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# Wireless Sensor Network based Fire Monitoring and Extinguishing System in Real Time Environment

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**ABSTRACT**

Firefighting is one of the most dangerous professions in which people are employed. The dangers associated 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 reducing the risks faced by the firefighters and assist in the process of rapid extinguishment of the fire. The standards, such as IEEE 802.15.4 and ZigBee, stimulated the development of numerous commercial products. Moving from early research in military applications, sensor networks now are widely deployed in diverse applications including home automation, building automation, and others.

This paper mainly presents the design and the implementation of wireless sensor network based fire monitoring and extinguishing system. Fire monitoring system continuously monitors the surroundings and keeps a track of the temperature recorded and the intruders detected, performed by monitoring node. Fire extinguishing system switches the extinguisher as soon as it detects the fire or when the temperature crosses a certain threshold level, performed by extinguishing node. Results indicate that the overall performance of the proposed approach is very good. The usage of zigbee monitored fire extinguishers in a hospital building has been demonstrated.

**Keywords** – Extinguisher, Firefighters, IEEE 802.15.4, Wireless Sensors, Zigbee

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## 1. INTRODUCTION

On a daily basis, firefighters enter potentially life threatening situations armed with little idea of the location, size and spread of the fire they are trying to extinguish [1]. One of the key factors that results in this lack of knowledge is that current fire alarms often just notify us about the presence of the fire. They provide little or no information about the location of the fire or its spread. Even though systems exist in some places, which provide information regarding the location of the fire; they are powered by electrical cables embedded in the building's infrastructure. These wires can also be attacked by fire resulting in a total loss of information. The most important pieces of information that are required during an emergency include proximity of the firefighters to the danger, health status of the firefighters, better radio communication, location and ambient temperature of the firefighters and the validity of building floor plans [2]. In addition to coordinating the overall response strategy, they must also manage the available personnel and the resources. Some of the dangers faced by firefighters that need to be concerned include sudden ignition of the contents in a room, explosions that occur when an oxygen starved fire suddenly receives the oxygen, hidden fires in the walls, the attics, and some unseen areas, structural collapse and release of the toxic gases [2].

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 manner of its spread difficult. In many cases, a fire investigator must rely on the eyewitness accounts of the firefighters who fought the fire or the 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 paper focuses on these challenges and shows how wireless sensor networks can be developed for initial detection of fire location and avoids subsequent spread of fire within a building.

### 1.1. WIRELESS SENSOR NETWORKS

Wireless sensor networks (WSNs) consist of a sensor field, which is the physical environment where the sensor nodes or the devices are widely deployed [3]. WSNs have been widely studied for enabling various applications such as environment surveillance, scientific observation, etc. Having made increasing efforts on the robustness and the reliability of WSNs under crucial and critical conditions, researchers have done little work targeting the network diagnosis for testing the operational sensor networks [4]. It is of great importance to provide system developer; the useful information on a system's working status and guide further improvement to the network.

A sensor network typically consists of a large number of resource-limited sensor nodes working in a self-organizing and distributed manner called as motes [5]. Each mote in a WSN is a self-contained unit comprised of a power supply (generally batteries), a communication device (radio transceivers), a set of sensors, analog-to-digital converters (ADCs), a microprocessor, and data storage. The motes self-organize themselves into wireless networks and the data is relayed from one mote to other neighboring mote until it reaches the desired destination for processing. Each mote has a limited resource in terms of processing speed, storage capacity and communication bandwidth. In addition, their lifetime is determined by their ability to conserve power. These limitations are a significant factor and must be addressed when designing and implementing a WSN for a specific application. The majority of the applications of WSNs may be split into data collection and event detection. In data collection applications, the sensors collect data only for shorter periods at set times of the day thereby conserving power as the sensor node will be in sleep mode for most of the time. In event detection applications, such as detecting the ignition of a fire, the sensor nodes must always remain awake thus consuming their precious limited power [6].

### 1.1.1. Applications of WSNs

There are numerous applications that are ideal for the redundant, self-configuring and self-healing capabilities of WSNs. Key ones include

• Home Automation — To provide more flexible management of lighting, heating and cooling, security, and home entertainment systems from anywhere in the home.

• Building Automation — To integrate and centralize management of lighting, heating, cooling and security.

• Industrial Automation — To extend existing manufacturing and process control systems reliability.

• Energy Management and Efficiency — To provide greater information and control of energy usage, better management of resources, and reduce impact on environment.

In rest of the paper, we discuss about the proposed fire monitoring and extinguishing system consisting of a network of monitoring, intermediate and extinguishing nodes along with the implementation details of each node. Some of the key results along with an example of wireless fire extinguishers in an hospital building have been discussed.

## 2. Fire Monitoring and Extinguishing System

Monitoring and control of a home or an hospital has become more and more common now a days, and perhaps even a necessity. However the monitoring costs for professional monitoring can be very expensive and provide limited remote control of the system. The WSN based monitoring system lays the foundation for a self-monitored home alarm and control system. Sensors have to be placed at different locations of a building to monitor the most sensitive areas. The data is read from these sensors and appropriate actions will be taken for the changes took place. An LCD is used to display the current room temperature. A speech recording unit is used to play the message when the temperature crosses the threshold or when an intruder is detected. A fire extinguisher kit is used to reduce the impact of fire accidents by extinguishing the fire automatically when detected.

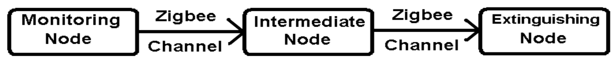


Figure 1 Fire Monitoring and Extinguishing system

Monitoring node, Intermediate node and Extinguishing node are the three important nodes that have been employed here. As shown in fig. 1, these three nodes form a network. Monitoring node continuously monitors and stores the changes in the temperature and the number of intruders. This data is forwarded to the extinguishing node using the zigbee channel. Whenever the temperature crosses a certain threshold, the extinguisher is switched ON to reduce the impact of it. An intermediate node is incorporated in between these nodes which acts a transceiver when the distance between them is too large.

### 2.1 Monitoring Node

In this node, we have a temperature sensor, a PIR sensor, a PIC microcontroller and a zigbee unit. These sensors continuously sense the changes around them and the sensed data is provided to the PIC Microcontroller. The continuous change in the temperature is displayed on the LCD. Any intruder passed by is also sensed and the same is displayed on the LCD. PIC Microcontroller processes the received data and provides it to the zigbee unit, which transmits the data to the extinguishing node. As shown in fig. 2, appropriate signal conditioning has to be done before the transmission of data.

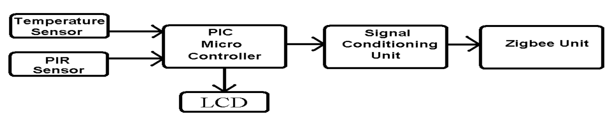


Figure 2 Monitoring Node

### 2.2 Intermediate Node

In this node, we have a PIC Microcontroller and a Zigbee unit. The Zigbee unit acts as a transceiver. As shown in fig. 3, the data is received from the monitoring node and the same is transmitted to the extinguishing node after conditioning. The intermediate node is used only when the distance between the monitoring node and the extinguishing node is very large.

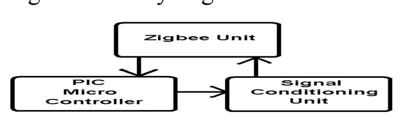


Figure 3 Intermediate Node

2.3 Extinguishing Node

In this node, we have a Zigbee unit, a PIC microcontroller, a speech recording unit and a fire extinguishing unit. As shown in fig. 4, zigbee unit receives the data transmitted by the transmitter and provides it to the PIC Microcontroller after signal conditioning. PIC microcontroller indicates the speech recording unit to play the messages as per the data received. Whenever there is an enormous increase in the temperature, PIC microcontroller indicates the fire extinguishing unit to switch ON the extinguisher that avoids the impact of fire accidents.

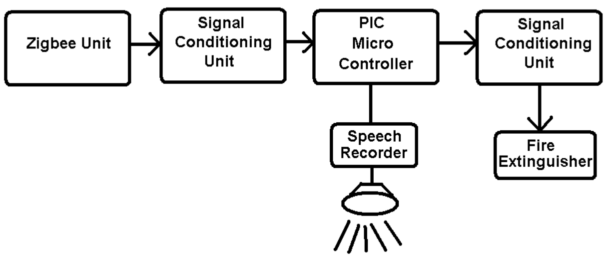


Figure 4 Extinguishing Node

## 3. IMPLEMENTATION DETAILS

### 3.1. MONITORING NODE BLOCKS

#### 3.1.1. Temperature Sensor

LM35 series sensors are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. Thus, it has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. It does not require any external calibration or trimming to provide typical accuracies of ±1⁄4°C at room temperature and ±3⁄4°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. Its low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air.

#### 3.1.2. Passive Infrared Sensor

Passive Infra-Red (PIR) sensors detect changes in IR radiation, in the form of heat emitted by a number of bodies including people, cars and, to a lesser extent, dogs or other small animals. The bigger the body, the more IR radiation is emitted and the easier it is for a PIR sensor to detect. The field of view is the area in which changes in IR radiation can be detected. The field of view can alter with changes in temperature and the size of the heat source. PIR sensors are passive devices and therefore they do not emit or radiate any energy or beams. It is an electronic ON – OFF switch designed specifically for switching lighting loads.

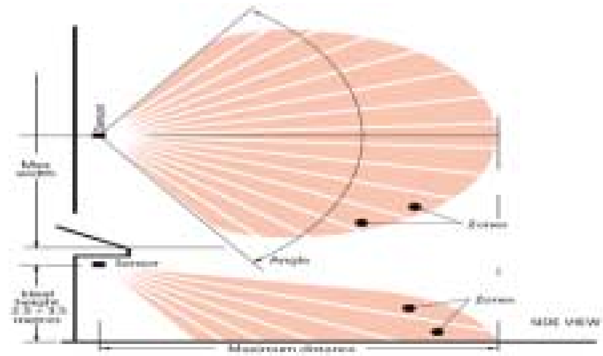

Figure 5 PIR Sensor

The construction of the PIR and the Fresnel Lens divide the field of view into a number of zones, as shown in fig. 5, both vertically and horizontally. Each zone is constantly monitored by the sensor. When a person or other heat source enters any zone, the level of IR radiation in that zone increases. This change is detected and processed by the sensor, switching on the connected lighting and starting the in-built time process. Time period begins after the last movement is detected. Providing the heat source (person) continues to move in the field of view, the PIR sensor will keep processing the changes in IR radiation and the lighting will stay on. If a person stands still in the field of view or moves out of the detection area, the sensor will not detect any changes in IR radiation between the zones and the lights will go out after the time period is complete. In order for the sensor to effectively detect changes in heat between zones, it is advisable to walk across the zones not up or along a zone.

#### 3.1.3. Liquid Crystal Display

BPI-216 Liquid Crystal Display (LCD) modules combine a serial interface with a 2-line by 16-character display. The combination receives serial data at 2400 or 9600 baud (switch selectable) and displays it on the LCD. The unit has two modes: text and instruction. It defaults to text mode; any data received appears on the screen. Send the string HELLO and HELLO appears on the LCD. To distinguish text from instructions (e.g., clear screen, position cursor, etc.), the interface looks for an instruction prefix (ASCII 254). The byte following this prefix is treated as an instruction. After the instruction code, the unit returns to text mode.

### 3.2. COMMON BLOCKS

#### 3.2.1. ZIGBEE

ZigBee takes its name from the zigzag flying of bees that forms a mesh network among flowers. It is an individually simple organism that works together to tackle complex tasks [7]. ZigBee has built on the IEEE 802.15.4 low-rate, wireless personal area network (WPAN) standard [8]. The IEEE 802.15.4 defines the physical layer (PHY) and media access control (MAC) layer. The PHY layer supports three radio bands, those are individually defined 2.4GHz ISM band (Worldwide) with 16 channels, 915MHz ISM band

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(Americas) with 10 channels, and 868MHz band (Europe) with single channel. The data rates are also individually defined 250Kbps at 2.4GHz, 40Kbps at 915MHz, and 20Kbps at 868MHz. The MAC layer controls access to the radio channel using the carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) mechanism. The transmission range is 1-100 meters. The ZigBee defines two types of devices: Full Function Device (FFD) and Reduced Function Device (RFD). The FFD can serve as a network coordinator or a regular device. It can communicate with any other device. The RFD is intended for applications that are extremely simple, such as a light switch or a passive sensor device. It can communicate only with the FFD.

ZigBee supports the following three types of networks.
1) Star network: The devices in the star topology can only communicate via the PAN coordinator.
2) Cluster Tree network: Routers move data and control messages through the network using a hierarchical routing.
3) Mesh network: It allows full peer-to-peer communication.

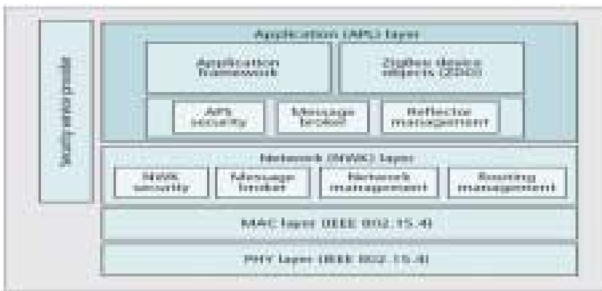

Figure 6 Zigbee Architecture

ZigBee stack architecture is as shown in the fig. 6. IEEE 802.15.4 defines the PHY layer and the MAC sub-layer. The ZigBee Alliance builds on this foundation by providing the network (NWK) layer and the framework for the application layer (APL). APL layer includes application support sub-layer (APS), application framework and the ZigBee device object (ZDO). In the framework the user defined application object is added. NWK handles the network level of the communication. It manages network structure and handles routing and security functions for the relayed messages [9].

3.2.2. Programmable Interface Control Microcontroller

Programmable Interface Control (PIC) Microcontroller belongs to a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640, originally developed by General Instrument's Micro-electronics Division. PICs are popular with both industrial developers and hobbyists due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability. PIC microcontrollers perfectly fit for many applications, from automotive industries and controlling home appliances to industrial instruments, remote sensors, electrical door locks and safety devices. It is also ideal for smart cards as well as for battery supplied devices because of its low power consumption. EEPROM memory makes it easier to apply for devices where permanent storage of various parameters is needed (codes for transmitters, motor speed, receiver frequencies, etc.).

### 3.3. Extinguishing Node Blocks

3.3.1. Speech Recorder

The APR9600 device offers true single-chip voice recording, non-volatile storage, and playback capability for 40 to 60 seconds. The device supports both random and sequential access of multiple messages. Sample rates are user-selectable, allowing designers to customize their design for unique quality and storage time needs. Integrated output amplifier, microphone amplifier, and other circuits greatly amplify system design. The device is ideal for use in portable voice recorders, toys, and many other consumer and industrial applications. APR9600 achieves these high levels of storage capability by using analog/multilevel storage technology implemented in an advanced Flash non-volatile memory process, where each memory cell can store 256 voltage levels. This technology enables it to reproduce voice signals in their natural form. It eliminates the need for encoding and compression, which often introduce distortion.

Figure 7 Fire Extinguisher

3.3.2. Fire extinguisher

The fire extinguisher is as shown in the fig. 7. The fire extinguisher valve is a high pressure type made of brass material, finished in nickel chrome and incorporates a safety disc inside. As soon as fire accidents take place due to the electrical shorts or so, it has to be extinguished very soon. Fire extinguisher extinguishes the fire by directing the jet of carbon-dioxide ($CO_2$) gas to the base of fire, thus covering the air around the fire and reducing the oxygen level at fire point. This will prevent the fire from spreading further and reigniting again. $CO_2$ fire extinguishers are used in food industry, electronic factories, ships, electrical plants or rooms, offices and hospitals. It is a clean extinguishing agent and do not leave any residue after it has been discharged. The $CO_2$ gas flow has been controlled by using a 12 volts DC solenoid valve. Whenever there is enormous increase in the temperature, the valve gets open and it extinguishes the fire and cools the place around immediately.

 

## 4. FIRE EXTINGUISHERS AT HOSPITALS

In this section, we discuss about the wireless sensor network based Fire extinguishers that are used at some of the important locations of a building or so. These are used to extinguish the fire automatically when detected and bring down the impact of the destruction due to the fire accidents. The example considered here is a hospital building and the placement of fire extinguishers at different locations of the hospital can be as shown in the fig. 8. Some of the important locations in a hospital building include patient wards, intensive care units, data processing centres, laboratories, food service centres, heliports, helipads, shipping godowns, operating room, server room, equipment room and so on. These places have to be specially monitored and specific actions have to be taken for the severe changes that could immediately have a destructive affect.

The temperature sensor will continuously monitor the temperature and it is displayed on the LCD. Whenever the temperature crosses the threshold level or the fire is detected, the monitoring system indicates this to the extinguishing system. Then the valve of the extinguisher is made to open and the CO2 gas is let out with great pressure to switch off the fire. The PIR sensor identifies the exact location of the accident so that the gas is guided in the same direction which fastens the process. As this message is also played through the speaker, the people around also get alerted and move towards the safer places. By the help of the PIR sensor, one can even know the number of people got stuck inside that place, so that they can also be saved.

Figure 8 Zigbee monitored hospital building

## 5. RESULTS

Our fire monitoring and extinguishing system combined ordinary, easily available wireless sensors with a custom built signal conditioning/amplification circuit as shown in the fig. 9. There is a 12 VDC solenoid valve controlled $CO_2$ fire extinguishing agent to extinguish fire. In addition to the detection and extinguishing of the combustible material, there is also a speech recording unit that plays the fire accident message which allows the notification of fire and security personnel in the event of a fire.

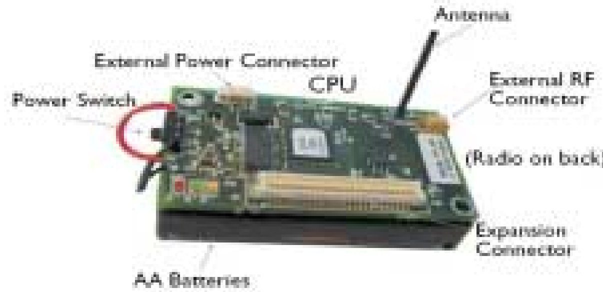


Figure 9 Fire monitoring model

As soon as the fire accident occurs, the system takes some time to detect the fire and respond to it. The response time of the system with reference to area is as shown in the fig. 10. Monitoring requires very less time when compared to extinguishing as it requires some time to switch OFF the fire.

The overall performance of the WSN based fire monitor and extinguisher with reference to the area covered is as shown in the fig. 11. The sensitivity of the monitoring system has been adjusted carefully so that false alarms are avoided. But the extinguishing system has to be highly sensitive and always be ready to perform its task. The overall performance of the proposed monitoring and extinguishing system is satisfactory and out performs all the present techniques currently used.

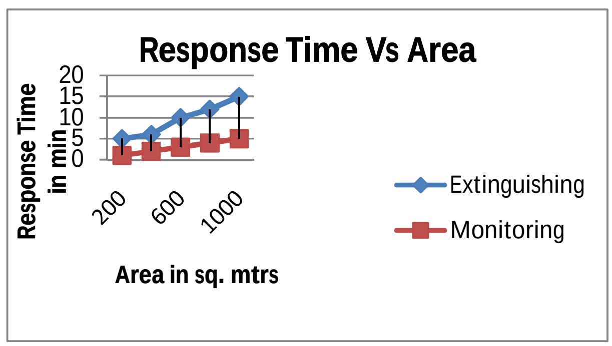


Figure 10 Overall Response time Vs Area

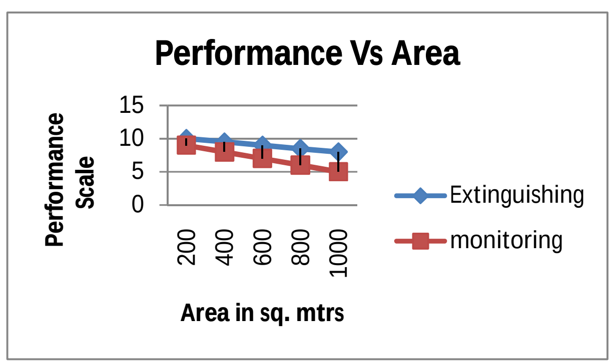


Figure 11 Overall Performance Vs Area

## 6. CONCLUSION

There are many risks associated with firefighting, not least of which are the unknown factors such as location and spread of the fire. This paper shows that the use of WSNs assist in diminishing these unknowns by potentially providing fire fighters with real time information regarding the location and spread of the fire.

There are many issues that have been addressed not least of which is the sensors that detect the fire can withstand the rapid temperature rises expected for long enough to transmit meaningful data. False alarms also do not affect too much as the extinguisher is made to turn OFF automatically when the temperature falls below threshold. Unauthorized users cannot gain access to this WSN and trigger false alarms or introduce malicious data. PIR sensor indicates the specific location of fire accident and the number of intruders/ people struck inside and waiting for a help from outsiders.

This wireless fire extinguisher can be used at all the fire accident prone places such as the petrol refilling stations, kitchen room at home, gaseous tankers, large buildings, industries and so on. The performance of the extinguisher completely depends on the sensitivity of the components used in the system that varies linearly with cost. Once the system gets installed, no additional charges apply to the user other than the extinguishing $CO_2$ gas that has to be refilled after use.

## 7. ACKNOWLEDGEMENTS

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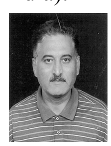

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