IMPROVING EMERGENCY RESPONSE USING WEARABLE WIRELESS SENSOR NETWORKS AND STRUCTURAL HEALTH MONITORING SYSTEMS

Sheikhi, E.[1], Cimellaro, G.P.[2] & Mahin, A.[3]

[1]Department of Control and Computer Engineering (DAUIN), Politecnico di Torino, Italy
[2]Department of Structural, Building and Geotechnical Eng. (DISEG), Politecnico di Torino, Italy
[3]Department of Civil and Environmental Engineering, University of California Berkeley, USA

gianpaolo.cimellaro@polito.it, erfan.sheikhi@studenti.polito.it, mahin@berkeley.edu

ABSTRACT. Structural collapse and damage which have been occurred during past decades have caused severe failures especially in strategic infrastructures and public buildings. A natural disaster may cause a large number of injuries and deaths expecially in public building which are usually crowded, therefore in order to improve their resilience it is necessary to decrease their probability of failure and improve their emergency response in rescuing the people inside. Since timing is important during an emergency, if the rescue teams search for victims faster, the nummber of survivors can increase. This paper presents a novel practical method to improve the emergency response of rescuers after a disaster using a structural health monitoring system (SHM) and a Wearable Sensor Networks (WSN). The proposed system includes fixed SHM nodes which measure structural related parameters like vibration, humidity, etc. It also includes mobile nodes which are wearable wristbands worn by people to collect data including approximate location of victims and health status. This system provides the rescue teams with data related to the damaged parts of the buildings, number of people who have been trapped inside the building, their location by means of indoor localization, and their vital status. These data which are collected and analyzed in real-time, are being used for building damage level assessment, but also to help rescuers to locate victims faster and save more lives. The fixed and mobile nodes construct a wireless sensor network which stays functional even during power outage by means of rechargeable batteries. Through this system, it is possible to assess the structural health of the building and also improve the emergency response of rescuers by optimizing their time when a disaster occurs.

KEYWORDS: Structural Health Monitoring, Emergency response, Resilience, WSN, Smart Sensors

1 INTRODUCTION

Nowadays, researchers are working on different fields to propose new ideas and tools to achieve resilient systems. These goals can be obtained by reducing the probability of failure, trying to decrease the consequences caused by a failure, and reducing the recovery time (or downtime) which is needed to return to the normal level of functionality. Based on the [1] and considering the physical resilience of facilities and seismic resilience, a system is resilient if it is able to decrease the chance of the shock, absorb it, and return to the normal performance quickly.

There are different kinds of disaster which a resilient system should deal with. These disasters can be divided into two groups: *natural* and *man-made*. Earthquake, flood, hurricane, fire, terrorist attacks, etc. are examples of natural disasters. As the authors in [2] state, one of the features of a resilient system is the ability to reduce the damage in terms of lives lost etc. Hence, in order to decrease the number of victims and saving more lives, it is mandatory to improve their emergency response. Since saving life is a time dependent procedure, first responders should be fast in critical situation where many people need help. For an efficient and fast search & rescue, lots of information like the level and distribution of damage, the potential location of victims, and many other information are needed. Hence, having access to a real-time and reliable database which includes the mentioned data is crucial,but, due to damage, the infrastructures may be out of service and transferring data trough common methods like Internet, telecommunication networks, and etc. may not be possible anymore.

In this project, a novel system for real-time damage assessment which is able to locate victims and can be used for post-disaster investigations is proposed. The data provided by this system will improve the emergency response and increase the resiliency of the system.

2 METHODOLOGY

In order to improve emergency response and in case of natural disasters, it is crucial to identify and locate areas which need assistance as fast as possible. This is a difficult task especially when a disaster unevenly devastates various parts of a large area. Thanks to the proposed system, it is possible to use SHM system besides other methods like processing satellite images [3] for damage assessment and create damage maps. These damage maps which show the damage level of each area may help emergency teams to act faster and more efficiently. As it was mentioned, SHM nodes have been used for rapid assessment of damage level and creating a damage map. These SHM nodes also have been used to create a reliable network to facilitate the emergency response by localizing victims and showing their vital status.

Fig. 1 shows overall concept of the proposed system. The final output of the system includes a maps which shows the location of people and also first responders.

3 SYSTEM OVERVIEW

3.1 Architecture

Each node (SHM and wearable) is equipped with a RF module which gives the ability to act like a node in the wireless sensor network. Data coming from each wearable node include indoor location and victims's overall status (dead/alive and conscious/unconscious). These data are real-time and in cases where there is no other means of communication like mobile network, rescue teams and authorized people can access to the data in order to manage searching and rescuing procedure, and consequently, save more lives.

By using rechargeable batteries, each sink (SHM infrastructures) has the possibility to work without any external power supply (in case of power outage) for up to 6 months and it is designed to be resistant against damage. Hence, when power outage happens, the network maintains its functionality and is able to receive data from wearable nodes (victims) and generate maps which contain the location and the

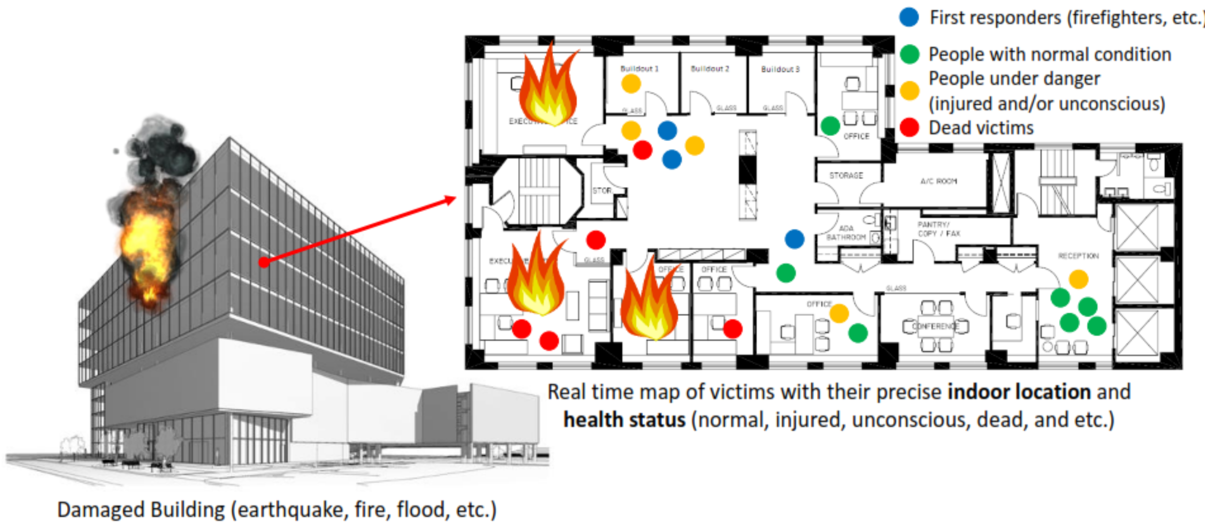


Figure 1: Overall concept of the proposed system.

overall status of victims. Since, this system provides the ability of indoor localization, it also has been used for post-disaster damage assessment. Each SHM node is equipped with an Inertial Measurement Unit (IMU) which has been used for motion detection. Based on the movement of each node after disaster and the direction of movement, a map has been created which depicts the damage level of each part of the building.

3.1.1 Network Topology

Two possible network topologies has been investigated for constructing wireless sensor network of this project. Fig. 2 shows these two network topologies.

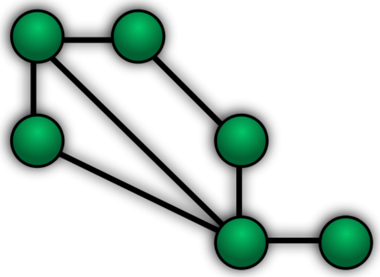
Considering the advantages of each topology, mesh network has been used as the network architecture. Mesh network provides a simpler network setup with more flexibility to expand the network, more reliability in environments where nodes may come and go due to interference or damage (disaster cases), and the possibility for all nodes to sleep, thereby increasing battery life.

3.2 Hardware

The wearable device is equipped with different kind of modules and sensors. Table 1 shows an overall overview of the sensors and modules that have been used in the wearable device.

Table 2 shows the list of sensors and modules that have been used in the structural health monitoring unit.

Fig. 3 shows the designed hardware which has been used as SHM and wearable nodes. Fig. 4 shows the size comparison of the wearable node with a watch.



(a) Mesh network (b) Star network

Figure 2: The two possible network topologies.

Table 1: List of sensors and modules used in the wearable device.

Item	**Description**
RF Module	Communicating with the other nodes and sinks / Used for constructing the wireless sensor network
GPS Module	Obtaining position data (Latitude, Longitude, and Altitude) / Used for outdoor emergency situations (flood and etc.)
GSM/GPRS	Communicating through mobile network in outdoor cases where there is no SHM infrastructure
Bluetooth Low Energy	Communicating with smart phone and Send & receive data
Heart Rate	Measuring heart beat and detecting the health status of the victim (Dead/Alive, Conscious/Unconscious)
Temperature (Body)	Measuring body temperature and detecting the health status of the victim (Dead/Alive, Conscious/Unconscious)
Temperature (Ambient)	Measuring ambient temperature and detecting different situations like fire and etc.
IMU	Combining the data coming from the heart rate and temperature sensors and detecting the overall status of victim (Dead/Alive, Conscious/Unconscious)

Table 2: List of sensors and modules used in the SHM system.

Item	**Description**
RF Module	Communicating with the other nodes wearable nodes / Used for constructing the wireless sensor network
Temperature	Measuring ambient temperature for structural health monitoring purposes / Used for fire detection
Humidity	Measuring humidity for structural health monitoring purposes / Used for fire detection
IMU	Measuring vibration for structural health monitoring purposes and detecting motion for damage level assessment

3.3 Software

The software of this system includes different parts. One part is the firmware which runs on the nodes and the other part is the software which takes care of the network and etc. There is also a real-time monitoring system which gives the user the ability to monitor each node and see the sensor data, heart rate, outdoor/indoor location, and other useful information. Fig. 5 shows a screenshot of the real-time monitoring application which has been developed in LabVIEW.

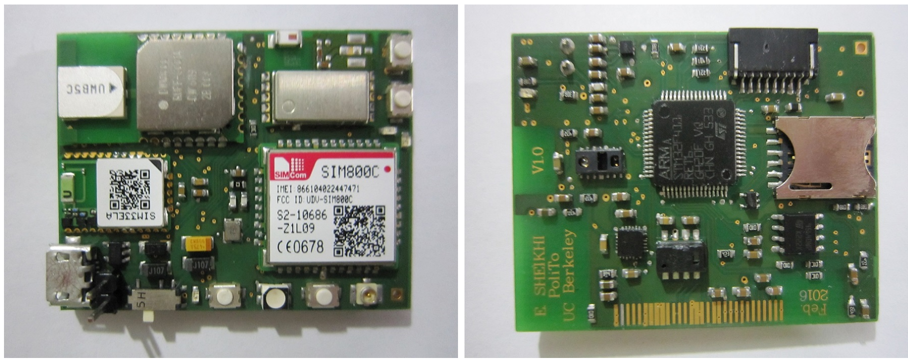


Figure 3: Top and bottom view of the developed wearable node.

Figure 4: Size comparison of the wearable node with a watch.

4 INDOOR LOCALIZATION

GPS performance in indoor cases is very limited due to impaired line of sight (LOS) to the GPS satellites. Hence, by using the proposed system, it is possible to use the WSN for the indoor localization in order to obtain the position of victims who have been trapped inside a damaged building and also in order to be used for post-disaster damage assessment.

Fig. 6 indicates a sample layout of the measurement area. The position of SHM nodes is fixed and known. The network of RF modules (wearable nodes and SHM nodes) provides the possibility to measure distance between two nodes. Using three SHM nodes and by means of trilateration method (Fig. 7), it is possible to detect the location of the wearable node which is in the communication range of those three SHM nodes.

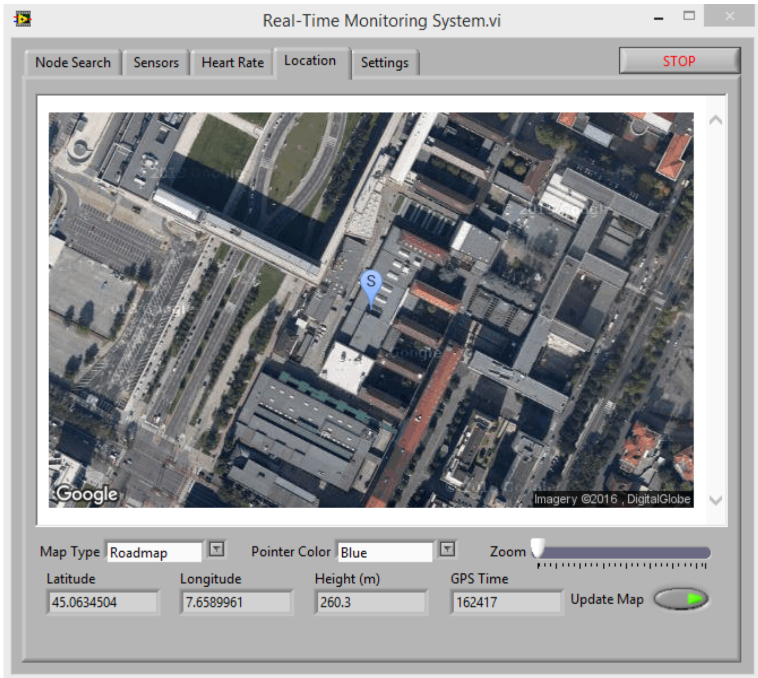


Figure 5: Screenshot of the developed real-time monitoring application.

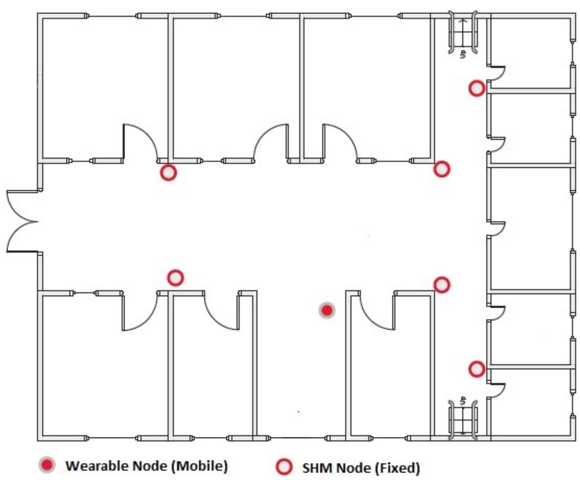


Figure 6: A sample layout of the measurement area.

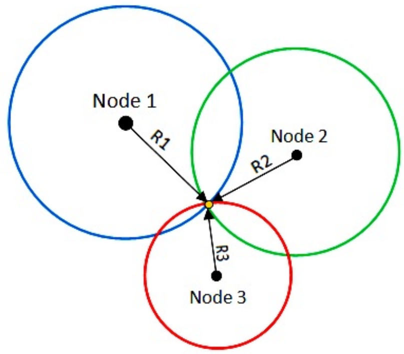


Figure 7: Trilateration method for localization.

4.1 Creating map of victims

Searching and rescuing are time consuming procedures. On the other hand, saving life is a time-dependent procedure and the faster rescue teams work, the more victims survive. Hence, time management in search and rescue missions plays an important role. After disaster, rescue teams start searching for victims while if they have access to a map that shows the approximate location and number of victims, their status, and other useful information, they can manage the time more efficiently and as a result help more people and save more lives.

After an earthquake, victims (dead/alive, conscious/unconscious) are trapped inside buildings and due to downtime of lifetimes like power and telecommunication network, there is no possible way to ask for help through common methods like cell phone. Moreover, victims may be unconscious so they cannot ask for help or respond to any signal.

Fig. 8 shows an example of the output data of the system which emergency responders will have an access to them. Age and gender have been entered to the system by users themselves (user profiles) and they may not be available in general.

Fig. 9 shows a heart rate data received from a wearable node. The heart rate in addition to data of other sensors (body temperature, body motion, etc.) can be used to obtain vital status of victims.

5 CONCLUSIONS

In this paper, a novel system for real-time damage assessment which is able to locate victims and can be used for post-disaster investigations is proposed. Using the proposed system, all the victims (dead/alive, ...) who have worn these wearable nodes are connected to the network and their locations are being estimated in real-time. Rescue teams have the possibility to connect to the network of victims through radio frequency and detect the location of people in the network and check their overall health status. Moreover, the network is able to depict the damage map and damage level of structures which are equipped with the proposed SHM system.

Figure 8: An example of the system application after earthquake.

Figure 9: Heart rate data of a wearable node.

This system is designed to work even in case of power outage, and since it uses its own radio frequency module, it is not dependent on common communication networks. This system has many advantages which are listed below:

- Independent from electrical power source and common communications infrastructure (Internet, WiFi, GSM, and etc.);

- Reliable and robust data transfer even in disaster cases;
- Possibility to localize victims with a reasonable precision and generate maps including the location of victims.
- Practical post-disaster damage assessment using the indoor localization feature;
- Possibility to define different network topologies;
- Possibility to link different buildings and connect them to a data control center through high range RF modules.
- Increasing efficiency and speed of searching and rescuing and saving more lives.

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