Design of a smart fire detection system

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***Abstract*— Conventional fire detection systems have a tendency of being triggered by false positives. In this paper, we discuss the design and implementation of a smart fire detection system using a Wireless Sensor Network (WSN) and Global System for Mobile (GSM) communication to detect fires effectively and reduce false positives. The proposed system uses smoke and temperature sensors. SMS capability via GSM was implemented so that occupants can interact with the fire detection system and aid in the detection of false positives. The aim of this work was to design and implement a fire detection system that detects fires effectively and reduces false positives. The results show that the system meets the specifications.**

Keywords— fire detection, GSM, wireless sensor network.

I. INTRODUCTION

Fire detection systems have been promoted immensely in the past few years and have helped in the safety of people and property against fire hazards [1]. The detection of fire hazards on the other hand can lead to unnecessary false alarms that can be very expensive if the occurrence happens in a commercial building. As well, false fire alarms have been a nuisance to the fire department and cause tie ups in resources and needless commotion that leads to panic [2]. The problem that was addressed by this work was to detect fires and reduce the occurrence of false positives in a kitchen environment.

The kitchen environment has a very high potential of being a source of fires. In South Africa alone the number of deaths has increased from close to 200 to almost 500 deaths between the years 2000 and 2011 [3]. These numbers do not include the injuries caused by fires in those years which makes it a very dangerous problem in the country. From formal dwellings the number of incidents recorded reach almost 4000 and in informal dwellings the number is just above that recorded for formal dwellings [3]. These numbers give an average of 21% of the overall number of fires that where recorded in 2011.

The first technical challenge in this work was the design of the WSN. Sensor networks are used to collect monitoring data autonomously [4] or with assistance of users [5]. WSN applications have been proposed to monitor the comfort of humans [6] and animals [7], while also being used in industrial applications, e.g. underground pipeline monitoring [8] where reliability of communication is important [9]. Interconnecting devices also allows for embedded collective intelligence, which could make distributed decision on how to react to given situations [10]. This sensor network should have incorporated existing technologies and must have been able to detect fire hazards effectively as compared to existing technology and also be able reduce the detection of false positives. The second technical challenge was the design of a mobile device voting system that involved the use of GSM communication. The two systems put together selected whether a threat was hazardous or not.

In Section II we discuss the methods designed to solve for the technical challenges and in Section III is the results section where all the outcomes of the design were presented. In Sections IV and V are the discussion and conclusions from the results determined in the experiments run during the design process.

II. OVERVIEW OF THE SYSTEM

At the core of the designed system is a combination of GSM and WSN communication. Thresholds and control variables act as indicators for when a fire is detected and when a false positive occurs. Fig. 1 shows the basic concept for the smart fire detection system which includes a processing device, a GSM communication device and a set of sensor nodes in a WSN.

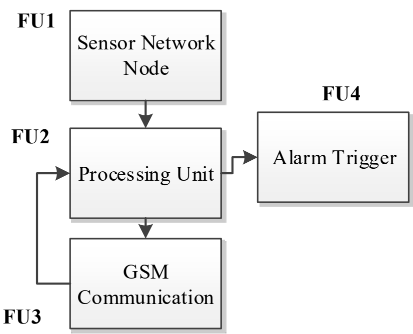

Fig. 1. Block diagram of detection system.

Functional unit 1 (FU1) consists of sensors which are used to detect the presence of fire and FU2 processes the information from FU1 to determine whether there is indeed a fire. FU3 connects to mobile devices via GSM.

III. DETAILED DESIGN AND IMPLEMENTATION

This section contains information on the design and implementation of the complete proposed system.

A. Hardware Design

For sensing in FU1, LM35 sensors are used to measure temperature, MQ-2 smoke sensors are used to detect smoke and XBee wireless modules (which are based on the ZigBee protocol) are used for wireless communication. Amongst the many possible solutions, XBee modules were because they have a peak receive current of 50mA and a peak transmit current of 40mA, with a maximum operating temperature of 85^0C and can transmit and receive data at low power [11]. These characteristics, coupled with the fact that these modules are low power and have a small footprint, were the motivation behind the selection of these devices as wireless modules for the system [12]. Fig. 2 shows the functional diagram of each node in the wireless sensor network.

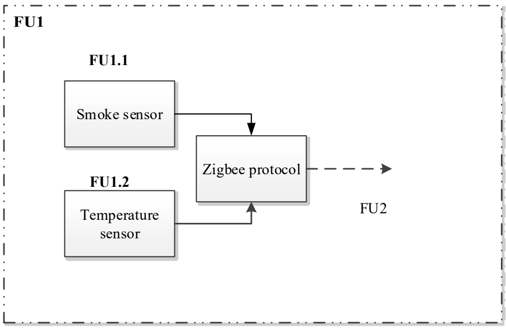

Fig. 2. Flow diagram of wireless sensor node.

For the setup of the wireless network, different topologies could have been used depending on the number of sensor nodes and how the information from each node is to be sent. The four most common topologies are (i) the Peer to peer, (ii) the Mesh, (iii) the Tree and (iv) the Star network [13]. On comparison of the star network and the others, it was seen that the star network setup was adequate for the sensor network node topology required for this design.

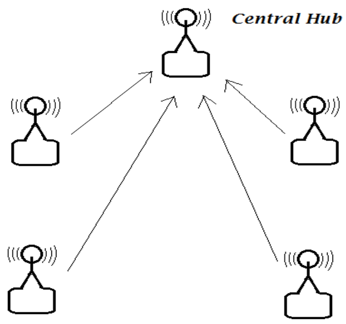

Fig. 3. Star network.

As noted before each node had a set of analog sensors connected to the Analog to Digital Converters (ADC) of the Xbee modules. On the ADC ports of these devices, a default threshold of 1.2V is used as the reference voltage for the 10 bit ADC. The Xbee has designated 4 analogue inputs pins and if any value above the required 1.2V is placed on the port it will result in a full ADC buffer [14].

The developed system detects if the temperature has risen above a predefined threshold and also detects whether there is a significant rate of change in temperature. In both instances, the system generates a warning signal out. For smoke detection a threshold is also used. If it is detected that the detected smoke levels exceed the threshold, this triggers an alert. Given the fact that the system is meant to be installed in a kitchen, the design was split into two sections. Each of the sections had one sensor node which comprised of temperature and smoke sensors. Fig. 2 illustrates this setup, where each section has one sensor node. The readings collected by each node are forwarded to control node. The network is configured with a star topology as previously described.

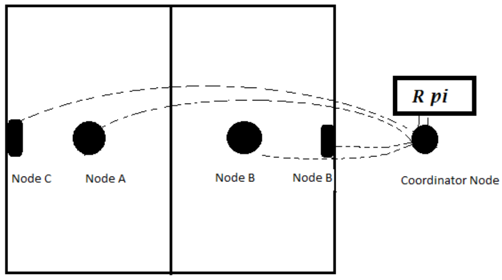

Fig. 4. Sensor network positioning setup.

Each Xbee device has a specific address that is used for addressing purposes. These are 64 bit values that are allocated to each Xbee by the manufacturer [14]. The software was coded in python language and by using the python module Xbee, the 64 bit addresses were the ones that determined which node/device was sending what information, at what time. The information gathered by the nodes was sent wirelessly to the centralized hub which was connected to the processing device. The processing device chosen for this system was the raspberry pi (RPI). The popularity of these devices is on the increase and has versatile functionality compared to other processing devices hence the choice of these devices.

The LM35 was the temperature sensor chosen. It is a linear device that gives a voltage out that varies linearly with the surrounding temperature increasing at a rate of 10mV per degrees Celsius. This means that at 25 ^{0} C the output read at the output pin will be 25mV while consuming less than 60µA of current with a maximum operating temperature of 150ºC [15]. Equation 1 below shows the scaling that was done to determine the actual temperature value read by the sensors.

$$\boldsymbol{Voltage\ out = ADCvalue * 1.2 * \frac{100}{1024}} \quad (1)$$

The smoke sensor that was the MQ-2 semiconductor sensor. Calibration of the MQ-2 sensor is based on the ratio of the sensor resistance in clean air R_o which was found to be 16kΩ and the sensor resistance in the presence of various gases, R_S which can be calculated from equation 2 and varies as the voltage out V_{RL} to the Xbee increases The value of R_L determines the sensitivity of the sensor and was chosen to be 10kΩ. The graph for the ratio of R_S /R_o against parts per million (ppm) values is given in the datasheet and after the ratio of R_S /R_o has been determined the true ppm value of the smoke can be found.

$$R_S = \left({}^{V_C}/_{V_{RL}}\right) * \ R_L \qquad (2)$$

Fig. 5 shows the circuitry inside the MQ-2 and the voltage out, V_{RL}. The final complete circuitry of the router and coordinator nodes is shown in Fig. 6 and Fig. 7, respectively.

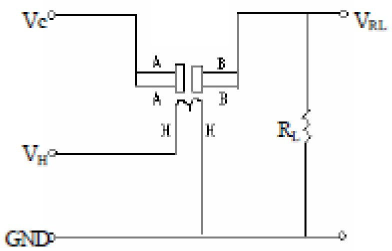

Fig. 5. MQ-2 circuitry [16].

The main motivation behind using GSM for the system was to allow the kitchen's occupants to disable the alarm in case the system detects a fire when in fact there isn't one (i.e. the system detects a false positive). To this end, the system's alarm can be activated and deactivated via SMS. This functionality was achieved by a universal serial bus (USB) 3G modem connected to the Raspberry Pi. The 3G modem is controlled via AT commands which are sent to the modem via a Python script.

B. Software design

For this system to have worked efficiently certain algorithms were developed to aid in the detection process and reduction of the detection of false positives.

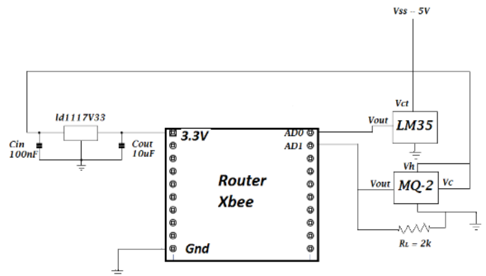

Fig. 6. Complete circuit for XBee router.

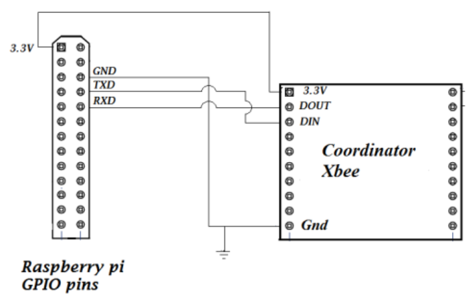

Fig. 7. Complete circuit for XBee coordinator.

In the developed system, both GSM and WSN communication are combined to effectively detect fire. The software running on the RPi starts by initialising the required modules for the Python script. This includes modules for the serial, general purpose input output (GPIO) and XBee. The system then checks if an SMS containing the word "Activate" has been received so that the alarm can be activated accordingly. Once this takes place, the system then reads the temperature values and determines whether the thresholds have been crossed. The complete pseudo code is listed below:

- Start program and check for the word activate in received sms's (Activate Alarm Protocol).
- Read Xbee frames that have been sent and store ADC data (Read ADC protocol).
- Enter sensor threshold protocol and check if any nodes are over threshold (Sensor threshold protocol)
- Loop back to check for activate in sms.

The 'Activate' alarm protocol is the first process that happens during the running of the python script for the detection system. This process checked for the word 'Activate' in every sms that was received by the 3G modem, and used that as a prompt to trigger the alarm system. The word 'Activate' was case sensitive and only these three variations of the word activated the alarm, (i) 'Activate', (ii) 'ACTIVATE' and (iii) 'activate'. The pseudo code is listed below:

- Check whether the modem is connected and initialise serial port.
- Send AT commands to read sms.
- Loop through messages and check for word 'Activate'.
- If trigger word found in messages delete all messages.
- Trigger alarm (Activate alarm protocol) if not continue without triggering alarm.

The read ADC was the next protocol in the python script for this system, this process involved the reading of the ADC values sent from the router Xbee's.

The sensor threshold protocol was the section of code that determined the levels that triggered the alarm and also sent out warning sms's. Their sms's are via the 3G modem as explained before and gave out a pre-warning to the occupants that the threshold for either temperature or smoke have been reached hence they need to check whether a fire is present or not. This would then lead to the voting system, where a selected number of occupants can vote on whether a fire hazard is there or not. The voting system worked in such a way that if any of the occupants responded 'yes' the alarm would trigger and only a 100% response of 'no's' would not trigger an alarm. The voting system responses were also case sensitive and only the following responses for 'yes' and 'no' would be counted as votes, (i) 'Yes' or 'No', (ii) 'YES' or 'NO' and (iii) 'yes ' or 'no'. The sensor nodes were calibrated to trigger at 200 ppm of smoke intensity and a temperature above 57 ^{o}C. If only one threshold is reached on Nodes A or B a pre-warning sms is sent out and the voting system is activated, the voting system will them come up with an answer of whether a fire is there or not depending on the cast votes of 'yes' or 'no'. Nodes C and D are designed to trigger the alarm only when the rate of change of temperature is above 8 ^{o}C / min and also send a pre-warning sms and activate the voting system if the temperature detected is above 57 ^{o}C [17]. The pseudo code is listed below:

- Read Xbee frame from Node A.
- Check if temperature or smoke in node A is above threshold.
- If yes send sms pre-warning, wait for votes and check if smoke threshold and temperature are both trigger alarm.
- If not continue to node B (Node B has the same pseudo code as Node A).
- Check if temperature node C is above threshold or if rate of change is high.
- If yes send pre-warning sms for temperature and wait for votes.
- If not continue to node D (Node C has the same pseudo code as Node D).

Sms's were sent out to occupants in the process of warning them about an apparent fire hazard. The pseudo code is listed below:

- Open serial port and connect modem.
- Set phone number and message content.
- Send AT commands for sms to be sent
- Disconnect phone.

The alarm trigger protocol was designed as a continuous loop that can only be exited either by sending the word 'stop' via sms to the server phone number or by pressing the deactivate alarm button. The deactivate button was a button that was used to deactivate the alarm when the alarm protocol has been entered. The word stop is case sensitive so only the following prompts will deactivate the alarm, (i) 'Stop', (ii) 'stop' and (iii) 'STOP'. After the alarm sequence has been exited, the detection system goes back to its original form and starts checking the sensors for any threshold breaches. If the threshold breach is still on the system will continuously trigger again until the temperature value or smoke value decreases beyond the set thresholds. A point to note is that in the design of this fire detection system the sensors are disconnected during the alarm protocol and any change in the sensor value has no effect on the alarm protocol. A buzzer and a red light was connected to the system via a relay circuit that will be controlled from a GPIO pin. This GPIO pin will be activated during the alarm protocol and continue to be on until the alarm protocol is exited. Below is the pseudo code for the alarm trigger protocol:

- Set loop value to 1.
- While loop value is equal to 1 do all in loop.
- Check if sms stopper is on.
- If no Execute send sms protocol.
- Set sms stopper.
- If yes skip sms protocol and setting of sms stopper.
- Activate buzzer and light via GPIO relay.
- Check if GPIO pin for switch is high.
- If yes exit alarm trigger protocol by setting loop value to 2.
- If not continue in loop.
- Open serial port for modem.
- Read sms in the modem.
- Check for 'stop' in the modem during the alarm sequence.
- Loop until all messages are read.
- If 'stop' is in read messages.
- Delete all sms.
- Set looper value to 2.
- Exit alarm protocol.
- If no stop in messages and no switch pressed. Continue in alarm loop.

IV. Results and Discussion

A. Experiment 1

The aim of the first experiment was to test the wireless sensor network. The XBee's 64-bit unique addresses were used to identify which XBee node on the network transmitted the information, and at what time the information was transmitted. The sampling rate of the Xbee was set to 1000ms.

B. Experiment 2

Experiment 2 was the testing of the temperature sensors. The LM35 temperature sensor responded linearly and gave a voltage that is proportional to the temperature reading in millivolts.

C. Experiment 3

Experiment 3 was the testing of the smoke sensors. During the production of smoke in the enclosure the output voltage rose to 0.7V and kept on rising with the increase in smoke intensity, below is a table of results, Table I for the experiment at the different intensities of smoke.

Table I. MQ-2 sensor output and ppm values.

Vout (V)	R_S (Ω)	R_L(Ω)	R_S /R_o	Smoke (ppm)
0.3	166k	10k	10	-
0.7	47.1k	10k	2.83	≈200
0.8	41.2k	10k	2.48	≈500
0.9	36.6k	10k	2.20	≈600
1.0	33k	10k	1.98	≈800

D. Experiment 4

The aim of Experiment 4 was to test the GSM communication system. The system is controlled by AT commands. A delay of 0.5 seconds is set such that there's enough time for a response. The observed time intervals between sending and receiving SMS's are shown below in Table II.

Table II. Sms communication response times.

	No of AT commands	Time taken(s)
Sending out sms	5	≈13.5
Receiving sms	5	≈16
Voting system	-	120

E. Experiment 5

Experiment 5 involved the testing of the fire detection specification of the system as well as how the system responded to false positives. The set thresholds for smoke and temperature were calibrated for the previous experiments and set, as designed for in the detailed design of this work. The results shown in Table III are for the detection system without the GSM communication. The test was performed 10 times for a 'fire' condition and a 'no fire' condition and showed that the system has a positive prediction value of 66.66% and a negative prediction value of 75%. It was observed that the activation of the alarm via SMS worked as expected (i.e. all received messages with the word "Activate" triggered the activation of the alarm).

Table III. Experiment 5 results.

		Condition		
		Fire	**No Fire**	
System Response	**Fire**	***True positive*** *8*	***False positive*** *4*	***Positive prediction value*** = 66.6%
	No Fire	***False negative*** *2*	***True negative*** *6*	***Negative prediction value*** = 75%
		Sensitivity *= 80%*	***Specificity*** *= 60%*	

F. Discussion

The results from the experiments showed that the fire detection system meets the required specifications. The complete system was meant to effectively detect fire and reduce false positives and also integrate a voting system to itself. The first 3 experiments showed how the system would effectively detect fire by means of a wireless sensor network shown in experiment 1, a temperature sensor in experiment 2 and a smoke sensor in experiment 3 though the calibration of the smoke sensors did not work very well and the sensors triggered with some irregularity.

These systems put together detected fire and gave a warning to show the presence of a fire in the form of a buzzer. Occupants were warned of the presence of a fire by SMS's sent by the developed system. This helped reduce the number of false positives since the SMS allows occupants to vote whether there's a fire or not. The warning procedure mentioned above takes approximately 13.5 seconds to send an SMS. The detection system can be deactivated and activated via an SMS. This was shown in experiment 4 with the response time shown in seconds, with a response time of approximately 16 seconds.

The results therefore show that the developed system is a reliable method of switching the alarm on and off. The main of this system was to reduce the number of false positives in a kitchen. False positives in a kitchen can be caused by variations in temperature above the normal as well as excess smoke generated by cooking. The system does not have the capability of determining the exact source causing the false positive but it is able to consider the overall effect and sees if there is an increase in temperature or smoke that is above normal.

V. Conclusion

The main objectives of this work were to design a smart fire detection system that reduces false positives using the wisdom of crowds, which was a voting system. Overall most of these specifications for the system were met. On the other hand there some difficulty due to the testing environment in proving this but again overall the system did what it was designed to do. For future work, the addition of a GUI (graphical user interface) for the setting of customised threshold can be done and also the capability for occupants to check the number of SMS's left in system and be able to recharge the SIM easily. In future we could also consider the autonomous calculation [18] and secure verification [19] of node location, which would assist in validating the position of the WSN node.

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