Wireless Sensor Networks for Indoor Search and Rescue operations

Alexander Chizhov, Andrey Karakozov

***Abstract*—Many people all around the world live in a daily threat of natural disasters, such as earthquakes or floods. Numerous projects study ways to predict natural disasters, but the number of research focusing on aftermaths is much smaller. Traditional ways first response teams use are, for example, radars and canines, which mainly search surface and near-surface regions of the rubble. Such methods, however, are quite ineffective in locating victims inside a rubble, as access to such regions is often problematic. A superior approach to this problem might be wireless sensor networks (WSN). WSNs are able to provide a more efficient way to deal with search and rescue operations, making them quicker and lessening the risk for both rescuers and victims, by autonomously collecting data about the situation inside the rubble. In this paper we review current WSN assisted indoor search and rescue operations projects and design issues that developers of such systems face with.**

***Keywords*—Wireless Sensor Networks, Disaster Relief, Search and Rescue**

I. Introduction

A Wireless Sensor Network (WSN) is a group of a large number of individual sensor nodes communicating between the datacenter and each other. Originally introduced to suit military applications [1], now they have many uses, such as agriculture [2], water distribution monitoring [3], and healthcare [4]. One of the more novel uses is the disaster management systems [5], [6]. The total amount of people affected by disasters from 2006 to 2015 years is considered to be around 2 billion, whereas the total amount of disaster estimated damaged is around 1.4 trillion US dollars [7]. Right now, there are many systems that focus on disaster detection and people warning [8], [9], [10], [11], but the number of projects focusing on the rescuing human victims is much smaller. Moreover, existing projects focus more on the saving surface victims, whereas the majority of victims are trapped inside the rubble, and only 20% of total survivors come from the interiors [12]. In the case of collapsed building, for example, rescuers main task is to identify victims' locations, which can be problematic due to long time needed to remove rubble, harsh environment, such as fire, or the collapse of cellular networks.

In this paper we review the applicability of WSNs in the indoor search and rescue operations. In Section 2 we discuss design challenges, that should be considered while developing a WSN for such purposes. Section 3 covers recent research in the field. In Section 4 we summarize and compare existing projects in this area. Section 5 provides a conclusion of the paper.

Manuscript received November 17, 2016.

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II. Design Challenges

There are a number of challenges that developers of WSN for search and rescue operations should consider. In this section we will discuss a few of them.

A. Deployment

Deployment process describes how the system should be installed. There are two possible ways to deploy a system: pre-disaster and post-disaster. The former way might be more suitable for commercial systems, whereas the latter might be more useful for state disaster relief teams. One should also consider the pattern of WSN deployment. There are four main deployment patterns: Random, Grid, Group Based, Grid Group [13]. Deployment pattern affects both routing protocol and sensor coverage area. The fact that we discuss indoor operations should also be considered, as an access to the disaster site might be troubled, which increases the restrictions imposed on chosen deployment method.

B. Network coverage

Coverage is one of the most important issues to address during the development of the system. There are multiple definitions of it, but in general, it can be defined as follows: "How well do sensor nodes utilize physical space?".

Coverage can be classified as follows: blanket coverage, barrier coverage, and sweep coverage [14]. Blanket coverage aims to provide as much area coverage as possible, with a possible lack of intersected coverage. Barrier coverage, on the other hand, aims to provide as much intersections coverage as possible, while possibly losing the area. Sweep coverage deals with moving sensor nodes so that the area is swept by mobile nodes.

Network coverage is especially important for indoor systems, because of many possible obstacles, such as rubble.

C. Mobility

The developed sensor system can be mobile (also called MWSN) and static (simply WSN). The concept of mobility is tightly coupled to the previous sections, as it might, for example, decide the deployment type. Although the static design is the simplest one, it has limitations, such as loss of area coverage because of node energy source depletion and lack of coverage due to permanent position of the node [15].

The more recent mobile design is usually based on one of the following approaches: mobile nodes, mobile base stations or mobile data collectors. Mobile base stations provide more wide area coverage, whereas mobile data collectors provide more efficient data collection, eliminating the need of complex data hopping. Mobile nodes can be either weak or strong mobile. Weak mobile nodes move only when there is a connection problem, whereas strong mobility is caused by an external agent. Furthermore, strong mobility can be divided into robotic, when the node can move by itself, and parasitic, when the node requires external force, such as wind [16], [17].

D. Types of sensors

Search and rescue operations mainly focus on locating human victims, hence the sensors to be used in such operations must be oriented on detecting survivors. There are a few possible options: motion sensors, microphones, cameras, infrared sensors – all of these can be used for both pre- and post-disaster. In the case of pre-disaster deployed nodes, there are a few more possibilities, such as GPS.

E. Energy consumption

Although it might seem that the lower the energy consumption is, the better, it might not be the case for indoor search and rescue operations. Consider the total length of such operation: victims should be found in the first 48 hours after the disaster [18]. Thus post-deployment systems might have a battery life of days to weeks, which eases the constraints on design and sensors. On the other hand, pre-deployment systems must have a battery life of years, to be active for 48 hours after the disaster happens.

III. Existing projects

There are a number of existing projects conducted for indoor search and rescue operations utilizing WSNs. Some of the projects use WSNs solely, whereas others utilize them in conjunction with robots. In this section we will review some of them. It should be noted though, that this field is quite novel and the papers presented here cover most of the works done.

A. SENDROM

SENDROM (Sensor Network for Disaster Relief Operations Management) is a system proposed to manage the rescue operations after large-scale disasters [19]. There are two types of nodes:

- Sensor nodes
- Collector nodes (cnodes)

There are two more types of sensor nodes:

- Snodes: they sense and report any living human around them.
- Inodes: they are associated with the individuals and report the status of that person.

Both *snodes* and *inodes* can come in two varieties:

- Embedded: *snodes* are mounted on home appliances, such as refrigerators, whereas *inodes* are embedded into person's individual belongings.
- Standalone: are standalone, matchbox sized nodes, located in places such as drawers or lockers.

Fig. 1. shows the SENDROM architecture after a disaster.

SENDROM Database Server (SDS) acts as an edge router and can be queried from the Internet allowing rescuers to gain an information on victims' state and location.

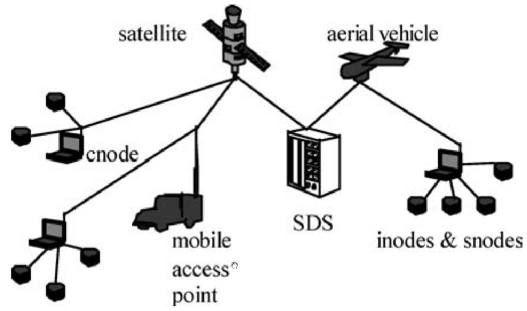

Figure 1. SENDROM state after a disaster

B. Search balls

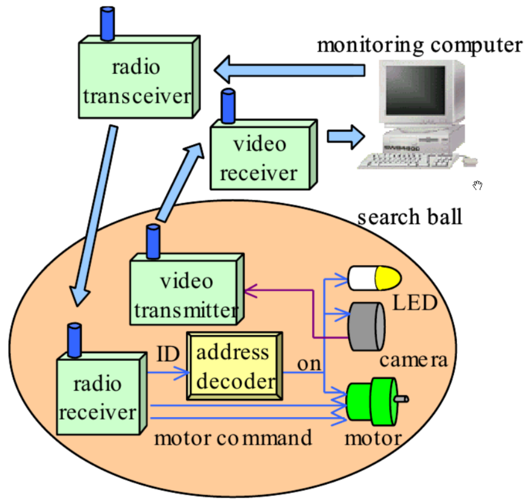

Figure 2. "Search balls" project architecture

In this project, proposed in [20], so-called "search balls" equipped with wireless cameras, radio receivers, batteries and infrared LED are used for searching victims in the ruins of collapsed buildings. The system architecture is shown on Fig. 2. There are two types of search balls: one with three static wireless cameras, and one with two wireless cameras rotated by a motor. The proposed way of operating is as follows:

1) The rescuers throw many balls into a building. The balls scatter around the building.
2) The cameras start to record information and transmit it to the rescuers.
3) Rescuers enter the building and with the aid of the sensor balls get close to the victims while removing rubble.
4) After rescuing victims balls are extracted and can be reused later.

C. A rescue-assist wireless sensor networks for large building

This is a project oriented on detecting falls and locating people in large buildings in case of emergency situation, such as fire [21]. As shown on Fig. 3, the rescue-assist WSN consists of static nodes, that are planted in office rooms, that act as routers, wearable tags, that act as end devices, and the base station, that acts as a coordinator. Although locating victims is not the only function of the proposed solution, we will concentrate on it, as the fall detection goes

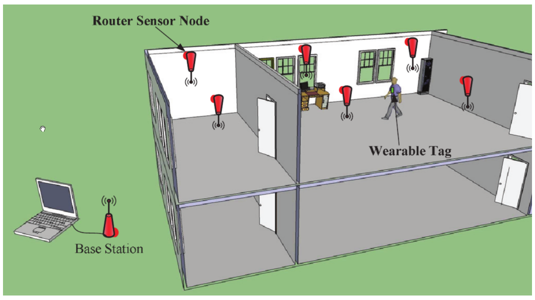

Figure 3. Rescue-assist WSN project architecture

out of the scope of this paper. According to [22] in complex indoor situations, a problem of non-line of sight (NLOS) rises, making detection of victims harder. To resolve this problem, authors propose Constrained Atomic multilateration (CAM) algorithm, that utilizes data both from wearable tags and router nodes. According to results of experiments, this algorithm provides relatively better performance, than Maximum Likehood Estimation (MLE) algorithm, that sometimes used in such projects.

D. RESRS: Robot Emergency Search and Rescue System

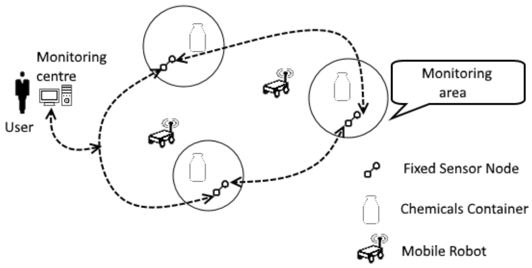

Figure 4. RESRS project architecture

RESRS is a project that integrates WSN with a robotic system for both monitoring and carrying out search and rescue operations in case of a chemical accident [23]. The solution architecture is presented in Fig. 4. It consists of three main parts: fixed sensor nodes, mobile robots and a monitoring center. RESRS can operate in two modes. During normal mode, WSN collects data on the surroundings state, while monitoring center analyzes it. When the accident occurs, the system switches to the other mode, with robots entering accident location, helping search and rescue team, e.g. by producing maps of victims' location, and monitoring center building leak model using the data of sensors.

E. A Biobotic Distributed Sensor Network for Under-Rubble Search and Rescue

A project that integrates Wireless Sensor Networks with biobots is proposed in [24]. According to the authors, existing technologies are yet to find a way to penetrate small gaps and voids deep in rubble. This project's solution is to surgically implant wires into a cockroach and equip it with a specially designed electronic backpack, consisting of sensors and ZigBee transceiver. The solution operates as follows:

1) A special first response team arrives at the site of the building ruins and places a swarm of biobots at the edge of rubble.
2) Biobots move through the rubble while maintaining some distance between themselves to maintain the network.
3) During their moving, the data map of rubble is created.
4) After hearing a possible sound of interest, biobot autonomously moves towards the source, while sending signals to the team.
5) Biobot finds a victim and rescue team decides on the best route to him or her.

Although this project is in its early stage, the authors have successfully conducted experiments on automatic steering towards the sound source.

IV. Discussion

The main common point of the projects described in this paper is their usage of the WSNs. Their primary task is acquiring data from the disaster site and providing rescue team with information.

Some of these projects propose wearable sensor nodes; others require the deployment of static nodes in buildings; and lastly, there are projects that use mobile sensor nodes based on robots or biobots.

Most of the projects deal with the problems of routing and power efficiency, as these are one of the most fundamental problems when considering the usage of WSNs in this field.

The Table I summarizes projects discussed in this paper by criteria we believe are amongst the most important in the field of search and rescue operations.

V. Conclusion

In this paper we review recent projects that utilize Wireless Sensor Networks to aid the indoor search and rescue operations and their design challenges. We can conclude that WSN is a good candidate for such applications, allowing a quicker response to the disaster, possibly providing access to the otherwise hardly accessible places and ensuring safety

Table I
Search and rescue projects comparison

Project / Criterion	**SENDROM**	**Search balls**	**Rescue assist WSN for large buildings**	**RESRS**	**Biobitic WSN**
Deployment type	pre	post	pre	pre	post
Mobile	no	no	no	both	yes
Need of personnel in close proximity	no	yes	no	yes	yes
Reusability	yes	yes	yes	yes	yes
Protocol	-	Custom RF	ZigBee	ZigBee	ZigBee
Types of Sensors	-	Wireless cameras	Accelerometer	yet to decide	Microphones

for both the victims and the rescuers. Compared to the other solutions, such as robotics, WSN allow for cheaper, smaller and more energy efficient way to deal with disasters, although possibly less mobile and autonomous. To overcome these limitations robots (or biobots) and WSN might be used in conjunction. Overall, we can conclude that WSN is indeed an effective solution to the problem and more research should be held in this field.

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