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Abstract—Current advances in localization and tracking technology have the potential to develop into much-needed tools for the saving of lives in emergency response and rescue missions, and for the safe-keeping of lives in military operations. However, civilian and military users face different environments and consequently have different user requirements. Even within the two broad fields of civilian and military applications, different types of personnel and indeed different types of missions face different needs and constraints. For instance, firefighters engaged in the suppression of a forest fire have other requirements than firefighters suppressing a fire in a high-rise building, or a conflagration in a large industrial complex full of hazardous materials. Military personnel engaged in counter-insurgency operations face requirements different from those tasked to rescue hostages held in a closed environment. This paper aims to survey the different requirements for localization and tracking technology by mission type, so that users can more easily determine their own specific technology needs. Although primarily aimed to describe requirements for military personnel, law enforcement officers, and firefighters, needs and constraints for several types of civilian applications are covered as well. Despite differences in requirements, it makes sense to develop technologies that will target several of these end-user groups. A new joint facility for development of requirements together with representatives from the various branches, and the evaluation of existing and emerging localization and tracking systems, would assist in the enabling of reliable and user-friendly capability to respond to, and recover from, all-hazards emergencies and combat operations.

Keywords — Localization and Tracking; High-accuracy systems; User Requirements

I. INTRODUCTION

Current advances in localization and tracking technology have the potential to develop into much-needed tools for the saving of lives in emergency response and rescue missions, and for the safe-keeping of lives in military operations. Law enforcement officers, firefighters, and military personnel would all be well served by the availability of a reliable personnel positioning system. Although other civilian users would find such a system useful as well, the requirements of these three groups would be most stringent, with particular attention being paid to positioning accuracy, robustness, accessibility, and weight and bulk of the system used. Any sober assessment of current and emerging localization and tracking technologies, intended for use in safety-of-life applications, would do well to begin with, and progress from, a survey of the requirements of these three groups. This paper aims to lay a foundation for the continued study, in detail, of several of these technologies.

While developments in Global Navigation Satellite Systems (GNSS) are very promising, serious problems remain in the acquisition of localization data from personnel in dense urban environments. These environments interfere with the satellite signals, in effect creating “urban canyons” of poor GNSS coverage. Satellite signals are vulnerable to interference, signal obstructions, and multipath propagation environments such as encountered in dense urban and indoor settings, as well as in regions of dense forest. In addition, GPS signals in particular are easily jammed. Although there are ways to integrate inertial and other sensor results with GNSS data, there currently is no available technical solution which provides the required accuracy and accessibility to successfully localize and track individuals during operations indoors, in densely built-up areas, or under conditions of electronic counter-measures (ECM). Under these conditions, a multisensor system with a sensor fusion capability will be needed, as illustrated in Fig. 1.

The primary use of a positioning system is deemed to be in the command and control (C2) system for the mission, which should be led locally in close proximity to the operation. This enables efficient command and control of the operation, and personnel accountability. Also, this would enable faster extraction of wounded soldiers or lost firefighters from inside buildings. The positioning results will first be needed by the commanders (squad, platoon and company) of the operation, then, as a secondary requirement, by units participating in the operation. Other essential user needs are personal alarm functionality and a self-navigation aid. Military and law enforcement personnel also need a means of reducing friendly-fire casualties and a robust and accurate target designation. The latter also implies the need for robust, accurate weapon heading estimation.

A robust communications system for both voice and digital data flow forms the backbone of any personnel localization system. Voice communications should be reserved for leading the operation, while positioning details can be transmitted as digital data. In addition, the command and control component of the operations team would often find its work facilitated by the ability to rapidly download critical information on the target
First responder positioning in urban operations

A robust, accurate positioning system for urban operations requires the use of a multisensor approach. Each fireman can be equipped with GPS, inertial sensors, magnetometers and radio-based ranging equipment. Cooperative navigation is a key factor for providing high accuracy and availability.

Figure 1. Concept for first responder localization and tracking system. A multi-sensor approach is deemed necessary, utilizing e.g. GPS-receivers, radio-based ranging, inertial sensors, magnetometers and barometers. In this scenario both short-range UWB ranging and ranging integrated into the communications waveform has been envisaged. The incident commander may have a tactical display with 3D-location information displayed on a raw building illustration, with position uncertainty information displayed as spheres (of different sizes) or through color coding.

location, for instance construction plans, data from heat and smoke detectors, and CCTV images in case of a firefighting operation, through its wireless communications network. Any needed information can then be transmitted to the personnel involved in the operation.

II. ESSENTIAL USER REQUIREMENTS

While law enforcement officers, firefighters, and military personnel have varying requirements for localization and tracking systems, all three groups share certain key requirements [1]. These are:

1. Stringent location accuracy, in the horizontal plane of no greater error than one meter in any environment so that the commander can determine the specific room in a building that the person occupies.
2. Stringent location accuracy in the vertical plane of no greater error than two meters so as to be able to determine the specific story in a building that the person occupies.
3. Constant accessibility for those who need the positioning data.
4. Physical robustness so that the system will operate reliably even under harsh conditions, including extreme temperatures and humidity.
5. Encrypted voice communications and data transfer.
6. Integrity monitoring, with automatic estimation of localization errors (uncertainty) combined with detection and warning in case of electronic attack.
7. Positioning data to be compatible to and integrated with other information, in particular personal health status (physiological monitoring).
8. Real-time map-building capability in the form of simultaneous localization and mapping (SLAM) approaches in unknown buildings as the team moves through it; SLAM should be automatic, without the need for the team members to aim cameras or other sensors in various directions.
9. The system should not depend on bulky antennas; antenna and cables should be incorporated into the individual’s uniform.
10. Weight of personal localization and tracking gear (including processing unit and visualization interface) to be less than 1 kg, and not bulky.
11. The system must be energy-efficient, with battery power to last for at least 24 hours but preferably up to a week, depending on type of mission.
12. Presentation of positioning data to be intuitive and easy to understand, in particular for the personnel actually carrying out the operation.
13. A modular system would be most useful, since even the same user may face different challenges on different missions and occasionally have no real need
for positioning data (users may differ on this need; soldiers and law enforcement officers tend to prefer a modular system, while firefighters instead expect always to carry the whole system).

14. Pre-installation of the localization system should not be needed.

15. In any armed operation, the visualization system should present heading to own troops and in particular the heading of the weapon. Data for distance and direction to targets and threats should also be presented.

16. In order to achieve a high market penetration the price of the complete positioning system should be below €1000. Hence, the cost of each sub-sensor must by necessity be kept low.

The operational environments encountered will be very diverse (see for instance the article in [1] to get a feeling for the scenarios and tactics employed in firefighter operations). This is possibly best exemplified by the firefighter example with operations ranging from fire-suppression in a wooden two-story family home to commercial concrete multi-story buildings with tens of thousands of square-metres. Furthermore, various user groups will have different stringent requirements, as well as different trade-offs concerning for instance cost versus accuracy. This can in turn be motivated by considering police officers assigned to traffic duty, or responding to domestic violence calls, when compared to the needs of special weapons and tactics (SWAT) operators. The same reasoning applies for soldiers performing patrol duty in rural areas with only small buildings when compared to building-clearing operations (as conducted not to long ago in Sarajevo’s so-called “sniper-alley”).

Hence, a modular system is desired, with different cost vs. performance trade-offs. However, smoke-diving (or Rapid Insertion Teams – RIT) firefighters, military personnel in urban combat operations or SWAT-team operators are believed to have similarly stringent requirements.

Stealth capability would be an advantage but remains of less importance, since voice radio can be expected to be used during the operation as well.

A requirement for many users operating in built-up commercial areas such as major department stores and malls may be compatibility with data from systems that are, or will be, installed to measure what retailers, who use such systems for commercial reasons, call “footfall,” that is, data on the number of people visiting a shopping complex and on how consumers actually move inside it. At present, footfall is primarily measured with CCTV cameras, although triangulation of GSM signals from mobile phones carried by customers would work as well. There are, however, emerging technologies for this that could be made compatible with other types of localization and tracking data, such as, perhaps, radio tomographic imaging which would rely on numerous pre-installed ZigBee transmitters broadcasting radio waves reflected from the object under observation.

III. MISSION-SPECIFIC USER REQUIREMENTS

In addition to the essential user requirements already described, there will be additional needs and constraints in localization and tracking capability. System requirements will differ depending on user and type of operation. For mission critical and life saving operations, some users will need Safety-Of-Life critical systems in which accuracy and accessibility are more important than cost. These include military special forces personnel, police special weapons and tactics (SWAT) teams, and firefighters.

Other users, including regular military, law enforcement officers, and private security guards will find accuracy, accessibility, and cost of roughly equal importance when deciding upon a localization and tracking system.

The range of operations in which localization and tracking capability would provide an edge is wide. The most common types are listed in Table 1. These will be described in some detail.

Table 1. Common types of operations in which localization and tracking capability would provide a key advantage.

<table>
<thead>
<tr>
<th>User type</th>
<th>Operations</th>
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<td>Military</td>
<td>Urban combat</td>
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<td>Building clearing</td>
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<td>Ship boarding</td>
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<td>Law enforcement</td>
<td>Hostage rescue</td>
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<td>Crowd control</td>
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<td>Firefighting</td>
<td>Residential and apartment building fires</td>
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<td>Complex building fires</td>
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<td>Ship fires</td>
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<td>Forest fires</td>
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<td>Subterranean Rescue Operations</td>
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<td>Civilian users</td>
<td>Detention facilities</td>
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<td>Private security guards</td>
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<td>Protection of sensitive facilities and</td>
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<td>transportation of hazardous materials</td>
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<td>Protection of Civil Servants</td>
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<td>Emergency Response Operations during</td>
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<td>Humanitarian Missions in Crisis Areas</td>
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<td>Localization of the Elderly in Nursing Homes</td>
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<td>Localization of Children</td>
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IV. MILITARY OPERATIONS

Most countries have recognized the need for improved soldier systems and they are currently pursuing soldier modernization programs. A few examples are FIST (UK), Soldato Futuro (IT), tdZ (GE), FELIN (FR), Land Warrior and Future Force Warrior (US), MARKUS (SW) and the 21st Century Soldier System (European Defence Agency), see for instance [2]. Many of these focus on C4I (command, control, computers, communications and intelligence), lethality (weapons and sights), mobility (navigation, size and weight), survivability (helmets, bullet-proof vests, NBC-protective gear, uniforms) and sustainability (logistics, food/water, power). Many of these systems already use, or plan to use, GPS-receivers in combination with dead-reckoning approaches for GPS-denied environments. All these programs include situational awareness for soldiers.

The notion of situational awareness systems for soldiers is a broad area, but some of the most important questions it could answer for the soldier are:
- Where am I?
- Where are my comrades?
- Where is the enemy?
- What is my current task?
- Where am I supposed to be?
- How do I get there, quickly and safely?
- Is it safe to shoot in this direction, or blow out this wall/door?
- Has the whole building been searched?
- Are my comrades OK?

It is noteworthy that these functions can to a large extent be performed through voice communications, which is why robust voice communications is the number one priority. It can be difficult and require much attention for team leaders to keep track of the positions and update team members on the situation constantly.

A. Urban Warfare

Urban warfare operations, in particular in a counterinsurgency context, pose particular challenges. Localization and tracking will be made more difficult by the built-up environment. In addition, it will be difficult to distinguish between civilians and enemy fighters, since the latter hide among the former and use civilians as cover or even as living shields. Furthermore, distances tend to be short, which also means that the tactical situation can and will change very rapidly. It is difficult to achieve a good situational awareness (SA) without technological aids.

In urban operations, buildings will need to be secured and searched for enemy fighters, arms caches, or contraband. Enemy snipers may hamper operations. The layout of buildings is usually unknown before the soldiers enter them. Floors and rooms will have to be secured and searched one by one. In particularly dangerous and difficult situations, the soldiers may need to blast holes in existing walls to reach otherwise inaccessible areas.

This means that the key use of a localization and tracking system will be to enable the commander in charge of the operation to lead efficiently, enabling the various squads and soldiers to support each other. It remains to decide upon what information squad, platoon and company commanders should be provided automatically (detailed information can be retrieved on demand). Also, the visualization interfaces may be different to better support their respective tasks. A key requirement is friendly-fire/blue-force-tracking capability (known as location accountability to first responders). It will be particularly important to ensure that no two teams enter the same room or storey at the same time, which easily might cause casualties due to friendly fire. This need also applies to long-distance supporting fire. It will be required to track the heading and stance of each individual weapon. It would also be helpful if the soldier’s own posture can be estimated, such as in what direction his body or head is facing.

In case the layout of buildings is known, this will facilitate the rapid and secure movement of troops through them. However, building plans are often unavailable, and then a requirement would be the ability to measure distances and the geographical position of the building’s corner from a known position. Such data, if used together with a localization and tracking system, would help the soldiers inside the complex to determine their relative position with regard to entry and exit points and identified enemy positions. The system should be able progressively to map the building by SLAM based on collected data. This will also facilitate rapid medical evacuation of wounded soldiers.

If the localization and tracking system also enables the commander to read the health status (physiological monitoring) of each individual, for instance in the form of readings of body temperature, pulse, blood pressure, and indicator of non-movement, he can adapt the operation to the physical capacity of the soldiers (as a group). Although the psychological factors may be as, or even more, important for an individual soldier’s combat readiness, a status system could make the commander aware and a simple voice check-up could often suffice. In particular heat stress may cause problems in a combat situation, since many war zones are located in warm climates and the use of body armor and the carrying of heavy equipment will affect the soldiers. Health status data could also facilitate automatic alarm in case of injuries, and trigger a rapid and safe medical evacuation.

Although the real value of localization and tracking in urban warfare will be during actual operations, the possibility to store data and use it during debriefings can be very useful. Such data may also provide important intelligence on whether enemy fighters were indeed killed or captured. Stored data will also be of great value in evaluating performance during exercises.

There may occasionally arise urban warfare situations in which it is possible to pre-install localization and tracking systems. Examples include major public buildings such as parliaments or presidential residences in a country threatened by insurgency, such as Iraq and Afghanistan. This would facilitate increased accuracy and accessibility in case of enemy raids or suicide attacks.

B. Safe Navigation through Minefields

Another possible usage is to enable safer navigation in dangerous areas. For instance, if a safe passage has been identified through a minefield, localization and tracking gear can enable soldiers to move through the area safely even in darkness and under silent conditions, for instance in preparation of an assault or raid. In this particular situation, however, the soldier needs to be ready for combat at any moment, so he must have his attention aimed forward and on his weapon, not on a screen. A requirement here would accordingly be that navigation commands are presented by means of, for instance, tactile belts in which vibrations indicate the direction in which the soldier should move. However, the use of tactile belts or other non-intuitive types of interfaces demands a high level of training in them to react instinctively on the stimuli (which will be difficult to achieve since humans in conditions of serious stress tend to suffer a reduction in sensory stimulation). More intuitive types of presentation interfaces such as personal digital assistants (PDA) and the like demand user interaction, which cannot always be ensured in a combat situation, work poorly in sunlight, and may reveal the user’s position to the enemy at night.

Unlike in situations of urban warfare, however, the soldiers will in these circumstances normally remain in environments within line-of-sight propagation paths to several GNSS. The technological challenge is thus at a first glance less than in urban warfare situations, but the GPS could be jammed during these scenarios. The presentation interface also faces different challenges. Even so, most of the requirements presented for urban warfare
may be of help in this situation as well, in particular blue-force-tracking capability in case of sudden exchanges of fire.

C. Caves and Underground Facilities

Military forces may encounter enemy troops holed up in tunnels or in underground bunkers. This poses problems since pre-installed positioning systems will definitely not be in place. The difficulties in searching and securing for large cave complexes are well-known from recent experience in Afghanistan. A localization system with accountability, mapping, self-navigation, friendly-fire avoidance and alarm functionality would increase the possibilities of keeping soldiers alive during these missions.

D. Discussion

Typical user requirements in military operations are discussed next. Basically, the requirements are very similar to those stated in the list in Section II above. Some differences exist and these are emphasized herein. Integrity monitoring is of crucial importance in military operations, especially if incorporating civilian GNSS-receivers into the system. A reliable estimate of the localization error is perhaps more important than a high localization accuracy to begin with. Size, weight, automation and power (SWaP) requirements are very important for soldier applications. Due to the large variety of operational scenarios, a modular system is desired. Weapon heading estimation is very important.

There are a number of other requirements relating to C2, which would be of key importance in military operations. Due to the nature of close combat, three-dimensional (3D) geospatial data should be transmitted to the squad leader and soldiers directly participating in the operation. They are the ones who need the positioning data most, and speed is essential, as is a non-obtrusive and intuitive visualization interface. It is of high interest to examine what information should be relayed to the individual soldiers, and how it could be visualized.

Higher-level commanders, that is, company and battalion commanders, normally need only positioning and status data on the squad, not its team members. However, there is a requirement that detailed 3D data should be available for presentation upon demand.

V. LAW ENFORCEMENT OPERATIONS

Localization and tracking gear can give the user the necessary edge to resolve a hostage crisis. Localization and tracking can also assist in coordinating major operations such as crowd control during major sports events, urban riots, and in the aftermath of major acts of terrorism.

In addition to the common user requirements already described, there are a number of others which would be of key importance in law enforcement operations. Such operations tend to be led from the site of operations. 3D positioning data should thus be made available to both the mission commander and those taking part in the mission. In addition, plainclothes operations will require covert localization and tracking gear that will not compromise the officer using it. In fact, law enforcement organizations fulfill a large number of different types of missions, each with different requirements, so a modular system that can be adapted to fit the mission is an additional requirement.

A. Hostage Rescue, Indoor SWAT Operations, and Ship Boarding Operations

The usefulness of a localization and tracking system increases with the size and complexity of the building in which the operation takes place. In a small building, there may even be no need for the system. However, even an operation that at first is limited to only one small building may, despite attempts to the contrary, evolve into a chase for perpetrators and possibly one or more of their hostages. If so, a localization and tracking system might well become the decisive tool to save the hostages and apprehend the perpetrators.

Ship boarding operations pose particular problems. Although ship plans are often available (can be acquired during the planning phase of the operation), many vessels are very large and also contain small closed areas such as staterooms and storage rooms. In addition, the bulkheads hamper efficient use of traditional radio communications and thus a radio-based positioning system while inside the ship. In cruise ships, the number of civilians may be very high.

Localization and tracking gear will enable the mission commander to lead the operation more efficiently. Since this type of operation often will be handled by SWAT teams, it will surprise nobody that the advantages offered by localization and tracking gear often will be quite similar to those experienced by military users. Such gear will, for instance, enable the mission commander and team members to log the location of the perpetrators, possibly based on reports from observers outside the building. It will facilitate navigation within the building, support the medical evacuation of casualties, and give the tactical ability to let reinforcements and medical teams follow the same way in that has already been used ("snail-tracks") and thus found not be booby-trapped.

As in a military operation, stored localization and tracking data can be used in post-operation debriefings. However, there is concern about how such a use of the data may affect the ensuing judicial process.

B. Crowd Control

Localization and tracking can also assist in coordinating crowd control during major sports events, urban riots, and in the aftermath of major acts of terrorism. Efficient command and control of personnel is enabled, as well as personal alarm and accountability.

A localization system will not show whether civilians or victims still remain in a building, but it can be used to safeguard that every part of the building is being searched. If the localization and tracking system can receive data from any pre-installed commercial footfall system, this would be helpful as a means to keep track of civilian movements and to correlate that law enforcement officers are moved wherever they are needed.

Jamming of police communications has occurred during riots and a localization and tracking system must be able to handle deliberate jamming attempts.

C. Discussion

Although the requirements vary depending on the type of mission, the key requirements for indoor scenarios correspond well to those discussed for military users. One example is that a patrol officer assigned to for instance traffic duty may prefer a lighter and smaller system, and
VI. FIREFIGHTING OPERATIONS

During major fires, localization and tracking technology can be an efficient means to coordinate fire-suppression operations. However, an accountability system that would give the incident commander information about firefighters that are lost or starts to behave erratically (e.g. move away from the other firefighters and/or the fire hose) is highly desired. Also, the situation where a firefighter is lost at the fire ground causes multiple casualties each year in the US alone. Rapid insertion teams (RIT) are then sent in to find and extract the firefighter and the ability to quickly and decisively guide them to the firefighter in need would save lives.

In many countries the tactics today is that the incident commander gives out orders and directs the firefighters over radio. The information about the positions of all firefighters should be relayed to the incident commander, but perhaps not to the individual firefighters. One can however envision several situations where the firefighters on scene would benefit from direct access to position information, e.g. in cases with radio coverage problems. Distance measurements between a RIT-team and the missing firefighter should also increase the speed of rescue. It is however a delicate task to decide upon how the information should be visualized to a firefighter during the extremely stressful and physically exhausting situations that commonly occur.

In addition to the common user requirements already described, many of which would be the same for military and law enforcement users, it should be emphasized that physiological monitoring, with an automatic alarm function, and also real-time map-making (SLAM) capability will of the greatest importance for firefighters. Searches of rooms performed by a RIT can be very slow due to the limited visibility. Floor-plans would increase speed. Also, the use of thermal imaging cameras helps speed up a search. Data need to be made available to the incident commander as well as to any reinforcements or medical evacuation teams entering the premises after the initial group of firefighters. Also, during larger firefighter operations reinforcements from other fire departments typically occur and the person designated as being the incident commander may change several times during the incident. An automatic situation awareness system is thus very valuable.

A. Fires in One- or Two-story Family Homes

Discussions with Swedish firefighters indicated that during ordinary residential fires there is typically little need for localization and tracking gear [1]. In contrast, firefighters in the US state that the residential fire is the most common one in all fire departments, and that this type of fire causes many casualties on the fire ground each year. Thus, there is a serious discrepancy in the initial requirements depending on where the system is to be deployed. The conflicting needs as stated by the end-users for similar scenarios is of interest to clarify somewhat. Although we do not have the necessary skills in firefighting operations to bluntly state the reasons as facts, we propose several motivations that could be further penetrated in cooperation with end-users from both countries.

Sweden has strict building regulations and we believe that the standard of housing is higher, concerning building insulation, fire safety and electrical wiring and equipment. It is thus believed that these residential fires are more intense in the US, and they occur more frequently. Also, traditionally US firefighters have probably more often entered buildings that are on fire, for fire suppression actions as well as searching for occupants. Thus, there are more often firefighters inside the buildings, and this in combination with the possibly more intense fires with possible structural collapse as a result could possibly explain the higher number of fatalities in residential fires in the US. Several firefighters die in this kind of fires each year in the US. In comparison, one Swedish firefighter has died the last five years in similar circumstances. This discussion is meant to give a motivation for the discrepancies in needs stated by the firefighters for residential fires. Whereas US firefighters may need to go in and, risking their own lives, find lost comrades inside burning buildings, Swedish firefighters may feel that their training suffices for handling the typically encountered fire scenarios with limited spread of the fire (e.g. bed-smoking accidents).

It is likely that differences in tactics and scenarios will result in varying requirements between end-users in different countries, but also between fire departments (albeit not as pronounced)

B. Fires in Multilevel Apartment Buildings

In comparison to residential fires, complications can easily take place when a smoke-filled multilevel apartment building must be evacuated. A localization system will not show whether victims still remain in the building, but it can be used to safeguard that every part of the building has been searched.

A conflagration in a large apartment building may escalate rapidly. If there is a sudden risk that the building will collapse, it is imperative to get all firefighters out as rapidly as possible. If a building collapses suddenly and without warning, a localization system could (if the localization and communication systems are physically robust enough) possibly serve as a means to locate them. However, if the firefighters survive but find themselves unable to exit the building the way they came in, then a localization and tracking system may be able to assist them in navigating their way out, that is, finding a safe exit path.

C. Fires in Complex Buildings

While a localization and tracking system may to some fire departments be considered of only auxiliary use in ordinary residential fires, the situation changes when a fire breaks out in a complex building such as a mall, night club, office building, or industrial facility. These kinds of situations are often characterized by buildings of considerable size, a large numbers of civilians on the premises, and unusual and often unexpected building layouts with many long corridors, large open spaces, and numerous rooms of varying sizes. Entrance and exit routes to the conflagration itself may be long and complex, and the fire may move rapidly into quite different and hitherto
unaffected areas. In addition, even parts of the complex not on fire may be severely affected by smoke, which can incapacitate and kill civilians there, and may cause panic that in itself causes fleeing civilians to get trapped (and in unfortunate cases even killed) or block access routes. A localization and tracking system could assist in mapping the building and in finding safe entry and exit routes for firefighters as well as trapped civilians.

In theory, building plans should be available. However, there is no guarantee that such plans can be located in time for the firefighters to make use of them. A SLAM capability would be an additional safeguard.

In hazardous materials facilities such as nuclear power plants and chemical industries, it will be possible to pre-install positioning systems. Such a system could serve to localize and track firefighters and other staff as well as the supplies of hazardous materials. It could also assist in guiding remote-controlled rescue robots. As an additional advantage, such a positioning system may also assist in guarding the facilities. However, any pre-installed positioning system runs the risk of being disabled in case of accidents so an alternative, mobile system would be needed as well.

D. Fires on Ships

Serious conflagrations on ships, in particular cruise ships and vessels carrying hazardous materials, pose very serious risks. While small fires on ships will be dealt with by the crew, major conflagrations may entail the use of land-based firefighters in an emergency response role. Although ship plans are usually available and can be studied en-route to the burning ship, the firefighters will not be able to bring all standard equipment but often will have to rely on resources already onboard the vessel. Since the layout of the ship may be complex, a localization and tracking system would certainly assist the firefighters engaged in such a rescue operation. The communication system as well as any radio-based ranging equipment will experience very different propagation characteristics during operations on ships.

E. Forest Fires

Firefighters engaged in reducing the impact of forest fires usually find themselves spread out over large areas (sometimes in remote locations). Localization and tracking data can be used to safeguard firefighters in the area, in case of sudden winds that cause the fire to change direction, but will also enable the mission commander to get a constantly updated map of the fire itself, which will make it easier to contain. Accuracy need not be quite as good as for indoor firefighting operations, but the transmission of health data and an automatically activated alarm function in case of injury will safeguard the personnel participating in the operation.

F. Subterranean Rescue Operations

Subterranean facilities such as tunnels, including those used for railways and other forms of public transportation, pose serious challenges for emergency response personnel, since the access route in case of fire or other disaster can be very long and, in complex tunnel environments, difficult to navigate. The environment causes problems for many radio-based positioning and communications systems as well. Pre-installed positioning systems in combination with body-worn sensor systems would seem to be the best choice; Yet, it would be foolhardy to assume that pre-installed systems will always be in place or in operation.

Rescue operations in commercial underground mining sites, such as coal mines, pose very similar problems and would benefit from the same types of technology. These environments are both physically harsh and accidents may occur that also destroys or damages pre-installed systems [5]. Underground mines are typically composed of very long and narrow tunnel complexes, sometimes instable, with heavy machinery and personnel at different locations. These scenarios typically also include several factors that make radio communications and positioning more difficult, e.g. limited line-of-sight conditions, electromagnetic noise, ionized air and potential gaseous hazards.

A combination of pre-installed and mobile sensors may be required in these difficult circumstances, especially since the localization and tracking system must function for at least one day. Such a system could also be used to reduce traffic accidents in larger mines, the visibility in mines from a large mine-truck for instance, is quite limited.

G. Discussion

Firefighters do not need weapon direction information, but for purposes of self-navigation it may be required to have estimates of the orientation of the body or head. They also have even more stringent requirements on physical robustness, concerning heat and water. Integrity monitoring is important, but the detection of electronic attack may not be as pronounced. The requirement of battery life-time may also be relaxed. Many fire departments state that they want the localization and tracking system to be an aid to the incident commander. In contrast to military and many police operations, the incident commander usually sits in a vehicle and leads the operation. More information can then potentially be visualized to the fire fighting incident commander, and larger visualization interfaces can be used. The question remains what situational awareness information should be automatically conveyed to the firefighters.

VII. ADDITIONAL CIVILIAN APPLICATIONS

Besides military, law enforcement, and firefighter users, localization and tracking systems can be profitably employed in many other lines of work. We primarily focus on discussing requirements for safety and security applications herein. For these groups, unlike the former, there will likely be another trade-off between accuracy and cost, since requirements for most other users are usually less stringent especially concerning accuracy.

Further, the current development within location based services (LBS) is extremely vivid, both concerning R&D of localization technology for mass-market platforms such as high-end mobile phones as well as the development of applications taking advantage of the existence of positioning systems within these platforms. Although we mainly focus on users that due to stringent requirements will require the development of stand-alone localization and tracking systems, we also anticipate that several of the applications discussed within this paper could actually be realized through for instance iPhone app’s (or similar equipment). It is exciting to follow this development and see what kind of accuracies and availabilities can be
obtained with these platforms. A personal alarm application on a mobile phone, which transfers position as well as voice (and possibly image) feeds to a security company or directly to the police, is in our view an example of a successful future application. Similar systems already exist, using GPS-receivers and GSM-modules, but seamless outdoor-indoor functionality is still lacking.

Furthermore, in many of the discussed applications there are delicate privacy issues that need careful consideration. Very few potential users that expect to use (benefit from) the system very seldom, for instance considering the alarm functionality, will accept that the position information is used for other purposes (e.g. work management or review).

A. Detention Facilities

Correction officers and other staff at detention facilities often experience threats and violence from inmates. A personal attack alarm function (essentially a wireless distress button carried on the person to be manually activated when threatened or under imminent attack) which upon activation would transmit position and an alarm message to the command center would be an extra safeguard, as would the transmission of health status data. Since most operations take place indoors, the localization and tracking system must be sufficiently robust to operate under such conditions. To some extent, a pre-installed positioning system in combination with building-layouts could be used, but a mobile back-up system would be advantageous to ensure operations under severe conditions, for instance during a fire or prison riot.

Localization and tracking gear can also be used to monitor the inmates. This could increase safety, decrease the risk of escapes, and possibly reduce violent crime between inmates as well. After a crime has been committed on the premises, the positioning data could be utilized in the evaluation of what happened and who were involved. This would naturally bring the requirement that the tracking gear can be placed on the inmates without them being able to remove or tamper with the device. A similar system already exists, in the form of electronic shackles. However, these systems are often not tamper proof, merely difficult to tamper with covertly.

B. Private Security

Private security guards often work alone. For this reason, a localization and tracking system could serve as an easy means to increase their physical security. Legislation in some countries, primarily those of the European Union, can be interpreted as giving greater emphasis on the protection of employees, which could convince firms to invest in additional security measures. The key benefit of having an localization and tracking system for security guards would be constant access to the physical location of the security guard and, if costs allow, possibly his health status as well so that he can be relieved if attacked or if disaster strikes. There is also scope for employing a localization and tracking system for asset tracking of money deposits, jewelry, and vehicles. Not only localization and tracking systems but also immobilization systems are already installed in many luxury cars and trucks/trailers to prevent theft. However, the threat of deliberate Incidents of GPS-jamming is present not only in military operations, jamming of vehicle GPS-systems have been reported [4].

C. Protection of Sensitive Facilities and Transportation of Hazardous Materials

The benefits of localization and tracking systems for security guards is further emphasized when it comes to the protection of sensitive facilities such as nuclear power plants, oil refineries and terminals, and chemical industries. Not only would the use of such systems enhance the ability to defend and protect the facilities against attacks, it would also serve to facilitate the evacuation of its staff in case of serious emergencies. Also, it would enable the personnel and emergency responders to keep track of hazardous material on the premises. In installations of this kind, pre-installed positioning systems can be employed to great effect. Also, building layouts should be available and they provide an efficient means of improving indoor localization accuracy when using dead-reckoning techniques. In case of emergency, it would be advantageous if the data can also be linked straight to the emergency response team.

The primary foreseen use is expected to be self-navigation, accountability and alarm system.

D. Protection of Civil Servants

Social workers, public officials, and many others at risk from disgruntled members of the public, as well as criminals, would benefit from the use of at least a simple localization and tracking system that in case of danger could sound the alarm to any local law enforcement or security function. The requirements for accuracy would be lower than for comparable first responder systems, and the weight and bulk of the personal system must be kept down even further so as to ensure that it is not left unused in the office. It should be possible to integrate this function in, for instance, a PDA or mobile phone. Cost must be kept low as well to ensure acceptance by the market. Pre-installed support systems and building-layouts could be used to reduce cost, but they are not always available (e.g. during home visits).

The alarm functionality could become the main application.

E. Emergency Response Operations during Humanitarian Missions in Crisis Areas

Crisis areas demanding international participation in emergency response operations (e.g. due to flooding, tsunamis or earth-quakes) are often located in remote and inaccessible locations. Also, criminals, kidnappers and insurgents sometimes pose a real threat to relief workers. Hence, data on the physical location of the team members, preferably with data on health status including alarm functionality in case of serious personal injury, should be transmitted to operations headquarters. Localization data should be updated regularly. The required update-rate does to some extent also depend on the possibilities for, and estimated time for, a rescue operation. Since locations tend to be remote and lack functioning communications infrastructure, satellite communications will often be the only practical solutions (HF-radios are often omitted due to weight considerations). However, data flow bandwidth will not need to be extensive. Accuracy would in most cases not need to be greater than approximately 10 meters (unless in conditions that entail movement through...
minefields, in which corresponding military requirements would apply). Energy efficiency, however, will be of great importance, since batteries generally must last for at least a week.

The primary foreseen use would essentially be self-navigation, and an accountability system with alarm functionality.

F. Localization of the Elderly in Nursing Homes

Localization and tracking systems could also be used to monitor patients suffering from Alzheimer’s, dementia, or related disorders in case they unexpectedly leave their home or place of treatment. A personal positioning system would assist in recovering lost patients and thereby save lives as well as resources by limiting the area that needs to be searched.

Such a tracking system must be cheap, small in size (corresponding to a wrist-watch or a mobile phone), require no user inter-action, and require little battery power. The key user requirement will be accessibility, since accuracy would not need to be higher than approximately 100 meters if the system only needs to locate the patient during a search operation. If it also should sound the alarm when the patient exits the premises, accuracy must be higher. However, in either case the tracking system must function indoors as well as outdoors. Accountability, alarm and search-and-rescue functionality are probably the main uses of such a system.

G. Keeping Track of Children

Similar requirements would apply for the automatic monitoring of children in indoor public facilities such as kindergartens. This is a concern in some countries, such as in the USA. It may then be worthwhile to introduce a system with sufficient accuracy to sound the alarm if the child leaves the premises, by accident or through an attempted kidnapping.

A pre-installed system, or utilizing building-layouts, could possibly be used in order to reduce cost. The user-units should be very small, low-weight and require no user-interaction. It could essentially be used as an automatic accountability system with alarm functionality.

Such an automatic monitoring system should not be confused with a localization and tracking system that would be able to foil a serious kidnapping attempt. Such systems exist but rely on different technology (often passive Radio Frequency Identification, RFID, tags) since they need to be invisible to the kidnappers.

VIII. CONCLUDING REMARKS

Military personnel in peace-keeping/enforcement operations, law enforcement officers, and firefighters face very similar needs, despite their differences in operational scenarios. It makes sense to develop localization and tracking technologies that will serve not only one but several of these end-user groups.

To facilitate this, we propose that a joint facility be established for development of requirements and evaluation of existing and emerging localization and tracking systems, in cooperation with these user groups [1]. Such a facility would benefit from a pre-installed high-accuracy system against which new stand-alone technologies can be compared and evaluated. Research on the human-machine-interface component would also be facilitated; the question of what information should be conveyed to the individual soldier or firefighter, and how it should be presented, is indeed a non-trivial task that requires significant attention.

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REFERENCES


