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Article

DIGITAL CELLULAR TECHNOLOGIES AND GNSS WITH UAV IN SAR MISSIONS FOR PUBLIC PROTECTION AND DISASTER RELIEF SERVICES

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Abstract.

The objective of this paper is to analyze Digital Cellular Technologies (DCT) and European Global Navigation Satellite System (EGNSS)-Galileo with Unmanned Aerial Vehicles (UAV) in Search and Rescue (SAR) missions dedicated for Public Protection and Disaster Relief (PPDR) services. Using desk research methodology authors will evaluate current activities being done in SAR operations in PPDR services, such as police, firefighters, military based on the new technology solutions for SAR operations that support those forces to find trapped victims or fugitives quickly and effectively, thus, improving their time-to-reaction. In conclusion authors stated that the DCT mobile SAR system based on Galileo presents the most sophisticated technology and features that go beyond the state of the art taking into consideration operation safety, reliability and commercial costs in comparison to other systems.

Keywords: Galileo, Unmanned Aerial Vehicles, Safety, SAR, Public Protection and Disaster Relief.

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1. Introduction

According to Annual Disaster Statistical Review 2013, the number and trends prepared by Centre for Research on the Epidemiology of Disasters of the Université Catholique de Louvain (Belgium), explain that there was an increase in the number of victims (1.74 million) in the year 2013 in comparison to the 2003- 2012 annual average (0.60 million) [1]. Total number of people reported killed in Europe was 1832 people. The situation is explained by the increase of meteorological and hydrological dis-asters. Moreover, damages from natural disasters in Europe in 2013 (USD 22.3 billion) were the fourth highest of the decade. Bearing in mind what is stated in the Climate change Synthesis Report of 2014 future geologic changes are likely to lead more extreme weather events, which may lead to more frequent natural dis-asters. The rise of globalization leads to opinion that large-scale natural disasters cannot be thought of as isolated or contained events [2].

It is estimated that the usage of helicopter in search and rescue operations costs be-tween 1500 and 2000 € per hour. Every volunteer firefighter receives up to 4 € per working hour, depending on a region. The cost of professional fire service is much greater. That is why cheaper UVs (Unmanned Vehicles) now play an increasing role in PPDR missions.

2. Unmanned Vehicles in Public Protection and Disaster Relief (Ppdr) Ser-Vices

Figure 1 below shows the increasing frequency of number of disasters versus their economic costs. Thus, the development of low cost and innovative SAR systems is necessary to reduce the government expenditure in these situations.

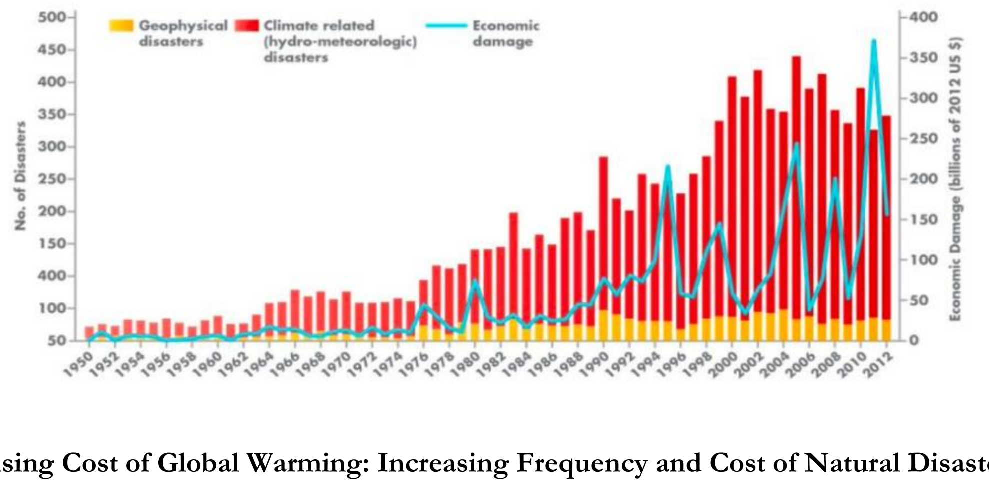

Figure 1. The Rising Cost of Global Warming: Increasing Frequency and Cost of Natural Disaster. Adapted from: "The 5 Most Destructive Natural Disasters of the Past 10 Years". Information available online: http://bostjanbb.hubpages.com/hub/Worlds-worst-natural-disasters#, accessed on January 13, 2022.

Every disaster generates direct losses and indirect losses (costs of rescue operation, long-term treatment, loss of health, loss of jobs, production downtime, etc.). Using mod-ern Search and Rescue system will cut cost and help minimize the damages.

The first time an unmanned robot was used to locate people in a disaster event was on 11 September of 2001- The World Trade Centre attack. In an emergency like this, the public protection and disaster risks agencies provide the Public Protection and Disaster Relief (PPDR) services (Adams, et al., 2009). These agencies, known also as first responders, are formed by police, fire services, military, health services and others. This catastrophe was the uprising of robotics systems and unmanned vehicles [3]. From then, unmanned vehicles have been used in uncountable situations either by land, sea or air [4]. As shows Figure 2, three levels are considered within PPDR services:

- Level 1, everyday incidents/events: road accidents, street crime, house fires, etc.
- Level 2, major events: major fires, kidnappings, etc.
- Level 3, natural and man-made disasters (catastrophes): floodings, earthquakes, debris, terrorist attacks, etc. [5].

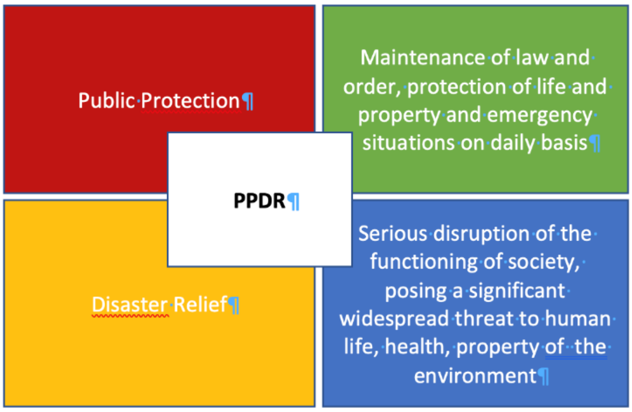

Figure 2. Definition of PPDR. Source: S.L.P. Yasakethu, O.Adigun and C. Politis, "Towards a Secure Next Generation PPDR Communication: SALUS Approach", October 2014. Information available online: https://eforensicsmag.com/towards-a-secure-next-generation-ppdr-communication-salus-approach/, accessed on January 13, 2022 [6].

UVs (Unmanned Vehicles) now play an increasing role in PPDR missions such as border surveillance, military training, weather monitoring, crop monitoring, wildlife surveys, local law enforcement and a long list of applications. Furthermore, with the events that occurred in recent years: Vanuatu cyclone in 2015, Japan's tsunami in 2011, Fukushima nuclear power in 2011, Haiti's earthquake in 2010, etc., the spending in unmanned systems for rescue operations is expected to double in the coming 10 years.

Four main types of UVs are found: Unmanned Terrestrial Vehicles (UTVs), Unmanned Sea Vehicles (USVs), Autonomous Underwater Vehicles (AUVs) and Unmanned Aerial Vehicles (UAVs). Current UAVs are normally equipped with video imaging, light, sound, infrared imaging, global positioning, mapping, sonar, biological and chemical detection [6]. However, no UAVs is exploiting the Digital Cellular Technologies (DCT) and European Global Navigation Satellite Systems (EGNSS) to locate people with-in buildings or under debris in inaccessible areas. The benefits of using EGNSS and DCT technologies will help the rescue teams and PPDR services locate the victims (or criminals) quickly and with high accuracy [7].

If we analyze the current activities being done in SAR operations, the fact is that they engage a number of rescuers, both professional and voluntary, and specialized equipment of considerable magnitude. If operations are realized in vast uninhabited areas, these operations require intense logistical preparations. Urban Search and Rescue (USAR) teams are of great importance in case of natural and man-made disasters. The example of tragic earthquake in Haiti in 2010 showed, that even if considerable forces are being used, the area of debris to be penetrated might be too wide compared to available human resources and technical capabilities.

In these type of operations, manned helicopters are also involved. However, their use presents some disadvantages. The response time might be long, whereas the magnitude of minutes might be crucial for a victim survival. Moreover, in harsh atmospheric conditions, it might be impossible to use a manned helicopter or at least not using it without risking the life of rescuers.

During SAR operations, dogs are employed to find alive victims in various conditions using the body outdoor. In fact, they are the first and the most common source of information to find trapped people. However, dogs, as every living being, have own physiological limits. The example of Haiti earthquake showed that in such severe conditions, dogs might become exhausted even faster than human. Before entering the area by the rescuers and heavy equipment, dogs are engaged. Searching through debris requires considerable energy effort. At the moment the dogs cannot work anymore, rescuers lose one of the most effective "tools" to quickly localize the victims. They still may use devices as geo-phones or search digital cameras, which are of limited application, e.g., geophones re-quire complete silence across the rubble and the victim might be able to generate regular noise e.g., by hitting the collapsed structure with a stone [8].

To increase the effectiveness of SAR operations, thermal imaging is commonly used. The equipment installed in a manned helicopters enables to detect IR radiation emitted by human body. This kind of activity is considered as highly effective, but at the same time expensive. It also depends on the material of the rubbles.

Another example–Fukushima 1 nuclear power plant disaster in 2011–proved, that it might not be safe to enter the disaster site for the rescuers. Considerable CBRNe contamination will require to engage even more human resources and even more technical equipment.

3. UAVs with DCT Signals to Detect Trapped People

The current state of art in terms of commercial solutions to search for people using UAVs is summarized in Table 1. The solutions have been classified according to the employed technology for locating victims: optical-based, WiFi-based, GSM-based and Radar-based [9].

Table 1. State of the art of current devices to detect trapped people (Source: based on MOBNET (MOBile NETwork for people's location in natural and man-made disasters), https://cordis.europa.eu/project/id/687338/results/fr , accessed on January 13, 2022)

Solution Type	Pros	Cons
Optical-Based	Wide Range of COTS (Component Off The Shelf) solutions Can be integrated into UAS, and specially into standard (larger) A/C Many different SWaP (Size, Weight and Power) options available.	Typically complex to integrate and to operate Do not necessarily provide an accurate localisation Expensive when looking for quality and accuracy Typically integrated into aircrafts that are slow to deploy
WiFi-Based	Cheap Possible to be integrated into micro UAVs. Very small SWaP Fast to deploy	Requires victims to have Wi-Fi activated. Accuracy in the order of 10m Possible false positives due to WIFI of laptops, WIFI in routers, and home appliances.
RADAR-Based	COTS Solutions Possible to be integrated into different A/C Possible to be extremely accurate (depending on RADAR type)	Expensive and heavy Large SWaP Typically need deployment over the disaster area to the localisation to be accurate
GSM Base Station-Based	COTS solutions available Different price ranges Possible to integrate in different A/C, from UAVs to standard ones. Typically allows the rescue team to talk and interface with the victims	Current solutions does not offer an accurate localisation of the victims Typically require a SWaP not suitable for micro UAVs Slow deployment comparing to micro UAVs based solutions.

The most widespread technology is the optical based, such as video cameras. There is a large number of large companies providing complete solutions based on this technology (Boeing, General Dynamics, Sikorsky, IAI, INDRA, THALES, etc.). Its main advantages are its reliability, large range of detection and COTS solutions. However, they cannot detect a person trapped within a debris.

In ISR (Intelligence, Surveillance and Reconnaissance) solution based on Wi-Fi signals is presented. The main features are its fast deployment capabilities, the low cost, the capability to locate victims thanks to the WIFI signal of smartphones and the capability to create a Wi-Fi network for communication. However, it presents three main disadvantages: the power of Wi-Fi signals of mobile phone is much smaller than that of the GSM signal, the detected signals can be confused by other Wi-Fi signals such as laptops or Wi-Fi routers, and the most important it requires that the victim has the Wi-Fi option activated.

When looking for a victim with radar-based systems, its location and the depth of the debris are important. Both elements determine the necessary efforts to rescue the victim. For example, the use of Ground Penetration Radar (GPR) permits to locate buried victims thanks to the respiration movements. However, it is usually limited to 50 cm of penetration [10]. In line with this approach, the Frequency Modulated Continuous Wave (FMCW) and Ultra-Wideband radars can be used for this task with higher penetration rates. This rate depends on the selected frequency: the higher the frequency, the shorter the penetration. Two commercial solutions based in radar signals can be founded: Finder (Finding Individuals for Disaster and Emergency Response) and Life Locator III [11]. Both solutions can accurately (below the meter) locate a person under collapsed building thanks to the respiration movements of the person with a range penetration of about 9 m. The main disadvantages of these solutions are its expensive price and its weight: about 15 Kg.

Finally, commercial GSM BTS-based systems are mainly portable systems in a back-pack for firemen, e.g., ASSA SAR Rescue and Emergency NET. They provide communication capabilities between the firemen and the control point as well as GPS positioning [12]. However, these solutions do not search the victims. In literature there is also explanation about new technologies for the search of trapped victims that uses GSM signals to locate victims. The system sends a beacon to the mobile phone and detects the echo that comes back from it. The main problem of this solution is that it is not feasible in modern smartphones. Although, it confirms the feasibility of using GSM signals for detecting the location of a victim. One of the main problems when locating using cellular phone signals in a rubble pile is the behavior of the electromagnetic wave: they can be heavily corrupted by multipath propagation and attenuation [13].

As shows Figure 3 below, the accuracy required by PPDR services (or first responders in the graphic) ranges between 1 m and 10 m.

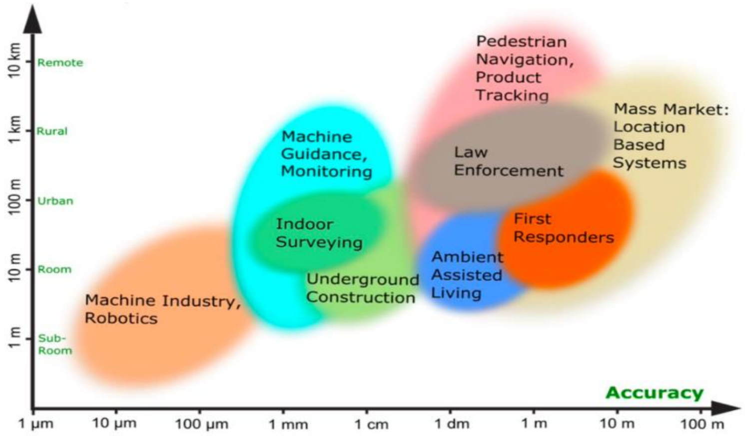

Figure 3. Overview of user requirements in terms of accuracy and coverage. Source: https://nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Symposia/2016-SUPDET/2016-Papers/SUPDET2016Rutimann.ashx , accessed on January 13, 2022.

A cellular network or mobile network is a wireless network distributed over land areas called cells, each served by at least one fixed–location transceiver, known as a cell site or Base Transceiver Station (BTS). They were conceived to communicate portable transceivers (mobile phones or smartphone) over large areas, though, the latest generations of mobile networks such as Universal Mobile Telecommunications System (UMTS) and Long Term Evolution (LTE), have included special features to allow real–time location services. However, in the case of a natural disaster this conventional communication networks (cellular network, fixed line network) will be probably collapsed or broken [14]. Furthermore, in the case of locating a smuggler, the accuracy provided in positioning with these technologies is in the order of hundreds of meters [15] as shows Figure 4 [16].

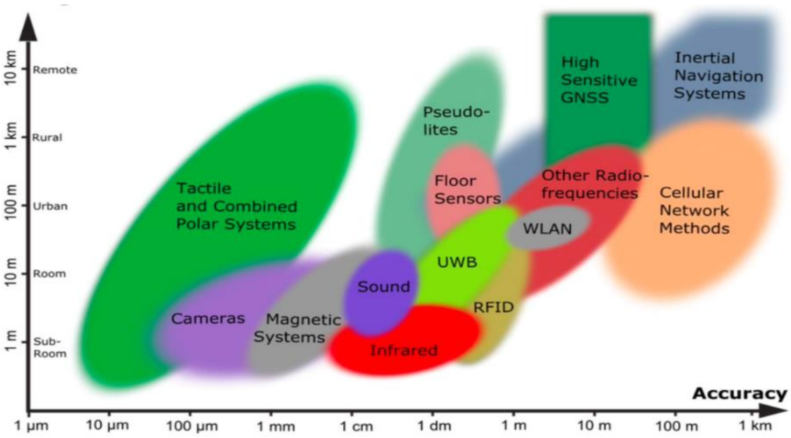

Figure 4. Technologies in dependence on accuracy and carrier wavelength.
Source: https://nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Symposia/2016-SUPDET/2016-Papers/SUPDET2016Rutimann.ashx , accessed on January 13, 2022.

The location of a mobile phone using DCT technologies (and in general in any wireless system) is estimated in two steps: ranging and positioning. Firstly, the ranging estimates, also called observations (angle, received power or time of flight), among each BTS and the mobile phone are calculated, using ranging algorithms such as. Normally, these ranging estimates are not equal to the real value since errors in the transmission or multipath deteriorate the signals [17]. Secondly, the position of each tag is estimated in the BTS using these ranging estimates or vice versa, the mobile calculates its own positioning and sends it to the network.

In this process, the synchronization accuracy and timestamp are crucial and usually needed in the range of nanoseconds to provide an accurate ranging estimate. Moreover, advanced digital processing techniques are necessary to detect the exact instant of arrival of a signal and/or its phase. Thus, from the point of view of Digital Cellular Technologies (DCT) technology, ranging accuracy directly determines the accuracy of the positioning obtained.

4. Improving the Egnss Localization

Satellite navigation or Global Navigation Systems (GNSS) consist of a set of satellites that provide autonomous geo–spatial positioning with global coverage in outdoor. It al-lows small electronic receivers to determine their location (longitude, latitude, and altitude) with high accuracy (within a few meters) using time signals transmitted along a line of sight by radio from satellites. Standard GNSS receivers provide up to four observations per satellite and per frequency at a specified rate, typically 1 Hz, as described by Table 2:

Table 2. GNSS observables (Source: based on MOBNET (MOBile NETwork for people's location in natural and man-made disasters), https://cordis.europa.eu/project/id/687338/results/fr , accessed on January 13, 2022)

Observable	Definition	Units
Pseudorange	Distance from receiver antenna to satellite antenna including receiver and satellite clock offsets, and other biases.	Metres
Carrier phase	Number of whole wavelengths (cycles) of received signal, after ambiguous integer number has been accounted for.	Wavelengths (cycles)
Doppler	Doppler shift with respect to nominal signal frequency; positive for approaching satellites. Used for calculation of user velocity.	Hz
Signal strength	Measurement of strength of received signal, dependent on the degree of thermal, background and intermodulation noise to which the signal has been subjected	dBHz

Then, positioning with GNSS is based on the Time-of-Arrival (TOA) concept which is used to calculate the ranges between the user and satellites. However, the receiver clock is not synchronized with GPS time, therefore these range measurements are named pseudo ranges. A minimum of four pseudo range measurements is needed to solve the equations for the position unknown latitude, longitude, altitude and the receiver clock offset. The error budget of the pseudo range measurements is often represented by the User Equivalent Range Error. Table 3 shows typical values of the individual error components.

Table 3. Major sources of range error in GNSS pseudo ranges (Source: based on MOBNET (MOBile NETwork for people's location in natural and man-made disasters), https://cordis.europa.eu/project/id/687338/results/fr , accessed on January 13, 2022)

Error source	Error magnitude
Residual Ionospheric Error	7 meters (Elevation dependent)
Residual Tropospheric Error	0.6 meters (Elevation dependent)
Ephemeris error	2-3 meters
Satellite clock error	1-2 meters
Multipath	1-2 meters (highly dependent on environment)
Receiver noise	1-2 meter

The major contributor is the residual ionospheric error which varies strongly with sunspot activity, geographical location, seasonal variations and daytime. Using dual frequency measurements 98% of the impact of the ionosphere can be eliminated. Alternatively, it can be eliminated using SBAS/EGNOS regional corrections or applying local differential GPS/GNSS corrections.

GNSS Augmentation systems are used to improve the quality of GNSS positioning and timing. The Satellite-Based Augmentation Systems (SBAS) EGNOS, WAAS and MSAS are regional systems which provide their services over Europe, continental US and Japan. Further regional SBAS implementations are under development. The SBAS broad-casts satellite ephemerides, clock corrections, ionospheric corrections and pseudo range corrections. The MOBNET / EGNSS module will apply SBAS corrections if operated with-in their service areas.

Local differential GPS/GNSS base stations broadcast pseudo range corrections relative to a reference position assuming that the pseudo range errors are nearly identical in the vicinity of the Differential-GNSS base station. Using differential corrections, the impact of the ionosphere, part of the troposphere, the satellite orbit and clock errors can be eliminated. The differential positioning quality degrades with the distance to the reference station. From few decimetres to sub-meter positioning accuracies can be realized within a local area service range of up to 50 km. As part of the MOBNET / EGNSS concept RTCM conform DGPS corrections will be generated by the GNSS base station and uplinked to the UAVs. The DGPS corrections will be used to correct the on board EGNSS observations.

Today there is a significant difference in cost between single and multi-frequency solutions. However, it is expected that multi-frequency GNSS solutions will drop in price significantly with the upcoming GPS L2C and L5 signals as well as Galileo E5. As shows Figure 5 below, the Global Market for GNSS is forecasted to increase by 8.3% annually between 2013 and 2019, growing faster than the forecasted global GDP in the same period.

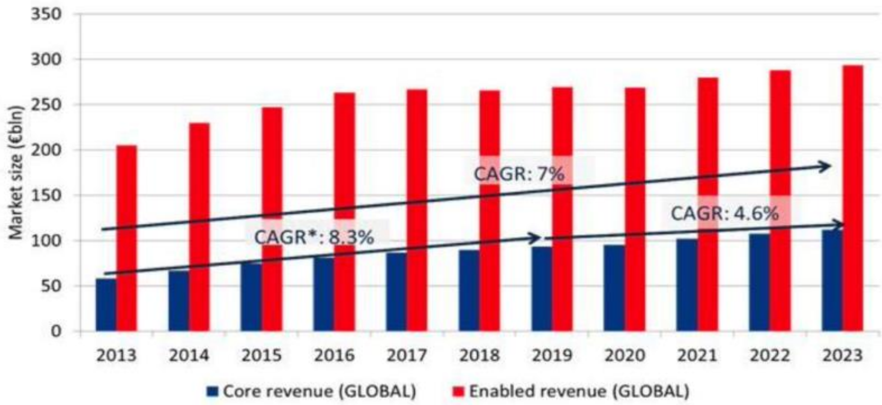

Figure 5. Global GNSS market size (€ bln). Adapted from: European Global Navigation Satellite Systems Agency (GSA), "GNSS Market Report", issue 4, March 2015. Information available online: http://www.gsa.europa.eu/system/files/reports/GNSSMarket-Report-2015-issue4_0.pdf, accessed on January 13, 2022.

- Galileo signals is permitting:
  - To develop Galileo-ready devices that will permit the location of, for example, people in situations of natural disasters.
  - To facilitate civil protection operations in harsh environments, speed up rescue operations for people in distress and provide tools for coastguards and border control authorities.
  - To link the Galileo's Search and Rescue (SAR) function to the operational Cospas-Sarsat system

5. SUMMARY

The DCT mobile SAR system based on Galileo presents the following features that go beyond the state of the art:

- High accuracy, in the order of meters.
- EGNSS based precision timing, in the order of 10 nanoseconds.
- Cost effectiveness and light weight.
- Easily and quickly deployed.
- Continuous monitoring of the affected area.
- No risk the rescuer's life.
- Independent of weather conditions and noisy ambient.
- No special training or qualification is needed to use it.
- Fasten the process of locating survivors.

It is estimated that the usage of helicopter in search and rescue operations costs be-tween 1500 and 2000 € per hour. Every volunteer firefighter receives up to 4 € per working hour, depending on a region. The cost of professional fire service is much greater. The average salary of fireman in Poland is 1000 € gross, however, in estimations some indirect costs are taken into account (increase of pension connected with activity, average costs of statistical sick leave, various cash bonuses, etc.). Adding to these the cost of operations connected with consumables, logistics, depreciation of the equipment, etc., considerable amounts are estimated. According to various estimations depending on the complexity of the operations, the average real cost of one man-hour of the operations will reach between 30 and 100 €.

Although it is hard to estimate cost reduction connected with the use of Aerial Vehicles (UAV) Search and Rescue (SAR) system in Public Protection and Disaster Relief (PPDR) services, certainly the lower engagement of people and equipment has direct relationship with the cost of search and rescue operations.

Not only money, but safety and time has a great value in all kinds of activity, where human life is endangered. As opposed to the structures of public services, electronic de-vices are available without any time delay. Electronic devices may operate constantly with same reliability. Electronic devices for sure will not substitute for human but might greatly assist him.

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