Development of human machine interface for supporting the disaster mitigation system in the city using wireless sensor network

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Abstract. Disasters that include building fires, earthquakes, and floods are the inevitable things in city life. Disaster mitigation should be undertaken to mitigate the adverse impacts of the disaster. Its activities span from an early warning system until the evacuation of the victim to a safer place. With the advancement of information technology, an integrated system can be built to support the disaster mitigation system in the city. This paper describes a development of a prototype of human machine interface for supporting the disaster mitigation system in the city. This prototype comprises sensors, microcontroller, communication module, and information system to capture and display the disaster location. Three parameters including smoke concentration, room temperature, and vibration are sent to the monitoring room at any time using the wireless sensor network framework. The building fire indicators are rendered by raising a smoke concentration and temperature up to the certain level, while earthquake indicators are provided by vibrations sent by vibration sensors. The location of the disaster site is displayed in the monitoring room and delivered to the city authority who handling the disaster via mobile phone. Disaster management office could work more effective due to the information on disaster locations and types of disasters could be known quickly.

1. Introduction

Human life cannot be separated from disasters, both natural disasters and disasters due to human factors. Such disasters include building fires, earthquakes, floods, and so forth. Reducing the worst risk is the most important part in disaster management [1]. An early warning system supports the efforts to reduce the worst risk because it provides initial information about the potential for disasters that will arise. Such warning is distributed to each community member or sent to related authorities to be followed up with immediate evacuation from the disaster area. This step is possible because the advancement of electronic and information technology supports the realization of a compact, small, and low power systems. In addition, such systems can reach distant places and remote area as well. In the context of disaster management, information sent to the authorities will accelerate victim handling and preparation of mitigation as well as logistics assistance mechanisms that must be prepared. It has been reported that decision makers are usually guided by bounded rationality under risk and uncertainty conditions and their actions depend on the psychological behaviour [2]. It takes time to respond and handle the
emergency effectively. In such cases, an early warning mechanism can fill in the gap in order to render the awareness promptly, either for the related authorities or the decision makers in the city.

This paper proposes on development of human machine interface to provide the relevant information regarding disaster management. This prototype comprises sensors, microcontroller, communication module, and information system to capture and display the disaster location. Three parameters including smoke concentration, temperature, and vibration are sent to the monitoring room at any time using the wireless sensor network (abbreviated WSN) framework. It has been widely known that WSN is more applicable for assisting the dedicated network due to scalability and low power consumption [3, 4]. With technical specifications that are increasingly sophisticated and efficient, WSN can be made portable so that it can be utilized optimally to assist the disaster management in the city. By putting the sensors at certain place of the buildings, data regarding the condition of buildings could be monitored at any time due to its data is broadcasted and received by receiver system installed in monitoring room of city authorities. Furthermore, a human machine interface (abbreviated HMI) which also developed in our recent work would provide complete information including building conditions, location where disaster happened, and an early warning for alerting the possibility of disaster. In addition, notifications about potential disasters are also sent to the appropriate authorities through mobile phones whose contact numbers are registered in the system. Thus, disaster management is more effective because information on disaster locations and types of disasters can be known quickly so that they can be handled appropriately.

The rest of paper is organized as follows. Section 2 describes on system design includes block diagram of the proposed system, flowchart, and hardware realization. The experimental results and its analysis are given in Section 3. The paper is closed by the concluding remarks and future recommendation to improve the recent work.

2. Methods
Block diagram of the proposed system is depicted in Figure 1. There are three parameters which detected by MQ2 sensor, LM35 sensor, and SW420 sensor. These sensors capture smoke concentration, indoor temperature, and vibration respectively. All parameters are processed by the Arduino microcontroller to then be sent continuously through the GSM module to the mobile phone whose number is registered in the system and Xbee module to the HMI system. While, LCD is employed to display the amount of above-mentioned three parameters and Buzzer is used to give an alert whenever the amount of such three parameters is higher than the threshold point.

Figure 1. Block diagram of the proposed prototype.

Possible implementation is shown in Figure 2. All sensors are placed on a certain location at the building. Data acquisition is rendered by microcontroller embedded in the system and XBee Pro based WSN. Due to scalability of WSN, we could make a receiver to collect and compile many data from
many buildings in the same time. In this case, the buildings in the city could be detected their conditions at any time. If there is potential disaster such as building fire, earthquake caused vibration or other factors due to its structural condition, and so forth, an alert mechanism is appeared in HMI system and broadcasted to the related authorities such as fire department, disaster management office, and so on.

![Disaster management framework in the city.](image)

**Figure 2.** Disaster management framework in the city.

While, schematic diagram for realizing the proposed prototype is given in Figure 3. It consists of the data broadcaster and the data receiver. The first comprises sensor circuit, Arduino microcontroller, XBee transmitter module, and GSM module, while the latter collects the transmitted data to be displayed in HMI or appeared in mobile phone.

![Schematic diagram of the data broadcaster (a) and the data receiver (b).](image)

**Figure 3.** Schematic diagram of the data broadcaster (a) and the data receiver (b).

MQ2 sensor can either detect or measure gasses like LPG, alcohol, propane, hydrogen, carbon monoxide, and even methane. It was used in some applications such as electronic nose [5], LPG detector [6], multi-sensor fire detection [7], and so on. In the proposed prototype, such sensor was employed to
transmit a smoke concentration data which may appear in the building. The measurable output voltage which read out from the MQ2 output pin is linearly proportional to the amount of smoke concentration. It is operated by the DC supply voltage around 3.3-5 volts. The smoke concentration that can be covered spans from 0 until 1000 ppm. If the amount of smoke concentration exceeds 100 ppm, then a warning message will appear in the HMI and be sent to the mobile phone whose contact numbers are registered in the system. The output of MQ2 sensor is connected to microcontroller via port pin A0. Meanwhile, the indoor temperature is detected by the LM35 sensor. It provides a precision temperature device with its output voltage is linearly proportional to the Celsius (centigrade) temperature. It has been widely known that LM35 sensor was almost applicable for all temperature based electronic systems [8-10]. The output of LM35 sensor is connected to microcontroller via port pin A1. The other sensor that used in this prototype is SW420 sensor. It is a vibration sensor which detect any vibration that beyond the threshold. The threshold can be adjusted by the on-board potentiometer. If vibration is below the threshold, the output voltage is quite low. In that case, no trigger is inserted in the microcontroller input. Conversely, if any vibration above the threshold is detected by SW420 sensor then the input voltage to microcontroller is high. Furthermore, the earthquake indicator signal will be sent to Xbee transmitter module to be broadcasted into the receiver. At the end, HMI will display the earthquake warning sign. Interconnection between Arduino microcontroller and the MQ2 sensor, the LM35 sensor, and the SW420 sensor respectively is shown in Figure 4.

WSN based disaster management is implemented by exploiting the XBee Pro S2 module. It consists of the transmitter module and the receiver module. The transmitter module is responsible for collecting the data taken from sensor and broadcasting them into the receiver module. This module operates on the 2.4 GHz ISM (Industrial, Scientific & Medical) band frequency which provides the ability to transmit data between devices with a range of distance capabilities that vary depending on conditions and place (indoor & outdoor). The pin to send and receive data respectively is on pin 2 as the OUT-data pin (Tx) and pin 3 as the IN-data pin (Rx). It needs the supply voltage of 2.8-3.3 V. Whenever the data is broadcasted by the transmitter module, the receiver module will capture the data by employing a small antenna to gain the data which is then processed by the HMI. Interconnection between Arduino microcontroller and the transmitter module of Xbee Pro S2 is depicted in Figure 5(a), while the receiver module is shown in Figure 5(b). Some works related to XBee based WSN including security event analysis in wireless mesh networks [11], real-time wireless data collection and processing using Java [12], wireless control robot with multiple sensors [13], wireless monitoring of chemical inventory [14], and so on. Olasupo et al. in [15] proposed an empirical path loss models for WSN deployment in indoor and outdoor car parking using XBe module. While, Chou et al. in [16] developed a remote glucose and lactate monitoring that was carried out by using wireless real-time sensing system based on XBe module.
Beside the all information regarding the building condition and disaster possibility appeared in monitoring room via HMI, the early warning mechanism is realized by sending the disaster locations and types of disasters to the appropriate authorities through mobile phones whose contact numbers are registered in the system. It was implemented by interfacing the GSM SIM900A module into Arduino microcontroller such that the information is sent to a certain mobile phone. This module supports dual band communication on 900/1800 MHz frequencies (GSM900 and GSM1800) so that it is flexible for use with SIM cards from various cellular phone operators in Indonesia.

3. Results and Discussion

The proposed prototype is realized by constructing a building replica which equipped with the sensor as depicted in Figure 6. While, the HMI is located in a monitoring room as shown in Figure 7.

The experimental test is carried out by monitoring the condition of a building replica which represented by temperature, smoke concentration, and vibration. An HMI which developed in a
monitoring room confirmed that the amount of the temperature and smoke concentration equals to the real condition. Display in HMI when the amount of temperature and smoke concentration in normal situation as well as no indication of earthquake is shown in Figure 8.

Furthermore, temperature in building is increased by heating up to 50°C and adding a smoke with its concentration above 100 ppm. In such case, fire warning would be alerted and HMI viewer as shown in Figure 9(a) and 9(b). The next experiment is done by giving a vibration beyond the threshold such that SW420 sensor detects an earthquake threat. In that situation, HMI viewer will display the information as given in Figure 9(c).

Whenever indication of disaster happened, the information also is sent to the mobile phones whose contact numbers are registered in the system. The information contains the location and type of disaster as displayed in Figure 10.
Another observation during experimental test is gaining a traveling time of sensor data subject to distance between sensor node and the XBee receiver module as well as the maximum distance between XBee transmitter module and its receiver module such that the information could be delivered accurately. The results are tabulated in Table 1. As can be observed from Table 1, the data can be transmitted accurately with the shortest time if the receiver module is located at a maximum distance 50 m from sensor node. The data is experienced the delay when distance is larger than 50 m. At a distance of more than 90 meters, the receiver module cannot receive data. This happens due to the receiver module is outside the maximum distance where data can be sent. The delay can be affected by the area's contours, the presence of obstacles, and noise in the external system. To overcome this condition, we could employ a collaborative link-aware protocols proposed by Chen & Chiu [17] to minimize the maximum delay or utilize some topology as suggested by Ayaz et al. [4].

| No | distance (m) | delay (s) |
|----|--------------|-----------|
| 1  | 10           | 0         |
| 2  | 20           | 0         |
| 3  | 30           | 0         |
| 4  | 40           | 0         |
| 5  | 50           | 0         |
| 6  | 60           | 3         |
| 7  | 70           | 3         |
| 8  | 80           | 5         |
| 9  | 90           | 6         |
| 10 | 91           | ∞         |

4. Conclusion
A prototype of human machine interface to support the disaster mitigation system has been presented. It provides all information related to the building conditions as well as an early warning for alerting the possibility of disaster. The prototype is developed by using wireless sensor network to render scalability and portability of the prototype. In addition, notifications about potential disasters are also sent to the appropriate authorities through mobile phones whose contact numbers are registered in the system. The experimental results show that the prototype works well according the design objective. The data can be delivered and appeared in the proposed human machine interface. The information regarding the location and type of disaster reach the certain mobile phone. However, the data is experienced the delay when distance between sensor node and the receiver module is larger than 50 m.

Further work to improve the performance of the prototype could be directed to extend the number of sensor node and building in order to maximize a capability of XBee module. Whenever the number of sensor node and others are increasing and the system performance is directed to automatic control and monitoring through the communication network, the networked control system framework should be adopted to overcome the existence of network parameters as reported in [18].

5. References
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Acknowledgments

The first author thanks to Direktorat Riset dan Pengabdian Masyarakat Ditjen SDID Kemenristekdikti (Ministry of Research, Technology, and Higher Education) who already supported this work in Penelitian Terapan Unggulan Perguruan Tinggi (PTUPT) Scheme for fiscal year 2018. We also acknowledge The Institute of Research and Public Services Universitas Jenderal Achmad Yani who already partially supported this work in Competitive Research Scheme for fiscal year 2018.