Indoor location systems in emergency scenarios - A Survey

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ABSTRACT

Indoor location data are critical in emergency situations. Command centers need to monitor their operational forces. Rescuers need to find potential victims to carry proper care and the building's occupants need to find the way for fast evacuation. Despite the growing body of research in indoor location, no technique is considered appropriate for different situations. Furthermore, few studies have analyzed the applicability of these techniques in an emergency setting, which has particular characteristics. This survey reviews works in indoor location applied to emergency scenarios, analyzing their applicability in relation to existing requirements in these types of situations.

Categories and Subject Descriptors

C.3 [**Special-purpose and application-based systems**]: Real-time and embedded systems; D.2.8 [**Computer-CommunicationNetworks**]: Distributed Systems—client/server

General Terms

Theory

Keywords

indoor positioning, indoor navigation, emergency management

1. INTRODUCTION

In emergency scenarios the fast conduction of victims to exit (evacuation) and the precise monitoring of the rescuers[1] position are both important to reducing deaths and injuries. To monitor rescuers command centers use radio communication, where the team member directly reports his/her position. In situations of stress, disorientation or unconsciousness the active reporting strategy may fail [11].

Location positioning systems can be used to automatically gather the positioning of rescuers and victims. The most usual location technique, the GPS, does not work well indoor because of interferences generated by physical barriers (such as walls and furniture) and sources of radio signal [17]. Thus, many techniques have been developed to provide the location of mobile devices in indoor environments with greater accuracy. However, emergency situations have particular characteristics (e.g., smoke, blackout) that can reduce visibility and make useless the current indoor positioning systems (IPS).

Most of existing surveys approaching location systems focus on the adopted technique, without considering the specifics of emergency scenarios [35, 19, 12, 14, 32, 39]. Only one review of indoor positioning systems for emergency situations was identified [6]. However, it is from 2011 and does not connect the characteristics of emergencies scenarios with most modern techniques.

Besides, there is a lack to categorize the requirements of emergency situations for indoor location systems. For example, luminosity is essential for indoor location techniques based on images. However, on emergency situation we can experiment scenarios as lack of power or presence of smoke that compromise the luminosity.

This work aims to present the state-of-the-art of solutions for indoor location in emergency scenarios. Our research questions are: "*What are the requirements for using indoor location systems in emergency situations?*"; "*Existent indoor location systems support those requirements?*"; "*There are unattended demands for a new indoor location solution for this domain?*".

The paper is organized as follows. Section 2 discusses related work. Section 3 presents the survey protocol. Section 4 reviews and presents a taxonomy of main indoor location techniques. Section 5 discusses the survey results, which include: a requirements list of indoor location systems for emergency scenarios, a summary and analysis of the main works in indoor location for emergency scenarios. Section 6 presents our conclusions and future works.

2. RELATED WORK

We identified only one study that performed a review of indoor positioning systems for emergencies scenarios [6]. It

[1]We consider "rescuer" as any operational forces member, comprising medical, police and fire brigade.

presents only radio and inertial-based systems. This study does not list the characteristics of emergency situations and does not address new techniques arisen since 2011.

Other studies performed surveys about location systems in general scenarios [32] and related to specific techniques: radio [35, 32], ultrasonic [14], optical [19] and inertial [12].

In [28] is presented a list of user requirements for location systems in emergency scenarios, extracted from interviews with firefighters, police and military personnel. This work also analysis performance and limitations of GNSS (Global Navigation satellite Systems), radio and inertial navigation systems. In [29] authors present a continuation of the research, bringing a more extensive list of requirements. However, this work does not consider the specifics of each type of emergency scenarios.

3. A TAXONOMY FOR INDOOR LOCATION TECHNIQUES

Since indoor location literature is vast, comprising different techniques and disciplines, we conducted a preliminary review[2] before performing the actual survey. The results of this review are presented in Table 1 classified according to: signal type, measurement method and infrastructure needs.

The **signal** categorization is related to which type of signal is used as reference for the location system. **Inertial systems** use the direction and acceleration of a moving body to infer its current position. They need to know the body starting position. **Optical systems** use photos, known markers or lights as reference to positioning. **Geomagnetic** techniques exploit disturbances on earth magnetic field inside buildings. The disturbances are caused by structural steel elements and they are unique in each building position. **Radio** techniques compute the radio wave travel time or use the radio signal strength to resolve the tracking. Signals like UWB, ZigBee or WiFi can be used. Similarly, **ultrasonic** techniques use sound wave travel time as the location system reference.

The **measure method** is related to how the signal is used to obtain the tracked device position. In **angulation** the object position is determined identifying the angle at which the signal emitted by the object arrives two or more reference points. The **dead-reckoning** method is based on analysis of data provided by inertial sensors: knowing the initial position, velocity and direction of the tracked object, one can estimate its current location. In **fingerprinting** the target area is divided on a grid and signals at each grid cell are captured, forming a map of signals. This map is used to perform tracking. **Lateration** identifies the object distance to at least three reference points to determine the object position. **Proximity** determines the location by detecting the presence of the tracked device in one or more sensors neighborhood. **Scene analysis** involves analysis of the interest location, looking for the tracked device or features that may give a clue to where the viewer is.

Infrastructure categorization examines whether pre-existing structure is needed to make the positioning system work. The **created** category is related to systems that create the location infrastructure on-the-fly. Within the **existing** category are systems depending on pre-installed infrastrucutre. The **no infrastructure** category includes systems that works with no infrastructure.

[2] A more detailed overview about indoor location techniques can be found in http://goo.gl/ULJRJG

4. SURVEY PROTOCOL

This study focuses on indoor location of victims and rescuers inside commercial or residential environments, when emergency situations arise. It seeks to answer the following general research question: "*Are there indoor location solutions that meets the requirements of emergency scenarios in indoor environments?*". Based on this general issue we seek to answer the following derived questions:

- **Q1** What are the requirements for indoor location systems in emergency scenarios?
- **Q2** How indoor location systems are positioned to support emergency scenarios?
- **Q3** Are there demands for new indoor location solutions for use on emergency scenarios?

4.1 Search strategy

The search string used is presented in Table 2. The search was performed in three major electronic databases: Scopus[3], Compendex[4] and Web of Science[5], which encompass the main digital libraries (ACM, IEEE, Elsevier, Springer and Wiley) and includes articles from journals and conferences.

Table 2: Survey search string.

("indoor" OR "in door" OR "interior" OR "inside" OR "personnel" OR "person" OR "personal" OR "pedestrian" OR "in-building" OR "in building" OR "room" OR "non-gps" OR "non gps")
AND
("positioning" OR "positioner" OR "position" OR "localization" OR "location" OR "locator" OR "locality" OR "geolocation" OR "tracking" OR "navigation" OR "guide" OR "guider" OR "orientation")
AND
("emergency" OR "emergencies" OR "crisis" OR "disaster" OR "disasters" OR "rescue" OR "firefighter" OR "firefighters" OR "relief" OR "first responders" OR "first responder" OR "escape" OR "evacuation" OR "danger" OR "dangerous" OR "risk" OR "risky" OR "hazard" OR "hazardous" OR "unsafe" OR "harmful" OR "critical" OR "distress")

4.2 Inclusion/exclusion criteria

The survey considers only primary and secondary studies written in English or Portuguese. The study should present a conceptual or practical implementation of an indoor tracking system facing emergency situations involving buildings evacuation or indoor location of rescuers. The exclusion criteria were applied in the following order:

1. **Not a paper**: tables, proceedings and non-scientific studies were excluded.
2. **Not written in Portuguese or English**: used to exclude studies outside the language domain of the survey executors.

[3] http://www.scopus.com/home.url
[4] http://www.engineeringvillage.com/
[5] https://sub3.webofknowledge.com

Table 1: Overview of the Taxonomy for Indoor Location Techniques with their advantages/disadvantages.

Category	Advantages	Disadvantages
Signal		
Inertial	No infrastructure need	Needs a reference system to reduce errors and determine initial position
Optical	High accuracy	In most cases is unfeasible to unknown places; requires high computational power
Geomagnetism	Requires only a magnetometer, being accessible for many devices	Needs mapping the enviroment in a offline phase; Suffers from holes
Radio	Can cover large areas; can take advantage of existing infrastructure; requires small amount of landmarks	Suffers from interference caused by objetcts and walls
Ultrasonic	High accuracy	Suffers from interference caused by humidity; requires high amount of landmarks
Measure Method		
Angulation	Requires only two reference points	Requires directional antennas
Dead-reckoning	Infrastructure independent	Requires another system to make periodic corrections and to provide initial position
Fingerprinting	Robustness	Unfeasible to unknown places; mapping phase can be expensive
Lateration	Position can be estimated based on reference points	Need at least three reference points
Proximity	Robustness	Requires high amount of landmarks
Scene Analysis	High accuracy	Requires high computional power
Infrastructure		
Created	Feasible to unknown places	Needs setup phase
Existing	No setup phase	Unfeasible to unknow places
No infrastructure	No setup phase; feasible to unknow places	Currently unfeasible

3. **Has no abstract**: studies with no summary were excluded.

4. **Duplicated study**: studies that appear more than once in the total search result were excluded.

5. **It does not cover emergency scenarios in the context of location of victims or rescuers**: such as work that deal with emergencies in hospitals, rebuke protests, among others.

6. **It does not address conceptual or practical application of indoor location**: such as studies focusing on outdoor location systems to collect signals in offline phases, hardware specification for location sensors.

7. **It does not address location of humans**: works exclusively addressed on robots location were excluded.

8. **Unable to get the paper**: works whose access was restricted and that could not be obtained even getting in contact with the authors were excluded.

4.3 Papers selection

In the first stage of selection (search string execution in databases), 129 papers were obtained. 60 papers were removed by duplicity and 38 papers were removed because they did not fit the study focus, meeting exclusion criterias 5, 6, and 7. In total, 31 papers were analyzed. Next section discusses results from analyzing those papers in the light of the research questions.

5. SURVEY RESULTS

From the 31 papers selected for this survey, 27 papers have functional indoor location systems, 3 papers only describe architecture and do not specify what kind of signal would be used and 1 paper presented a survey about indoor location in emergency scenarios [6].

Furthermore, from 30 studies (architecture or practical application), 23 aimed to support the location of rescuers, 4 instructed victims in an emergency and 1 supported both (victims and rescuers). Two papers did not specify the target user.

Section 5.1 present the list of requirements extracted from this survey (research question Q1). Section [**sec:ips-emergency**] analyzes the solutions (research questions Q2 and Q3).

5.1 Emergency scenarios requirements

Many applications of indoor location systems exist, each having its own set of requirements. Currently no technique is suitable for all scenarios. The most common types of user for these situations are the military, police, firefighters and civilians [29].

Although different users have different location system requirements, part of the requirements are common. In [29] authors present a list of requirements common to military, police and firefighters lifted from discussions and interviews with members of these groups. We have identified some gaps in this list of requirements: 1) the degree of importance of each requirement is not presented; 2) requirements are not facing location systems that meet the victims of emergencies. To fill this gap we performed two actions: review the requirements list proposed by [29] with information collected from the survey papers; and apply a questionnaire with emergency experts to evaluate the new requirements list.

To enhance the requirements list, we extracted the requirements identified by the authors of each paper. Table 3 shows the new requirements list. We classified the requirements according to seven categories:

- **Performance**: accuracy, precision and speed requirements.

- **Robustness**: resistance to adverse conditions, battery time and availability.

- **Volume and weight**: physical measurements of the carried device(s).
- **Usability**: ease of use, learning and setup.
- **Interface**: requirements related to user interface aspects.
- **Security**: requirements related to security aspects.
- **Others**: requirements that do not fall into the previous categories.

From this table we can to observe conflicts with some requirements, extracted from distinct works (P1, P2 and P4; R8 and R9; V2, V3 and V4). Some requirements are precisely specified (P2, P3, P6, R8, R9, R15, V1, V2, V3, V4, U8 and O6) while others abstract (P1, P5, R10, V5, V6 and O7). Requirement R12 seems to be significant when considering an inertial based location system, given that only this system category is sensitive to movement types. Similarly, U1 is significant considering systems that use created infrastructure. I1, S1 and S2 are applicable to scenarios where armed operational forces are tracked. Requirement U8 was extracted from a paper that presents a system geared to use in urban emergency in Korea. The author explains that in this environment there are small gaps between buildings. Only the front side and indoor environment of the building can be used for the indoor positioning system, which limits the number and position of base stations outside the building.

We decided to conduct a questionnaire directed to specialists in emergencies, with the aim of: revise/update the list of requirements provided in [29]; identify the degree of importance of each requirement of this list and of Table 3; and produce also a list of requirements focused on evacuation of victims of emergency situations. The complete list consisting of the requirements of [29] plus the requirements extracted from this survey papers (Table 3) was consolidated and used to compose an online questionnaire, which asked the participant to sort the list as the priority, considering a indoor location system for victims and other one for rescuers.

5.2 Analyzing indoor location systems for emergency scenarios

Table 4 presents an overview of the indoor location systems analyzed in this survey, sorted by year in descending order. It shows that there is a predominance of work facing rescuers and systems that use radio signals, especially for the use of RFID. The most adopted measure method is lateration. You may notice an increase in the volume of work per year, demonstrating the interest of the community area, and a larger amount of hybrid system in more recent studies. Oddly, many studies do not report the accuracy obtained. It is a crucial information for the analysis of the proposed location system. Another important information omitted is the precision, reported by only 2 works.

The main conclusions achieved from the analyzed works are:

1. Most works use **radio signals for indoor location systems**, with emphasis on Ultra Wide Band (UWB). The main reason for adopting this technology is the ability to create infrastructure at the time the emergency occurs, using base stations present in cars or carried by rescuers..
2. There is a **predominant focus on rescuers** as users for the tracking systems, with space for proposals to locate victims and provide escape routes, especially using smartphones.
3. The majority of published studies present **systems for use by firefighters**. Only one selected work had focused on military/police.
4. **No analyzed work is being used in real situations**, because all failed to meet a minimum set of requirements to emergency situations.
5. The studies use different methodologies to evaluate the accuracy/precision of the proposed systems, so that is **difficult to compare the performance** (such as accuracy and precision) between them. The papers do not detail the experiments whereby the reported accuracies were obtained (many even present precision data). Researches to define test standard methodologies for tracking systems and results documentation are needed.
6. Works using Bluetooth to provide indoor location in emergency scenarios were not found. With the recent emergence of **Bluetooth Low Energy (BLE)** [9], and marketing of smartphones and tablets supporting this protocol, there is a tendency that this technology becomes common in providing context information such as location.
7. Currently **there is no location technology that is best suited for all types of indoor environments**. There is a strong tendency for commercial and residential buildings incorporate different indoor location systems to provide context-sensitive information. This creates a heterogeneous scenario where **definition of protocols and services that enable both the rescuers and victims use different infrastructure or location information becomes relevant**.

6. CONCLUSIONS AND FUTURE WORK

This work presented a survey of indoor location systems focused on emergency situations. First related works were presented, highlighting a similar survey [6]. Thus, we detailed the research protocol. The main indoor location techniques were presented, categorized by used signal, measure method and infrastructure need. The contributions of this survey are: a a list of requirements for indoor location systems in emergency scenarios; a list of indoor location systems, classified according to used signal, protocol, infrastructure exigency, analysis method, target user and reported accuracy.

The requirements were used to compose a questionnaire that will be applied to specialists in emergencies. Future work includes finalize and report the results of experts questionnaire, analyze the requirements identified and relate them with the works included in this survey.

As stated in Section 5.2, other interesting future works possibilities are: the proposal for standardized test methodologies for indoor location system; the development of co-

Table 3: Requirements for Indoor Positioning Systems applied to Emergency Situations. Legend: "User" column: S=Rescuer, V=Victim; "From" column indicates the paper that presents the requirement.

N	Requirement	User	From
	Performance		
P1	Horizontal accuracy of about 1m.	S	[27, 6, 2]
P2	Horizontal accuracy < 1m.	S	[11, 4]
P3	Vertical accuracy < 2m.	S	[11]
P4	Room level accuracy.	S	[18, 10]
P5	Speed of calculating and presenting location information.	S	[18]
P6	Speed of calculating and presenting location information > 1Hz.	S	[2]
P7	Location and tracking in 3 dimensions.	S	[4]
	Robustness		
R1	Resistance to heat.	S	[18, 25]
R2	Resistance to humidity.	S	[2]
R3	Resistance to smoke.	S	[18, 2]
R4	Resistance to fire.	S	[2]
R5	Resistance to water.	S	[18]
R6	Resistance to NLOS.	S	[2]
R7	Resistance to physical damages.	S	[18, 11]
R8	Battery should last for at least 4 hours.	S	[31]
R9	Battery should last for at least 24 hours.	S	[11]
R10	Should be power efficient.	S	[27]
R11	Constant accessibility for those who need the positioning data.	S	[11]
R12	Should be adaptable to environment change (eg: walls colapse).	S	[6, 2]
R13	Must work with different movement types (eg: climb, walk, crouch, etc.).	S	[27]
R14	Should work on all building types.	S	[6]
R15	Must be able to track at least 100 users simultaneously.	S	[4]
R16	Automatic estimation of localization errors (uncertainty).	S	[11, 25]
R17	Distance to reference nodes: 100-500m.	S	[2]
	Volume and weight		
V1	Carried device volume should be less then $107cm^3$.	S	[18]
V2	The weight of a node should not exceed 100g.	S	[31]
V3	The weight of the tracked device should not exceed 1000g.	S	[11]
V4	The weight of the tracked device should not exceed 1150g.	S	[18]
V5	Volume should be small.	S	[11, 27]
V6	Weight should be small.	S	[27]
V7	Should be fit into first responder backpacks.	S	[18]
	Usability		
U1	Should be easy and fast to setup (created infrastructure).	S	[18]
U2	Sould support a heterogeneous WSN with mobile nodes.	S (firefighter)	[31]
U3	Should be easy to use when wearing fireman gloves.	S	[31]
U4	Must be able to do SLAM.	S	[11]
U5	Should not require site-specif training.	S	[6]
U6	Should not require pre-installation.	S	[11, 27]
U7	Device should be exible and configurable.	S (firefighter)	[31]
U8	Should work with a maximum of 2 base stations, placed in front of the buiding.	S (firefighter)	[20]
U9	Should work in unknow buildings.	S	[2]
U10	Should work in buildings with no communication infrastructure.	S	[2]
	Interface		
I1	Must display where the user is facing.	S	[11]
I2	Should notify users when a emergency occurs.	V	[16]
I3	Should provide emergency exit guidance.	S	[4]
	Security		
S1	Detection and warning in case of electronic attack.	S	[11]
S2	Encrypted voice communications and data transfer.	S	[11]
	Others		
O1	Must store information that allows assessment of the operation.	S (firefighter)	[31]
O2	Must store information that allows improvement of future operations.	S (firefighter)	[31]
O3	Data format compatible to and integrated with other information, in particular personal health status.	S	[11, 4]
O4	The system should be modular.	S	[11]
O5	Restricted to equipment that is brought on-site by the relief units themselves.	S	[6]
O6	Cost: <1000 [EUR].	S	[11]
O7	Should not be expensive.	S	[27, 6]

munication protocols for hybrid and ubiquitous location systems; and the research of indoor location systems based on Bluetooth Low Energy.

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Table 4: Evaluation of the Indoor Positioning Systems. Legend: "Signal" column, R=Radio, I=Inertial, M=Geomagnetism, O=Optical; "Inf. (Infrastructure)" column: E=Exist, C=Created, N=None; "U (User)" column: S=Rescuer, V=Victim; In all columns: ?=Not informed, *=All, -=Not apply.

Ref	Year	Signal	Protocol	Inf	Analysis Method	U	Accuracy
[18]	2014	R	*	C	Lateration (RSSI)	S	<=2.02m
[5]	2013	R/I	802. 15.4 + RFID	E	Lateration(RSSI)/ Proximidity	V	<=1.7
[11]	2013	I	-	N	Inertial (ZUPT)	S	<=2m
[21]	2013	R	802.15.4	C	Lateration (TOA + SLAM)	S	<=2m
[23]	2013	R/I	802.11	N	Lateration (RSSI)/DR	S	?
[7]	2013	R	RFID	E	Proximidity	S	?
[37]	2013	M/I	-	N	DR (ZUPT)	S	2,60m, environments with stairs
[3]	2013	R	RFID	E	Lateration (RSSI)	V	168cm average
[36]	2013	R	UWB	C	Lateration (TOA)	S	From 0.03m to unfeasible
[26]	2012	R/I	*		-	S	-
[8]	2012	I	-	N	DR (ZUPT)	S	-
[40]	2012	R	?	E	Lateration (TDOA)	S	?
[27]	2011	R/I	UWB	N	Inertial (ZUPT)	S	3.5m in a 194m route
[25]	2011	R	RFID	E	Lateration (RSSI)	S	?
[1]	2011	R/O/I	RFID	E	Fingerprinting (Wifi)/DR	S	Between 2.58m and 19.9m
[6]	2011	-	-	-	-	-	-
[22]	2011	R	ZigBee	E	Lateration (RSSI)	V	?
[31]	2010	R	802.15.4	C	?	S	?
[38]	2010	R	802.11	E	Lateration (RSSI)	?	Between 68.9% and 80.6%.
[13]	2008	R	UWB	C	Lateration (TOA)	S	<=1m
[34]	2008	R	UWB	C	Lateration (TOA)	S	?
[30]	2008	R	RFID, UWB, WiFi	E	Proximity, Lateration and Fingerprint	S	?
[16]	2008	R	VHF	E	?	V	?
[41]	2008	R	RFID	E	Proximidity	?	?
[24]	2007	I	-	N	DR (ZUPT)	S	98% in 15 minutes routes.
[2]	2007	I	-	N	DR (ZUPT)	S	?
[4]	2007	R	?	C	Lateration (TDOA)	S	<1m
[10]	2006	R/I	RFID	E	Proximidity	S	-
[33]	2005	R	802.11	E	Lateration (TOA)	S	<=6m
[15]	2004	R	UWB	E	Lateration (TDOA)	*	?

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