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An Intelligent Fire Detection and Mitigation System Safe from Fire (SFF)

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ABSTRACT

Safe From Fire (SFF) is an intelligent self controlled smart fire extinguisher system assembled with multiple sensors, actuators and operated by micro-controller unit (MCU). It takes input signals from various sensors placed in different position of the monitored area, and combines integrated fuzzy logic to identify fire breakout locations and severity. Data fusion algorithm facilitates the system to discard deceptive fire situations such as: cigarette smoke, welding etc. During the fire hazard SFF notifies the fire service and others by text messages and telephone calls. Along with ringing fire alarm it announces the fire affected locations and severity. To prevent fire from spreading it breaks electric circuits of the affected area, releases the extinguishing gas pointing to the exact fire locations. This paper presents how this system is built, components, and connection diagram and implementation logic. Overall performance is evaluated through experimental tests by creating real time fire hazard prototype scenarios to investigate reliability. It is observed that SFF system demonstrated its efficiency most of the cases perfectly.

Keywords

fire, sensors, fuzzy logic, data fusion, MCU, intelligent system, expert system

1. INTRODUCTION

Fire causes huge loss of lives and properties every year in Bangladesh. Analyzing past fire incidents, facts are revealed. Some of the main causes are insufficient fire defense materials, electric short circuit from faulty electrical wiring, presence of inflammable materials, violation of fire safety and lack of adequate awareness etc. Some factories and recent buildings have proper installation and fire safety arrangements such as fire alarm, fire extinguishers, water supply system etc. But the argument is these conventional fire extinguishing systems are not enough to take prompt action during fire and save life. Traditional manual system does not ensure 24/7 monitoring from fire protection. Moreover, existing fire protection system could spread panic inside the whole building since it does not announce the location of fire or intensity. It only raises alarm whenever fire is detected at any place. Frightened people could starts to run away haphazardly. As a result buildings full of workers in the factories women, children could be smashed by the outgoing pressure of the frightened crowd and injured severely. On the contrary, Sometimes people does not realize the intensity of the fire and not willing to evacuate fire affected building quickly. It could lead a devastating result.
In this paper SFF system is presented that can minimize these hazard. Along with fire alarm this system announces locations of fire and able to detect severity. To prevent fire from spreading: some efforts are extremely important. Such as: breaking electric circuits of the affected area, releases fire extinguishing gas on the hazard spot, calling fire service, inform promptly building monitoring committee by text messages or telephone calls. SFF intelligent system takes prompt attempt to accomplish these tasks.

2. LITERATURE REVIEW

In this section latest fire accident detection technologies and intelligent prevention system are discussed. The progress on fire detection technologies has been substantial over the last decade due to advancement in sensors and microelectronics [1]. In [2] a review of progress in various emerging sensor technologies for fire detection and monitoring is elaborated. Mostly fire detection technologies are categorized into two groups, one is vision based [3] [4] technique that analyzes video frames and process images to detect fire and another one is sensor based fire detection.

With the increase of number of surveillance cameras, vision based fire detection with the same equipment sets become an attractive opportunity. Since it does not incorporate additional hardware budget. However, video frame detection based approach is not appropriate for early stage fire detection. Because during the early stage fire there might be only smokes or very minimal fire flames. video frame detection based approach can miss detecting fire at that moment. while with gas sensor fire can be detected even before inflammation by identifying the type of leaking gas [5]. To detect smoke with cameras several smoke detection researches have been published [6, 7, 8]. Since smoke is grayish and semi-transparent, edges of high frequency image frames losses their sharpness and becomes an indicator for smoke. Also smoke is distinguished by checking the variations of background color tones, segmentation of

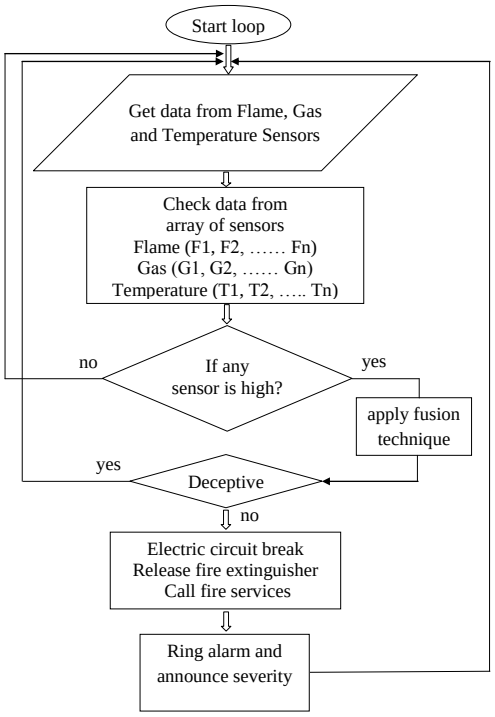


Fig. 1: Flow chart of SFF system implementation

smoke colored pixels, blur background, illumination etc [6, 7, 8]. However it is not clear though how this technique can distinguish between foggy weather and smoke. To overcome this problem motion analysis is also included in vision based technique to detect smoke accurately [9, 10]. But sensors based fire detection techniques are easy to install, cheap in price and system becomes much more easily deploy-able.

In [11, 12, 13] along with computer vision-based fire detection algorithm for fire color modeling and motion detection, sensor networks are combined. These combined approach seems very attractive however it could increase the expenses of the system and the system complexity will increase for installation and deployment [11]. Compared to the above techniques and approaches stated before SFF strategy of detecting fire is simple, less expensive and effective to handle deceptive fire scenarios. It is also effective for early fire hazard occurrence detection.

3. SYSTEM DESCRIPTION

Since it is shown in the previous section several research papers have been published about fire detection and prevention system before. Compared to these system SFF is a complete package specified all the necessary jobs needs to be done during fire. Also it can detect deceptive fire. Similar to [14] for the fire detection a group of sensors data are combined. These sensor have one smoke sensors, one flame sensors and one temperature sensors. Adaptive fusion method is used [15] in each group for fire detection, and deceptive event isolation. A flow chart is shown in figure 1 for the SFF system implementation. According to the flowchart an algorithm is written to explain how this system logic works. In this flowchart (figure 1) it is clearly revealed that three different types of sensors are used in SFF system implementation. One group of sensors is used for the flame detection purposes, $F1$, $F2$, ..., Fn. Similarly for the gas detecting purpose gas sensors have been used, which are $G1$, $G2$, ..., Gn and so on for the temperature sensors $T1$, $T2$, ..., Tn. At the beginning there is an infinite loop which checks whether there is any high value for any sensor in any place. After that it checks are there any sensor values high? If it does then it look for a set of values combined with flame, gas and temperature sensors. Adaptive fusion method is used here to determine the deceptive fire identification.

An algorithm for the SFF system is shown below in algorithm 1. From that algorithm it is revealed that there is data logging functionality which provides the advantage to save data for future analysis of fire accident. This algorithm shows more clear and vivid outline of SFF system software program implementation logic. In this algorithm various Arduino library has been used. one of the example was using alarm library [16]. Whenever fire is detected this library instance is called that generate a fire alarm sound using Alarm::ring() method (see line number 24 in algorithm 1). Send-

Algorithm 1: Algorithm for the SFF system

```
1.  Initialization: Assign sensors, servo pin and position
2.  /*prepare array of sensor data*/
3.  Flame[Flame SenNum] ⇐ {F1, F2,..., Fn}
4.  Gas[Gas SenNum] ⇐ {G1, G2,..., Gn}
5.  Temp[Temp SenNum] ⇐ {T1, T2,..., Tn}
6.  Calibration: Initialize sensors and servo motor direction angle
7.  while sensor value = high do
8.      LogData(Flame, Gas, Temp)      /*Save data*/
9.      D ⇐ DataFusion (Flame, Gas, Temp)
10.     if D == True then
11.         /*Save deceptive data*/
12.         SaveData(Flame, Gas, Temp)
13.         /*Send SMS from GSM module as warning*/
14.         SendTextMessage()
15.         break;
16.     end
17.     else
18.         RelayPinVolt ⇐ high     /*break circuit/*
19.         GasReleaseValvePinVolt ⇐ high     /*release fire
            extinguisher gas*/
20.         SendTextMessage()
21.         /*Call fire services and play predefined audio e.g. Fire,
            Fire .....*/
22.         DialVoiceCall()
23.         while !D = True && ( Flame[] = high || Gas[] = high ||
            Temp[] = high) do
24.             Alarm::ring()
25.             /*Cumulative result of all the sensors*/
26.             AnnounceFireSeverity() /*Announce location of all
                the sensors*/
27.             AnnounceFirelocation()
28.         end
29.     end
30. end
```

TextMessage() and DialVoiceCall() methods are included from GSM module. See section 6 for details.
One of the significant constraints of SFF system is, this system needs to know exactly where the sensors are mounted or attached to detect the exact location of the fire spot. The location needs to predefined specified in angle between the fire extinguisher and adjacent sensors. From the adjacent angle between the sensors fuzzy logic determines the exact location of fire. Then whenever the fire detected it sends SMS to fire services and building maintenance committee, releases fire extinguisher gas, ring alarms and announce severity. Severity is nothing but a cumulative counter of the numbers of sensors reading. If there are more sensors provide reading of fire then fire is spreading and growing intensively. From the mounted position in the building, SFF knows the sensor index and corresponding location of fire.
The circuit diagram for the SFF system is shown in figure 2. This figure shows a abstract schematic diagram of SFF system implementation. The actual SFF circuit diagram contains more modules and components. To keep the schematic diagram drawing simple an abstract schematic view is shown here. It shows how the GPS SIM900 model shield is attached with main Arduino circuit diagram board, how the flame sensors, gas sensors and fire extinguisher motors are attached. Here, fire extinguisher relay (see figure 5b), temperature sensors, and gas extinguisher gas valve attachment are not shown which are included in SFF circuit prototype.

4. SYSTEM EQUIPMENT AND EMULATION SETUP

SFF system is incorporated with multiple modules and components attached with Arduino circuit board. Arduino has been chosen for SFF system development and hardware prototype design. In the following subsections 4.1, 4.2, 4.3, 4.4 Arduino and others modules are described.

4.1 Arduino based Processing Unit (figure 3)

For controlling the signals from various sensors, and combined modules Arduino has been used in SFF. Arduino is a physical computing platform for managing and handling electronics. It has an open source platform independent IDE, that facilitates programmer to process the electronics signal from the attached components and control them. Most popular Arduino board Arduino Uno consists of 8-bit Atmel AVR microcontroller clock speed 16 MHz. Using Arduino sensor modules and components are programmed in SFF and algorithm logic is implemented. There are some other alternatives to Arduino board for hardware prototype system design such as: Netduino, Rasberry Pi, PIC controller etc. But one of the biggest advantage about Arduino is there are numerous examples are given in online. Moreover, most of the sensors, modules are available in the market is Arduino compatible. Also the board is not expensive, freeware and has very active developers community. Considering all these scenarios

4.2 Controlling Fire Extinguisher Spraying Position

In this project servo motor is used to move the fire extinguisher sprayer to spray fire extinguish fluid at the exact position of fire affected area. Servo motors are mainly used for armature movement. Servo motor is a kind of motor that uses gears to the control wheel accurately and it can only rotate up to 180°. The servo serves as a rotor in SFF of moving the Fire Extinguisher Sprayer towards precise location.

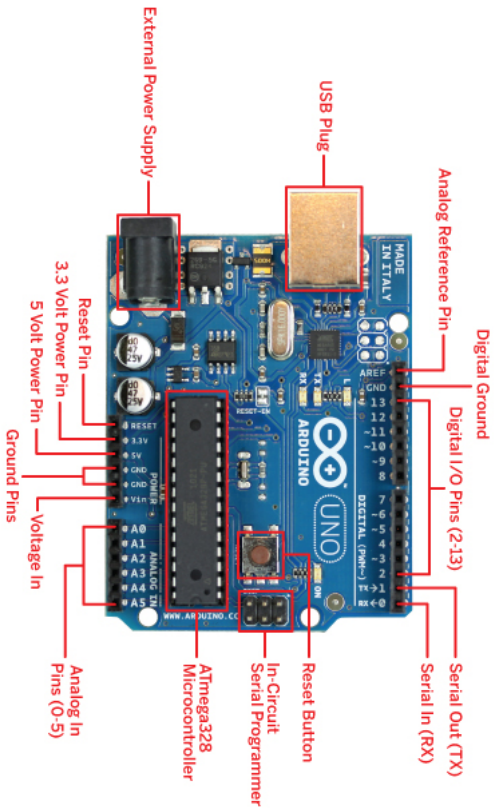


Fig. 3: Physical outlook of Arduino Uno R3 [17]

4.3 Flame Detection Module (figure 4a)

To detect fire flame sensor module has been used in this project [18]. This module is sensitive to the fire and basically flame spectrum. The way it works it just detects the light wave length between the range of 760nm-1100 nm which is actually the range of typical infrared light. However, its detection range is almost 3 feet and detection angle 60° which is not very large to monitor a single room. But it is very low cost sensor, light weight only 8 gram, response time is very fast and easy to use, which makes it a right choice to work with, for prototyping and experiment. There are digital and analog pin output with the module and a potentiometer to change the flame sensitivity. If temperature reaches very high, then output high and low threshold needs to be adjusted accordingly.

4.4 Gas Detection Module - (figure 4b)

MQ-2 gas sensor module is used to detect smoke [19]. Basically gas sensor module have a small heater inside and a chemical sensitive sensor to detect a range of gases. For an instance, MQ-2 gas sensor module can distinguish Liquefied Petroleum Gas (LPG), Carmon Monoxide (CO), Hydrogen (H_2), Methane (CH_4), Smoke, Propane (C_3H_8) and Alcohol ($-OH$) gases. This sensor is popular because of its precision, fast response time, and sensitivity, high reliability, longevity and cost effectiveness. The sensor output is actually is an analog resistance, which is attached with a load resistor and connected with an Analog to Digital Converter (ADC). By reading the resistance level, leakage gas can be detected. Since

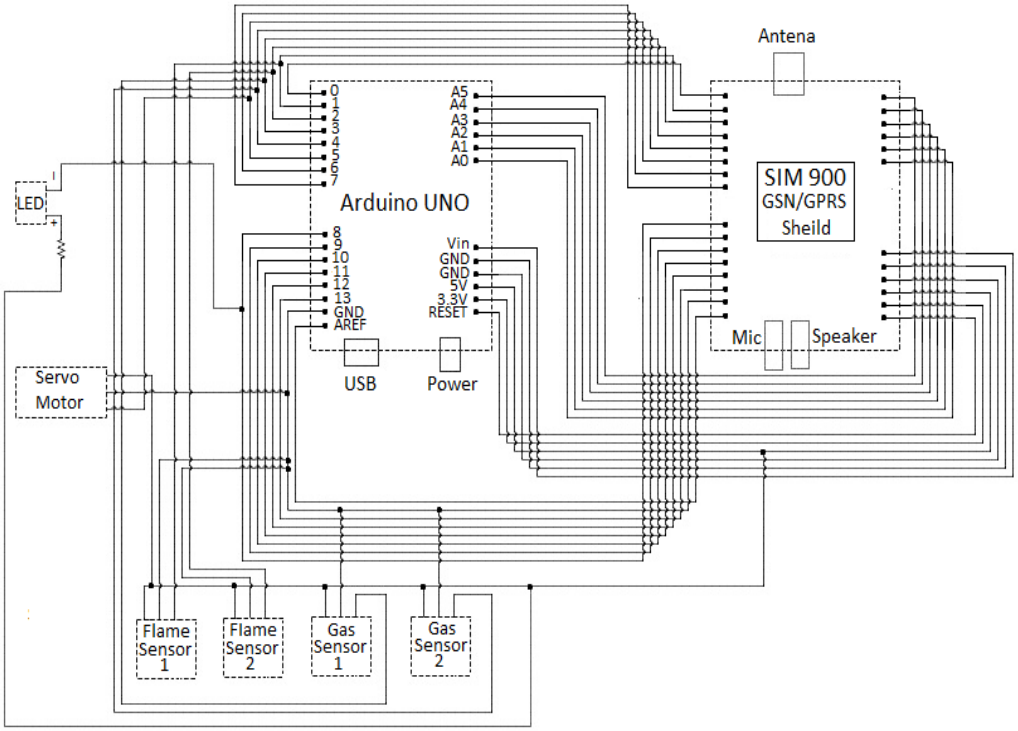
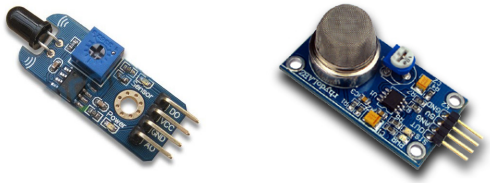


Fig. 2: Circuit diagram for prototype design (N.B. actual circuit diagram contains more components and modules)



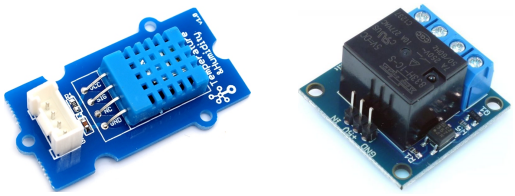
(a) Flame sensor (b) Gas Sensor

Fig. 4: Flame and gas sensors module [19, 18]

MQ2 module has been used, load resistance was attached with the module circuit board by default. MQ2 sensor can detect gas as low as 200ppm to high limit 10000ppm. Therefore, it has the capability to sense gas very low density to high volume of range.

4.5 Temperature Sensor Module (Figure 5)

For temperature reading SEN11301P model sensor has been used. It can provide temperature and humidity reading simultaneously [20]. SEN11301P sensor has accuracy of $\pm 2^{\circ}C$ for temperature measurement.



(a) SEN11301P sensor (b) Relay module

Fig. 5: Temperature sensor [20] and one channel relay

4.6 Text Messaging and Call Module (figure 6)

In hardware assembly Geeetech GSM module has been used [21] for Text Messaging and Calling purpose. This module can communicate via GSM cellular network and can able to provide services of SMS, MMS, Voice call and GPRS. It supports TCP/IP stack which facilitates to push data in to a web server. Therefore, it can be interfaced for Machine 2 Machine (M2M) applications and controlling

Other specifications	
Signal Collecting Period	2 Seconds
Work Voltage	3.3V∼5V
Sensitivity	$1^{\circ}C$ Temperature

Table 1. : Specification of SEN11301P temperature sensor [20]

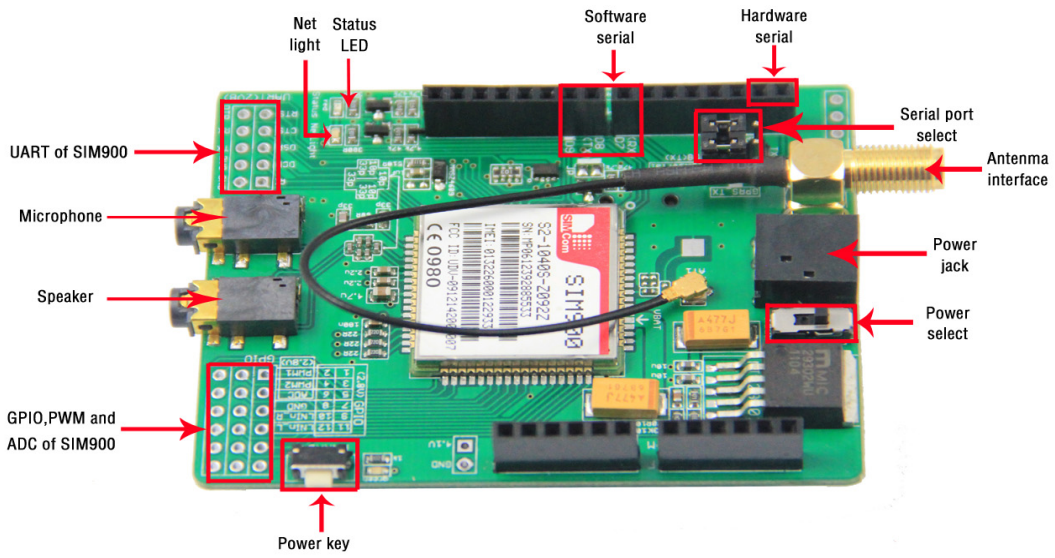


Fig. 6: Physical overview of GSM module [21]

appliances remotely such as: applications related to wireless sensor networks, GPS tracking system etc. In SFF system, to inform the fire service committee and others this GSM module has been used. This GSM shield is used for communicating with the responsible authority from a remote location via SMS or call after getting fire detection signal.

5. METHODOLOGY

The SFF system follows complex problem solving approach of Fuzzy engineering [22]. Fuzzy engineering is a mathematical model to deal with a combination of large sets of logic that provides the facility to extend the usual boolean logic. Applying this method, it can handle partially true or imprecise spectrum of input data. Therefore, rather than dealing with the exact true or false values, system logic can deal with a range of values between completely true to false. Another well known algorithm data fusion [23] is applied in SFF system to combine result or aggregate observed data from multiple sensors. The main objective of employing fusion technique in SFF system implementation is to produce more reliable fire information signal possible. In the following section fuzzy logic and fusion techniques are illustrated on the context of SFF system.

5.1 Fuzzy Logic for Location Detection

Fuzzy logic has been chosen to decide exact location of fire [24]. Because fire could rise in any location within the monitored area. Since the number of sensors to detect the fire are mounted on different positions of the sensor deployment area, sometimes detecting the fire location precisely becomes difficult. Without the fuzzy logic from the actual readings of the adjacent sensors, relative position of the fire can be determined. Since, the exact angle from three or four different sensors mounted in different location, one single location point can be estimated. However, it does not provide satisfactory results in various scenarios specially whenever the range of the sensors are less and if there is large number of sensors. For larger area monitoring with inexpensive short range sensors this type of situation can easily happen. Hence, fuzzy logic algorithm has been incorporated in to SFF system. Fuzzy logic is used in servo motor library for fire extinguisher handling purposes [25]. It determines the exact angle to target the fire position. Appropriate location is determined based on the fuzzy logic and considering intensity of adjacent sensors readings mounted in different positions. Thus servo motor point the exact location of the fire and release fire extinguisher.

5.2 Fusion Method for Data Aggregation

It is a widely used technique based on probabilistic statistics of observations and processes used for various multi-sensor applications such as: pattern recognition, mapping environmental data etc [26, 23]. Fusion method is implemented in SFF to discard the deceptive fire occurrences to reduce the false alarm such as smoke from cigarettes, welding fire, kitchen fire etc [27, 28]. Since it can differentiate the deceptive fire occurrence, whenever deceptive fire scenario is detected it able to send signal before the fire incident as a warning. One set of sensors are incorporated together and data fusion technique is adopted to find out the best possible outcome to track the fire accidents and diagnosis sensor error [29]. If it is found that only flame sensor is high or gas sensor detects gas it will only send deceptive fire occurrence signal. Hence, SFF system fire signal generates more accurate, complete, and dependable fire alarm signal.

6. RESULT DISCUSSION

To do the experiments cigarette lighter has been used as a fire source. Whenever cigarette lighters are lighted it send signal and trigger fire incident. The experimental results indicate that the adaptive fusion method is a suitable solution for fire sensor for fire detection and isolation of deceptive fire occurrence scenarios. The fire detection module can transmit the decision results to mobile phone through the GSM module. The experimental results are shown in

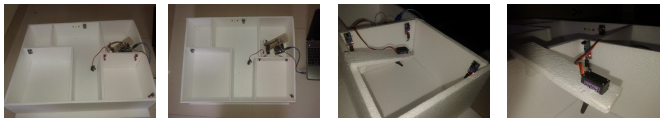


Fig. 7: Physical prototype structure of inside a building with flame, gas, temperature sensors and servo motor module

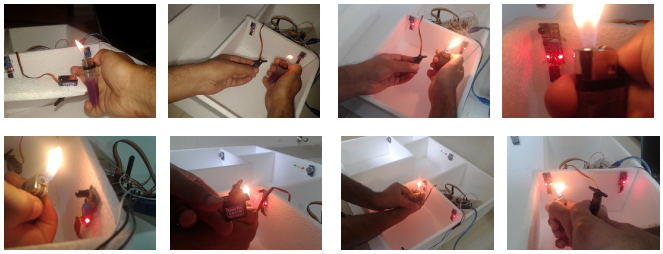


Fig. 8: Servo motor rotation, location detection testing of fire occurrence area, flame intensity and alarm testing)

various figures. Figures are figure 7 to figure 8. The accuracy of the SFF system is over 95%. Except some unusual scenarios to detect deceptive fire hazards. Actually this problem happened because SFF system considered multiple numbers of sensors input to determine the actual fire event. Since, it takes multiple reading sometimes actual fire can be determined as deceptive fire. However, since there is an warning alarm sending scheduler that sends deceptive occurrence hence ambiguous fire hazard scenarios also can be detected. By which fire monitoring or security committee can be aware and take precautions.

7. CONCLUSION

There is an immense need of implementation of automatic fire extinguishing system to protect lives and assets from fire hazards. In this paper full fire protection system is explained. SFF takes most of the preliminary initiative to prevent fire from spreading and does all necessary activities. Hence it's a complete package of fire protection system. This type of system is absolutely necessary for the perspective of Bangladesh. Garments factories, industries, multi complex shopping malls, super shops, this type of system is not only a requirement must be mandatory. Government should impose rule that SFF or automatic fire extinguisher system must be installed. Hence, this noble system can be used in every smart buildings and cities to protect invaluable lives and assets from fire and assure safety.

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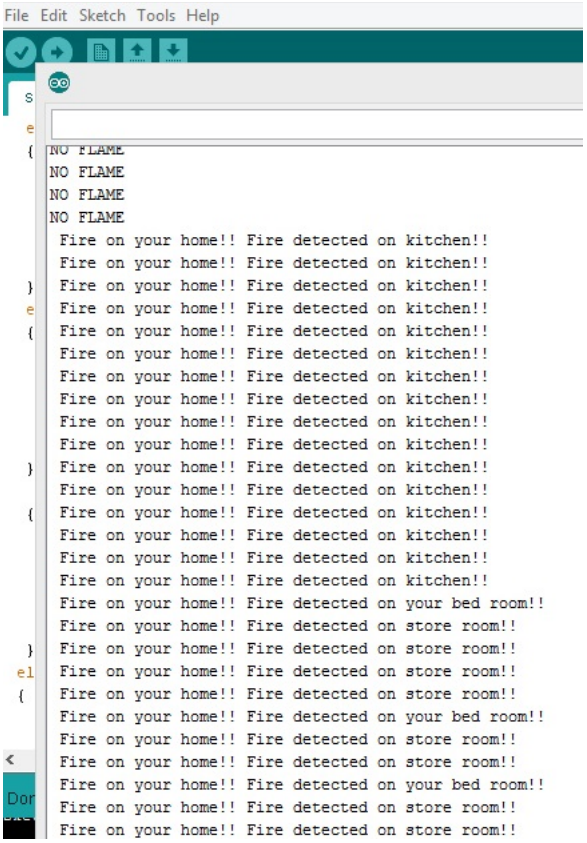

Fig. 9: Alarm logs are shown in serial monitor of Arduino

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