Miniaturized Water Flow and Level Monitoring System for Flood Disaster Early Warning

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Abstract: This study presents the performance of a prototype miniaturised water flow and water level monitoring sensor designed towards supporting flood disaster early warning systems. The design involved selection of sensors, coding to control the system mechanism, and automatic data logging and storage. During the design phase, the apparatus was constructed where all the components were assembled using locally sourced items. Subsequently, under controlled laboratory environment, the system was tested by running water through the inlet during which the flow rate and rising water levels are automatically recorded and stored in a database via Microsoft Excel using Coolterm software. The system is simulated such that the water level readings measured in centimeters is output in meters using a multiplicative of 10. A total number of 80 readings were analyzed to evaluate the performance of the system. The result shows that the system is sensitive to water level rise and yielded accurate measurement of water level. But, the flow rate fluctuates due to the manual water supply that produced inconsistent flow. It was also observed that the flow sensor has a duty cycle of 50% of operating time under normal condition which implies that the performance of the flow sensor is optimal.

KEY WORDS: Flood Monitoring, Early Warning System.

1. Introduction
Flooding is usually a result of overflow of river over the river banks due to high water rise contributed by the intense rainfall. Apart from rainfall, a number of factors are responsible for this phenomenon such as melting of ice at the North and South pole, tidal waves and seasonal wind and direction of flow [2]. According to [1,8], flood accounts for 40-50 percentage of global disaster with huge consequences on lives, economy and infrastructure. In the year 2014, Malaysia lost 21 lives to flooding and assets worth of 12.685 million US dollar [4,5]. Flood have resulted to a number of other geohazard disasters such as landslide and mudflow in Cameroon Highland and other locations in Malaysia leading to many lives been lost and properties destroyed. For instance in 2010, Kedah(Malaysia) an estimated 5615 residents were affected by flood and lost vast area of agricultural land[5].
Flood can hardly be controlled, but understanding flood prone areas and availability of timely information about water discharge especially during heavy rainfall can help mitigate the impact of this event [15]. A number of studies have been done by the geospatial engineering experts to map areas that are prone to flooding in different parts of the country [6,7,8,9]. Likewise, a number of systems have been put in place to monitor river water flow and level to provide early warning to adjoining communities on the imminence of the event [10,11,12,13]. Despite these efforts, the situation persist yearly with enormous social and economic disruption. Can we say the systems are not working? Far from it. The challenges with the existing systems is the fewer number of monitoring stations and the cost of installation. Available systems are heavy, costly and difficult to be deployed at any particular location of choice. Therefore, it is essential to have a miniaturised system that is less expensive, portable and capable of being deployed to any location along the river course.

The aim of this present study is to design a prototype water flow and level sensor and to test its performance under controlled laboratory environment. Experimental apparatus is designed with the water inlet positioned vertically which allows natural gravity pull water down the pipe. Since the gravity has a constant acceleration, the velocity of the water moving downward is also assumed to be constant. However, at the elbow joint the pressure is expected to drop because, naturally, elbow joints cause friction loss resulting to drop in pressure [18]. This is expected to increase the rate of water flow into the reservoir in reference to Bernoulli’s principle which states that an increase in fluid flow only occurs when there is a decrease in pressure or potential energy [19]. The effect of frictional loss to elbow piping is not significant at this stage to affect the accuracy of the result. The success of this study will allow densification of existing systems and make data more available for precise flood prediction, adequate for early warning and disaster preparedness. The paper is organization starts with the materials and method section followed by the result and discussion section and finally the concluding section.

2. Materials and Method

2.1 Selection of microcontroller and sensor

The microcontroller used in this project is an Iteaduino, a predecessor of Arduino uno, which makes serial communication with the USB port of a computer. Arduino gets its power via the USB port or alternatively it can be powered with Lithium ion battery. Iteaduino has both digital and analog pins that enables it communicate with the sensors. The microcontroller powers the sensor with between 3.3 and 5 volts. Furthermore, it comes with its own integrated design environment (IDE) called Arduino IDE that allows programming codes and graphical sketches and their output to be read on serial monitor [17]. The microcontroller works with contact type water level sensor and Saier SEN-HZ21WA flow sensor. The sensor employs a float switch mechanism with a magnet inside the floating blob that detects the opening and closing circuit. For the flow sensor, three wires red, black and yellow, for deignated functions. The redwire connects the 5 volts power of the Arduino pin, the black to the ground, and the yellow connects the digital pin. This connection powers the sensor up and gets it ready for sketching and water flow rate measurement. The flow sensor utilizes a hall effect sensor that detects magnetic pulses installed on a fan blade inside the casings[17]. The flow sensor gets the reading of the flow rate passing through the inlet of the flow sensor using the expression in equation (1) [16].

\[ Q = V \times A \]  \hspace{1cm} (1)

where \( V \) is the volume flow, \( V \) is the velocity and \( A \) is the cross sectional area.
2.2 System design and laboratory setup

Functional code is the heart of the system; programming was done in Arduino IDE to record the flow and water level readings. The Digitalwrite Mode code reads the water height by observing whether the pinMode of the sensor is high or low. An interrupt and digitalread code enables the flow sensor to sense the pinMode of the magnetic pulse designed to count in every 4.5 seconds that read and calculates the flow rate of the water. The code function in such a way that each float switch reads water level at the instant when the pin mode is high. Severity of rising level is indicated using different thresholds for water level and flow rate. The degree of severity is categorised as safe at the lowest flow and water level, caution level when it is averagely filled and dangerous when high water level and flow rate reach maximum.

For the experimental setup, five float switches were installed on a PVC pipe at approximately 34 cm in length and 2.8 cm diameter (Figure 2). The laboratory experiment was conducted using a plastic container, hereafter called the reservoir. The reservoir is about 18 cm high with average diameter of 25 cm and has a water retaining capacity of 5.8 litres. Built in the reservoir is PVC pipe of about 2.8 cm. On the pipe is attached five float switch sensor arranged at 5 cm interval along the vertical direction to record the water level. Another 20 cm PVC pipe of the same diameter was fixed some to the reservoir as water inlet. The inlet supplies water into the reservoir at approximately 2 cm from its base. The flow sensor is placed right on-top of the water inlet beneath a handmade funnel to read the flow rate of the water coming into the reservoir.
To compare the efficiency of the design above, a printed circuit board (PCB) (Figure 3) level sensor was also utilized. PCB is a simple process because the design involves making a drawing of the lines that represent the circuit. But rather than a loop circuit, linear and parallel circuit was designed in this project with adjacent lines decreasing by few centimeters. The steady decrease of the tracing lines is to reduce resistivity between each line and to allow reasonable amount of current to activate the PCB level sensor. The design was followed by printing of the sketch on a copper plate and subsequently a photo-platter was used to print the circuit onto the copper plate. After that, the circuit was flashed under fluorescence for about 180 seconds to imprint it onto the PCB. The imprint was later etched to remove the unused copper plate. Finally, the ink used to cover the copper tracing was removed using acetone solution and all necessary wire connections soldered to their respective components for water level measurement.

2.3 Flow and water level measurement

The sensor has been pre-calibrated to measure between 1litre to 30 litres per minutes; however, for accuracy the PCB water level was calibrated using the microcontroller and a DC multimeter. The DC multimeter measured the voltage difference between the reference PCB and the copper tracing to obtain current for each copper tracing. The amount of input voltage needed to be decided so that sufficient current can be generated to activate the transistors on the signal conditioning circuit (Figure 4). The wire from the tracing copper was connected to the analog pins of the Arduino to get the
calibration of the PCB water sensor ready. The analogRead code reads the voltage value that is detected for each copper tracing. This voltage readings are recorded and used to set boundaries to print out designated water level at the instant the rising water touches the tracing copper.

![Signal conditioning circuit diagram for PCB level sensor](image)

Figure 4: Signal conditioning circuit diagram for PCB level sensor

The system was tested in the laboratory by taking experimental readings. This was done by manually supplying water into the reservoir through the funnel. As the water passes through the flow sensor, the instrument record the flow rate. Similarly, the water level sensors record the rising water level at each sensor position. The result to the output water level was measured was multiply by 10 to assume our readings as metre. Both the flow rate and water level readings are automatically logged into Microsoft Excel using Coolterm software as numerical values. A total number of 80 flow rate reading were taken and their corresponding water levels observed continuously untill the reservior was filled up. Meanwhile, the water was passed through the inlet pipe using a glass baker. Two experiments were conducted with each taking approximately 10 minutes. The flow sensor shows a quick response to the rate of flow of water. The total time delay between consequetive flow rate reading is approximately 1ms. The flow rate increases as water rushes through the water inlet and enters the opening of the flow sensor. The same concept exists from the simulation that was done in the Matlab Simulink which shows motor response when there is a voltage applied across it. The mechanism works with the movement of the fan blade which creates a voltage surge and caused transient reponse when the fan blade rotates. Some basic statistical analyses were done to evaluate the result obtained.

3. Results and Discussion

Sensitivity of each line of the PCB copper tracing representing water levels was evaluated by comparing the voltage output of each line (Figure 5a). The result shows unstable pattern with average voltage of 3.6V. Between water level of 0 m and 1.5 m, voltage reading displays an undulating wave-like graph that rises steadily between each level around 3.59 – 3.65V. The voltage pattern changed between water level 1.5 m and 2 m dropping to approximately 3.15V. This happens because of insufficient voltage received by the signal conditioning circuit at that level and did not pass through a filter that can regulate the voltage readings and assign a specific voltage to each copper tracing [15]. This indicates that float switch is much better for water level sensor than PCB level sensor because it produces consistent output, usually converting the voltage to 0s and 1s (Figure 5b). In addition, it has a simpler circuit construction.
The flow rate and the corresponding water level readings were automatically recorded and stored as a database in excel (Table 1). It can be observed that the system record water level reading in a decreasing order of frequency as the water level rises. The descriptive statistics of the readings is presented in Table 2.
Table 1: experimental recorded data

| Flow rate | Water level | Flow rate | Water level | Flow rate | Water level | Flow rate | Water level |
|-----------|-------------|-----------|-------------|-----------|-------------|-----------|-------------|
| 1         | 0.5         | 5         | 0.5         | 5         | 1           | 4         | 1.5         | 6           | 2           |
| 6         | 0.5         | 5         | 0.5         | 4         | 1           | 6         | 1.5         | 4           | 2           |
| 6         | 0.5         | 6         | 0.5         | 6         | 1           | 4         | 1.5         | 7           | 2           |
| 6         | 0.5         | 6         | 0.5         | 6         | 1           | 5         | 1.5         | 6           | 2           |
| 6         | 0.5         | 6         | 0.5         | 7         | 1           | 7         | 1.5         | 6           | 2           |
| 6         | 0.5         | 5         | 0.5         | 7         | 1           | 7         | 1.5         | 7           | 2           |
| 6         | 0.5         | 6         | 0.5         | 3         | 1           | 7         | 1.5         | 3           | 2           |
| 7         | 0.5         | 7         | 0.5         | 4         | 1           | 7         | 1.5         | 5           | 2           |
| 7         | 0.5         | 7         | 0.5         | 5         | 1           | 7         | 1.5         | 6           | 2           |
| 7         | 0.5         | 3         | 0.5         | 4         | 1           | 7         | 1.5         | 3           | 2           |
| 7         | 0.5         | 4         | 0.5         | 5         | 1           | 7         | 1.5         | 5           | 2           |
| 6         | 0.5         | 4         | 0.5         | 7         | 1           | 3         | 1.5         | 4           | 2           |
| 6         | 0.5         | 3         | 0.5         | 6         | 1           | 6         | 1.5         |              |             |
| 1         | 0.5         | 4         | 0.5         | 7         | 1           | 6         | 1.5         |              |             |
| 1         | 0.5         | 5         | 0.5         | 7         | 1           | 6         | 1.5         |              |             |
| 6         | 0.5         | 6         | 1           | 6         | 1.5         | 6         | 2           |              |             |
| 5         | 0.5         | 4         | 1           | 5         | 1.5         | 5         | 2           |              |             |

Table 2: Quantitative Analysis of the Flow Rate and Water Level

| Variable    | Obsn | Min | Max | Mean  | Std. dev |
|-------------|------|-----|-----|-------|----------|
| Flow Rate   | 80   | 1   | 7   | 5.400 | 1.498    |
| Water level | 80   | 0.5 | 2   | 1.081 | 0.571    |

XLSTAT, an add on to Microsoft Excel, was used to produce the graph of flow rate against water level and flow rate and water level against time was plotted from the readings (Figure 6). The water level steadily increases with time while the flow rate fluctuates similar to the study of [10]. The flow rate produce unstable wave because the water was manually discharged through the inlet. Although this does not affect the level reading, but it certainly makes the consistency difficult to evaluate since water discharge, volume and rate of discharge account for different stages of flooding [10].
Linear regression and correlation of the flow rate and water level were examined (Table 3). The Pearson correlation matrix produced a value of 0.073 which shows relativity of independent to each other; however, the closer the value to 1 the stronger relationship. Similarly, the coefficient of determination of this test yields $R^2$ of 0.005 indicative of how closely the points are fitted. The inconsistency arises from the manual water supply during the experiment and insufficient variability of the experimentation process.

| Correlation Matrix | Co-efficiency of Determination($R^2$) |
|--------------------|--------------------------------------|
| Variables          | Water level | Flow Rate | Water level | Flow Rate |
| Water level        | 1           | 0.073     | 1           | 0.005     |
| Flow Rate          | 0.073       | 1         | 0.005       | 1         |

4. Conclusion

This study presents the initial stage of the design of a miniaturized prototype of a water level sensor aimed at providing an integrative early warning system for flood emergency response. The system, under laboratory experiment, produces a promising system that can efficiently measure water flow rate and water level rise. However, several other factors are still required to ascertain its capability in real-life situation. For instance, the size of the experimental setup and manual supply of water affects the accuracy and consistency of the result obtained. Upon completion of this study, it is expected that causality arising from flood disaster will be reduced to minimum in Malaysia and elsewhere because of the density of installation and the volume of information arising therefrom for precise evaluation and analysis. Future work will use controlled water input mechanism by varying the pressure of the inlet to assess the consistency. Besides, the system will be tested under different conditions, including real-life deployment in an experimental natural flowing river. For outdoor usage, the system will be mounted on fixed poles and the sensors firmly strapped to them to avoid being washed away by water current.
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