A novel prototype of flood early warning system using analytical hierarchy process (AHP) based internet of things (IoT)

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A NOVEL PROTOTYPE OF FLOOD EARLY WARNING SYSTEM USING ANALYTICAL HIERARCHY PROCESS (AHP) BASED INTERNET OF THINGS (IOT)

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Abstract. *Flood disaster becomes an important issue that can cause harm, even the threats to human life the prone. The danger posed depends on the ability to prevent or anticipate the precipitation of the floods so that community readiness is very important in facing the threat of flood disaster. In order to know the level of vulnerabilities or potential flood disaster in the area of the prone flood, we develop a flood early warning system using Analytical Hierarchy Process (AHP). One of the approaches to combining the condition of rainfall, water level and flow rate in AHP analysis is to produce a prediction of the flood disaster. The use of the Internet of Things (IoT) technology is combined with mobile applications, which provide the information about warning flood for the public in real time.*

Keywords: Early warning system, Flood, Analytical hierarchy process, Internet of Things

1. **Introduction.** Flood disaster often occurs particularly during the wet season due to overflowing rivers and excessive rains. The chance of a flood event is rare in a low intensity of rainfall. This is because the rain in relatively small quantities of water can still be absorbed into the soil and accommodated in drain, creeks, and rivers [1]. The high-intensity rainfall can cause the volume and velocity of the water flow increases. If the volume and velocity of the water flow are not proportional to the drain, creeks, and river, it may cause the volume of excess water will flow on the surface and if it lasts longer it will potentially cause flooding.

Many impacts are caused by floods, not just casualties. The flood can also cause material losses such as the destruction of human settlements, the destruction of facilities and infrastructure (bridges, roads, etc.), destruction and loss of property, the difficulty of getting clean water, and the incidence of various diseases (due to the dirty environment during and after the flood) [2].

Flood disaster can occur at any time. If it happens during the day, the impact is caused especially the loss of life that can be minimized because people can know and realize the presence of the disaster, but if it happens at night when the population is sleeping, it can claim more lives and result in greater losses.

Scientifically flood can be predicted. Therefore, people can reduce the risk or impact of the flood if the community is better prepared in the face of the coming of the flood. One of the ways is to analyze the speed of water flow, rainfall, and water level data to find out as much as the big potential for flooding.

In the era of globalization, information and communication technology are growing rapidly with a variety of discovery of a superior product in the field of information and

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communication, such as laptops, net books, smart phones, and tablets. This has an impact on the ease, which people get to deliver and to get information. The efforts are able to be made to perform detection of the early flood that one of them is by combining technology in the field of instrumentation with the development of information and communication technology.

In this study, we aim to analyze and forecast the flood hazards using analytical hierarchy process to inform a danger before disaster strikes. The Internet of Things (IoT) is used to enable remote monitoring in many areas prone to flood, including the condition of the water level, rainfall, and water flow rate. Furthermore, in this proposed method we utilize data retrieval from it to make decisions in the AHP process. The assessment of the risk level in the area consists of flood alert, flood warning, and severe flood warning. We also build the mobile application to help people monitor the current condition and anticipate before the flood disaster happens.

2. **Literature Review.** The objective primary of a flood early warning system is to reduce the impact of flooding by giving alerts people in preparedness before the flood event has potential becoming a disaster. Flood early warning system studies are classified based on three different approaches: (1) type of measurement of an environmental parameter, (2) communication or dissemination of alerts and warnings, and (3) methods for analyzing and predicting flood disaster.

M. A. Wister at al. [3] developed a water level monitoring of the river based on the IoT. This system utilizes social networking, Facebook to post data from the sensor about the water level in the river. Another study was conducted by A. N. Yumang et al. [4] designing a real-time flood water level monitoring system. The monitoring system of water level is done by integrating sensor by using Arduino Uno and GSM shield. To increase the people in the community preparation in facing flood disaster, LED lights and SMS are used as early warning notification to flood. The weakness of this system is the use of SMS media to provide information related to the results of flood detection. This information may only send at pre-registered numbers so that it is not flexible and very limited in use. On the other hand, [5] has developed a flood monitoring based on IoT, combined with an Artificial Neural Network (ANN) for flood disaster prediction using environmental parameters like humidity, temperature, pressure, rainfall, and river water level.

I. R. Widiasari et al. [6] proposed deep learning Multilayer Perceptron (MLP) methods to predict flood events on the basis of environmental data, i.e., rainfall time series data, and water levels in a weir. In this study, they used a wireless sensor network to collect the data sensed from a sensor in the field. This method was compared with the multiple regressions linear. It is an indication that the proposed method can give better results in predicted water elevation level on the downstream canal. Another flood prediction system proposed by S. S. Mane and M. K. Mokashi used a Naïve Bayes algorithm based on data set from the direct measurement [7]. This data set includes data on water level, temperature, humidity, and vibration.

The authors of [8-10] build flood risk mapping using Analytical Hierarchy Process (AHP) with natural breaks classification. This classification is divided into three risk levels, that is, low, medium, and high. Related with those three preceding studies the data are obtained from the National Disaster Management Agency.

Based on previous research, this study proposes a new approach to flood disaster prediction model using AHP with criteria factors including water level, rainfall, and water flow rate obtained from the direct measurement. Furthermore, our model analyzes these criteria deriving status of possible flood level. The purpose is to provide the flood warning service and provide important information to monitor the current situation of an area at risk of flooding.

3. Research Methods. The flood early warning system is an approach to demonstrating the potency that may arise from an event of the flood disaster. This approach is used to show the relationship between water level, rainfall and water flow rate to measure the level of flood risk in the region. The potency of negative impacts is calculated based on the degree of flood vulnerability. The criteria determine the level of flood danger based on water level, rainfall and, water flow rate. This criterion affects the level of potential floods used in this study.

According to the requirements of the sensor system, it can be divided into the following modules: sensors, microcontroller and communication device. The sensor section consists of three main components: water level, rainfall, and water flow rate sensor. The basic block diagram of the overall system is shown in Figure 1.

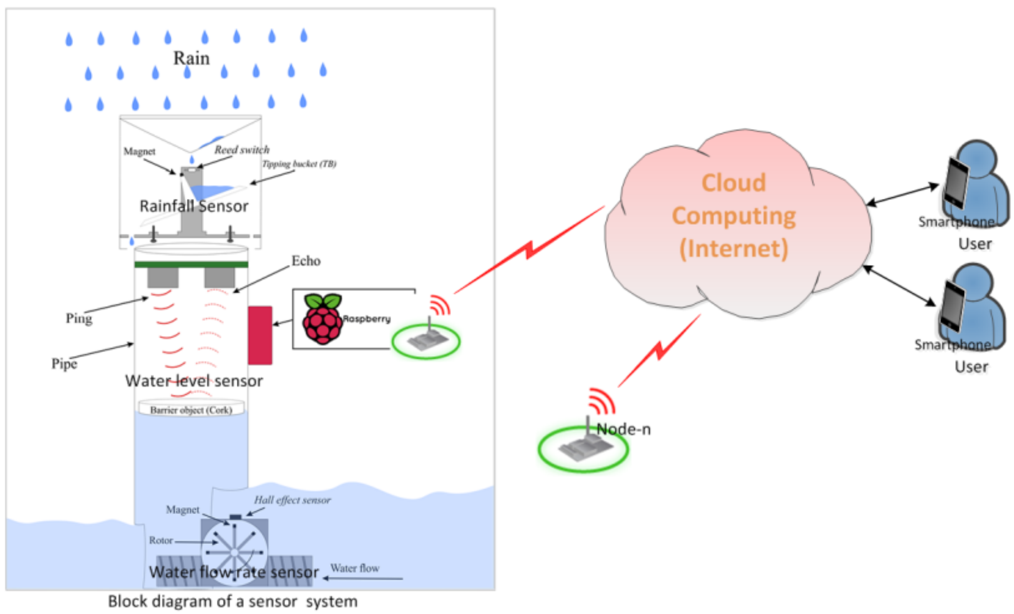

FIGURE 1. Flood early warning system

The water level sensor uses an ultrasonic sensor to determine the level of water. The operation of the sensor is based on the measured propagation time of the ultrasonic signal. At the height of the water increasing, then automatically the obstacle object made of cork on the sensor will also lift up. When the sensor emits an ultrasonic wave to the surface of a barrier object (cork), it will reflect back to the receiver of the sensor, and then the sensor calculates the difference between the sending time of the waveform and the reflected wave time. The formula to calculate the water level is as follows:

$$\text{Water level (m)} = h - t * p \tag{1}$$

where h is high sensor from ground level, t is the time of reflecting the wave, and p is pulse detection.

The rainfall sensor is calculated by using a tipping bucket rain gauge. This sensor utilizes a reed switch that produces output in the form of the digital pulse. In the beginning, the tipping bucket position is unbalanced. In this state, there is no barrier to the output condition of off pulse, while the barrier in the middle of this state is assumed to be on stage. When the bucket starts to hold the water and the bucket tripped, the barrier passes through the middle of the reed switch resulting in a pulse. The microcontroller will count the number of readable pulses, and then put into the equation:

$$\text{Rainfall (mm)} = \frac{\text{JT} \times \text{V}}{\text{L}} \tag{2}$$

where JT is the number of tipping, V is the volume of tipping (ml), and L is the wide mouth of a funnel (cm^2).

The working principle of this velocity sensor of water flow is to measure the flow of water by counting the rotation of a rotor in a sensor that automatically rotates when there is a stream of water passing through it. In the rotor, it is pinned magnet and when rotating it will produce a magnetic field based on the principle of Hall Effect. When water flows through the rotor, it occurs in a continuous change of magnetic field which causes a pulse. This pulse will be calculated to generate the value of the velocity of water flow which passes the sensor. The formula for calculating the velocity of water flow is as follows:

$$\text{Velocity of water flow (liter/min)} = (n * 60 * 2.25/1000) \tag{3}$$

where n is the number of pulses.

In the microcontroller, a Raspberry Pi microcomputer serves as a data processor. A Raspberry Pi device will take the data measurement results periodically from the three sensor modules, i.e., water level, rainfall, and water flow rate. The data is processed through the process of calculating the weighting results of each reading of data from the sensor against the criteria value that has been calculated from the AHP method so it produces an early warning status decision of potential flood hazard.

The procedure for implementing decision-making process related to early warning of potential flood disaster by using Analytical Hierarchy Process (AHP) consists of the following steps.

a. Arrange hierarchical structure

Floods disaster risk level calculation uses AHP to compute AHP hierarchy factors including water level, rainfall, and water flow rate value. The tree of flood disaster risk hierarchy can be seen in Figure 2. The first level is the goal to be achieved. Hierarchy II is the criteria used in this study and hierarchy III is types of flood early warning status that are used as alternatives.

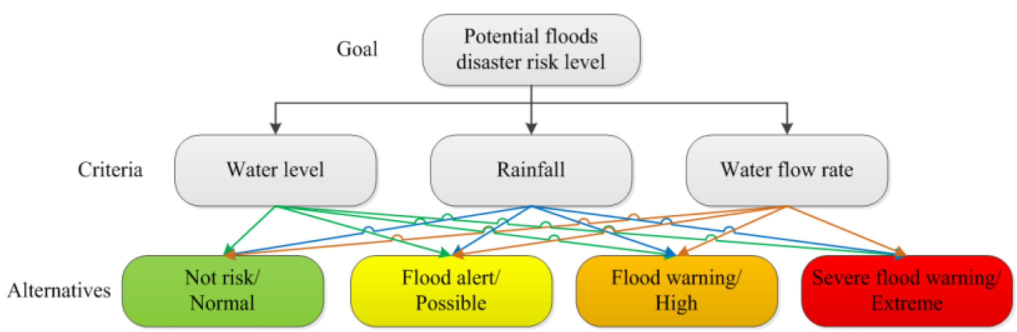

Figure 2. AHP hierarchy

b. Determine the relative importance of attributes

The scale of relative importance used in AHP refers to [11]. Table 1 shows the description of weighting value to compare each criterion.

c. Value determination of priority weight

The mathematical process to normalize and calculate the overall weight in terms of each attribute is developed by using Expert Choice as a tool. The result of weights for each criterion and alternative can be seen in Figure 3.

TABLE 1. The result of the pairwise comparison on criteria

	Water level	Rainfall	Water flow rate
Water level	1/1	5/1	5/1
Rainfall	1/5	1/1	1/1
Water flow rate	1/5	1/1	1/1

	Normal	Possible	High	Extreme
Normal	1/1	1/2	1/3	1/4
Possible	2/1	1/1	1/2	1/3
High	3/1	2/1	1/1	1/2
Extreme	4/1	3/1	2/1	1/1

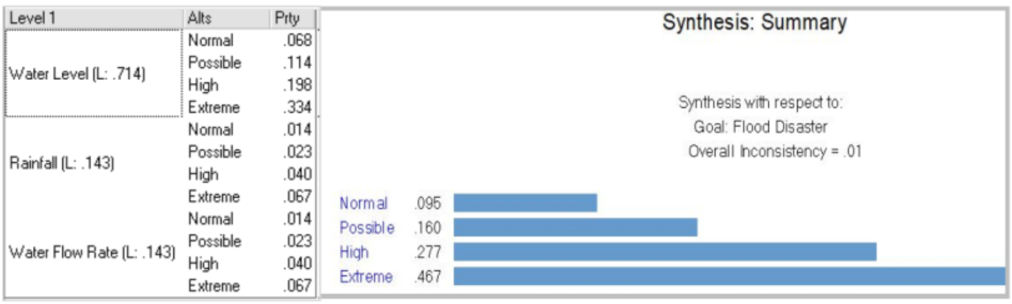

FIGURE 3. The overall weight of each alternative calculation result

d. The weight determination of data readings from the sensor

Criteria calculation

The classification is designed to support decision making in AHP by determining the weight of each criterion. To do this, the classification results for each criterion are converted to a weighted score.

The water level and rainfall

The table below shows the water level and the rainfall data value with each interval classification.

TABLE 2. The value of water level classification

Weight	Water level	Rainfall	Classification
0	0	0	Nothing
1	$0 < x \leq 0.3$ m	< 1.2 mm/hour	Very low
2	0.3-1 m	1.2-3 mm/hour	Low
3	1-2 m	3-15 mm/hour	Medium
4	2-3 m	15-60 mm/hour	High
5	> 3 m	> 60 mm/hour	Extremely high

The water flow rate

Table 3 shows the water flow rate data value with each classification interval.

e. Decision making

With the weights shown in Figure 3, all criteria to determine the level of flood danger are evaluated, which corresponds to the alternatives in the hierarchy of the developed AHP algorithm. The crossing of all status decision of potential flood hazard using all criteria determines the final priority in relation to the desired goal. The mechanism calculates

Table 3. The classification of water flow rate

Weight	Water flow rate	Classification
0	0	Nothing
1	< 120 liter/hour	Low
2	120-600 liter/hour	Medium
3	> 600 liter/hour	High

the final results by summing the multiplication of each criterion's weight by its weight of the sensor reading. This is done by the formula:

$$\text{The final results} = \sum(0.71 * \text{wl} + 0.14 * \text{wr} + 0.14 * \text{wf}) \quad (4)$$

where wl is the weight of the water level sensor reading, wr is the weight of the rainfall sensor reading, and wf is the weight of water flow rate sensor reading.

The value of the final result is compared with threshold values which are already set on the weight of each alternative calculation result on AHP. After comparing these values, then it is divided into four levels, normal, possible, high and extreme to determine the flood hazard warning status. Table 4 shows threshold values set for the status of flood hazard.

Table 4. Threshold value set of flood hazard

Level	**Status**	**Range**
Normal	Not risk	$x \leq 0.95$
Possible	Flood alert	$0.95 \leq x \leq 1.6$
High	Flood warning	$1.6 \leq x \leq 2.77$
Extreme	Severe flood warning	$2.77 \leq x \leq 4.67$

Table 5. Early warning status of potential flood

No	**The weight**			**Final result**	**The flood hazard warning status**
	Water level	**Rainfall**	**Water flow rate**		
1	0	2	0	0.28	Not risk
2	1	3	2	1.42	Flood alert
3	1	3	1	1.28	Flood alert
4	2	3	0	1.85	Flood warning
5	2	4	1	2.14	Flood warning
6	3	4	1	2.85	Severe flood warning

In order to exemplify this process, Table 5 shows the process for an alternative early warning status decision of potential flood hazard.

After the identification of the early warning status of flood hazard done completely, all of the data, i.e., water level, rainfall, water flow rate, and the flood hazard warning status are processed by Raspberry Pi delivered in the cloud via web service by using WIFI or GSM modem depending on the available connection in the area. Raspberry Pi has been equipped with wireless module IEEE 802.11n technology and operated with an additional GSM module. This implementation offers an alternative in transmitting data over the Internet.

The mobile application has been developed to display stored data in cloud computing based on Android. In the application view, there are three main menus, i.e., water level, rainfall and water flow rate as shown in Figure 4. The displayed data are the result of

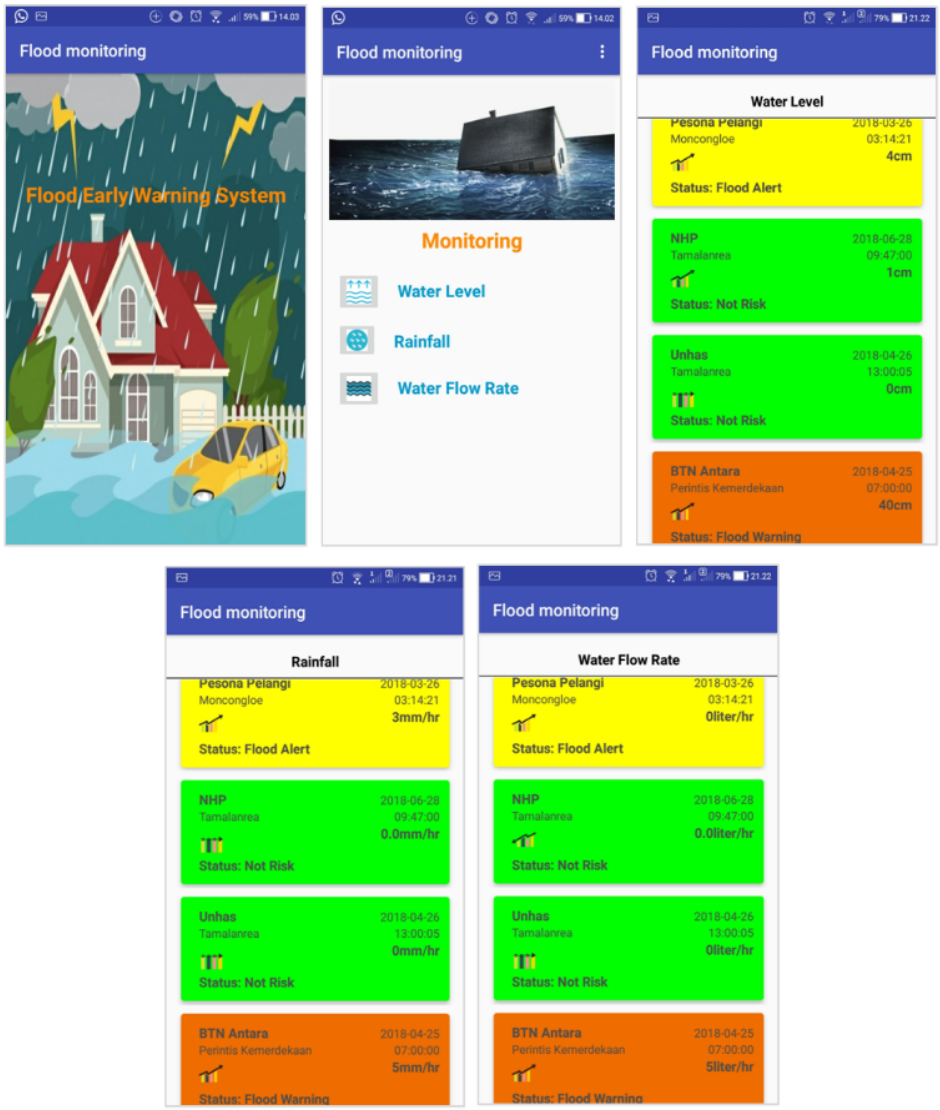

FIGURE 4. Screenshots of flood early warning application built using Android

sensor measurement and the status of early warning of the flood disaster in real time. This application can respond according to the category of early warning of flood disaster threats, which is shown from the color change in the status bar and category text on the application that will change according to the criteria of potential flood hazard.

4. **Conclusions.** This work developed a flood early warning system wherein it monitors the real time of water level, rainfall, water flow rate and the status of early warning of the flood disaster. The system is composed of three sections: sensor network, data processing and analytics, and user visualization. Each node of a sensor network consists of three sensors: water level, rainfall, and water flow rate. The real-time data of the measurement results, retrieved from the sensors, are analyzed through the analytical hierarchy process to predict the flood disaster threats, which are providing the flood hazard warning status. The measured data and the early warning status of flood hazard transmitted into the

Internet cloud through a WIFI or GSM communication modem. In addition, we developed the mobile application to monitor the early warning of flood disaster threats in the specific areas in real-time condition. The system will help to anticipate flood disaster risk and minimize the damage that is caused by the flood. In future works, we are planning to design the map evacuation zone functionality in applications. The maps show flood zone and evacuation zones that are recommended during potential worst-case flood disaster.

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