Sensor and internet of things based integrated inundation mitigation for smart city

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ABSTRACT

Flooding is a natural phenomenon that often occurs in tropical countries. Drainage design is one of the efforts to prevent floods, however, when the rainfall is high, there are still several inundation points that occur. This requires comprehensive handling to reduce the impact of these inundations, to get an adaptive solution, the use of internet of things based (IoT) tools is one of the alternatives proposed. This study proposes an IoT-based flood inundation monitoring system, which includes a water level reader, a web-based inundation monitoring system, a flood inundation area and depth reporting system as evaluation materials for the government city. The sensor module that we propose is a series of sensors in a hollow cylinder design to reduce water ripples. The server application is displayed in the form of an interactive area mapping which is divided into 4 layers for 4 different analyzes so that central officers can quickly coordinate with field officers to carry out mitigation actions in the affected area. The module requires a low cost and easy installation process compared to a liquid sensor, besides that the display in the form of a web makes it easier for officers to access monitoring applications anywhere compared to geographic information system based (GIS) applications. This research has been carried out and tested in one of the major cities in Indonesia.

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1. INTRODUCTION

Rainfall in tropical countries tends to be higher compared to non-tropical countries [1]. High rainfall results in fast inundation of water and if not immediately addressed can cause flooding. There are several causes of inundation when heavy rainfalls, including a city drainage system that is unable to drain large amounts of water and a short amount of time or problems or obstructions in the drainage system so that it is unable to drain inundation [2]. In general, the main cause of the flooding is the destruction and escalation of human behavior in changing the balance of natural functions [3]. Changes have occurred in protected natural areas spatial planning on a massive scale so that the carrying capacity of nature in maintaining balance decreases dramatically. This is supported by the growth of settlements and industries that change the function of the environment, even the retention areas of flooding in nature have also been exploited for their benefits

[4]. This situation can significantly affect water absorption drastically. Sometimes the drainage system of settlements is inadequate so that in certain rainfall, it causes inundations everywhere [5]. The exploitation of nature worsens the environmental water system because the capacity of river catchment and drainage decreases and water overflows occur. On the other hand, it turns out that in certain regions, in general, there is no effective policy implementation to control the exploitation of nature and changes in spatial functions in the upstream river area [6]. These activities and changes further increase the flow of water that enters directly and quickly to the river body, and ultimately because the capacity of the river and drainage has decreased, the river water overflows into residential areas, rice fields, and industrial areas [7].

To obtain an adaptive solution, inundation data collection that occurs in the field is important and needs to be done. The inundation data collection process based on the manual recording cannot accurately record depth. This is also difficult to do, due to limited access and survey personnel. We propose integrated and real-time flood monitoring tools sensor with internet of things (IoT) based, so that field staff can move quickly to flood-prone flooding points. Ultrasonic sensors have the disadvantage of not being able to accurately reflect distances in rippling water, so to improve accuracy, we propose a tube design to reduce water ripples which make reading difficult. In addition, the system we propose requires lower costs because it uses ultrasonic sensors that are cheaper than liquid sensors. The sensor module that we propose has been tested and implemented in Indonesia with low cost and easy installation.

The concept of a smart city is a city that utilizes information technology and artificial intelligence (AI) in managing and building cities [8]. Automation-based governance aims to improve operational efficiency, share information with the public, and improve the quality of government services and the welfare of citizens of the city [9]. The supporting components of smart cities are policy, technology, IoT, and the city community that has a role in realizing the smart cities [10]. So that the creation of the goal of a smart city is to optimize the functioning of the city and encourage economic growth while improving the quality of life of its citizens using smart technology and data analysis [11]. Trends in the use of automation, machine learning and the IoT are driving the realization of smart city [12], [13].

Automation in both the industry and various hardware sectors has increased since using IoT technology [14]. IoT itself is a system of interconnected computing devices, mechanical and digital machines, objects, or people equipped with unique identifiers and the ability to transfer data through networks without requiring interaction between humans or humans and computers [15], [16]. The role of the IoT in realizing the concept of smart cities is quite important, the IoT device is capable of sending information and following up through the network with the minimum amount of human power so that it can perform various functions automatically [17]. With IoT, hardware data that was previously only retrieved manually can now be processed simultaneously by sending the data to the server using internet facilities [18], [19].

Sustainability is the hope of implementing a smart city [20], [21]. Smart technology will help cities maintain growth and improve efficiency for prosperity [22]. Sensors equipped with IoT devices can read ambient conditions and report them in an integrated way. Information sent on an ongoing basis can be used as big data analytics that produces analysis and predictions [23], [24]. Big data analytics are used to help make decisions by the government. Some parts of the smart city apply sensors and IoT to facilitate monitoring and city governance. For instance, to adjust the quality of power in a city, the sensor measures the power and uses global system for mobile communications (GSM) to inform the customers [25]. Piezoelectric sensors can be used to measure flow rates in pipes and pipe bends by planting them integrated into pipes [26]. Integrated sensors can also be applied to monitor the temperature and acidity of water in real-time [27]. Gas pressure and temperature can also be measured simultaneously through an integrated sensor based on in-fiber micro-cavity and fiber-tip [28].

Flood mitigation is one of the important smart city application concepts in tropical countries [29]. High rainfall if not balanced by an effective drainage system will cause high inundation to flood. Therefore, we need a monitoring process that can monitor the movement of water levels in various areas of the city remotely. Sensors installed in various corners of the city are equipped with IoT modules so that they can send their information to the data center. The benefits of this monitoring sensor are for flood mitigation management and areas far from the city center are easier to monitor, as well as reducing field workers who have previously checked manually to the location.

The application that we are proposing is a set of main modules consisting of ultrasonic sensors for reading water levels equipped with several other supporting sensors. We use ultrasonic sensors for reading inundation heights because of their low cost and easy installation. We propose a module casing design to optimize the performance of the ultrasonic sensor, namely with a hollow cylinder design at the bottom for the flow of water. The second module is the IoT module which consists of NodeMCU and GSM which functions as the internet to transmit data. The third module is the application center in the form of the final status of the water level in the form of maps and big data analytic functions. In addition, our interactive application display uses the web with a map library, making it easier to access anywhere compared to geographic information system (GIS).

2. METHOD

This study consists of four interrelated stages, the initial stage is to build a module to measure the height of a pool of water, then the second stage is the construction of the IoT module, this module serves to send sensor readings to the database server. The third stage is the database module where at this stage we are building a website application to present data that has been stored in the database so that it is easier to read and monitor by the authorities in this regard. The last stage is the processing of big data as data sets that are processed into AI for analysis and prediction purposes.

2.1. Inundation monitoring sensor

The water height measuring module consists of one component circuit with battery power and with the main sensor that is ultrasonic. The way the sensor works in reading water levels is by emitting a signal by an ultrasonic signal transmitter with a certain frequency and with a certain time duration. The signal has a frequency above 20 kHz. To measure the distance of objects (proximity sensor), the commonly used frequency is 40 kHz. The emitted signal will propagate as a sound wave with a speed of around 340 m/s. When mashing an object, the signal will be reflected by the object. After the reflected wave reaches the receiver, the signal will be processed to calculate the distance of the object. Object distances are calculated based on (1).

$$S = \left(\frac{340.t}{2}\right) \tag{1}$$

Where *S* is the distance between the ultrasonic sensor and the reflected field. 340 is a constant for calibration from ultrasonic waves to distance, then t is the difference between the time the beam is transmitted by the transmitter and the time the wave is reflected back and received by the receiver. In this study, we used an ultrasonic sensor with a receiver and transmitter module that has become one sensor. The ultrasonic sensor circuit consists of Piezoelectric, Transmitter, and Receiver.

The transmitter functions as a wave transmitter device with a magnitude of 40,000 Hz generated by the oscillator. To produce a 40 kHz frequency, an oscillator circuit must be made and the output of the oscillator proceeds to the signal amplifier. The frequency is determined by the RLC/crystal component depending on the oscillator design used. The signal amplifier will provide an electrical signal that is fed to the piezoelectric and a mechanical reaction occurs so that it vibrates and emits waves that correspond to the frequency at the oscillator. The transmitter circuit on the ultrasonic sensor can be observed in Figure 1.

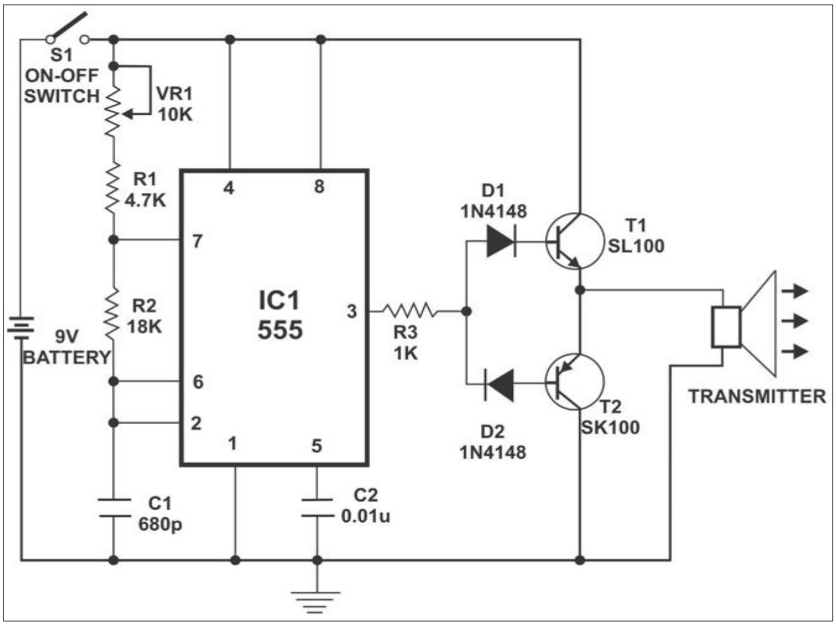

Figure 1. Ultrasonic transmitter circuit

The next component of the ultrasonic sensor is the piezoelectric. Piezoelectric is part of an ultrasonic sensor that functions to convert electrical energy into mechanical energy. A piezoelectric material is a material that produces a magnetic field so that it can produce strain or mechanical stress. If the circuit operates in the pulse mode of the same piezoelectric element, then the ultrasonic sensor which has an electric piezo can be used as a transducer and receiver. However, the frequency generated can depend on the oscillator adjusted to the frequency of each transducer.

The receiver consists of an ultrasonic transducer using piezoelectric material, which functions as a receiver of reflected waves originating from the transmitter which is worn on the surface of an object or direct wave line of sight (LOS) of the transmitter. Because the piezoelectric material has a reversible reaction, the ceramic element will generate an electrical voltage when the wave comes with a resonant frequency and will vibrate the piezoelectric material. The receiver circuit on the ultrasonic sensor can be observed in Figure 2.

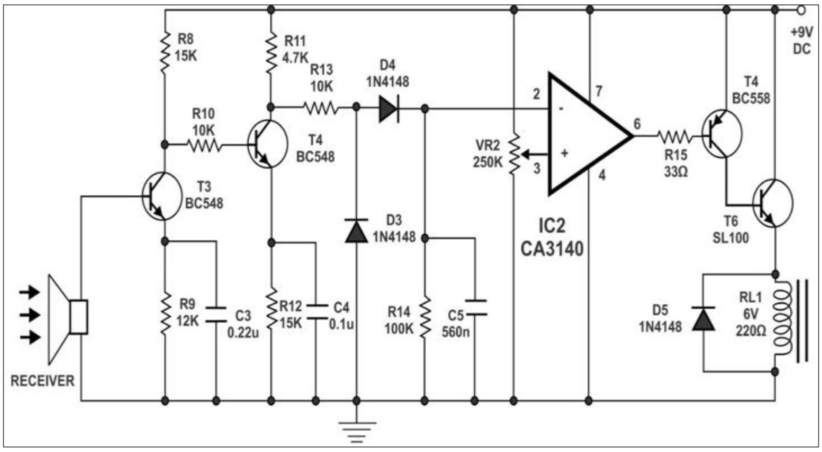

Figure 2. Ultrasonic receiver sensor circuit

Ultrasonic sensors are used to measure the distance of objects from 2 cm until 4 m with an accuracy of 3 mm. This tool has 4 pins, voltage common collector (VCC), ground (GND), trigger, and echo pins. VCC pin for positive electricity and GND for the ground. Trigger pins to trigger signals from the sensor and Echo pins to capture reflected signals from objects. When we provide a positive voltage on the Trigger pin for 10 uS, the sensor will send an 8-step ultrasonic signal with a frequency of 40 kHz. Next, the signal will be received on the echo pin. To measure the distance of objects that reflect the signal, the time difference when sending and receiving signals is used to determine the distance of the object.

This water level reading module consists of an ultrasonic sensor and an electronic chain. For the power needed to activate the module using a battery. In areas far from the center of monitoring, the power to activate the module uses an adapter whose electricity is directly connected to power on the lamp, because the module is attached to or supported by a public lighting lamp post. The module is wrapped in a box specifically designed for the tool and made of aluminum. To avoid a short circuit on the sensor if exposed to rain, the top of the module box will be shaded again with a layer that is wider than the module box so that rainwater does not go directly down to the module.

2.2. IoT module

The procedure to send data from all modules to the center, the module is added Arduino NodeMCU series or GSM module if Wi-Fi is not available in the area where the module is installed. Data received by each module will automatically be stored in the database server. Then the data can be displayed directly on the web page so that it is easily monitored both from the center or in various place.

Our proposed IoT module are integration between sensor, internet, and application center. In Figure 3 it can be observed that the sensor module can be equipped with solar panels or can be directly connected to general electrical lighting. We add a relay as a control in the sensor reading. The current sensor and voltage sensor function to measure the stability of the power flowing to the sensor. The results of the reading of the current and voltage sensors are also sent to the data center as a basis for analyzing the performance of the ultrasonic sensor.

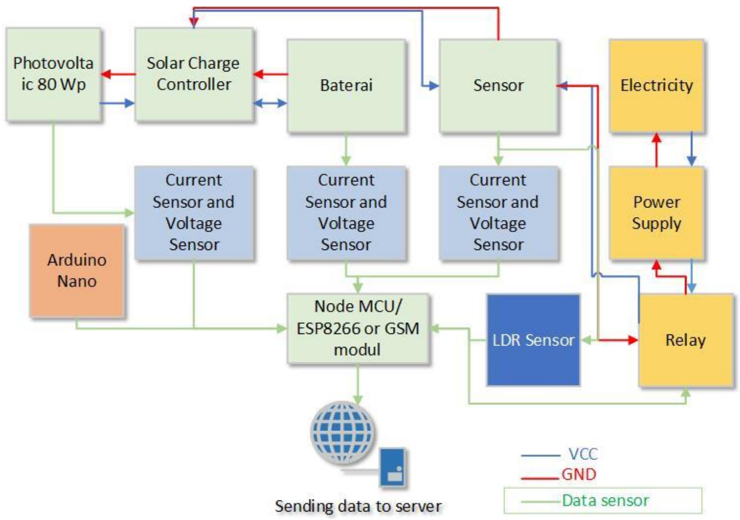

Figure 3. Sensor module architecture

2.3. Mapping application development

Data received by each module will automatically be stored in the central application. Then the data can be displayed directly on the web page so that it is easily monitored both from the center or in the field. To facilitate the monitoring process, we display all sensor points in the form of nodes on the map. Basically, the nodes on the map are blue, but for sensors that read the water level exceeds the normal specified standard, the nodes on the sensor will turn red. So that the center officer can immediately be informing the field officer if there has been a high inundation in the area.

On our proposed application, to find out the status of inundation heights, click on the node on the map. Meanwhile, to find out the history of inundation height changes can go to the table page that presents all sensor reporting records that are sorted from the results of the latest altitude reporting. The information displayed in the table is sensor point, sensor address or position, water level, date, and time. In the date variable, we use the time stamps data type, which is a data type that can provide hour until second information, this is because in one day 96 status heights can be recorded. We set the sensor reading delay and send data to the central server every 15 minutes or in one day there are 96 data records. Therefore, hours and seconds are also needed to see the history of changes in water level that can be processed in the future as a prediction and flood management.

3. RESULT AND DISCUSSION

The module trials that we built were conducted in areas in the city of Surabaya, Indonesia which is prone to standing water during the rainy season. From a number of tests, we experienced problems with the module implementation. We tested a number of casing designs for the sensor module in order to read the water level. Our initial design, the casing only enclosed the sensor but there was a short circuit due to the falling rain seeping into the ultrasonic sensor transmitter. Then our second design is to add a top cover that is wider than the module casing, concave upward to the module so that water cannot leak into the module. But another obstacle we encountered was that ultrasonic sensors cannot read accurately on moving water so the reported data is not accurate. The cylindrical design which has lighting inside is the most appropriate design in our case study, the design can be observed in Figure 4.

The final design that we propose is a sensor module made in the form of a cylinder that extends with two holes at the bottom for water flow. With a cylindrical design, water will slowly enter the tube thereby reducing water turmoil and the ultrasonic sensor can read with precision. To minimize errors caused by rainwater that continues to move, we add a float at the bottom of the cylinder tube so that the movement of altitude can be read more stable.

Table 1 explains the test results of the sensor module. Each row is the average value of reporting data in one month that is a number of + -280 originating from 96 (data reported in one day) multiplied by 30/31 days. The sensor report is the average height value reported and real inundation is the average height value of the actual inundation. RE is a relative error value calculated based on the data read by the sensor minus the actual inundation height data then divided by the actual value. The relative error calculation method can be observed in (2).

$$RE = \frac{measured\ value - real\ depth}{real\ depth} \tag{2}$$

Relative error assessment to measure how efficient the casing design that we propose to reduce water ripples and improve the accuracy of ultrasonic reflections. The analysis result of our proposed system can be observed in Table 1. The negative value on the relative error indicates that the sensor data reporting tends to be lower than the real data. SD is the standard deviation value of all reported sensor data; we use the standard deviation as an analysis of the movement of the inundation height in the observed area.

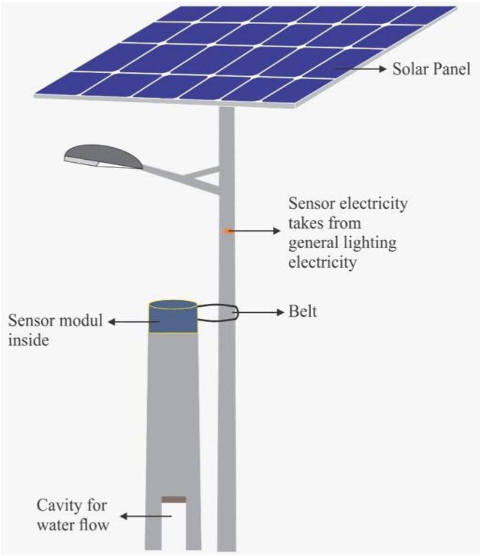

Figure 4. Sensor module design with hollow cylinder model

Table 1. Analyze the difference between sensor readings and the actual inundation height (outside the tube)

Area	Sensor Report (mm)	Real Data (mm)	Relative Error	Standard Deviation	Server receive (minutes)	Time setting (minutes)	Delay (minutes)
Point 1	53.2118	53.2001	0.0002	0.0721	15.07	15.00	+0.07
Point 2	46.3108	46.3108	0.0000	0.1680	15.00	15.00	0.00
Point 3	76.4598	76.4598	0.0000	2.5025	15.30	15.00	+0.30
Point 4	13.4114	13.4114	0.0000	0.1377	15.10	15.00	+0.10
Point 5	16.1314	16.1314	0.0000	0.0409	15.00	15.00	0.00
Point 6	15.5671	15.5671	0.0000	0.1733	15.04	15.00	+0.04
Point 7	15.0535	15.0535	0.0000	0.0341	15.00	15.00	0.00
Point 8	37.2274	37.2274	0.0000	2.3401	15.10	15.00	+0.10
Point 9	47.5176	47.5242	-0.0001	2.0092	15.50	15.00	**+0.50**
Point 10	31.2325	31.1172	0.0037	2.5834	15.70	15.00	**+0.70**
Point 11	1.6814	1.6814	0.0000	0.1444	15.28	15.00	+0.28

The performance of the sensor module is also measured by the timeliness of receiving data. The process of re-reading the water level is set every 15 minutes, and the tolerance of the data received by our server limits a maximum of 30 seconds. The delay column in Table 1 is the average time data received by the server that exceeds 15 minutes. In that column, it can be observed that of the 11 sensors tested, only 2 sensors display an average delay in receiving data beyond the tolerance limit. This can be caused by the sensor area that does not have an internet signal properly, resulting in data transmission delays. The location of every sensor can be easily detected by the mapping page which can be seen in Figure 5.

We monitor the elevation of water throughout the city on the map to find out the area affected and take immediate action for the area and the surrounding area as can be observed in Figure 5. We use the Java Script Leaflet library to create an interactive map view. Library Leaflet has several functions that can display maps with several layers on hypertext preprocessor (PHP) pages. We use the layer functions on the Leaflet to display monitoring in several classifications, first of which is information on the entire area, then areas that are prone to inundation, and possible areas around which are affected by the inundation. Layers can help us make the right decision support systems.

Figure 5. Real time inundation monitoring display on an interactive map in Surabaya City, Indonesia

4. CONCLUSION

Inundation mitigation as a flood prevention measure is an essential component of implementing intelligent cities in tropical countries. During the rainy season, tropical countries have high rainfall, if it is not balanced with a good drainage system, will cause flooding. In this study, we propose an integrated and IoT-based inundation monitoring sensor. The system we have built includes sensor modules, sensor casing designs, IoT modules, and displays in the application server. The sensor module we are proposing uses an ultrasonic sensor which is easy to apply and costs less than a liquid sensor. To optimize the sensor reading performance we designed the sensor module wrapper in the form of a hollow bottom cylinder so that it can withstand water turmoil. We present the results displayed in the form of a map with 4 layers so that it is easier to analyze and to make it easier for users to access anywhere compared to GIS applications.

In the future, the development of our proposed integrated system for smart cities is a mobile application for city residents so that every confirmed person can participate in reporting the status of standing water in their place of residence. Previous research used lidar sensors and liquid sensors to detect inundation heights. However, from our test results, the ultrasonic-based sensor technology that we propose has a higher level of stability and lower construction costs compared with lidar and liquid sensors. So, we can propose that our technology is more effective and efficient than some of the previous sensor applications.

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