Evaluation of RFID and Wireless Sensor Technologies for Local Search and Rescue Data Storage

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***Abstract*— Retrieving local information is vital for efficient search and rescue operations in a disaster area after a natural disaster strikes buildings and their residents. This local information includes the information about the neighborhood (e.g., transportation plan of the area, usage types of buildings), buildings within the neighborhood (e.g., layout plans, contents of buildings and the number of residents) and their residents (e.g., personal and health information). Although it seems reasonable to store the required local information in a centralized database, experiences indicate that search and rescue teams cannot retrieve local information from these centralized databases since the information infrastructure is usually damaged or overloaded immediately following a disaster. The Search and Rescue Data Access Point (SR-DAP) system is designed for storage and retrieval of the required local information in/from data storage units that are deployed on buildings. This study aims to empirically evaluate and analyze two key technologies, namely RFID tags and wireless sensors as local storage units within SR-DAP. The presented results of the field experiments validate the success of the proposed system and evaluate the technical feasibility of utilization of the selected technologies for the purpose of this study. As the results of the experiments illustrate, the system can be designed using both technologies with differing superiorities on different performance criteria.**

I. Introduction

In case of an earthquake, urban search and rescue (S&R) operations are performed to locate and rescue victims who are trapped in collapsed structures and to provide immediate medical treatment. Once a building is selected for S&R operations, the S&R teams need to know about the building layout and design (e.g., location of stairwells, elevator shafts) to identify the possible locations and voids where people might be trapped. To collect this information, a member of a S&R team walks around the damaged building and makes a sketch of the building, highlighting its outstanding features. In the meantime, another team member talks to people in the neighborhood to gather information about the building, its contents and residents. Collecting the required information manually has two main potential drawbacks: (1) it is time-consuming to collect information through observations at site and by talking to people in the neighborhood who are familiar with the buildings and witnessed the disaster, (2) the collected information is not always reliable because local people are also the victims of the earthquake and they may mislead the S&R teams.

To overcome these problems, The Search and Rescue Data Access Point (SR-DAP) system is designed to locally store the information items that are needed by a team during S&R operations on local data storage units before an earthquake occurs, and these information items are made readily available for use on demand. S&R teams access this information to make effective decisions and to perform S&R operations in an efficient way. Once the S&R operations are completed in one of the buildings, the S&R assessment information is stored into the local data storage unit to document the performed activities for use by other teams.

The S&R teams carry a handheld computer (e.g., PDA) integrated with a receiver unit to retrieve data from data storage units or to store data in them. Currently, two technologies hold potential as local data storage units: Wireless sensors and Radio Frequency Identification (RFID) tags due to the properties they exhibit such as long communication range, low power consumption, and ability to store information locally. Therefore, these two technologies are utilized as decentralized databases that store local information related to an area for use on demand during S&R operations. Details on the SR-DAP design with sensors are given in the earlier work [1], [2]. In this study, RFID tags are also used as storage units. The empirical evaluations of both technologies are performed on real hardware and an analysis is presented to compare two technologies for the given domain.

II. Related Work

Existing disaster management systems are mostly developed for identification, prediction and recovery phases and do not support real-time response activities [3], as in [4]. In the recent studies, frameworks for disaster management systems that cover the response phase were developed [3, 5 and 6]. Various components such as GIS, web collaboration tools, robots, sensors, building black box systems and RFID are incorporated in frameworks that are proposed by

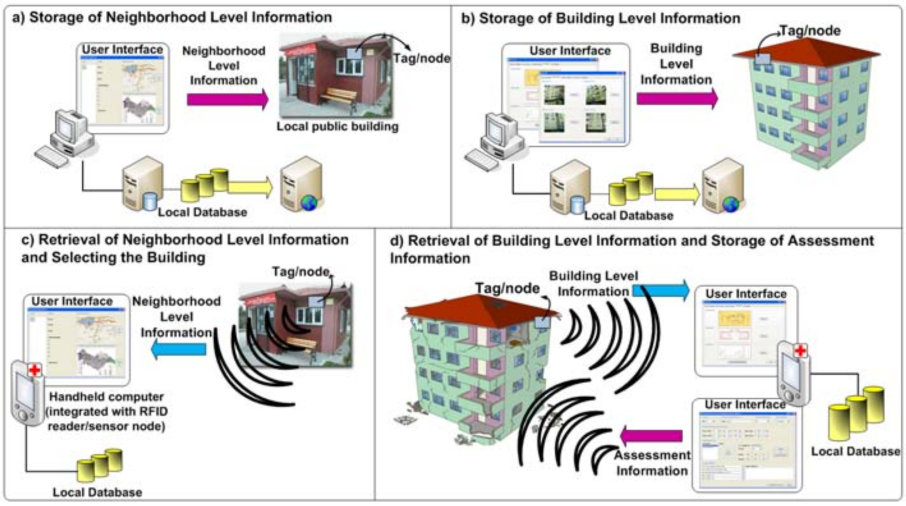

Figure 1. SR-DAP: The main components of the the system and their usage in different phase

researchers such as [5] and [6]. Their focus was on establishing effective ad-hoc communication among those mobile devices used by the responders and aimed to improve collaboration. Additionally, [6] and [7] presented a conceptual building black box system that integrates advanced building sensing and control systems to provide information about a building and its residents during S&R.

SR-DAP is different from earlier work as it is a standalone local data storage system utilizing RFID and sensor nodes which can easily be deployed at existing buildings since it does not need to interface with other advanced systems [1], [2].

III. Search and Rescue Data Access Point

Search and Rescue Data Access Point (SR-DAP) is designed to assist S&R operations with its capabilities on storage and retrieval of local information in/from storage units deployed on exterior walls of buildings. Three different types of information are used in the system: building level information, neighborhood level information and S&R assessment information [8]. The relevant information items to be stored are determined based on interviews conducted with earthquake experts and S&R responders from Istanbul Technical University, Turkish Civil Defense Association and AKUT (Turkey Search and Rescue Association) [8]. These information items that are needed by a team during S&R operations are stored locally on data storage units before an earthquake occurs, and they are made readily available for use on demand. S&R teams access this information to make effective decisions and to perform S&R operations in an efficient way. Once the S&R operations are completed in one of the buildings, the S&R assessment information is stored into a local data storage unit to document the performed activities for use by other teams.

Fig. 1 illustrates the main components of SR-DAP and how they are used in different phases [1], [2]. At each neighborhood, storage units are placed at the exterior sides (1) of a local public building to store neighborhood information (Fig. 1a) (2) of each building to store building information (Fig. 1b). Information that is necessary for S&R operations needs to be entered to the storage units beforehand. To retrieve/store data from/on the storage units, a handheld computer (i.e., a PDA or laptop) integrated with a sink sensor node/RFID reader will be carried by the S&R teams. Following a disaster, S&R teams query the storage units, retrieve the related neighborhood or building information (Fig. 1c and Fig. 1d) and finally enter assessment information to the storage units attached to the related building once S&R is completed at that building (Fig. 1d). A data redundancy is provided by storing the same data in multiple storage units so that if a storage unit is damaged, the required data would be available in other storage units.

SR-DAP system utilizes RFID tags and wireless sensor nodes as data storage units that store the necessary local information within their memories. The main difference between the RFID tags and the wireless sensor nodes is that the sensor nodes can communicate with each other, whereas, RFID tags cannot. This would make a difference in terms of usage of these two technologies within the system.

Since all the necessary information items are proposed to be stored in storage units, which may have limited memories, low memory requirements should be met. To minimize the storage space needed for all information items, a proper data encoding mechanism is used [1]. With this encoding, building level information items including the pictures of the building and the residents are stored in 661 kB memory space. The required memory space is 454.25 kB for the neighborhood level information and 5.1 kB for the S&R assessment information. Local database is assumed to exist in the computing hardware of either operators or rescuers for encoding data that is stored in the units.

After identifying the building to be searched, S&R teams need to retrieve the relevant building level information from the corresponding unit attached to the building. In congested areas, multiple units of different buildings might be in range. To facilitate selection of the corresponding storage unit, a high level protocol is designed in which only a limited amount of building level information, the primary information, is transmitted to the receiver unit. The primary information of a building was stored in 10,05 kB and includes the following items: name of the building, purpose of use, number of floors, type of structural system, year of construction, coordinates of the building, a picture of the front face of the building, renovations/(structural) strengthening that changed the original layout of the building and the latest data update date. This information is sufficient for an S&R team member to select the related storage unit from which further building level information is to be transmitted. The details of the protocol are given in [9].

IV. Experiments and Results

An extensive set of experiments is conducted to analyze the performance of the two technologies (i.e., RFID and sensor) within SR-DAP under different environmental conditions. This section presents results of these experiments which both validate the success of SR-DAP and measure feasibility of the selected technologies to be used within the purpose of this study.

A. Experimental Setup

Sensenode v.2.1 sensors by Genetlab are used as the sensor components in the field experiments. They are low power sensors with 1024kB external flash memories. i-Card CF card reader and Intelligent Long Range (ILR) active tags by Identec Solutions are used as the RFID components. i-Card CF card readers, compatible with ILR tags, have reading rate at 35 tags/s. The ILR tags have 32 kB storage spaces (of which only 25kB of them can be used for data storage). Therefore, only the primary information can be stored in RFID tags while the building level information can be stored in sensors. The maximum range of data transmission in a straight line on the ground level is 65 meters for RFID tags and 85 meters for sensors. Data transmission rate is 115 kbps for RFID tags and 250 kbps for sensors. The batteries of RFID tags are not renewable but have an average of 6 years lifetime. On the other hand, the batteries of sensor nodes have an average of 3 months lifetime but they are renewable.

Field experiments were conducted at (1) Electrical and Electronics Faculty (EEF) building of Istanbul Technical University (Fig. 2) and at (2) a residential apartment building (Fig. 3). While, the EEF building (Building-1) has four floors, each 4.5 meters high, Building-2 is in a residential complex and has ten floors above the ground at the front side. Experiments on this building are performed at the windows located in the stairwell area where the height is 2,8 meters (Fig. 3). While data storage units are located at the window stools at each floor of the buildings, the receiver unit to be used by the S&R team members is located at the ground level.

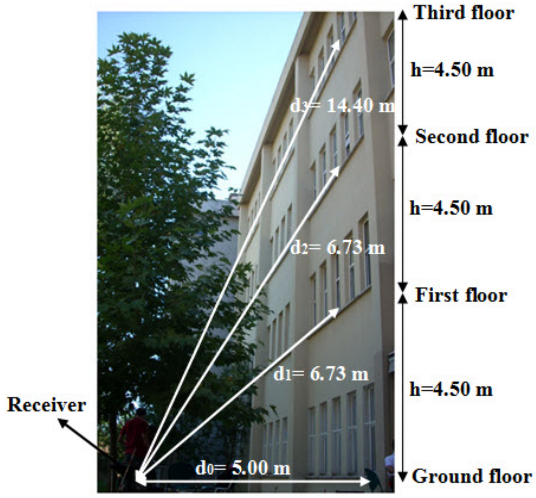

Figure 2. EEF Building-1 and measurements

Figure 3. Residential complex and test environment at Building-2

B. Experimental Results

The first set of experiments focuses on analyzing performance of the storage units for different sizes of stored data. In the second set of experiments, communication success is measured for different orientations of a transmitter unit (i.e., the one attached on the building) communicating to the receiver unit (i.e., receiver node carried by an S&R team member). The third set of experiments is conducted to evaluate the overall performance of the system in terms of transmission success and time for both low-rise and high-rise buildings. In the fourth set of experiments, performance of the system to retrieve relevant information in a congested building environment is determined.

1) Scalability Analysis

This set of experiments is conducted to measure the performance of the system with respect to the increasing data size. Since only 25 kB of the RFID tag memory can be used for data storage, conducting experiments with large amounts of data were not possible with an RFID tag. When a limited amount of data is analyzed, a gradual linear increase in the

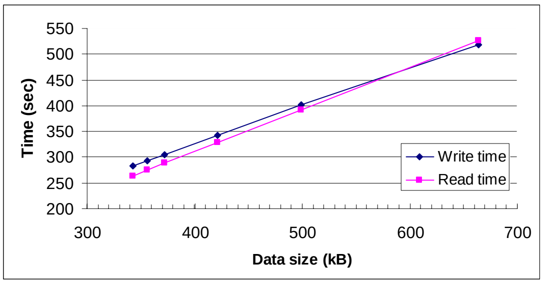

Figure 4. Average read/write time for sensors versus data size

write time with respect to the increasing amount of data is observed with the highest value as 13 seconds for an information package (19,64 kB). This information package includes data for a four floor apartment with ten people (no pictures are stored), five different hazardous materials, four pictures of the building (i.e., each 3 kB), and a floor plan picture (i.e., 4 kB). The average read time for this information package was 11 seconds.

Since a Sensenode v.2.1 sensor is able to store a larger amount of data than an RFID tag, an extensive experiment for all building level information is conducted. The varying parameter in these tests is the number of people (i.e., 1, 5, 10, 25, 50, 100), which accordingly changed the size of the stored/transmitted data. The transmitter sensor is placed near the receiver to minimize packet retransmission and to focus the analysis on read time performance for different data sizes. Fig. 4 illustrates time to read/write the corresponding data. As expected, there is a proportional relationship between the read/write time and the data size.

2) Orientation Analysis

In these tests, performance of the units is analyzed for different orientations of the transmitter unit. The receiver unit is placed on the x-y plane where its antenna is in the x axis direction. The transmitter unit is located at a 7-meter-distance to the receiver and it is rotated by 45 degrees between 0-315 in x, y and z axes during the experiment. The stored/transmitted information package in this experiment includes the primary information (i.e., 10,05 kB) of a building. Table I reports the transmission duration for both RFID and sensor units. The results are given as the averages of five independent measurements for each angle. Transmission of data is successful for all cases with both RFID and sensor units. Read time of RFID units is slightly shorter than that of sensor units. These results illustrate that the relative orientation of the transmitter unit does not have a critical impact on the success of the reading operation.

Packet loss rates for different angle values were observed in tests with sensors. In this case 10,05 kB of data, represented by 115 packets, were sent without using any protocol for preventing packet losses. From the results given in Table II, the best relative angle (between the transmitter and the receiver) with the minimum packet loss was

TABLE I. TRANMISSION TIME– ORIENTATION

Angle	x-axis		y-axis		z-axis	
	RFID	***Sensor***	***RFID***	***Sensor***	***RFID***	***Sensor***
0	**11,96**	12,55	**11,95**	12,56	**11,96**	12,56
45	**11,98**	12,87	**11,93**	12,83	**11,99**	12,59
90	**11,93**	12,84	**11,93**	12,83	**11,95**	12,62
135	**11,93**	12,86	**11,91**	12,81	**11,92**	12,62
180	**11,93**	12,7	**11,92**	12,55	**11,92**	12,59
225	**12,01**	12,73	**11,96**	12,56	**11,98**	12,61
270	**11,94**	12,64	**11,96**	12,64	**11,94**	12,63
315	**11,97**	12,63	**11,93**	12,66	**11,95**	12,66

a. All time values are in seconds

TABLE II. SENSOR PACKET LOSS RATE ROR DIFFERENT ANGLES

Angle	Packet loss rate (%)		
	x-axis	*y-axis*	*z-axis*
0	**0**	**0**	**0**
45	0	0,35	0
90	0	0,35	0
135	0	0,35	0
180	**0**	**0**	**0**
225	0	0	0,17
270	0	0,17	0
315	0	0,17	0,17

observed as 0 (also no loss in 180 degree) for all axes. This result validates the intuitive estimation that the best performance would be observed when the antennas of the receiver and the transmitter are facing the same direction.

3) Overall Performance Analysis

Overall transmission performance analysis is performed for both Building-1 and Building-2.

a) Experiment-I on Building-1

These tests are carried out both with sensor nodes and RFID tags to analyze the read time of each technology at different levels of the Building-1. In the tests with sensor nodes, building level information that includes the records of 50 people (i.e., 498.75 kB - 10.05 kB of which was represented as the primary information) was stored in the transmitter sensors attached at each floor at Building-1. A similar experiment but with only primary information was conducted on RFID units due to memory limitations. Fig. 5 illustrates the time needed to transmit only the primary information using both the RFID and the sensor nodes at varying distances between the transmitter and the receiver. The results show that the read time was hardly affected by the distance between the receiver and transmitter for both technologies. The overall time to transmit the primary information was shorter for RFID nodes than sensor nodes.

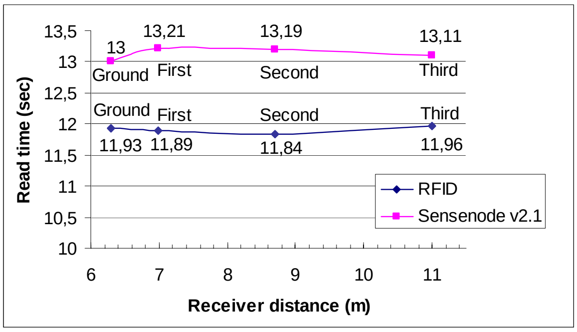

Figure 5. Average read time on different levels of Building-1

TABLE III. RFID READ TIME ON DIFFERENT LEVELS OF BUILDING-2

Level	Distance (m)	Time (sec)
1	23,50	-
4	24,96	11,94
7	28,89	12,41
9	32,47	12,35
10	34,46	-

TABLE IV. SENSOR READ TIME ON DIFFERENT LEVELS OF BUILDING-2

Level	Distance (m)	Primary Info Read Time (sec)	Building Info Read Time (min)
1	23,50	12,66	6,36
4	24,96	12,99	6,36
7	28,89	12,92	6,37
10	34,46	12,67	6,37

b) Experiment-II on Building-2

The setup of this experiment was the same with Experiment-I but on Building-2, which is a high-rise apartment building in a sparsely spread residential community. During the whole experiment, the weather was rainy. Therefore, performance of the system under different weather conditions could also be analyzed. Since Building-2 is taller than Building-1, these tests were conducted to validate the success of the system on tall buildings. Another purpose of this experiment is to analyze the relationship between the distance and the transmission time for greater distances. Tests on this apartment building were conducted at the windows in the stairwell of the building. There were ten floors above the ground level at the front side of the building.

In the first phase, the system performance with RFID tags is measured. Tests are performed for different levels, five times each. Although RFID tag could not be read at 10th window due to the range limitation, transmission was successful with slightly changing average transmission duration for the lower levels except the first floor (Table III). The metallic window fence in front of the building is thought to have a distortive impact on the first level transmission.

The same experiment is conducted with sensor nodes. In this case, sensor units could be read at the highest level of

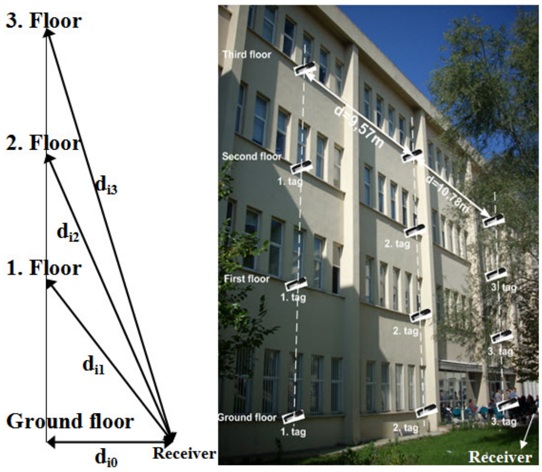

Figure 6. Placement of tags on Building-1 and representation of distances according to the floor number (dij, i: number of tag, j: number of floor)

TABLE V. DISTANCES FOR DIFFERENT LEVELS AND UNITS

Floor	The 1st unit - receiver	The 2nd unit - receiver	The 3rd unit – receiver
0^{th}	d_{10}=10,80 m	d_{20}=5,00 m	d_{30}=11,88 m
1^{st}	d_{11}=11,70 m	d_{21}=6,73 m	d_{31}=12,71 m
2^{nd}	d_{12}=14,06 m	d_{22}=10,30 m	d_{32}=14,91 m
3^{rd}	d_{13}=17,30 m	d_{23}=14,40 m	d_{33}= 17,99 m

Building-2. The results given as average values of five independent measurements for each level were reported in Table IV. The results show that the reading operation was successful at all floors of the building. It was also observed that the read times for different floors are close to each other.

4) Dense Building Environment Performance Analysis

In these tests, the performance of the system is analyzed for the case where the units of different buildings were in the range of the receiver. Tests were conducted using both RFID tags and sensor nodes that are placed in a matrix form at Building-1 (Fig. 6). By having such an arrangement, three data storage units of different buildings are placed in the range of the same receiver at the same time since different parts of Building-1 are represented as different buildings. Distances between the units are reported in Table V. During these tests, the unit selection protocol is applied on the primary information (10,05 kB). Performance on recognizing all building units and transmission of the primary information of all these units is analyzed. The tests are repeated five times for each floor. These values are reported in Table VI. The results illustrate that all tags in range could be read at all floors using both units. These results also illustrate that the system could recognize several units located in a congested area and could facilitate selection of appropriate building unit among them to retrieve relevant information. As reported in Table VI, the results also show that the total read time of all RFID tags of neighboring

TABLE VI. RESULTS OF NEIGHBORING BUILDING TESTS

Floor	RFID		Sensor	
	Average number of recognized units	*Read time (sec)*	*Average number of recognized units*	*Read time (sec)*
0^{th}	3	39,12	3	30,05
1^{st}	3	39,11	3	30,37
2^{nd}	3	39,39	3	29,91
3^{rd}	3	39,12	3	30,06

buildings is longer than that of sensor nodes. Note that, tag exploration time was also included in the total time calculation for RFID tags.

C. Discussion

The performance of the two data storage mediums (i.e., RFID and sensor units) integrated into SR-DAP is investigated to determine whether they can meet the specified requirements in the presented field experiments.

While sensor nodes can store building level information in their external memories, current limited memory size of RFID tags makes it impossible to store the whole information of a building. This limitation can be overcome either by attaching an external memory to tags or by using several tags to store different parts of data. Tests conducted with these two units reveal that both technologies are fulfilling the need for long communication ranges. However the observed actual ranges seem lower than ground level ranges when the units are placed at different levels of the building. This could be caused by the varying angle between the transmitter and the receiver when they are placed at different levels. The read time for both units is almost steady with respect to the change in the distance (i.e., level) and the orientation of units. The results suggest that although the read time for a single RFID tag is shorter for the primary information, the communication range is wider for sensors (both in theory and practice).

It has been observed that the units of different buildings can be recognized successively and relevant information is retrieved from them during the tests performed in a densely located building environment. This is made possible by the designed unit selection protocol. In a dense installment, data redundancy property of the system may be useful such that information about a building that is likely to be damaged severely could also be stored in units at the neighboring buildings. The results also show that, although the read time of an RFID tag is shorter than that of a sensor node for a single unit, multiple unit exploration and read time takes longer for RFID tags. These experiments also illustrate that data transmission is robust to rainy weather conditions.

In terms of power management, the batteries of RFID tags are not renewable but have an average of 6 years lifetime. On the other hand, the batteries of sensor nodes have an average of 3 months lifetime but they are renewable. Communication among nodes is not supported for RFID tags while it is the case for sensors. This ability of sensors makes them usable for further services. For example, centralized updates could be performed from a distant point in the sensor network or even when a relevant sensor is not in the range of the receiver, it can still transmit its data through the network. Considering all these facts and observations, designing SR-DAP with sensors as local data storage mediums is more beneficial for efficient S&R operations with the current technology.

V. CONCLUSION

This paper presents SR-DAP as a standalone local data storage system to assist S&R operations. RFID and wireless sensor technologies are utilized, for the first time within this study, for local data storage and retrieval for S&R operations performed after an earthquake. Numerical evaluations of RFID tags/sensors as data storage units within SR-DAP are presented and a detailed analysis of the results are given. The results reveal that both technologies could successfully be integrated into SR-DAP. Even for high-rise buildings, the observed results are promising for both of the storage mediums. However, memory limitations of current RFID tags and their shorter communication ranges make them less efficient for this domain.

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REFERENCES

[1] S. Sariel-Talay, E. Ergen, G. Avdan, and C. Eroglu, "Sensor-based data storage for search and rescue", The 4th Intl. Conf. on Intelligent Sensors, Sensor Networks and Info. Processing, 2008.

[2] E. Ergen, S. Sariel-Talay, and G. Guven, "Providing local information for search and rescue using sensor-based local databases", ASCE Intl. Workshop on Comput. in Civil Eng., 2009.

[3] A. Pradhan, D. F. Laefer, and W. J. Rasdorf, "Infrastructure management information system framework requirements for disasters", J. Comput. Civil Eng., vol. 21 (2), pp. 90-101, 2007.

[4] FEMA 2007: "HAZUS - FEMA's software program for estimating potential losses from disasters", http://www.fema.gov, 2007.

[5] H. Asama et al., "Rescue infrastructure for global information collection", SICE-ICASE, Intl. Joint Conference, 2006.

[6] A. Y. Chen et al., "A collaborative framework for supporting civil engineering emergency response with mobile ad-hoc networks", ASCE Intl. Workshop on Comput. in Civil Eng., 2007.

[7] M. H. Tsai, L. Y. Liu, and P. M. Feniosky, "A building black box for urban disaster response and relief," ASCE Intl. Workshop on Computing in Civil Eng., 2007.

[8] E. Ergen, G. Guven, and S. Sariel-Talay, "Identification of Local Information Items Needed During Search and Rescue Operations Following an Earthquake", unpublished, available at: http://www2.itu.edu.tr/~sariel/publications/ASCE2010EEGG.pdf

[9] E. Ergen, S. Sariel-Talay, G. Avdan and G. Guven, "Sensor/RFID-based wireless data access for search and rescue", unpublished, available at : http://www2.itu.edu.tr/~sariel/publications/SRDAP2010EESST.pdf