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BIM-Based Indoor-Emergency-Navigation-System for Complex Buildings

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Abstract: The imminence of terrorist activities and the necessity of the maximum possible disaster preparedness in the sense of indoor-navigation support have been brought to evidence by several catastrophes, e.g., the fire at Istanbul Airport in May 2006 or the terror attacks on the London Underground on July 7, 2005. Since 2001 ten terror attacks have been thwarted only in Great Britain. For that reason the aim of the presented research project is to develop a solution for response and recovery to support rescuers in finding the shortest way within a public building and provide them with important information in their particular spatial context. Existing building information models (BIM) are used for displaying plans on mobile devices and for routing purposes. The indoor navigation system is based on wireless LAN (WLAN), ultra-wide-band (UWB), and radio frequency identification (RFID). These technologies are described in detail and an overview on data formats which are used to retrieve building data out of the BIM for generating routing networks is given.

Key words: indoor positioning; RFID; UWB; WLAN; disaster preparedness; response and recovery; BIM

Introduction

In order to save human lives and material assets complex buildings like airports are equipped with different safety and security systems. To save people and buildings from fire the prevention and detection of fire are very important. For that reason the Frankfurt Airport has about 50 000 automatic fire detectors. These are connected to alerting lines. If a fire detector triggers, the fire brigade is informed. To find the detector the rescuers take the arrival instruction for that alerting line and immediately start for the building in which the alarm has been activated. The arrival instruction contains only few information about the building. Usually only the building number, the number of the fire detection line, and the way to the fire brigade terminal are drawn on a small map. Once the respective building is reached a central fire alarm station displays the fire detection line and the exact fire detector that has caused the alarm. At these terminals building maps are available printed on paper (route cards) (see Fig. 1).

Fig. 1 Fire brigade route card

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Using these route cards the fire brigade can find the fire detector. Figure 2 shows the operating sequence.

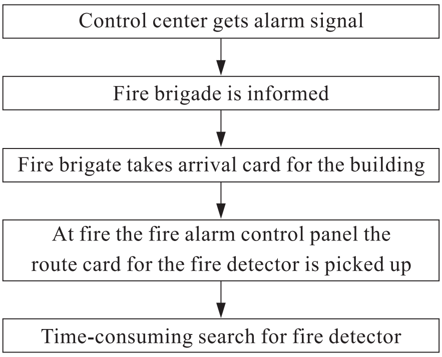

Fig. 2 Work sequence of fire brigade

In complex buildings it is very difficult to find the exact fire detector because of insufficient orientation. Due to changes in usage, especially, airports often undergo reconstruction work. It takes enormous efforts to keep these building maps on an up-to-date level and to distribute them to the different central fire alarm stations. In alarm cases at least six fire-fighters are involved for 30 to 45 minutes only to locate the fire detector and to return to the fire station. Most alarms are so-called false alarms (triggered by a detection failure: e.g., pressure fluctuation in a sprinkler system). The fire brigade of the Frankfurt Airport has about 5000 alarms per year. 95% of them are false alarms but in each case concentrated efforts of the fire brigade are necessary: Fire detectors and extinguishing systems have to be checked immediately. The current situation is not only time consuming. In cases of real fire the orientation within a building and information about the direct way to the fire detector, the exact position of the fire detector, and the areas where passengers and employees are located are very important to save human lives. For the officer in charge it is nearly impossible to keep track of all activities and the particular positions of the rescuers within the building.

In this research project "Context sensitive indoor-emergency-navigation-system for complex buildings"— funded by the German Federal Ministry of Transport, Building and Urban Affairs and in cooperation with the Frankfurt Airport (Fraport) Fire Brigade and a fire protection engineering office — different methods and technologies for indoor position sensing and a BIM-data-export are developed to enable indoor navigation (positioning and route calculation). Such a support improves the orientation and safety for rescuers in buildings in general. The basic of the new system is the multi-method-approach for indoor real-time location systems (RTLS) in connection with routing networks generated from the building-information model (BIM). Besides this the overall system architecture is presented in this paper.

1 BIM-Based Indoor-Emergency-Navigation-System

The aim of the presented research is to improve disaster preparedness by providing a better orientation within a complex building in general. Therefore, the development of a new reliable indoor positioning system for fire-fighters is of central interest. Especially, important building information within the spatial context of the rescuer will be provided by the system, e.g., gas pipes or high voltage panels. These aspects are of high interest of the project partner, Fraport Fire Brigade.

The approach envisages that each rescuer will use a mobile device (PDA or other mobile computer) which will be equipped with indoor positioning, routing, and important building information that will be displayed in the spatial context of the rescuer. Therefore, information of the BIM is exported and prepared for the use on mobile devices.

1.1 Multi-method-approach

As satellite based navigation systems such as GPS or Galileo (in future) do not allow position sensing inside of buildings[1], different methods and technologies are needed. However, technologies like WLAN, radio frequency identification (RFID), infrared and ultra-wideband allow position sensing inside buildings but each system has its own application range for usage.

A survey and analysis of the different indoor positioning technologies is given in Ref. [2]. Based on this analysis the Institute of Numerical Methods and Informatics in Civil Engineering developed a multi-method-approach (see Fig. 3) to integrate different position sensing methods and technologies which are appropriate for all different environments of the Frankfurt Airport.

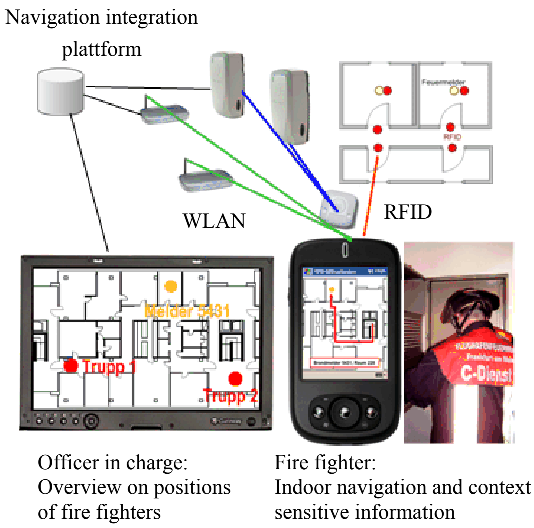

Fig. 3 Multi-method-approach

We concentrate on wireless LAN, ultra wide band, and radio frequency identification. These methods and technologies are advanced, combined, and integrated in our navigation integration platform.

1.2 Navigation integration platform

The navigation integration platform combines three different indoor positioning systems, CAD-building-plans, routing maps for indoor routing, and information about building elements, e.g., information about fire detection systems. This information will be provided to rescuers during the rescue mission. The multi-method-approach especially covers the demands of complex buildings such as airports: Firstly, rooms with few technical building infrastructures, e.g., cellar rooms or underground car parks will be equipped with active RFID-tags. If a fireman is in footprint of a RFID-tag, the system detects its position. Therefore, active and passive RFID-tags have been tested. Antennas of passive RFID-tags are larger than antennas of active RFID-tags and do only allow radio reception in one direction. Antennas of active RFID-tags allow the detection of tags while walking by without adjustment of the antenna in the direction of the RFID-tag. As bar antennas of active RFID-tags are small they are suitable for easy handling with mobile devices.

Secondly, ultra wide band (UWB) is appropriate for position sensing in halls. UWB is less influenced by metals and high humidity than other radio communication technologies and is, therefore, the choice for passenger and baggage halls. With the use of high sensitive antennas only few sensors are needed to enable position sensing in halls.

Thirdly, in office areas existing wireless LAN networks can be used for position sensing. Wireless LAN is capable of being influenced by human beings walking by or by structural measures. On this account active RFID-tags will be added to recalibrate the system.

In order to support the fire fighter with relevant building information on his operation context sensitive CAD- and facility management data is required. The aim is to export the 3D building model and to automatically generate a routing network for navigation. Information about the fire extinguishing system and other building services engineering will also be exported and used to display—as mentioned above—context sensitive information for fire fighters.

As indoor position sensing is the basis of navigation the methods and technologies of the used real-time location systems (RFID, UWB, and WLAN) are described in the next section.

2 Real-Time Location Systems (RTLS)

According to ISO/IEC 24730 systems for position sensing are called real-time location systems if the position is updated within an interval of one minute[3]. In the following the three methods and corresponding technologies we use in this research project will be described in detail.

2.1 Radio frequency identification (RFID)

In the research project experiments have been made with active RFID-tags from Identec Solutions[4]. These tags use the frequency of 868 MHz and include 8 KB flash memory. For mobile use, the PDAs are equipped with an RFID-compact-flash-reader, which enables reading distances of about 8 m in buildings. Our first attempt is to use these tags as position-reference if the reader is in footprint and to analyze the signal strength. Our own experiments and experiments in Ref. [5] showed that the signal-strength of active RFID-tags for calculation of distances is not precise enough. Measurements on different days showed a precision of about 80% within a precision of 10.5 m (35 ft)[5]. We are now experimenting to improve the accuracy by varying the sensitivity of the reader dynamically.

2.2 Ultra wide band (UWB) RTLS

UWB RTLS consists of precisely timed short pulses of radio frequency (RF) energy. The term UWB comes from the fact that radio transmissions actually consist of many individual frequency components and due to the very short time duration of UWB pulses they actually consist of a very wide spectrum of different fundamental frequencies. The US FCC defines any system using a frequency range greater than 500 MHz as an ultra wide band system[6].

Position sensing via RF is based on calculation of the distance between sender and receiver (antenna). Normal RF RTLS have to cope with overlapping signals of the direct signal and signals reflected at walls, windows, etc. (multipath effect). The advantage of UWB is the use of very short pulses which are possible because of a wide range of frequencies[7]. These short pulses allow an identification of direct signals and reflected signals which enables a precise position sensing up to 15 cm by use of the time difference of arrival (TDOA) or the angle of arrival (AOA) of the signals (see Fig. 4).The European CEPT has approved UWB for license in the 3.4 to 4.8 GHz and 6 to 8.5 GHz bands, respectively. In the project the UWB RTLS of Ubisense[8] has been prototypically connected to the central navigation server to enable precise positioning in large halls.

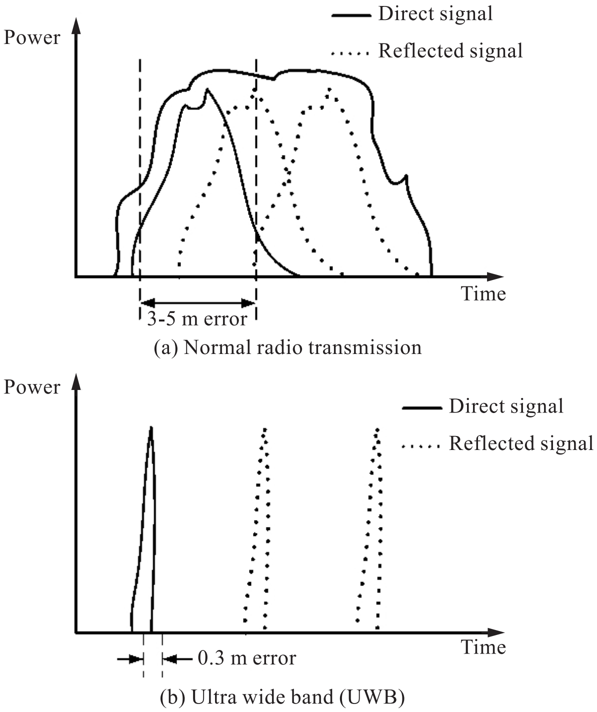

Fig. 4 Overlapping signals (according to Ref. [7])

2.3 Wireless LAN

Wifi RTLS enables position sensing by using existing wireless LAN routers. Based on this technical infrastructure indoor positioning is possible in two different ways. Firstly, the position is determined by triangulation: the signal strength is used to calculate the distance to at least three WLAN access-points. Secondly, positioning can be achieved by using points with predefined respective signal strength (so called "fingerprint method")[9]. Multipath propagation and heavy shadow fading let the accuracy of WLAN positioning engines hardly be foreseen. Experiments mentioned by Ref. [10] showed that an accuracy of 1 to 3 m can be achieved.

In the presented research project the Wifi RTLS of Ekahau Inc.[11] has been prototypically integrated in the navigation integration platform. Ekahau uses predefined paths in his real-time location system to improve the accuracy of the positioning. This ensures that the position is automatically corrected to positions on one of the path ways. A software installed on the client detects, firstly, the signal strength of the access-points in footprint (fingerprint method), and secondly, sends the measured data to the real-time location server.

In order to enable indoor navigation a combination of the three RTLS-systems with a BIM is necessary. An overview on possible CAD data formats of a BIM will be given in the next section.

3 Overview on BIM-Data Formats

To enable routing within buildings CAD building plans on mobile devices are required to display the section where the user is located and to calculate routes to guide the user. This information needs to be in a format which can be used for data analysis and route calculation. Building plans in an image format such as jpeg or gif are not adequate. International accepted data formats should be preferred. But the manifold requirements such as

- semantic information about building elements, dependencies of rooms, walls, and doors,
- coordinates with a unique origin,
- referenced information on facility management data,
- small file size for use on mobile devices,
- and routing possibilities

are not yet fully supported by any available standard.

VRML or its successor X3D are 3D graphics standards, which accomplish all requirements in terms of 3D visualization. But they do not consider building elements. With those standards it is not possible to define building elements (such as rooms, walls, or doors) or attach material properties to these elements.

CityGML (geography markup language) is a common information model for the representation of 3D urban objects. It provides a geometric, topological, and semantic data model. It defines the classes and relations for the most relevant topographic objects in cities. It includes generalized hierarchies between thematic classes, aggregations, relations between objects, and spatial properties. It is extensible, and missing object types can be added to the object type definitions or included through additional object types for specific applications. For the use of indoor applications the Level of Detail 4 (LoD4) is useful since it considers rooms, stairs, and furniture[12].

The IFC (Industry Foundation Classes[13]) is an exchange format for building models. It has been specified by the IAI (International Alliance for Interoperability). It became an international standard and is supported by most CAD-software products. It defines an exchange format and contains object classes for storeys, roofs, walls, stairs, etc.

Green Building XML (gbXML) was developed to facilitate the transfer of building information stored in CAD building information models, enabling integrated interoperability between building design models and a wide variety of engineering analysis tools and models[14]. Today, gbXML has the industry support and wide adoption by the leading CAD vendors, e.g., Autodesk, Graphisoft, and Bentley. GbXML is reduced to surfaces and surface types of walls which are connected to rooms. The relations of doors belonging to walls, which are components of rooms, are implemented in the XML schema.

For the use in the BIM-based indoor-emergency-navigation-system, a data format is needed which contains the information in a unique structure to use only one tool for displaying the plans on mobile devices or generating routing maps. This is very important as different CAD software products for different buildings are in use depending on which product is used for facility management. For this reason we concentrate in the following on IFC and gbXML.

IFC has many object classes which are not needed in this project and this inflates the file size. Most CAD software products support IFC 2×3 but not IFC XML. This would require a parser and a conversion into an own data structure. GbXML has an XML structure and can directly be used for displaying building models. For that reasons gbXML has been chosen to export building plans for mobile devices. The relations of the XML-schema of doors belonging to walls etc. can directly be used for generating routing networks.

Exported CAD building information is stored together with positioning data in the central database, which will be described in the next section.

4 System Architecture

The positions of rescuers in the building will be transferred to the central positioning database by web services. Web services are defined by the W3C[15] as "a software system designed to support interoperable machine to machine interaction over a network." Web services can be accessed over a network like the Internet. They are web APIs to execute methods on a remote system. Normally XML messages that follow the SOAP (simple object access protocol) are used for communication between server and client.

The navigation integration platform administrates the actual positions of the rescuers, the organizational structure including work schedules, the building information exported from CAD, generated routing networks for navigation, and information on fire protection and building elements which is provided to the rescuers within their spatial context (see Fig. 5).

Mobile devices communicate directly with the positioning engines of the UWB and WIFI RTLS. These engines transfer the actual positions of rescuers via web services to the navigation integration platform. Each mobile device has an RFID-reader which identifies the RFID-tags to detect the actual position which is transferred to the navigation integration platform too. The communication between the mobile devices and the web service of the navigation integration platform can be established by WLAN, GPRS, UMTS, or other possibilities for Internet access.

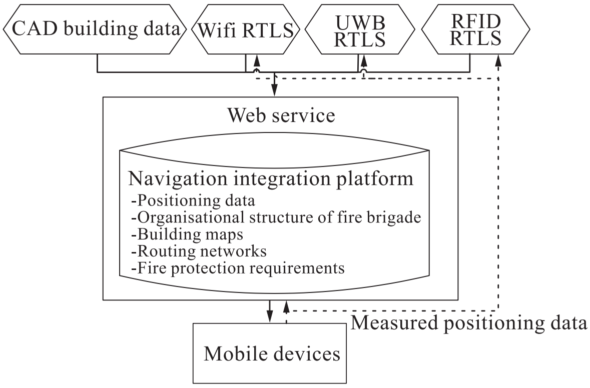

Fig. 5 Navigation integration platform

5 Conclusions and Verification

The paper introduces a BIM-based indoor-emergency-navigation-system to support rescuers in finding the shortest and fastest way in a complex building. With the multi-method-approach, wireless LAN, RFID, and UWB RTLS are combined to fit for different environments in complex buildings. BIM-data is exported via gbXML for displaying plans on mobile devices and generating routing networks including route calculation. Maps on paper will be replaced by digital plans which are able to provide additional information within the spatial context of the rescuer. The system described in this paper enables a better overview over the situation by localization of rescuers within a few meters in buildings. The system is evaluated in a testbed at the university and will be verified in a next step by practical tests at the Frankfurt Airport considering the accuracy of localization and the operation time used with and without the indoor-emergency-navigation-system.

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