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ORIGINAL ARTICLE

An IoT Based Flood Monitoring and Response System

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ABSTRACT - The emergence of the Internet of Things (IoT) has greatly impacted various fields. Its widespread adoption has allowed new applications to be developed without interference from humans. This study aims to establish the pragmatism of IoT in the field of smart cities to improve the response and detection of disasters. Through the pervasive computing of sensor networks and IoT, it allows the authorities to improve the response time and efficiency of their operation during disasters. The concept of an integrated flood detection system involves the use of a raindrop sensor and an ultrasonic sensor has been proposed for the smart disaster detection and response system. The data collected by the system via its environmental sensing was used to trigger an action for alerting users. The system allowed users to be notified if a condition has been labeled as 'danger', or an indication of flood from buzzer (onsite notification) and a web-based application (remote monitoring) for continuous observation. The system is designed to provide reading such as monitoring the status of the water level impacted by the volume of rainfall based on a set time interval of 30 minutes. The prototype has been tested through the conducted experiment at a controlled environmental condition.

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INTRODUCTION

Highly adaptable IoT can be the next game-changer; as the need for concrete infrastructure, installation, or complex restoration can be eliminated and replace with simpler pervasive computing such as sensor networks. Cooperatively, sensors can be placed virtually anywhere in the driving adoption of IoT technology [1]. IoT enables digital innovation where computing devices, digital machines, objects or people to be interconnected while producing data integration and analytics hence delivering solutions to various domains. The infusion of technology has become a promising communication paradigm to address societal challenges while envisions a future in which the object of everyday life will be equipped with microcontrollers, sensors, and transceivers that will make devices to be interconnected with the users [2]. The paradigm of IoT can be envisaged in conjunction with an effective data collection strategy and the ability to share such data. Furthermore, often neglected information can now be studied and put to better use for efficient data collecting, data analyzing, monitoring, and ultimately making intelligent decisions for infrastructure or service management. This technology has adequate potential to realize complex decision support systems by delivering the required services in a more precise, organized, and intelligent manner. One of the eminent domains that can benefit from the technological innovation of the IoT is emergency preparedness and response. IoT innovations could not only help in disaster preparedness but also disaster resilience. Flood is one of the most significant disasters in the world. More than half of global flood damages occur in Asia [3]. Plan and operation on integrated flood disaster and risk management often focus on reactive responses which sometimes will be too late, causes great disturbance such as the destruction of property and loss of precious lives. IoT can address this pressing issue and provide a proactive risk reduction solution to lessen the intensity and magnitude of the disaster. This study presents a smart management sensing system that explores the application of flooding. It provides an alerting system and can detect threatening events. This enables the public to be notified of potential danger

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(flooding) and action can be taken to reduce the adverse effect of the event. As such the primary objective of the flood detection system is to notify the resident of potential danger before such disaster.

LITERATURE REVIEW

The IoT Architecture

The architectural design of an IoT often consists of a heterogeneous network of a physical object embedded with electronics devices, software, sensors, and connectivity. The main objective of IoT is to enable these components to achieve greater value and service by exchanging or relaying collected data with other connected objects via the internet [3]. Figure 1 shows the architecture of a basic three-layer IoT system [4].

Figure 1. The fundamental three layer of an IoT architecture

Residing at the lowest level, the perception layer contains embedded devices that make use of sensors that gathered real-world data by measuring various key performance metrics [4]. Sensitive to its environmental changes, the sensor detects and responds to physical input such as temperature, presence, humidity, motion, light, orientation, substance, etc. These sets of the input signal will ultimately be converted into significant data either through pre-processing or detailed data analysis. Meanwhile, moving up the layer; the network layer provides the mechanism and protocols that allow the sensed data to traverse across the Internet via wired or wireless communication allowing the transferring of data from the perception layer toward the database/cloud (application layer) for further processing [4]. The IoT gateway ensures internet connectivity of upstream WAN (cellular telecommunication or fixed wireless) and downstream LAN (wireless or wired). All data movement goes through this layer. Finally, the application layer specialized in data processing and storage [4]. This layer also provides access to either cloud application, mobile application, or web-based application. It is responsible for delivering application-specific services to the user. Depending on the need of the system, the function of an application layer can often be elevated into complex data processing and analytics. Data analytics will require to customize procedures or algorithms to extract the massive information gathered by the sensor in the perception layer. However, the IoT architecture is customizable to the requirements of the application making it unique and adaptable for various domains [5]. Solar systems are regarded as a key tool in providing energy for current and future generations. A solar cell or photovoltaic cell is a device that transforms solar light into useable energy. The quantity of solar light that can be converted into electricity is called solar panel efficiency. Certain factors must be taken into account to ensure the maximum efficiency of solar panels.

Wireless Technology

Wireless technology plays a vital role in the industry of IoT for providing continuous connectivity and seamlessness. Examples of wireless technologies that can be widely used for the development of the IoT domains are cellular networks, Bluetooth, and wireless fidelity (WIFI). Typical applications that are suitable for cellular communication are automotive, time-sensitive industrial automation, etc. Cellular connectivity aims at data over long distances and wide coverage. The cellular next-gen (3G, 4G, and 5G) are able to provide high bandwidth, low latency, and high-speed mobility; critical for applications with imperative demand and the needs of mobility [6]. On the other hand, Bluetooth is a short-range communication technology that is suitable for Wireless Personal Area Networks (WPAN) [7]. The Bluetooth network (piconets) uses the master/slave model. The pairing between two connected devices requires only minimal configuration and the role between master/slave devices is easily switchable. Bluetooth technology is considered to be useful and hassle-free in sending a short burst of data. Small-scale consumer IoT applications such as fitness and medical wearables can provide convenient communication and a friendly user interface via data visualization in mobile devices. Lastly, WIFI technology offers a wide variety of profiles [7]. Its proven and standardized technology made it easy for system integration and reduce network architecture complexity. The application that is attached to ready infrastructure can benefit from the WIFI technology. Besides, WIFI technology is also suitable to be implemented as a gateway or backbone providing stable bandwidth and low latency ensuring high data availability. Examples of IoT applications that can benefit from its characteristics are smart cities, facility management, agriculture, industrial automation, and etc.

METHODOLOGY

The IoT Flood Monitoring and Response System

The flood monitoring and response system comprise four major segments: the input, the processing unit, the communication unit, and the output. Figure 2 shows the relations between the main components of the flood monitoring and response system. The ultrasonic sensor (HC-SR04) and raindrop sensor were used to measure their respective key parameters which are the water level and the raindrop intensity. Both of the input data were sent to the processing unit, Arduino UNO for further execution and processing. Finally, the collected data were relayed back to the web via the WIFI module (ESP8266) through the WIFI gateway. A display of data visualization through the web page was obtained based on a set time interval. The web-based platform allows the data stream to be gathered, viewed, and analyzed at real-time intervals. However, if the collected data generated a warning signal, the buzzer will be trigger immediately on-site to notify the resident of the possibility of an incoming flood. Details of the sensor will be discussed in the following section.

Rain Sensor

The rain sensor is used to measure the existing and the intensity of the water droplet (rainfall). Based on the concept of resistance, the module (SN-RAIN-MOD) measures the rain using its nickel-coated lined board [8]. The raindrop sensor uses analog output pins to assess moisture and outputs a digital signal when the moisture threshold is exceeded. Referring to Ohm's Law in Equation (1), where v is voltage in volts, I is current in amps and R is resistance in ohms. Raindrops reduce resistance because it is an electric conductor, and the presence of water links the nickel lines in parallel, resulting in lower resistance and a lower voltage drop across it.

$$I = \frac{V}{R} \tag{1}$$

The lower the resistance (or more water), the lower the voltage output [8]. The voltage output decreases as the resistance (or the amount of water) decrease. Conversely, the lower the water content, the higher the analog pin output voltage. For example, a fully dry board will cause the module to output 5 volts. See Figure 3.

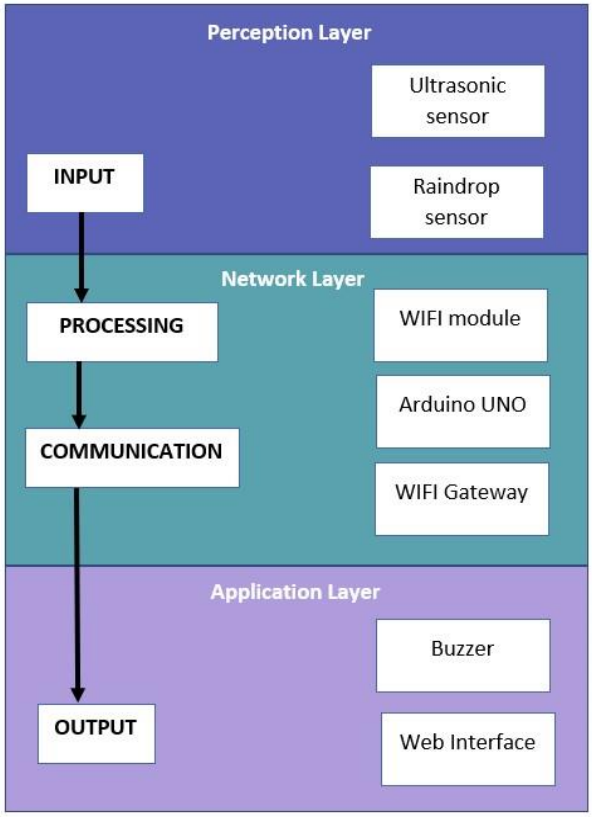

Figure 2. Components of the flood system

Figure 3. Raindrop sensor (sensing pad) [8]

Ultrasonic Sensor

The HC-SR04 ultrasonic sensor is used as a water level gauge that transmits an acoustic waved of frequency [9], see Figure 4. It is a ranging module that provides a non-contact measurement from the range of 2 centimeters to 400 centimeters, with a precision level of up to 3 millimeters. The module consists of ultrasonic transmitters, a receiver, and a control circuit. The process begins with a short 10 microseconds applied to the Trigger pin. A reflected signal will be detected by the Echo pin whose width varies between 150 microseconds to 25 microseconds respective to time [9]. The width of the received pulse is then used to calculate the distance to the reflected object based on time [9]. The distance (water level) can be calculated using the distance-speed-time equation, Equation (2).

$$\text{Distance} = \text{Speed} \times \text{Time} \tag{2}$$

The speed of the sound has been determined to be 340m/s. Thus, if it takes 500 microseconds to receive the reflected signal, the distance will be equated to 8.5 centimeters. The calculation will have to be divided into 2 as it indicates the round trip of the signal. See Figure 5.

Figure 4. HR-SR04 Ultrasonic sensor [9]

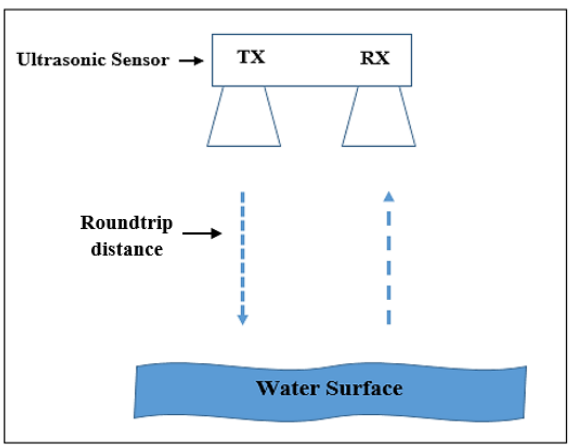

Figure 5. Distance of ultrasonic sensor to water surface

WIFI Module ESP8266

The ESP8266 is a low-cost Wi-Fi microchip, self-contained SOC (System-On-Chip) with an integrated TCP / IP protocol stack [10]. The module provides on-board processing and storage capability, allowing the integration between sensors and other application-specific devices with minimal development up-front and loading runtime. The ESP8266 module comes pre-programmed with an AT (Attention) command set firmware making it easy to be embedded into an Arduino device [10]. It contains a self-calibrated RF (radio frequency) permitting it to work under all operating conditions, and requires no external RF parts. See Figure 6.

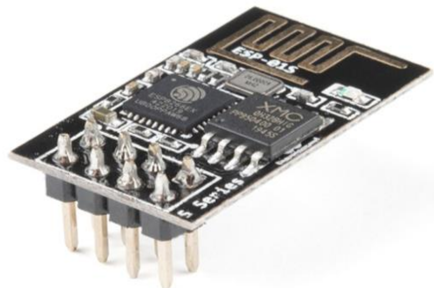

Figure 6. WIFI module ESP8266

The Flood Monitoring and Response Algorithm

The flood monitoring and response system consolidate two sensors. For the raindrop sensor, the analogs output is employed to determine the water droplet based on three rainfall intensities (reading): 5V as 1023 (No Rain), 2.5-3V as 500 (Moderate Rain), and 1V as 300 (Heavy Rain). When there is no rain on the rain detecting pad, for example, the voltage at the analog output will be approximately 5 volts, giving the reading of 1023. Meanwhile, the ultrasonic sensor is a measure based on the water surface area to the sensor (water level). The shorter the distance, the nearer the water level is to the surface. The water level has been established into three distances: above 100 cm is normal or safe, 60 cm to 80 cm is critical or warning, and below 50 cm is unsafe or dangerous. The alerting or responses are set to green (safe), yellow (warning), and red (danger) for algorithm explanation purposes. Upon reading the inputs, the buzzer will only go off when alerting is at 'danger' stage. Table 1 shows the algorithm that has been established for the flood monitoring and response system.

Table 1. Flood Response and Monitoring Algorithm

If Water Level is normal, and Rainfall is normal, then alert is Green. If Water Level is normal, and Rainfall is moderate, then alert is Yellow. If Water Level is normal, and Rainfall is high, then alert is Yellow.
If Water Level is warning, and Rainfall is normal, then alert is Green. If Water Level is warning, and Rainfall is moderate, then alert is Yellow. If Water Level is warning, and Rainfall is high, then alert is Red.
If Water Level is danger, and Rainfall is normal, then alert is Yellow. If Water Level is danger, and Rainfall is moderate, then alert is Yellow. If Water Level is danger, and Rainfall is high, then alert is Red.

RESULTS AND DISCUSSION

The flood monitoring and response system has been tested in a controlled environment. Two units of the prototype have been deployed in a longhouse (Bawang Assan, Sibu) where recurrent flooding often occurred, see Figure 7 and Figure 8. Bawang Assan is an Iban settlement comprising of nine longhouses and is approximately 30km away from the Sibu township. The longhouse is situated near a river (Batang Lebaan) that can causes flooding during high tides or Monsoon season. The prototype has been tested from the month of April to June. During the placement, the sensors transmit back data in 30 minutes time intervals. The prototype is placed 100cm above the flooding surface. When the distance of the water level is below 50cm and the rain sensor gives a reading of below 300, the buzzer will go off. Figure 9 shows an example of continuous data monitoring from the web application for the water level (ultrasonic) and rain intensity (rain).

Figure 7. The flood monitoring and response system place above the flooding surface

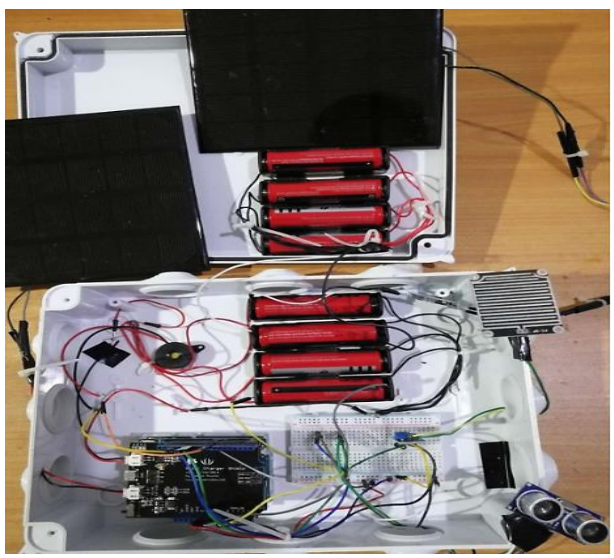

Figure 8. Prototype of flood response and monitoring system inside a junction box

Table 2. Data of Water Level and Rain Intensity

Date / Time	Water Level (cm)	Rain Intensity (mm)	Alert
2019-06-02 18:10:59 +08	129	295	Warning
2019-06-02 18:26:55 +08	128	184	Warning
2019-06-02 18:42:51 +08	128	607	Safe
2019-06-03 18:05:57 +08	134	440	Warning
2019-06-03 18:21:52 +08	134	604	Safe
2019-06-03 18:37:48 +08	137	1008	Safe
2019-06-04 17:53:02 +08	109	260	Warning
2019-06-04 18:08:57 +08	110	258	Warning
2019-06-04 18:24:51 +08	106	249	Warning
2019-06-05 17:52:38 +08	135	593	Safe
2019-06-05 18:08:35 +08	137	309	Warning
2019-06-05 18:24:31 +08	136	448	Warning
2019-06-06 17:59:29 +08	108	288	Warning
2019-06-06 18:15:24 +08	107	287	Warning
2019-06-06 18:31:21 +08	107	290	Warning
2019-06-07 18:01:32 +08	115	359	Warning
2019-06-07 18:17:27 +08	117	450	Warning
2019-06-07 18:33:22 +08	117	495	Warning
2019-06-08 17:56:03 +08	117	402	Warning
2019-06-08 18:11:59 +08	119	407	Warning
2019-06-08 18:27:54 +08	116	415	Warning

The flood monitoring and response system were able to capture 8190 sets of data from April 2019 till June 2019. Table 2 shows some samples of the data collected in the span of seven days from approximately 6 pm till 6:30 pm. For example, on the 2nd of June 2019, heavy rain occurs at 18:26:55 but quickly stops since the reading at the next half hour indicates the rain subsides to normal rain and the water does not increase much thus the alert has change from a warning to safe. Similarly, scenario happened on the 3rd of June 2019. For the rest of the week heavy and moderate rain occurred at approximately the same time but the rain has not caused the water level to rise to a dangerous level. On the same dates, the average rainfall in mm (millimeter) has been measured. For a flood to occur, more than 30 mm of rain must fall on said specific day [11]. Referring to Table 3, the total rainfall in one day from 2nd of June 2019 to 8th of June 2019 has never exceeded 30mm [12]. Thus, justify that the water level will never increase to a dangerous level.

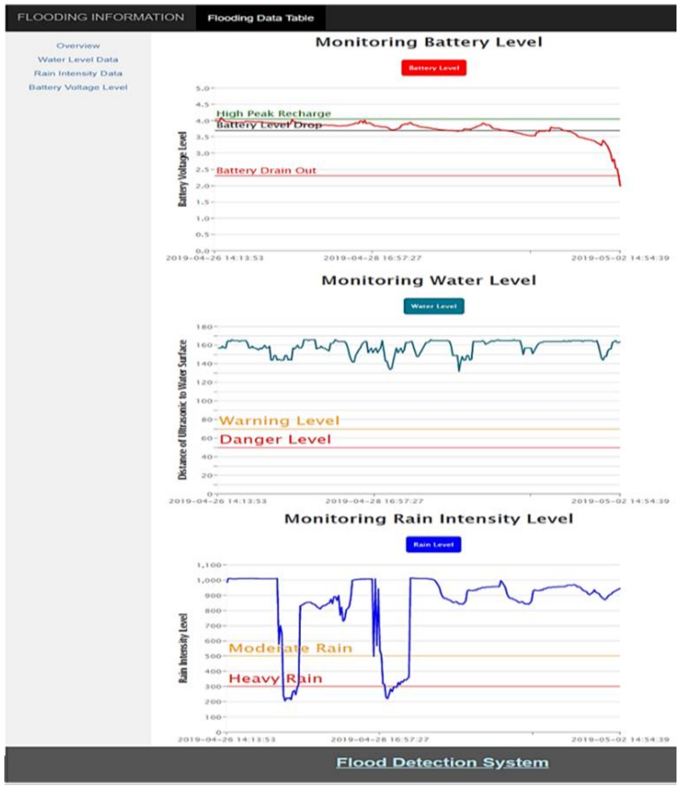

Figure 9. Web interface displaying flooding data

Table 3. Rainfall 2nd of June 2019 to 8th June 2019

Date	Rainfall (mm)
2019-06-02	27
2019-06-03	16.5
2019-06-04	0.5
2019-06-05	11.5
2019-06-06	10
2019-06-07	5
2019-06-08	6.5

CONCLUSION

The flood monitoring and response system is successfully established and it can be further improved to gain a predictive result through statistical techniques. The relationship between the considered parameters can then be studied and a statistical prediction model on flood can also be developed based on regression analysis in order to predict the possible flood in future.

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