The Fourth Layer in Collaborative Navigation – Going Underground

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Key words: Underground structures, 3-D positioning, multi-sensor system, layered multi-platform sensing, emergency situations, guidance and rescue.

SUMMARY

Collaborative navigation is the method for determining the location of a group of users or sensor platforms absolute and relative to each other. Thereby users are equipped with different sensors of varying quality in terms of performance and achievable positioning accuracies. The concept arose from and follows up the multi-sensory approach where one user has different sensors, such as GNSS receiver, IMU, accelerometers, digital compass and gyro, barometric pressure and step sensor, image sensors including digital cameras and Flash LiDAR, as well as UWB receivers, Wi-Fi and RFID. Now a network of user groups is located and they share their information among each other.

In the beginning of the concept development, only two layers have been considered for collaborative navigation which were the ground level where the group of users had to be navigated, next came spaceborne satellite navigation systems. Due to the recent introduction and use of Unmanned Aerial Vehicles (UAV's) or other flying objects, such as helicopters or light aircrafts, this concept has then been extended with a third layer – the airborne layer in between the ground and the satellites.

The author of this article proposes to introduce an additional fourth layer into the concept, namely the underground. In cities a branched network of tunnels such as underground public transportation tunnels, road tunnels, subways, sewer canal systems, etc. is present. In this paper the question is raised why we are not using these underground structures, for instance, to guide emergency crews to the affected area and rescue people when it is not possible to perform this task above ground. In this paper, possible underground structures are identified and suitable localization technologies for the underground environment in conjunction with users above ground are elaborated and discussed. Thereby, special emphasis is placed on the use of RFID as an easy to deploy absolute positioning technology.

As the author believes that the underground will play an important role for such application scenarios, he calls upon the research community of geodesists and researchers in related fields for international collaboration and participation to develop this idea further. His call is formulated as: Let's extend the layers of the collaborative navigation concept with "Going underground"!

ZUSAMMENFASSUNG

Unter Collaborative Navigation versteht man eine Methode für die absolute und relative Lokalisierung von einer Gruppe von Nutzern oder Sensorplattformen. Die Nutzer sind dazu mit verschiedenen Sensoren unterschiedlicher Qualität im Hinblick auf deren Leistungsfähigkeit und den erreichbaren Positionierungsgenauigkeiten ausgestattet. Das Konzept entstand aus dem seit einiger Zeit gebräuchlichen Ansatz der Nutzung von Multisensor Systemen, bei dem ein Nutzer mit unterschiedlichen Sensoren, wie zum Beispiel GNSS Empfänger, Inertiales Navigationssystem (INS), Beschleunigungssensoren, digitaler Kompass und Kreisel, Barometer, Schrittzähler, bildgebende Sensoren wie digitale Kameras und Flash LiDAR, sowie UWB Empfänger, WLAN und RFID, ausgestattet ist. Beim erweiterten Konzept wird nun eine Gruppe von Nutzern gemeinsam lokalisiert und es erfolgt ein Austausch von Informationen untereinander.

Am Anfang der konzeptionellen Entwicklung wurden nur zwei Ebenen der Collaborative Navigation betrachtet, nämlich die Erdoberfläche, auf der die Nutzergruppe lokalisiert werden musste, und die Ebene im Weltraum, wo sich die GNSS Satelliten befinden. Als kürzlich die Verwendung von Flugobjekten (wie zum Beispiel Drohnen) sowie Helikopter und Leichtflugzeuge in das Konzept des Collaborative Navigation eingeführt wurde, wurde es somit um eine weitere, dritte Ebene ergänzt, nämlich der Ebene der Flugobjekte zwischen der Erdoberfläche und den Satelliten im Weltraum.

Der Autor dieses Artikels schlägt die Einführung einer vierten Ebene in das Konzept vor. Bei dieser Ebene handelt es sich um den Untergrund. In Städten existiert ein ausgedehntes, verzweigtes Netzwerk von Tunneln, wie zum Beispiel U-Bahn- und Straßentunnel, Unterführungen, Kanäle, etc.

In diesem Artikel wird vom Autor die Frage gestellt, warum bis jetzt dieses unterirdische Netzwerk nicht genutzt wird. Eine mögliche Anwendung wäre zum Beispiel das Leiten und Führen von Einsatzkräften zu ihrem Einsatzort und die Rettung von Menschen durch das unterirdische Netzwerk, wenn dies oberirdische nicht möglich ist. Neben der Identifikation von brauchbaren unterirdischen Netzwerken werden in diesem Beitrag die möglichen Positionierungsmethoden vorgestellt und diskutiert. In weiterer Folge wird auch der Zusammenhang zwischen der Positionierung der Nutzer unter und über der Erdoberfläche beleuchtet. Besonderes Augenmerk wird dabei auf die Nutzung von RFID gelegt, da diese Technologie einfach in Tunneln angebracht werden kann.

Nach Meinung des Autors wird diese vierte Ebene eine entscheidende Rolle für die erwähnten Anwendungsfall spielen und er ruft daher die internationale Forschergemeinschaft auf dem Gebiet der Geodäsie und den mit ihr verwandten Disziplinen auf, sich an der Weiterentwicklung dieser vierten Ebene zu beteiligen. Sein Aufruf lautet: „Going Underground“ – Lasst uns gemeinsam das Collaborative Navigation Konzept um die Ebene der unterirdischen Netzwerke erweitern!

The Fourth Layer in Collaborative Positioning – Going Underground

Guenther RETSCHER, Austria

1. INTRODUCTION AND MOTIVATION

Positioning and guidance of emergency crews and first responders, dismounted soldiers, teams of robots and other sensor platforms including vans and swarms of Unmanned Aerial Vehicles (UAV's) is heavily dependent on the availability of GNSS signals. In challenging environments such as urban canyons or indoors and transition environments, GNSS positioning may be limited or may fail. An integrated positioning solution termed 'collaborative positioning' (also called 'cooperative positioning') has been developed where groups of users are positioned relatively to each other (see e.g. Grejner-Brzezinska et al., 2009; Kealy et al., 2012). This strategy leads to a further improvement of the navigation capability of the group of users. Thereby the users are equipped with different sensors for GNSS augmentation in the sense of a multi-sensory navigation approach which provides positioning and guidance capabilities for all of them. For sharing of their absolute and relative localizations of the different platforms, location sensors with different performance and accuracy are employed as not all users can be equipped with high performance and costly sensors. Sensors that are usually employed consist of Inertial Measurement Units (IMU's), magnetometers, odometer, digital compasses and gyros, barometric pressure sensors, step sensors, image sensors including digital cameras and Flash LiDARs, as well as UWB receivers, Wi-Fi and RFID, etc. Applications range from pedestrian and vehicle navigation, to georeferencing remote sensing sensors in land-based and airborne platforms (see Grejner-Brzezinska and Toth, 2013). A description of selected technologies may be found in Chiang et al. (2003), Grejner-Brzezinska (1999), Grejner-Brzezinska et al. (2006, 2007 and 2008), Niu and El-Sheimy (2005), Retscher and Thienelt (2004), Retscher et al. (2012) and Skaloud (2002).

Grejner-Brzezinska and Toth (2013) state that collaborative navigation is facilitated not only within a network of similar users (or so-called nodes), but among various networks, that are (1) ground-based, (2) airborne, and (3) spaceborne. They think of the layered sensing navigation concept as a de facto navigation constellation to another network whose access to GNSS (top layer) may be cut off for an excessive time period. It is a multi-faceted, complex system, which requires extensive research on many levels. Its objective is to maintain the required Position, Navigation and Timing (PNT) performance for a network of sensing systems when GNSS is degraded or not available for prolonged times, and sensor calibration within a single network may not be possible, thus, a single network of users may lose its navigation capability.

Three layers in the concept have been considered until now, i.e, the users or platforms on the ground level, spaceborne on the altitude level of the GNSS satellites and airborne in between with platforms such as UAV's, helicopters and light aircrafts. In the opinion of the author, the considered three layers in the above mentioned application fields and positioning scenarios can be extended with an additional layer by going underground on land. It is suggested to consider underground structures in smart cities, such as underground metro or public transport tunnels and subways, sewer tunnels, long-distance heating tunnels, etc. In the case of large buildings such structures can also be emergency escape routes, air wells or hoistways. In this contribution the concept and the use of this fourth layer is investigated and discussed. The ultimate research goal is to enable robust multi-sensory collaborative navigation, including seamless transition between different types of navigation platforms that navigate collaborative together in the four different layers.

The paper is organized as follows: First a historical retrospective of developments towards collaborative navigation is given. Then the concept of collaborative positioning and navigation is examined in detail followed by a discussion and investigation of the extension of the layered sensing from three to four layers. Concluding remarks and a call for international collaboration complete this contribution.

2. HISTORICAL NAVIGATION DEVELOPMENT RETROSPECTIVE

Navigation technologies have changed through history crucially. The beginnings of the developments arose in the field of marine navigation. Each new method has enhanced the mariner's ability to complete his voyage. Open-seas navigation using the astrolabe and the compass started during the Age of Discovery in the 15th century. In the 18th century a highly important breakthrough for the accurate determination of the geographical longitude came with the invention of the marine chronometer. In the same century also the sextant for lunar distance measurements was developed. In the end of the 19th century radios, in form of wireless telegraphs, began to appear on ships at sea. An early prototype radio direction finder was then used for the first time. Other developments included the use of landmarks such as lighthouses and buoys close to shore to act as marine signposts identifying ambiguous features, highlighting hazards and pointing to safe channels for ships approaching some part of a coast after a long sea voyage. 1921 saw the installation of the first radiobeacon. In the year 1940 the initial suggestion for an electronic air navigation system was made which led to the development of LORAN (Long Range Navigation System). During the Second World War the first LORAN-C System was placed in operation with four stations between the Chesapeake Capes and Nova Scotia in November 1942. This system deployment can be seen as start for the successful era of radio navigation systems for marine and air navigation.

Then the development of navigation technologies has seen a rapid change in the last decades. In 1957 the world's first artificial satellite called Sputnik was launched. Scientists used measurements of Sputnik's doppler shift yielding the satellite's position and velocity. In the following, the idea of working backwards, using known satellite orbits to determine an unknown position on the Earth's surface began to be explored. This led to the TRANSIT satellite navigation system. The first TRANSIT satellite was placed in polar orbit in 1960. The system, consisting of seven satellites, was made operational in 1962. Then on July 14, 1974 the first prototype Navstar GPS satellite was launched. By 1985, the first 11-satellite GPS Block I constellation was implemented. This can be seen as the breakthrough of satellite navigation. The Full Operational Capability (FOC) of GPS was announced on July 17, 1995. Nowadays GPS and Glonass are continuously undergoing modernization and Galileo and Compass (Beidou) are implemented. Forecasts say that we will have a fully deployed multisatellite system constellation by 2020. In addition, regional augmentation systems (e.g. EGNOS in Europe) are already available in most parts of the world.

Due to the development of satellite navigation systems these days, modern navigation applications mainly rely on GNSS. As GNSS may be of inadequate availability, limited accuracy continuity, and may not be available at all in challenging environments alternative systems are needed. To overcome the lack of GNSS positioning, firstly, multi-sensor systems were employed. Modern trends in multi-sensor navigation are focusing on terrain-based or image-based navigation, where imaging sensory data, acquired by, for instance, optical digital cameras and laser scanners, and digital elevation models (DEM's) are used to recover the user's location based on image matching techniques or image-to-DEM matching (see e.g. Campbell et al., 2005; Kealy et al., 2011; Toth et al., 2008 and 2009; Veth et al, 2006a and 2006b; Zaydak et al., 2012). The multi-sensory approach has then been further extended by the concept of collaborative positioning and navigation (Grejner-Brzezinska and Toth, 2013). In the following section the collaborative navigation concept is discussed in more detail.

3. COLLABORATIVE NAVIGATION CONCEPT

Individuals or a group of multiple users (or networks) in the area may be navigated together using combined useful satellite signal information and other sensor observations. This can be seen as the main principle of operation of the collaborative positioning and navigation concept. As Grejner-Brzezinska and Toth (2013) pointed out, collectively, a network of GPS users (also referred to as network nodes) may be able to receive sufficient satellite signals, augmented by inter-nodal ranging measurements and other sensors, such as IMU's or active/passive imaging sensors, in order to form a joint position solution. Therefore collaborative positioning can improve the individual navigation solution in terms of both accuracy and coverage, and may reduce the system's design cost, as equipping all sensor platforms (e.g. vehicles and pedestrian users or robots) with high performance multi-sensor positioning systems is not very cost effective. The goal is to enable multi-sensor, low-cost and robust navigation solutions based on multiple users and different types of platforms and sensors having different quality in terms of performance and positioning accuracy and assuring seamless transition between different sensors, different platforms and different navigation approaches, when transitioning between different environments (outdoor to indoor and vice versa).

Collaborative navigation uses mainly range measurements (referred to as inter-nodal range measurements) between network nodes (see e.g. Grejner-Brzezinska et al., 2009; Kealy et al., 2012). Since more than one inter-nodal measurement vector at the targeted mobile user to other users is generally available, all the intermodal vectors from the known (or more accurate) positions to the unknown location can be established. In this network-based approach all inter-nodal range measurements can be used to obtain more accurate estimates for the unknown positions, including all other pre-estimated positions (i.e., the reference nodes). Therefore, the collaborative navigation technique based on the network approach has the advantage that the errors at the user positions due to challenging terrain and vegetation can be compensated by other known (or more accurate) positions of other mobile userswhichd may result in the improvement of the navigation solution for the entire group of users (see e.g.

Grejner-Brzezinska et al., 2009; Lee et al., 2010, Kealy et al., 2012).

The key components of a collaborative network have been identified by Grejner-Brzezinska et al. (2009). They are the (1) inter-nodal ranging sub-system (each user can be considered as a node of a dynamic network), (2) optimization of dynamic network configuration, (3) time synchronization, (4) optimum distributed GPS aperture size for a given number of nodes, (5) communication sub-system, and (6) selection of master or anchor nodes.

Figure 1 illustrates the concept of collaborative navigation in a dynamic network environment. Sub-networks of users navigating jointly on the ground level can be created ad hoc, as indicated by the circles in Figure 1. Thereby some users (nodes) are part of different sub-networks. In a larger network, the selection of a sub-network of nodes is an important issue, as in case of a large number of users, computational and communication loads may not allow for the entire network to be treated as one entity. Information exchange among the sub-networks, however, must be assured. Conceptually, the sub-networks can consist of nodes of equal hierarchy or may contain a master node that will normally have a better set of sensors and will be collecting measurements from all client nodes to perform the collaborative navigation solution. The concept of a master node is also crucial from the standpoint of the distributed GPS aperture, where it is mandatory to have a master node responsible for combining all available GPS signals (Grejner-Brzezinska and Toth, 2013). This master node can communicate with sub-master nodes of the different sub-networks, thus the computational and communication loads will be reduced and tractable. A master node can be one emergency crew member as shown in Figure 1 in one ad hoc network or the mobile rescue operation center at the fire-fighting vehicle in another sub-network. As said above it is essential that these master nodes are equipped with a high-performance GNSS receiver and other sensors of better quality. The operation center is also responsible to establish communication links between all users in the sub-networks.

Apart from the two layers in the early concept development stage (which included only ground-based platforms and GNSS) it has been extended to include UAV's and other flying vehicles, such as helicopters, light aircrafts, etc., in a third layer, i.e., the airborne layer. The introduction of this layer enables the ground-based users also to perform measurements between these flying vehicles and the users on the ground in a similar manner as between the ground-based users, thus increasing the number of inter-nodal measurements. Another advantage of using UAV's in urban canyons is that their GNSS receiver may have a higher satellite visibility than the users on the ground. Therefore they may assure and strengthen the navigation solution significantly and improve the availability and reliability for positioning of each user. Ad hoc sub-networks between the ground-based users or nodes and the airborne platforms can be formed. An example for such an ad hoc network between to two emergency crew members on the ground and two UAV's is shown in Figure 1 illustrated with a yellow circle. In addition, from the on-board optical digital cameras in the UAV's image matching techniques or image-to-DEM matching can be employed.

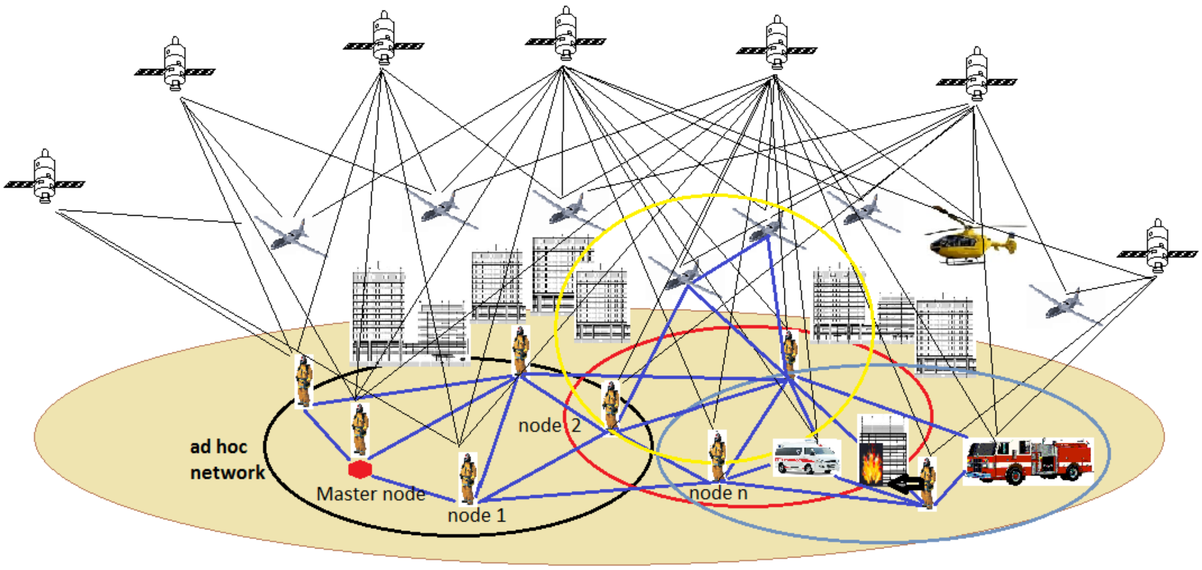

Figure 1: Collaborative navigation concept for emergency crews in smart cities

Table 1: Overview of most commonly used sensors for collaborative navigation
(extended excerpt from Retscher and Thienelt (2004) and Grejner-Brzezinska and Toth (2013))

	Sensor /Technique	Navigation Information	Typical accuracy
Radio frequency (RF)	GPS Position coordinates Velocity	X, Y, Z v_x, v_y v_z	~ 10 m (DGPS: 1 – 3 m) ~ 0.05 m/s ~ 0.2 m/s
	Pseudolites (e.g. Locata)	X, Y, Z v_x, v_y, v_z	comparable to GPS
	UWB	X, Y, Z	dm-level
	Wi-Fi Fingerprinting	X, Y	3 – 5 m
	RFID cell-based RFID Fingerprinting	X, Y X, Y	depending on cell size 1 – 3 m
INS	Accelerometer	a_{tan}, a_{rad}, a_z	< 0.03 m/s^2
	Gyroscope	heading φ	0.5° – 3°
Optical systems	Image-based	X, Y, Z	few meters
	Optical sensor network	X, Y (Z optional)	few meters
	Laser	X, Y, Z	cm to dm
Others	Digital compass / magnetometer	heading φ	0.5° – 3°
	Barometric pressure sensor	Z	1 – 3 m
	Temperature sensor	T	0.2° – 0.5° C

As pointed out above, the sub-networks can consist of nodes of equal hierarchy or may contain a master node. To achieve a collaborative navigation solution different sensors and techniques such as GNSS, UWB, Wi-Fi, RFID, IMU's, MEMS-based accelerometers, gyroscopes, magnetometers, barometric pressure and temperature sensors, as well as optical systems and image-based sensors (i.e., digital cameras, Flash LiDAR and laser) may be used. Table 1 gives an overview about the most commonly used sensors and their specifications. A comprehensive description of major types of network configuration and sensor integration techniques may be found in Grejner-Brzezinska et al. (2009).

Field experiments revolving around the concept of collaborative positioning and navigation were performed in an international cooperation of the joint IAG Working Group WG 4.1.1 and FIG WG 5.5 on ‘Ubiquitous Positioning Technologies and Techniques’ with participating members of the University of Melbourne, Australia, the Ohio State University, Columbus, USA, the University of Nottingham, UK, the University of New South Wales, Sydney, Australia, the National Technical University of Athens, Greece, and the Vienna University of Technology, Austria at the University of Nottingham in May 2012. During these experiments, different sensor platforms have been fitted with similar type of sensors, such as geodetic and low-cost high-sensitivity GNSS receivers, tactical grade IMU’s, MEMS-based IMU’s, magnetometers, barometric pressure and step sensors, as well as image sensors, such as digital cameras and Flash LiDAR, and UWB receivers. The employed platforms in the tests include two personal navigators, one from the Ohio State University and the other one from the University of Nottingham, a train on the building roof of the Nottingham Geospatial Institute, and two mobile mapping vans. Some impressions of the experiments are given in Figure 2.

Figure 2: Impressions from the Nottingham field experiments showing Charels Toth with the personal navigator from the Ohio State University, USA (left), and Dorota Grejner-Brzezinska with the personal navigator of the University of Nottingham, UK (middle)

Results of these experiments are presented in the papers of Kealy et al. (2012, 2013a and b). Other experiments conducted at the Ohio State University (see Grejner-Brzezinska and Toth, 2013) indicate that collaborative navigation is capable for significant navigation improvements, as well as enabling navigation in otherwise challenging environments. The most important aspect is the continuity and availability of the navigation solution, particularly in the transition environments. Sub-meter to a few-meter level of accuracy can be achieved indoors and in transition environments, if image-based navigation is properly integrated with the IMU-supplied navigation information, using (1) tight integration and (2) sensor calibration using GNSS signals during the clear line-of-sight navigation period (Grejner-Brzezinska and Toth, 2013).

The data processing and evaluation of the Nottingham experiments is still ongoing. The observation data has been made available online for interested researchers. Further information can be found at http://ubpos.net/. Follow-up experiments motivated by the author of this contribution shall be conducted in the near future, considering the fourth layer in the collaborative navigation concept. In the following section this extension is introduced and discussed.

4. THE FOURTH LAYER IN THE NAVIGATION CONCEPT

So far we have seen that the concept of collaborative navigation revolves around three layers which are the (1) ground-based, (2) airborne, and (3) spaceborne level (compare Figure 1). The author proposes to extend this three-layered concept into the underground. In large urban environments a widely branched network of underground tunnels exists-. The proposed idea is to make use of this wide network, for instance, to guide emergency crews to their site or rescue people when roads are blocked at the ground level. The useable underground structures can consist of underground metro tunnels, road tunnels, subways, sewer tunnels, long-distance heating tunnels, etc. Such an extension is especially necessary and beneficial for larger smart cities. In the following the usage of this fourth layer is examined and discussed.

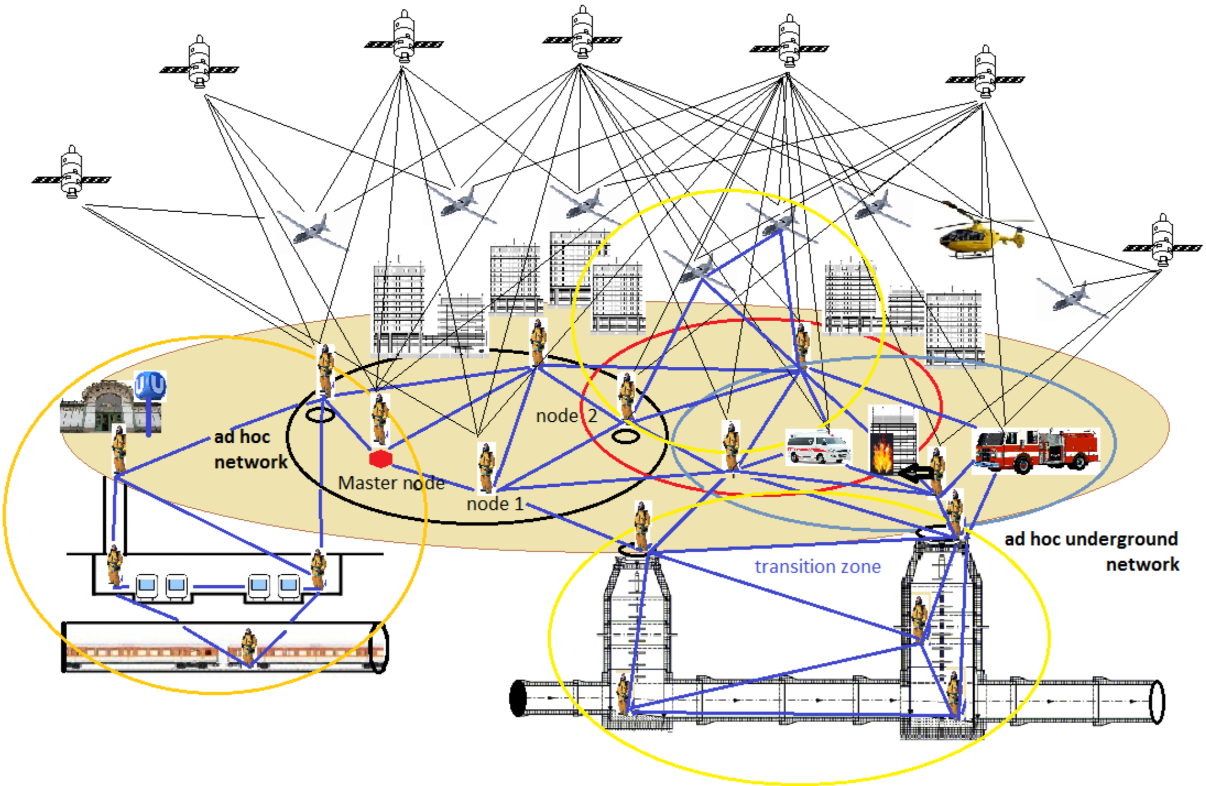

Figure 3: Collaborative navigation concept for emergency crews extended from a three layer concept with the fourth underground layer

Figure 3 shows the extension of the collaborative navigation concept from Figure 1 with the additional underground layer. As can be seen, the concept makes use of similar ad hoc networks as on the ground level or between ground-based users and airborne platforms. Most of the positioning methods and technologies in Table 1 (apart from systems requiring line-of-sight) are applicable in the underground environment. Predestinated are systems which operate autonomously and would not require any infrastructure. A suitable technique is dead reckoning using IMU's or a combination of low-cost MEMS-based accelerometers, magnetometer and/or digital compass. Therefore an emergency crew member should be equipped at least with a magnetometer or compass and step sensor based on MEMS-based accelerometers. Then the heading (direction of movement) and distance travelled can be estimated and the current location is obtained using dead reckoning. When using an additional barometric pressure sensor, it is also possible to determine the altitude of the user, hence the level below ground can be estimated. For altitude determination also a temperature sensor is required for the conversion of the barometric pressure measurements into heights (see eg. Li et al., 2013).

Due to large drift rates of low-cost MEMS-based IMU's, however, a frequent update using either ZUPT's (Zero Velocity Updates), map matching or an absolute positioning technology is required. Map matching as a first approach could be used for improvement of the positioning solution. Then the relative measurements of the dead reckoning sensors can be matched to the underground infrastructure network yielding the user's trajectory. This requires, however, that a detailed 3-D geographic information system (GIS) of the underground structure exists. It can be expected that smart cities have such a GIS already or in the near future. In case of an absence of a detailed infrastructure GIS of parts of the underground tunnel structures, however, other technologies serving as an absolute positioning method have to be employed in combination with the dead reckoning sensors. As the emergency crew members are carrying a smart device with communication capabilities the current position can be determined with cellular phone localization techniques if base stations are present in the tunnel (e.g. in public transport or road tunnels). Other radio networks may also be used. The different localization techniques are widely used and are therefore not discussed in the following. A discussion of these techniques can be found in Chen (2012). In this contribution the emphasis is laid on a new concept for the use of RFID.

The RFID technique was originally designed as a contactless and low energy consumption device for automatic identification of objects. Since it uses a Radio Frequency (RF) interface to implement the contactless functionality, it can be employed for identification and location determination by analyzing the signals received. The advantages of using RFID in indoor or outdoor personal positioning include the simplicity of the system, low-cost of the device, high portability, ease of maintenance and the capability of penetrating obstacles. A typical RFID system consists of three components, namely a transponder or so-called tag, an interrogator or reader (which receives the information from tags) and a control unit (which operates the system and processes the information). A passive RFID tag, on the one hand, contains very simple components to respond with its ID information to the signals triggered from an RFID reader. This type of tags do not use their own electronic power source for signal transmission as the energy for the tag's circuit is transmitted from the reader via magnetic or electromagnetic fields (but it may use a battery to maintain memory in the tag or power the electronics). Passive tags have practical reading ranges of about a few cm up to 15 m depending on the radio frequency used. In contrast, active RFID tags have a longer reading range (due to built-in batteries. The range of the signal transmission, as well as cost, is determined by the battery used in the RFID tag. The advantages of active tags are that they provide a longer communication range and a larger memory than the passive tags and the ability to store additional information (apart from the tags' ID) sent by the transceiver. Long-range active tags can read up to several hundreds of meters in range.

Two general strategies for using RFID for positioning are possible. The first scenario is that RFID readers are installed at specific locations or waypoints of interest. The user to be positioned is then equipped with an RFID tag and can be located in a certain section between two waypoints. The second scenario is a reverse approach. In this case, tags are mounted at certain known locations of interest (so-called active landmarks) and the mobile user is equipped with a reader. The tag's ID and additional information (e.g. the 3-D coordinates of the tag) can be retrieved in the given read range if the user passes by. The second scenario is usually less expensive than the first as a high number of low-cost tags may be installed at known locations instead of more expensive readers.

It is suggested that the second positioning scenario for the use of RFID in the underground tunneling structure is employed. Parts of the underground network can be fitted with passive RFID tags serving as active landmarks, for instance, at important crossings of the widely branched underground infrastructure network. If no permanent installed RFID tags are present in case of an emergency, tags may also be deployed temporally. They are placed at landmarks on the way to the emergency site. In case of an evacuation the tags can then lead the way for the emergency crew and people to be rescued away from the site. In other words, the tags serve as active landmarks for an efficient rescue out of the effected emergency area. The emergency crew members have to carry RFID readers which may be integrated into smart devices. If a tag is in the reading range of a reader its ID can be obtained. By reading the ID a cell is defined around the RFID tag. Hence, the most suitable way for location determination is the cell-based approach (a.k.a. Cell-of-Origin (CoO)) where the tag and the reader are assumed to be within the cell with radius equal to the reading range and the cell, centred around the tag which positions is known. A comprehensive discussion of this method and further localization techniques using RFID may be found in Retscher et al. (2012).

In addition, RFID tags can serve for identification marking in case of a fire in a building or in the underground structure. An example would be that rooms or sections in the building or tunnel which have been already checked by the fire-fighters are marked with RFID tags. For that purpose passive RFID tags are deployed e.g. on room doors or between building sections. Then it can be assured that no people in danger are behind these doors or in these areas. Additionally, a meaningful combination of active and passive tags for certain applications in dependence of the required reading range is possible.

Apart from RFID also image-based technologies using digital cameras or flash LiDAR may be employed. The personal navigator of the Ohio State University shown in Figure 2, for instance, includes a combination of digital cameras, video cameras and a flash LiDAR system. Quite a large number of researchers are working on image-based technologies. Here only two studies are briefly mentioned. The use of a single digital camera in conjunction with INS is described in Hide et al. (2010) and in combination with 3-D maps in Li et al. (2010) for an indoor application. They found that navigating in indoor environment is still very challenging with image-based technologies because it is very labor-intensive and costly to build up a reference database of an indoor environment so that a match can be performed of current images of the scene taken with the one stored in the database. In underground networks such as sewer canals or underground metro tunnels it would be much more difficult to identify unique features in the images. Hence, such an approach for using cameras is not applicable for underground networks. A suggested alternative is the use of deployable markers, for instance, with QR-codes, serving as landmarks in the same way and purpose as RFID tags. Following this strategy, the markers are deployed at certain waypoints and points of interest in the underground network permanently or temporally for leading the way to the emergency site. Thereby the marker with its unique QR-code is linked to a certain landmark in the underground network. A visual identification of the marker using the in-built digital camera in a smart device yields the current location of the user. As with RFID tags the markers can also be employed for identification marking.

To summarize it can be said that the possibilities and applicable positioning technologies for navigation and guidance in an underground structure are manifold and future methods may further facilitate this development direction. The aim is that the emergency crew is guided and finds his way through the branched underground tunnel systems. As in Augmented Reality applications, for instance, a fire-fighter may wear a head-mounted display showing him the current 3-D location in the underground GIS and the way to and away from the emergency site. As usually, communication links have to be employed to transfer the current locations of the emergency crew members in the underground network system to the mobile operations centre above ground. For that purpose the developement of new approaches for establishing communication links is required.

Apart from underground structures this concept and the related measurement technologies can be employed also in large buildings. Usable in-built pipeline structures can be emergency escape routes, air wells or elevator hoistways. Even a combination between the underground network and these structures is possible. Emergency crews can then make their way, for instance, from a large sewer tunnel into the building or nearby outside the building. The same measurement technologies can be applied as described above. In addition, if an indoor positioning infrastructure is present such as Wi-Fi or UWB this may also be used.

The author calls upon the scientific research community in the field of geodesy and related fields to further develop this concept of the usage of the fourth layer – i.e., going underground – including international collaboration and research projects. Also experts from communication industry shall be involved in the development.

5. CONCLUDING REMARKS AND CALL FOR COLLABORATION

In this contribution the author has raised the question why the international research communities of geodesists and researchers in related fields are not considering the underground layer in the current collaborative navigation concept for emergency situations so far. Until now only the ground-based, airborne and spaceborne layers have been considered. The idea of the additional usage of the underground layer is introduced and discussed. This layer can play an important additional role, e.g. for the guidance of emergency crews to their site or rescue of people when roads are blocked. Possible localization technologies for continuous positioning and guiding are elaborated and discussed in this article. They include, for instance, IMU's, MEMS-based accelerometers, gyroscopes, magnetometers, barometric pressure and temperature sensors for relative positioning using dead reckoning, as well as absolute positioning methods such as RFID, UWB, Wi-Fi and optical systems using image-based sensors (i.e., digital cameras, Flash LiDAR and/or laser). As usual in collaborative navigation, a combination of selected technologies must be employed that an emergency crew member finds his way to the site and back.

The author believes that the additional use of the underground will play an important role in emergency situations for rescuing people. A call for participation and international collaboration in exploring and developing the fourth layer – the underground – is made. Now it should be and it is of highest priority for going underground!

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