a pressing task in all cases.

6. CONCLUSIONS

Safety and protection applications cover two ways of the GNSS use: on prevention application purpose, and on action operational. In each of them are joint base elements as described above, and specific elements with different attributes. The joint elements must include basic GPS-positioning equipment and systems, which are equivalent for any purpose and developed on measurable principles. Improving the accuracy of positioning coordinates in practical applications of emergency and security activities and tools remains a pressing task in all cases. The relevant public authorities should consider the feasibility of introducing in the medium-term, national mapping web platforms designed to monitor emergencies with the ability to edit their content by real-time internet users. It is advisable to include the materials from the above topics in the curricula of vocational education of personnel in the field of civil protection and professional training of persons of the rank and command staff of civil protection bodies and divisions, as well as to bring to the attention of the population in the framework of exercises at all levels.

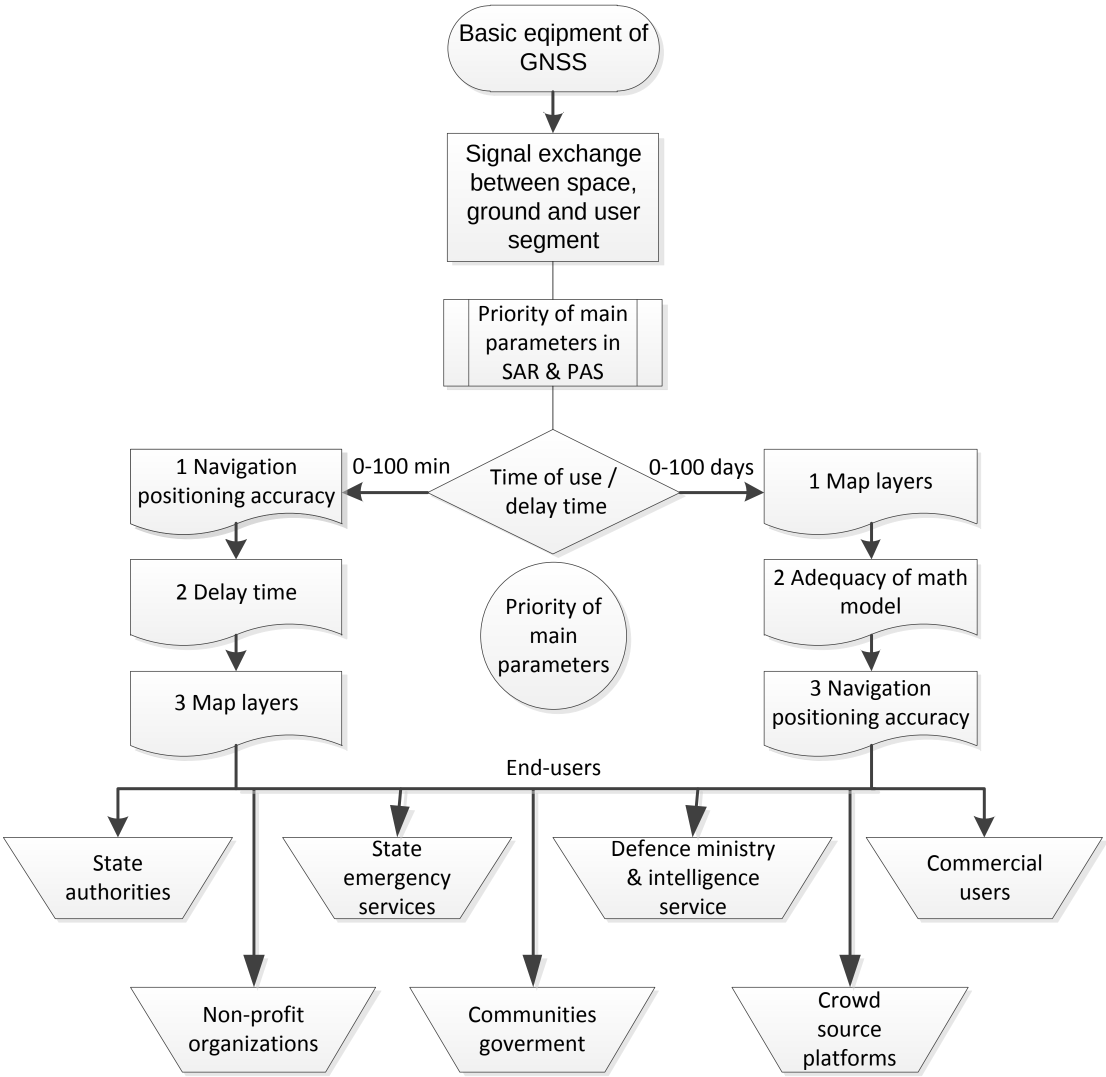

Fig. 3. Diagram of GNSS usage process in safety applications (PAS – protection and safety aims)

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