International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:7, No:7, 2013

Sensor Network Based Emergency Response and Navigation Support Architecture

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Abstract**—**In an emergency, combining Wireless Sensor Network's data with the knowledge gathered from various other information sources and navigation algorithms, could help safely guide people to a building exit while avoiding the risky areas. This paper presents an emergency response and navigation support architecture for data gathering, knowledge manipulation, and navigational support in an emergency situation. At normal state, the system monitors the environment. When an emergency event detects, the system sends messages to first responders and immediately identifies the risky areas from safe areas to establishing escape paths. The main functionalities of the system include, gathering data from a wireless sensor network which is deployed in a multi-story indoor environment, processing it with information available in a knowledge base, and sharing the decisions made, with first responders and people in the building. The proposed architecture will act to reduce risk of losing human lives by evacuating people much faster with least congestion in an emergency environment.

Keywords**—**Emergency response, Firefighters, Navigation, Wireless sensor network.

I. Introduction

ACCORDING to the statistics of New York 9/11 incident, approximately 400 firefighters died during the rescue operation and the total death was estimated to be over 6000. The number of victims could be reduced if a rich emergency navigation system would have been deployed. Emergencies such as fire, gas leakages, earthquakes, tsunamis, terrorist attacks bring long lasting suffering to any community. Due to the severe loss of human lives and valuable assets in an emergency situation, there is an increasing interest in developing emergency navigation systems with the aim of minimizing the severity of the impact caused by an emergency.

First responders offer immediate help to victims in case of an emergency. During the different phases of a rescue operation, the responsibilities of first responders will be shared among several important job roles, which vary depending on the complexity of the incident. During a typical fire emergency, those job roles can be identified as incident commander (IC) who coordinates the overall emergency response, firefighter who directly involves with emergency and sector commander (SC), Crew Commander (CC) etc. [1]. Different job roles need information only specific to their responsibilities for emergency response and navigation. Moreover the victims in the emergency situation also need assistance to exit from the emergency, if the support from first responders is not available or get delayed.

Recently navigation with wireless sensor networks (WSNs) has become the most heated debated research area. WSNs raise many exciting opportunities to minimize the impacts caused by emergencies [1]-[4]. These studies show the benefits of a sensor network to support Emergency Response (ER) and navigation.

WSNs are an attractive option for indoor environments today, due to the recognition of the importance of energy conservation [5] and emergency/rescue operations [3], [6]. While sensor networks can be installed in new buildings at the time of construction, they can also be easily installed in older buildings due to their wireless nature. Most previous emergency navigation studies use only WSNs as the infrastructure. The architecture we propose in this paper integrate the WSN based knowledge with the soft knowledge acquired from various data sources (i.e. traffic data, human inputs) for the emergency navigation support.

However, there is a lack of coherence among research that has been reported for emergency support area. Correct decision making from the corrupted data gathered from the WSN, distributing the information to relevant decision making points (i.e. fire fighter job roles, victims), incorporating an efficient knowledge manipulating mechanisms are the most critical aspects in emergency response and navigation, which are partially addressed in previous architectures.

In this paper, our main focus is to illustrate the emergency response and navigation support architecture to cover key aspects during an emergency. The system caters the navigation requirements of both the firefighters and victims, by integrating the knowledge gathered from various sources and distributing them to relevant parties efficiently. Furthermore this is a generic architecture. Even though any suitable algorithms, frameworks can be plugged into the architecture, we propose some efficient methods that can be incorporated at each layer.

The remainder of the paper is organized as follows. Related work is presented in Section II. Challenges in ER and navigation are presented in Section III. The proposed emergency response and navigation support architecture is presented in Section IV. Detailed description of each layer of the architecture is described in Sections V, VI, and VII. Conclusion and future work appears in Section VIII.

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II. Related Work

The work reported in [3] proposes a high-level architecture of the system that is capable of deploying the human computer interfaces suitable for supporting various fire fighter job roles during a fire ER. Moreover it has gathered actual information, requirements from first responders; this information was highly useful when gathering basic knowledge on emergency environments in our research. Work presented in [7] proposes system architecture for emergency management mainly addressing network topology, configuration, data management in the ER. CodeBlue [2] is a framework explores the use of WSN in ER including medical care. However the navigation support for victims and fire fighters is not addressed in above mentioned proposed systems. Moreover these researches are mainly concerned with data capturing, decision making and presentation. Localizing and optimizing the network parameters (i.e. communication delays, retransmission rate) are not captured in the above researches.

The majority of previous work on emergency navigation [4], [8] that has been reported, propose emergency navigation algorithms to eliminate key dangerous areas and save trapped people, however a high level architecture for emergency navigation targeting major roles involve in an emergency situation is not addressed.

III. The Challenges in Emergency Response and Navigation

The nature of an emergency is highly dynamic and demanding. Real-time data retrieval, processing and management are required.

The identified challenges in an emergency response and navigational support are,

- Real time information retrieval from various sources (i.e. WSN), processing, and managing information dynamically.
- Need of separate robust algorithms for victim navigation and first responder navigation.
- First responder and victim navigation algorithms require different types of information. Differentiate the gathered information among different types of navigation algorithms is another challenge.
- WSN deployed inside the building need an efficient communication protocol to optimize the energy usage, communication delay, packet retransmission, etc.
- First responders may add stationary and mobile sensor nodes (sensors attached to firefighters) to the WSN. Integrating and tracking the newly added nodes is also a challenge.
- Addition to the information from WSN, information about environmental conditions of the surrounding region i.e. wind speed, landmarks should be acquired from separate data sources.
- Knowledge sharing mechanism among WSN and other data sources.

To cater all the above listed challenges in one architecture is the main challenge we address in this paper. Additionally we mainly address localization, self-organization of the network and navigation algorithms.

IV. Proposed Architecture

The proposed layered architecture shown in Fig. 1 consists of three major layers. Namely, WSN Perceiving and Prediction layer, Navigation Support layer, and Knowledge Manipulation layer. These will collaboratively function to create a complete WSN which can be adaptable for emergency situations and support rescue and navigation operations. Each layer consists of sub layers as described further in the following sections.

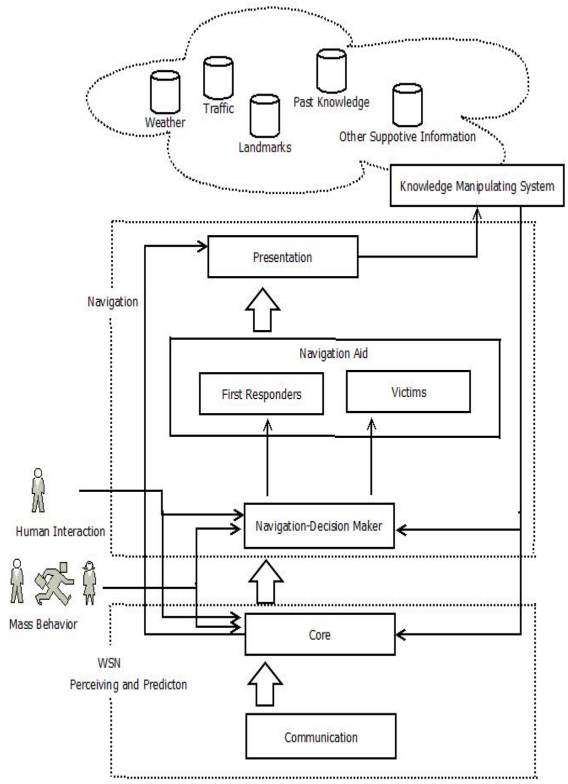

Fig. 1 Proposed emergency response and navigation support architecture

V. WSN Perceiving and Prediction Layer

In an emergency using a wired network for data gathering and processing causes many problems due to failures in connection. Therefore using WSN for such situation gives many advantages based on the characteristics of it, such as easy deployment, adding nodes to the network at any time, sustaining the network connectivity even though some communication links failed and etc.

Hence, in the proposed architecture, WSN is used to gather information about the building environment parameters. The main objective of this layer is monitoring the building environment and process sensed data to get meaningful idea. Then the processed information is displayed on the presentation sub layer appears in navigation layer. After processing data, if it detects an emergency, passes the required information to navigation decision maker, to perform first responder navigation information and victim navigation information.

More detailed description of this layer shown in Fig. 2. WSN Perceiving and Prediction layer consist of two sub layers. Communication sub layer and Core sub layer.

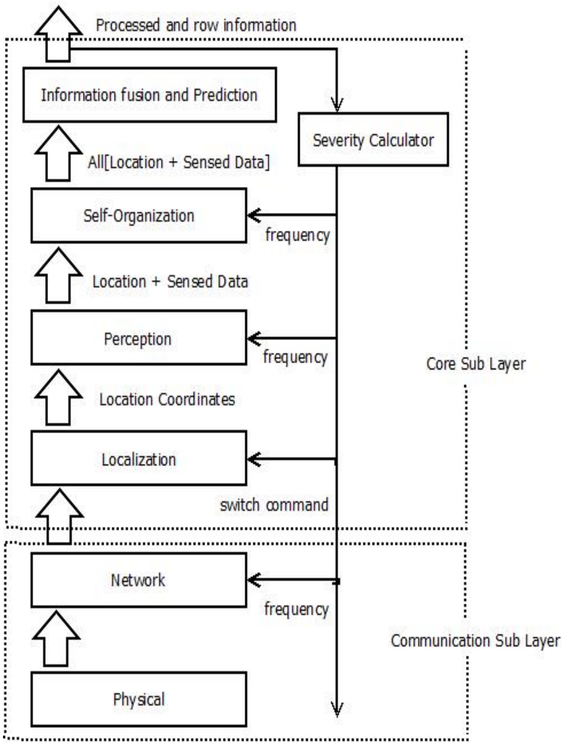

Fig. 2 Detailed description on WSN perception and prediction sub layer

A. Communication Sub Layer

The communication sub layer is responsible for physical deployment of sensor nodes over the building environment and communication among them including medium access.

Under the physical deployment network topology, power levels of sensor nodes, frame rates, antenna arrangements etc. are few major aspects to be considered. After the deployment, sensor nodes communicate with their neighbors using medium access protocols such as Carrier Sense Multiple Access (CSMA) and pass the message to the core layer.

B. Core Sub Layer

The core sub layer is responsible for finding the location of sensor nodes, perceiving, optimizing network parameter and data processing. The output of the communication sub layer feeds as the input to the core layer. Thereafter, passes relevant processed data to the presentation sub layer and navigation-decision maker sub layer.

Core layer can consist of five subsections, the localization subsection, the perception subsection, the self-organization subsection, the information fusion and prediction subsection, and the severity calculator.

C. Localization Subsection

This subsection will locate the sensor nodes with either absolute or relative coordinates. Most of the sensor nodes in WSN do not know their own location due to unavoidable constraints on the cost and size of sensors, energy consumption, the implementation environment (GPS is not accessible in indoor environments), and the deployment of sensors (e.g. sensors may be randomly scattered in the region). In an emergency, first responders add new stationary nodes to the network to monitor the environment parameters and mobile nodes (Sensor nodes attached to firefighters are important for IC to continuously monitor the health status of the firefighter and track their locations). Therefore those newly added nodes also need to be located.

WSN localization algorithms can be divided broadly into two categories; ranged-based and range-free. Range based techniques exploits the either distance or angle information between neighbor nodes and then uses the trilateral or multilateral localization methods to locate the unknown nodes, such as TOA, AOA, TDOA and RSSI [9]. Range-free algorithms use estimated distances between nodes instead of measured distances locate the sensor nodes. Several such range-free localization algorithms are Centroid, DV-Hop, Amorphous, MDS-MAP and APIT [10]. Since the environment considered in this paper is indoor and dynamic it is more suitable to use a distributed localization algorithm with range-free techniques.

Localization subsection receives a message from core sub layer and then the location information passed to the upper subsection to combine with environmental sensed data.

D. Perception Subsection

This sub layer will collect the data about monitoring environment (such as temperature, humidity, air quality, smoke, etc.) generated at each sensor node. Then the perceived data will combined with location information received from location sub layer and passed on to the upper layer for further processing.

E. Self-Organization Subsection

The ad-hoc deployment of the sensor nodes in the environment, prevent pre-planning of the network organization. Therefore, WSN need to self-organize the sensor nodes to interact with their environment to monitor or sense physical parameters and transmit this data to a central location. Additionally this sub layer is responsible to optimize network parameters such as energy, communication delay, retransmission methods, etc.

In a WSN one of the most critical parameters is considered as energy usage, which can be optimized by compressing data, decreasing wasteful energy consumption as a result of overhearing and retransmissions due to packet loss, etc. The clustering algorithms have been identified as an effective energy saving WSN self-organization method under which above techniques can adopt. LEACH [11], SEP [12], HEED [13] and EDCR [5] are some clustering algorithms optimizing the energy usage of WSN. Using energy based Cluster Head rotation mechanism (which result in prolonging the network lifetime) is the advantage of EDCR over others.

Obtaining real time sensed data is another important aspect of an emergency response system. Therefore the communication delays in the network need to be minimized. Zheng et al. [14] proposed a clustering algorithm to minimize link delays. This approach is completely distributed, in which each node only depends on its neighbors to implement node clustering. Another major aspect need to be optimized in the network is packet retransmission method. This is based on the reliability of the data and the bandwidth utilization of the network. If WSN uses a large packet size, bandwidth utilization is high. But if it is small, error recovery is hard and data is less reliable. To overcome this problem Raghu et al. [15] has proposed a mechanism called Seda. Seda treats the packets as a continuous stream of bytes. It breaks the data stream into blocks, and retransmits erroneous blocks only.

After configuring the network topology, the perceived data combined with location received from the lower subsection will then be passed to the upper subsection for further processing.

F. Information Fusion and Prediction Subsection

This is the layer where the data manipulation and calculations take place. It uses the received data from the lower subsection and information from knowledge manipulation layer as inputs and provides predictions for dynamically varying situations using knowledge based algorithms developed based on approaches like Dempster-Shafer formalism, Bayesian, Neural network, Fuzzy Algorithms [16], [17]. Depending on the output of this layer several actions will be taken. The processed data will then be passed to both the presentation sub layer and navigation-decision maker sub layer.

G. Severity Calculator

This provides feedbacks to the sub layers in order to adapt the system. In this layer most of the important parameters such as network refreshing rate, perceiving rate, clustering rate will be set. On the other hand it will switch the node localization algorithms if there is an emergency

VI. Navigation Support Layer

This architecture focuses on, an indoor emergency environment in which several dangerous areas can exist which are threats to human safety such as fire, smoke, obstacles, etc. Thus, people need to evacuate from the building as quickly as possible while keeping away from those dangerous areas. Also first responders need to have an idea of emergency's spreading in the building and the locations of trapped people. Hence, the main objective of this layer is supporting the victims to evacuate from the building and navigate responders through the building to find their way to save human lives and combat emergencies.

Navigation support layer consists of three sub layers; Navigation-Decision Maker, Navigation Aid, and Presentation. This layer gets the input from the WSN Perceiving and Prediction layer, knowledge manipulation layer and human behaviors. Then the output displays on a Graphical User Interface (GUI). Also, some of the decisions made in navigation aid sub layer are stored in knowledge manipulation layer.

A. Navigation-Decision Maker Sub Layer

The main role of this sub layer is dividing the processed data receiving from the WSN Perceiving and Prediction layer, knowledge manipulation layer, human interaction, and human mass behavior to, two navigation aid sub sections. Moreover, the data needed for the first responder navigation algorithm and the victim navigation algorithm are different. Therefore, the main objective of this sub layer is according to the rules specified, make decisions and separate the processed data into two categories. Then pass this information to two navigation sub layers respectively.

B. Navigation Aid Sub Layer

The main objective of this sub layer is providing navigation information to both first responders and victims. Navigation aid sub layer gets information from navigation-decision maker and output of its display in presentation sub layer. Also, decisions made on this layer stored in knowledge manipulation layer via the presentation sub layer. This sub layer consists of two subsections namely first responders and victims.

1. First Responder Subsection

Use of body area network (BAN) for first responder navigation has become more important in order to fight with the incident and save human lives. The dangers associated with this activity are the result of a number of factors, such as lack of information regarding first responders (i.e. location and health state), the environment surrounding (i.e. spread of emergency, temperature) and mental and physical stress in an emergency environment [18].

Indoor navigation of first responders deals with guiding them from its present location by avoiding obstacles and hazardous regions to save human lives and combat hazards. Hence, these navigation algorithms need information such as environment characteristics (heat, smoke, dust etc.), hazardous areas, locations, real-time map of the building, trapped people and etc. This information is fed to the first responder subsection from the navigation-decision maker sub layer. With this information the navigation algorithms proposed in [18], [19] can be performed to guide the first responders.

The decisions made by this layer, stored in the knowledge manipulation layer via presentation sub layer for future use. Also the output of navigation algorithm is passed onto the presentation sub layer to guide the first responders.

2. Victim Subsection

In an emergency, victims may hard to find a way out from the building because of hazardous areas or other obstacles. At any time, any spot may turn dangerous. Therefore providing navigation information only for first responders to exit from hazardous areas is not enough. As a result, finding safe and efficient escape paths for victims under dynamically changing environment is the main objective of this subsection.

In this subsection, it takes the input from the navigation-decision maker sub layer which contains information on hazardous areas, emergency spreading, congestion areas etc. and can perform navigation algorithms proposed in [4], [8].The decisions made by this subsection, stored in the knowledge manipulation layer via presentation sub layer for future use. Also the output of navigation algorithm is passed onto the presentation sub layer to guide the victims.

C. Presentation Sub Layer

The presentation sub layer is responsible for displaying the processed information in a GUI and taking the necessary actions. In normal state without an emergency, the conditions of the building environment (temperature, humidity, color etc.) can be presented in an easily readable building map. If an emergency is taking place, this layer can be used to inform the conditions of the environment to relevant parties (i.e. first responders). Also during an emergency, presentation sub layer is responsible of displaying navigation information to victims through LCD displays or lighting bulbs and transferring navigation information to first responders through BAN or other relevant way.

Moreover all the outputs receiving from core sub layer and navigation aid sub layer (output of first responder and victim sub sections) are displayed in a meaningful manner to make the correct decision on the situation.

VII. Knowledge Manipulation Layer

An addition to the information from WSNs, the information gathered from various other data sources such as traffic data, atmospheric conditions, information regarding important locations etc. [3], can be used to make the whole emergency response system more accurate and efficient.

In this layer, we introduce several possible components to manipulate knowledge gathered from several sources. Dynamically varying results of this layer are sent back to the core layer and to the navigation layer to further refine the results at each layer. This layer will be deployed in a central location, to gain knowledge on disaster management of a particular geographical region. The connectivity between Knowledge Manipulation Layer and other layers in the architecture can be accomplished by using any suitable communication methods, via gateways.

The main objective and aim of this layer is to support emergency response and navigation by providing a rich collection of knowledge to the system.

A. Information of Road Traffic

Once an emergency alert is received and confirmed at the rescue operations center, the response time of the first responders towards the emergency situation is very critical. Providing real-time and forecasted road traffic related information appropriately to the firefighters would improve the response time effectively. By retrieving the real time and forecasted traffic information, firefighters will be able to find the most suitable path to the emergency location and reach immediately. This information can be stored in a database and update dynamically.

B. Information of Atmospheric Conditions

First responders can acquire valuable insight knowledge on the incident site by getting dynamic information related to atmospheric conditions in the vicinity of an incident. According to this information firefighter can capture nearly accurate surrounding environment of the emergency site, and take relevant equipments and human resources to the site immediately. Moreover, forecasting on the propagation of the emergency (i.e. spread of fire according to the wind speed) is possible and evacuating the relevant other surrounding crowds (who are not in the emergency site currently) is also possible.

C. Information of Important Surrounding Locations

Information about the nearest hospitals, lakes and other water sources, dangerous locations (i.e. power plants, chemical storages) is very important to the first responders in order to make correct and immediate decisions on emergency response. Especially according to this information the resources they supply to the emergency site will be varied. This information will be stored in the database and most probably will be static.

D. Knowledge from Past Emergencies

Information about the past emergency incidents will be saved in a database. The perceived past knowledge can be used and combined with the current emergency information to further refine the knowledge of the incident. Forecasting on future emergencies and filtering current noisy information during an emergency can be achieved.

E. Information Gathered from Various Websites

There may be important websites to get more information on the emergency environment. The websites can be previously identified as important websites or real time search results on the web. Web mining technologies can be incorporated into this part to extract meaningful information related to the incident.

F. Knowledge Manipulating Framework

The algorithm(s) run in this framework should be able to retrieve information from various sources and update the relevant databases. Moreover it will provide information to various layers and components in the system when needed. In a nutshell this framework adds following services to this layer,

- Retrieve information from various sources and update the databases.
- Distribute raw information to relevant layers when the raw information is needed.
- Manipulate, combine [20], [21] all the information gathered in real time and provide more detailed knowledge to relevant parties/layers when needed.
- The forecast for the event of interest and provide information to relevant parties/layers when needed.

Efficient maintenance of a large database system, saving, retrieving, managing large sets of data real time and off line is crucial to optimize the response time in an ER.

VIII. Conclusion and Future Work

In this paper we have proposed an Emergency Response and Navigation Architecture which supports rescuers to assist evacuees along safe paths while reducing the congestion and save trapped victims. In the proposed architecture - decision making in emergency response, and providing navigational support, acquires the required information from WSN and the knowledge manipulating system. The architecture provides a separate sub layer to distribute the relevant information to first responders and victims. This will help victims to navigate through the building even without the assistance of first responders. Also different fire fighter job roles will get relevant information without any ambiguity.

In addition to the work proposed in this paper, the connectivity between the knowledge manipulation layer and lower layers should be investigated. During an emergency this connection could be affected. Therefore an efficient and reliable connection topology should be identified. Also the proposed architecture mainly concerned on emergency detection and response, and navigational decision making. It needs to be further explored on other aspects like, providing users the information on highest possible time lines and if a transmission failure occurred, notify it to the user/application as quickly as possible. Further a common data structure needs to be used with higher flexibility and proprietary formats. Communication topology, resource management, and security are some other aspects need to be looked over.

Acknowledgment

This research is financially supported by National Research Council (NRC) Sri Lanka under the Grant No. 11-113. We would also like to pay our gratitude towards research advisors for review of paper and suggestions for improvement.

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