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WIRELESS SENSOR NETWORKS FOR FIREFIGHTING DANGEROUS PROFESSIONS AND FIRE INVESTIGATION

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ABSTRACT

Firefighting is one of the most dangerous professions in which people are employed. The dangers associated with this profession are the result of a number of factors such as lack of information regarding the location, size and spread of the fire. The use of wireless sensor networks may be one way of decreasing the risks faced by firefighters and assisting in the process of rapid extinguishment of the fire. They may also be able to provide fire investigators with additional knowledge that could assist in determining whether a fire was maliciously ignited.

INTRODUCTION

On a daily basis, firefighters enter potentially life threatening situations armed with little more than a vague idea of the location, size and spread of the fire they are trying to extinguish. One of the key factors that results in this lack of knowledge is that current fire alarms often do little more than notify us of the presence of a fire. They provide little or no information as to the location of the fire(s) or its spread. Where systems exist which can provide some information regarding the location of the fire, they are powered by electrical cables embedded in the buildings infrastructure. As a result, they can be attacked by fire resulting in a total loss ofinformation.

Although the main hazard to life is reduced significantly once the fire is extinguished, problems remain for a fire investigator. Frequently, the destruction caused prior to the fire being extinguished makes the determination of its origin and the manner of its spread difficult to determine. In many cases, a fire investigator must rely on the eyewitness accounts of the firefighters who fought the fire and/or individuals present when the fire was first discovered. Any system that can provide knowledge to the Fire Department prior to the entry into the fire ground and additional information to a fire investigator must be beneficial. This project focuses on the various challenges that must be addressed for the deployment and use of wireless sensor networks for initial detection offire location and subsequent spread of fire within a building.

WIRELESS SENSOR NETWORKS

Before looking at how wireless sensor networks can be used to assist firefighters in the performance of their duties, it is first necessary to know something about wireless sensor networks in terms of how they work; their capabilities and limitations.

A Wireless Sensor Network (WSN) is a network comprised of numerous small independent sensor nodes or motes. They merge a broad range of information technology; hardware, software, networking, and programming methodologies [1].

Wireless Sensor Networks can be applied to a range of applications [1] monitoring of space which includes environmental and habitat monitoring, indoor climate control, surveillance etc.; monitoring things for example structural monitoring, condition-based equipment maintenance etc.; and monitoring the interactions of things with each other and the surrounding space e.g., emergency response, disaster management, healthcare etc. The majority of these applications may be split into two classifications: data collection and event detection.

Each mote in a wireless sensor network is a self-contained unit comprised of a power supply (generally batteries), a communication device (radio transceivers), a sensor or sensors, analog-to-digital converters (ADCs), a microprocessor, and data storage [1, 2]. The motes self organize themselves, into wireless networks (**Figure 1**) and data from the motes is relayed to neighboring motes until it reaches the desired destination for processing [2].

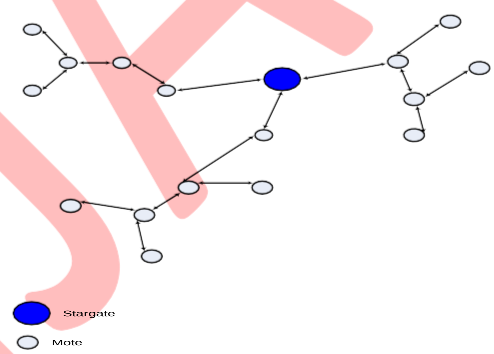

Figure 1: Example of a Flat Network (adapted from [3])

Each mote has very limited resources in terms of processing speed, storage capacity and communication bandwidth. In addition, their lifetime is determined by their ability to conserve power [4]. These limitations are a significant factor and must be addressed when designing and implementing a wireless sensor network for a specificapplication.

DATA COLLECTION VERSUS EVENT DETECTION

As stated above, in general wireless sensor networks can be categorized into one of two types, data collection or event detection networks. In many applications where data collection is the goal, the sensors may be required to collect data for short periods at set times of the day. In this case, most of the time the sensor node will be asleep thus conserving power. However, where a wireless sensor network is to be employed for event detection, such as detecting the ignition of a fire, it would be anticipated that the sensor nodes must remain awake thus consuming their precious limited power [16].

HARDWARE AND TOOLS FOR DEVELOPING A WIRELESS SENSOR NETWORK

A variety of hardware and tools are available for deploying and testing wireless sensor networks. Brief descriptions are provided hereafter.

SENSOR MOTE HARDWARE ARCHITECTURE

Currently one of the most popular research platforms is the Mica2 sensor mote shown in **Figure 2**. It uses the TinyOS (TOS) Distributed Software Operating System, has a 325, 433 or 868/916 MHz multi-channel radio transceiver and an expansion connector that can be used for light, temperature, RH, barometric pressure, acceleration/seismic, acoustic and magnetic sensor boards [5]. **Figure 3** shows the standard indoor injection molded housings available for the Mica2.

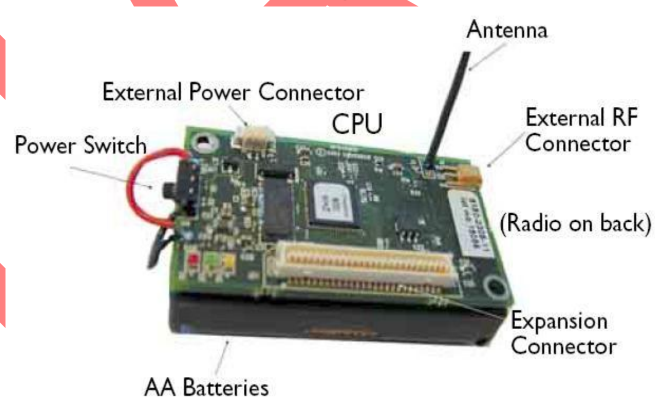

Figure2: Mica2 Sensor Mote

Figure3: Injection molded housing assembly for the Mica2

CURRENT RESEARCH INTO WIRELESS SENSOR NETWORKS AND FIREFIGHTING

In the past, research into using wireless sensor networks for fire detection has predominantly focused on the detection and tracking of wildfires. It is only in the last few years, since the attack on the World Trade Center, there has been increasing focus on the safety of and communication between firefighters on the fire ground. This has resulted in researchers looking at the possibilities of using wireless sensor networks when fighting structural fires.

One group at UC Berkeley has been working on a project called FIRE (Fire Information and Rescue Equipment) [9]. The objective of this project is to develop both hardware and software tools to improve the safety, efficiency and effectiveness of firefighting.

The research is comprised of three sections, a wireless sensor network called SmokeNet, which forms the basis of the whole project, a head mounted display unit for individual firefighters called FireEye, and an incident command system called eICS which will be a visual display showing information such as resource allocation, location of personnel on the floor plans of the building, and biometric data of firefighters including air supply and heartrate.

The SmokeNet implementation is based on TinyOS and utilizes Crossbow wireless smoke and temperature detecting sensor nodes. In a non-alert state, these nodes check the status of the environment every 10 seconds and send data obtained along with their battery condition via a multi-hop network to a central building node logger computer every 5 minutes. On detecting a fire, a node sends an alert message which places the whole network in an alert state. In this state, each node checks for fire every five seconds and reports to the data logger every two minutes if no fire is detected to confirm that it is still alive [10].

The system also allows for the Incident Commander to connect into the wireless sensor network, via eICS, to determine the location of the fire and also track firefighters and their health status. It also allows for data to be sent to firefighters wearing the FireEye.

Another group has been working on a project called "Siren – Context-aware Computing for Firefighting" [11]. The system that they are developing supports tacit communication among firefighters using a context-aware messaging application. Each firefighter carries a WiFi enabled PDA with a built in Berkeley motes sensor board. The mote in the PDA collects data from motes which are pre-deployed in the building to inform the firefighter of hazards and immediate danger. In addition, the pre-deployed motes also serve as location beacons, thus enabling a firefighter to navigate his/her way through the building. Each PDA connects to the PDA's of other firefighters in a peering mode.

THE CHALLENGES FACED BY FIREFIGHTERS

As stated above, over the last few years, two groups [10, 12] have been carrying out research into development of information providing tools for use by firefighters. In order to better understand the needs of firefighters, both groups interviewed personnel from the Fire Department. Their findings are directly relevant to this project and are reviewedhere.

The interviews of Steingart et al [10] revealed that the Fire Chiefs considered the following as the most important pieces of information during an emergency:

1. Proximity of the firefighters todanger.
2. The health status of thefirefighters.
3. Better radio communication.
4. Location and ambient temperature of thefirefighters.
5. The validity of building floorplans.

The firefighters interviewed indicated that although they believed that technology was a good thing, they were concerned about unreliability and increasing dependence on technology. Another significant factor that was identified was that Fire Departments have little money for technology or equipment that is not mandated by a standards body.

In their research, Jiang et al. [12] identified the incident commander (IC) as being the most information intensive position, since in addition to coordinating the overall response strategy, they must also manage the available personnel and resources. In terms of the dangers faced by firefighters, the IC's were concerned with being aware of the followingdangers:

1. "Flashover, sudden ignition of the contents in aroom."
2. "Backdrafts, explosions that occur when an oxygen starved fire suddenly receivesoxygen."
3. "Hidden fires in walls, attics, and other unseenareas."
4. "Structural hazards, including structural collapse and toxic gases from burning hazardous materials."

Jiang et al. noted that at the present time, there are no special technologies available to firefighters to assist in avoiding the problems described above.

Another important factor identified in both studies was that information regarding the status of the fire is predominantly communicated face to face or via radio. The firefighters interviewed stated that the noise associated with the fire and firefighting activities made communication difficult. This was exacerbated by the presence of radio dead zones on the fire ground.

FIRE DATA

In order to develop a wireless sensor network for use in fire detection and tracking, it is important, not only to identify the challenges faced by firefighters, but also to gain some understanding about the potential temperatures involved, the factors may affect them and the development of smoke. An appreciation of this sort of information enables assumptions to be made when designing the wireless sensor network in terms of deployment, protection of the sensors, and determining the increases in temperature that will cause the sensors to trigger an alarm.

The information presented here is from a full scale house fire experiment [13]. The structure used for the experiment was a two story, single family dwelling of wood construction. The simulation involved the accidental ignition of a flaming fire by a space heater. Two arrays of thermocouples were used, one array located in the room where the fire was ignited, at a distance of approximately 3 meters from the point of ignition and the other array in an adjacent room. The thermocouples were distributed at various distances from the ceiling downwards.

Figure 4 shows the temperatures recorded by the thermocouple in the room where the fire was ignited. As can be seen, there was a significant temperature rise, 121°C in the first five seconds, and 187°C in the first twenty seconds after the fire was ignited at the thermocouple located at a height of 2.26m (7.42 ft).

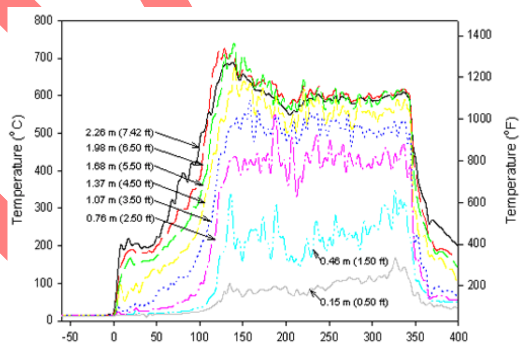

Figure4: Thermocouple temperatures from the room in which the fireignited.

Figure 5 shows the comparative data from thermocouples located in the room adjacent to that which the fire was ignited. It can be seen that the initial temperature rise is not as rapid. In the first five seconds, the temperature at the thermocouple located at a height of 2.26m (7.42 ft) rose only 7°C in the first five seconds, and 121°C in the first 20 seconds after the fire was ignited.

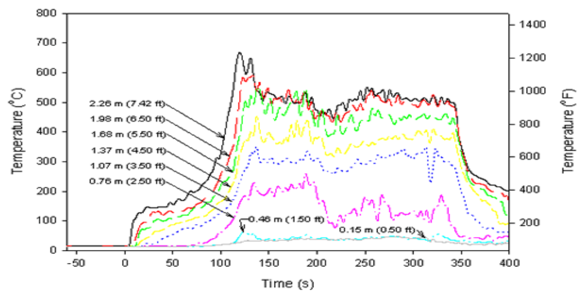

Figure 5: Thermocouple temperatures from the room adjacent to the one in which the fire ignited.

From both figures 4 and 5, it can be seen that the greatest temperature rise is recorded by the thermocouples located closest to the ceiling, the temperature rise being considerably less the closer the thermocouple to the floor.

It should be noted that this is not a comprehensive investigation into fires and their associated temperatures, but rather a small snapshot. The initial ignition and subsequent spread of a fire will depend upon many factors, such as whether the fire was accidentally or maliciously ignited (with the use of accelerants), the type of structure in which the fire occurs, ventilation, fire loading (amount of combustible materials present) and whether the fire ignites as a flaming fire or a smoldering fire etc. It should be noted the initial temperature rise in a smoldering fire will be negligible in the early stages of thefire.

REQUIREMENTS FOR WIRELESS SENSOR NETWORKS FOR FIREFIGHTING

It is apparent that many of the issues and information needs identified by the Fire Department could be addressed by the use of pre-deployed wireless sensor networks. **Table 1** shows the problems to be addressed and the potential wireless sensor network solution.

Problem	WSN Solution
Proximity of firefighters to danger	Pre-deployed temperature, smoke,oxygen, accelerometer and olfactory sensors
Flashover	Pre-deployed temperature sensors
Backdrafts	Pre-deployed oxygen sensors
Hidden Fires	Pre-deployed temperature and smoke sensors
Structural collapse	Pre-deployed Accelerometers
Toxic gases	Pre-deployed Olfactory sensors

Table 1: Potential Wireless Sensor Usage (adapted from [15])

In designing and implementing a pre-deployed wireless sensor network for firefighters, there are number of requirements that must be satisfied, first and foremost whatever system is implemented, it must be reliable and cost effective, otherwise whatever its potential benefits it is unlikely to be generally adopted. Assuming the reliability and cost issues can be overcome then the following are the challenges that must be addressed:

1. The possibility of false alarms must be minimized. It should be obvious that the occurrence of false alarms should be minimized as they waste the time and resources of the Fire Department and can potentially result in fire fighting resources being unavailable to immediately attend genuineincidents

2. The wireless sensor network must be secure in order to prevent malicious triggering of false alarms and malicious sending of falsedata.

3. Due to the rapidity with which fire can spread, it is essential that the sensor node(s) detecting the event begin transmitting data as soon as and event is detected. Failure to do so could result in alarms not being triggered and data of value to the Fire Department being lost. Inaddition, the sensor node(s) detecting the event should also wake other sensor nodes in the vicinity of theevent.

4. The Fire Department must be able to connect to the wireless sensor network in the building of interest. A system for monitoring a fire is only of value if the Fire Department can connect into the network to retrieve thedata.

5. The network must be self modifying to ensure that data can still be transmitted if/when individual sensors fail. The very nature of a fire will undoubtedly result in the destruction or failure of sensors. Consequently, in order to ensure that data regarding the condition of the fire continues to be sent and/or received, the network must be selfmodifying.

6. There must be rapid transfer of data. To be of any value to firefighters, data from the various sensors comprising the network must be rapidly and correctlyreceived.

7. The positions of the sensors must be known. In order to provide an accurate picture of the location and spread of the fire, the locations of the sensors within the building must be known.

8. There should be a visual display show the location and spread of the fire and temperatures within thebuilding.

9. The sensors and their housings must be protected as much as possible from the heat generated by the fire in order to keep them functional as long as possible, without degrading the ability of the sensors to detect changes in temperature or any other parameters that they aresensing.

In order to address all of the needs highlighted in Table 1, a multitude of different sensors would need to be pre-deployed in a building. Although motes are rapidly decreasing in price, this option does not seem feasible at the current time. In addition, until the true value of a wireless sensor network system can be proved, it would seem sensible to concentrate on a minimal set of sensor motes that could provide the basic information required by the Fire Department.

On the basis of the above and the assumption that in general fires within buildings are detected by smoke or rapid temperature rises, this project considers the deployment of temperature and smoke sensors as a bare minimum.

FUTURE WORK

This paper has focused on the important aspects with regard to the types of sensors deployed, how they should operate in the event of a fire etc. Obviously, there are many other aspects that need to be considered, for example, how the wireless sensor network connects, communicates and transfers data to the graphical user interface, the self modification of the network in the event of a mote failure. These are all issues that need to be addressed in future work are briefly describedbelow.

- **Viability of Temperature Sensors in a FireEnvironment**
- **TOSSIMSimulation**
- **Development of Graphical UserInterface**
- **Inclusion of AdditionalSensors**
- **Wireless Sensor NetworkSecurity**
- **Physical Testing of Implementation**

CONCLUSIONS

There are many risks associated with fire fighting, not least of which are the unknown factors such as location and spread of the fire. On a theoretical basis, it would appear that the use of a wireless sensor network, such as FAWSNet, could assist in diminishing these unknowns bypotentially providing Incident Commanders with real time information regarding the location and spread of the fire.

At the current time, FAWSNet remains theoretical. There are many issues that must still be addressed not least of which is can the sensors which first detect the fire withstand the rapid temperature rises expected for long enough to transmit meaningful data. Before further work is undertaken on this project, it would be advisable to establish if currently available sensors can withstand the temperatures to which they are likely to be exposed, and what if any protection can be provided that will allow to remain operational for as long as possible in the environmental conditions experienced in a fire.

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