A Survey of Wireless Indoor Positioning Technology for Fire Emergency Routing

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Abstract: Fire emergency response needs positioning solutions to assist evacuation and rescue operations. Therefore, we have to carefully review the candidates for this purpose. These indoor positioning technologies show different levels of applicability in fire emergency response. According to the varying demands of emergency response, flexible localization solutions should be provided. Thus, we guide a first step to implement this concept in three pre-defined emergency scenes. At last, we conclude several key features for indoor positioning solutions for emergency routing and three future research topics.

1. Introduction
A routing task should have a starting position and an end position, and then this task can be finished by searching from the source to target. Nevertheless, the indoor emergency routing always accompany with dynamic changes on path-finding request. Besides, as the hazard could endanger the emergency responders, it is also vital to acquire their accurate positions.

We may first look at how the outdoor localization problem is solved to promote us to face the indoor localization problems. When the people are standing in the open space, they could use a receiver of the Global Positioning System (GPS) signals to generate geographic coordinates of their accurate positions [1, 2]. Nevertheless, this solution is not quite applicable for the indoor emergency responding mainly from two aspects:

- The current accuracy of GPS is not qualified for indoor localization usage. As the indoor space is more compact than outdoor space, the localization radius larger than ten meters would even disallow us to determine whether this positioning object is inside the building or not.
- The working mechanism of GPS causes it usually not to function properly inside buildings. The two main reasons causing this problem are the propagation and multi-reflection for the GPS signal passing through the building materials.

Although the GPS cannot function properly inside the building structures, people still find other ways to overcome the indoor localization problems. Unfortunately, a complete review of the indoor positioning system (GPS) in the context of fire emergency routing does not exist. Therefore, we try to fill this gap by taking a survey of existing indoor positioning solutions in depth from the emergency aspect.

This paper is organized as follows: The second part will take a general review of the existing indoor localization methods. The third part will discuss the impacts on the indoor localization technologies introduced by the hazards. The forth part proposes several possible combined indoor localization solutions for three pre-defined hazardous scenes inside building. And in the final part, we

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conclude the state-of-the-art of the indoor localization methods for the emergency routing and propose several promising future research topics.

2. Existing indoor localization solutions

We can classify the indoor localization schemes into 11 main categories by their usage of position technologies. The “indoor localization position” phrase here equals to the “wireless indoor localization position”, for most of main stream indoor positioning technologies do not use physical connections like cables between the positioning device and referenced beacons [3, 4].

As is known to all, GPS is the most widely used positioning technology in the world. Nevertheless, this technology is not so promising for solving the positioning request under indoor situation. As described in the introduction part, the GPS suffers from low accuracy and weak signal strength in building space[5].

Global System for Mobile (GSM) and Code Division Multiple Access (CDMA) based 3rd generation communication technology build up a solid foundation for localization with mobile phones. Therefore, the indoor positioning solutions using GSM/CDMA is easily accessed [6].

Wi-Fi technology is a widely used wireless communication technology, and for its popularity many localization plans take it as the main physical layer for positioning. Normally, Wi-Fi indoor position system needs more than one Wi-Fi adapter to play as the function of beacons in the positioning process [4, 7-9]. Bluetooth technology is a local communication technology with a feature of low power consumption. Unlike Wi-Fi, which could cover a radius of more than 100 meters, the Bluetooth transmitter usually could only cover a space with a radius below 100 meters[10, 11].

Radio Frequency Identification (RFID) is a popular identification and positioning technology. It is originally used to identify each device with an intelligent label that could store a specific amount of information like device ID, but extended to many positioning solutions that use scanners to identify position of objects with RFID labels attached [12, 13].

Quick Response Code (QR Code) is a matrix code that keeps a comparative large amount of position information than standard barcode. It can be attached to some key areas of the buildings to wait for scanning to provide its positional information from database [13].

Computer vision technique is firstly used as an indoor localization method in the robotic navigation. The robots use camera generated data to locate their most probable standing position in the surrounding environment by pattern matching principles [14, 15].

The mechanism of applying ultrasonic techniques for indoor positioning utilizes a device to receive signal echoes sent by its antenna earlier [6, 16, 17]. Then we can calculate the distance by the time difference between the original signal and echoes. Ultra-Wide Band (UWB) is a new communication technology that uses the bandwidth of more than 500MHZ in the radio spectrum. This technology is used as a new method to measure the distance in the indoor environment due to its advantage of overcoming multi-reflection effect in the signal transmission process [16, 18, 19].

Magnetic field detection technology is being researched for a long time. It is originated from the biological positioning system existing in several spices of animals, and firstly introduced in to the positioning system for satellite [20, 21]. The Inertial Navigation System (INS) is a dead reckoning navigation technology, which normally contains an accelerometer and a gyroscope to survey and record the data of acceleration and rotation angle during movement. Then we could use computers to calculate these data with existing models to generate the current position, direction and speed of the INS device without additional reference information [14, 22-24].

3. Concerns of the emergency indoor positioning

We may introduce two major issues influencing the performance of localization solutions for emergency routing: the type of fire emergency routing and the impact of hazard spreading.

3.1. Type of fire emergency routing

Generally speaking, there are two types of fire emergency routing: Egress routing and ingress routing. The egress routing assists evacuee to escape from the hazardous building in a short time, and the ingress routing guides emergency responders to fast move into the corresponding scenes in the hazardous building to mitigate damage and rescue survivors.
For the egress routing, the time cost for the localization should be minimized. Waiting for several minutes to locate the accurate position of evacuee may greatly decrease their surviving chance. Thus, according to the experience of fire emergency responding, the first 10 minutes is very precious for the self-evacuation in the emergency area[25].

About the ingress routing, as the emergency responders may need the accurate position of evacuee in the hazardous building, they will encounter some legal barriers between them and the privacy of the evacuee[26, 27]. Therefore, a workable solution for this issue such as providing a fast accessing function of positional information by just validating the basic credentials of emergency responders is needed[23].

3.2. Impact of hazard spreading
The high temperature caused by the fire or plume spreading over the hazardous scene is very common for fire emergency routings; so is the high humidity introduced by the water from the fire hose. Thus, the localization technologies with strict working condition requirements on the surrounding environment will possible become malfunction under these circumstances.

The power issue is another important factor when the emergency happens. As the emergency development may cut off the power supplies to the building, the positioning solutions have to run with their own power source.

The portability of indoor positioning technology is also crucial for emergency responders, who have to transport the localization devices in the emergency responding process[28, 29]. We cannot expect the fireman carrying a large heavy positioning device during the intensive firefighting and rescuing operation.

Fortunately, a low threat-level emergency may not really influence the information communication for the building structure. But if the emergency is severe and destroying the information infrastructure, then we have to consider the reestablishment of the local communication network with some wireless technology.

3.3. Reanalysis of existing solutions from the fire emergency routing aspect
After the general introduction of existing localization solutions and fire emergency influences, we could analyse the positioning technologies from three aspects: accuracy, cost of deployment and user experience.

3.3.1. Accuracy
From the accuracy aspect, the indoor positioning solutions using acoustic methods usually could achieve the highest accuracy level, such as ultrasonic and UWB. The accuracy of these solutions could achieve centimetre level. Besides, the localization solutions using pattern recognition principles like magnetic navigation and computer vision can also achieve the centimetre level accuracy. While the accuracy of Wi-Fi and Bluetooth technologies normally could only achieve less than one meter level, and by using several additional pre-defined referenced points they could increase the accuracy to sub-meter level. The positioning accuracy of RFID and QR code solutions are affected by many elements. If the scanning devices are with the positioning objects, the static RFID tags or QR code stickers should have their coordinates precisely measured before the positioning process. Then the moving RFID tag or QR scanner should function properly when passing through the static objects. And the accumulated error in these two processes could lead to a positional accuracy lower than 1 meter level. Being different from all the above solutions, the INS system normally has a consistently accumulated error, which has a linear correlation with its total transportation distance. GPS and GSM/CDMA can only achieve a comparative low accuracy level, and they could only assist the indoor positioning by providing preliminary spatial scopes of the considering building.

3.3.2. Cost of deployment
Most of the localization solutions need a deployment process before functioning. The ultrasonic and UWB needs sensors attached to the positioning objects. The Wi-Fi and Bluetooth needs the antenna carried by the positioning objects and a whole network of access points deployed in the environment. The magnetic field solution requires a magnetic field survey executed across the whole area to acquire the magnetic field distribution. The computer vision solution needs the camera being placed properly.
The RFID and QR Code solutions could only work after the setup of the scanning device and RFID tag or QR code sticker being deployed. While the INS only needs a whole inertial navigation package being carried with the positioning device. Apparently, GPS and GSM/CDMA have a low deployment cost. From the deployment view, the INS, GPS and GSM/CDMA are the best option for emergency indoor positioning.

3.3.3. User experience
The aspect of user is always crucial for indoor positioning solutions, and the ease of usage and availability are the two key issues. The GSM/CDMA, Wi-Fi and Bluetooth are the best solutions for evacuees, because these solutions are integrated into almost every mainstream mobile phone or other portable computing device. Besides, the inertial navigation technology could be the second promising candidate, for it is also widely used in the modern digital life. From the aspect of special users like handicapped person or emergency responder, the popularity of positioning technology for the normal people may not be an essential condition. These special users are eager to pay extra cost and effort to deploy some additional localization solutions. Thus, the accuracy and robustness of these solutions may be the real important factors for these users. Therefore, the acoustic localization methods with a centimetre level of accuracy are the mostly sounding option for these special users.

3.3.4. Feasibility of indoor positioning applications
According to the previous analysis of the positioning solutions, we could generally describe the most promising application scene for the current indoor localization solutions in the fire emergency routing. The GPS and GSM/CDMA localization solutions could only be utilized as a reference for some more accurate positioning solutions, due to their inaccurate localization feature. Because of the popularity, the Wi-Fi and Bluetooth could be the most sounding candidate for the evacuees to locate their positions and execute navigation task like scheduling optimal escaping path. For the computer vision solution, they should be deployed in the sensitive buildings that requires online monitoring and measuring specific object position in the secured areas like museum and used to guide people evacuating from these areas. As for the RFID and QR code solutions, they could be utilized in the object tracking after the fire hazard destroyed all other localization devices. The magnetic field detection method could be taken proper usage when the magnetic field distribution has been previously surveyed and not altered during the hazardous development. The ultrasonic and UWB solutions are the best option for the emergency navigation scene that needs an accurate position measurement and can work with only battery as the power source. The INS could not be used independently for its accumulated error feature, and should be combined with any other indoor localization solution generating absolute position.

4. Sounding positioning schemes for indoor emergency routing
According to the preliminary study of the emergency impacts on indoor localizations, we try to apply indoor positioning technologies for three proposed hazardous scenes.

4.1. Scene 1: Evacuee escape from a building with fire spreading in a small area
Under this circumstance, the fire spreading is limited to a very small area, which does not disrupt the function of information infrastructure. Then we could select the most suitable positioning solution such as Wi-Fi/Bluetooth for locating the position of evacuee and provide them with egress plan (figure 1a).

4.2. Scene 2: Evacuee escape from a building with fire spreading in a large area
For the fire develops to a considerable large space of the facilities, the positioning technology will face a big challenge. All the non-robust indoor localization technology, which needs consistent power supply or stable working conditions like a limited range of working temperature, will possibly become malfunction. But robust localization solutions like the QR code and RFID will still be working in the area surrounding hazard to guide people evacuate (figure 1b).
4.3. Scene 3: Emergency responders enter a building with severe fire spreading to mitigate damage and rescue survivors

This scene seems very extreme, but it might be a usual scene that emergency responder have to face. Under this situation, the entire building infrastructure is severely damaged, and positioning assistant devices in this building are totally disabled. Thus, the emergency responders may fast establish a positioning network by attaching new RFID tags into several key regions of the rescuing scene like exits of stairways, and use a GSM/CDMA network to locate the coarse spatial range of survivors (figure 1c).

5. Conclusion and future work

We could perceive that there are many available solutions for indoor localizations, but most of these solutions have to be adjusted or optimized for the emergency situations. We have to consider the hazardous influence on the information communication and power infrastructure for these solutions. Some indoor localization technologies are immune to these hazardous influences due to their work-alone feature, which are composed of the ability of offline working and large sensing range. Nevertheless, guidance for people using some localization solutions before the emergency really happens is the most practical measure to face the threat brought by the potential hazard.

Besides the guidance for people to use some indoor positioning solution, researchers still can improve the current solutions by taking several approaches:

- The manufacture of wireless communication technology like Wi-Fi should consider integrating batteries to enable these devices working for a long time period even without the main power source.
- We may improve the accuracy of some existing localization solutions by using principles like RSSI, which sets up several carefully chosen reference points in the building structures [7].
- A high accuracy localization network should be deployed for some building with extreme dangerous working condition like the nuclear power plant and biological chemistry research facilities.
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