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Prediction of flood depth detection system from rainfall with normal, alert and hazard levels based on fuzzy logic

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Abstract

Floods are natural calamities that frequently transpire and are of primary concern for governmental entities due to their potential for significant losses and casualties. Heavy rainfall and overflowing water stand as the primary triggers for flooding. Many communities lack adequate knowledge to forecast floods, thus necessitating technological interventions for early water depth detection and issuing flood warnings. This study devised a water depth detection system based on fuzzy logic using Arduino as a microcontroller. The system employs ultrasonic sensors for water level detection and a Tipping Bucket for precipitation measurement. Its primary objective is to establish a system capable of issuing early flood warnings through alarms. The outcome of this research entails the implementation of an Arduino Uno-based flood detection system that aids users in monitoring water levels and anticipating floods. Safety considerations are also addressed by incorporating fuzzy logic technology to forecast flood potential based on water level and rainfall data. The utilization of fuzzy logic enables the system to navigate uncertainties and ambiguities in data, thus furnishing more precise and dependable early warnings. Consequently, the findings of this study serve as a groundwork for the advancement of more sophisticated and efficient flood detection systems in the future. In conclusion, the development of Arduino Uno-based flood detection tools has proven successful and can assist users in identifying and anticipating flood occurrences.

Keywords: Arduino, Fuzzy logic, Floods, HC-SR04, Rainfall.

INTRODUCTION

Advancements in information technology and embedded systems during the digitalization era are progressively driving research in control systems, automation, IoT, and artificial intelligence (Siskandar et al., 2022). The Internet of Things (IoT), commonly referred to as IoT, is a concept where specific objects have the capability to communicate with each other as part of an integrated system using the internet network as a connector, without requiring human-to-human or human-to-computer interaction (Shubhi Maulana et al., 2021). IoT is a system that links devices directly or indirectly to the internet, enabling remote control functionality for the devices (Siskandar et al., 2020). The rapid advancement of technology and scientific knowledge has led to the emergence of the fourth industrial revolution, which prioritizes communication between devices using IoT and AI (Tri Wahyudiningsih et al., 2022). Therefore, it can assist in constructing a system that can be utilized by the community to anticipate flood-related issues.

Flood disasters are natural occurrences that can happen unpredictably and frequently lead to casualties and property damage. Damages from floods can vary, ranging from structural harm to buildings, loss of valuable possessions, to disruptions preventing individuals from attending work and school. Flood occurrences can be forecasted by monitoring rainfall and water flow patterns. Occasionally, floods may emerge suddenly due to stormy winds or breaches in levees, commonly known as flash floods. Factors contributing to flooding encompass intense rainfall; low-lying land relative to sea level; areas situated in basins encircled by hills with limited water drainage; construction of buildings along riverbanks; obstruction of river flow caused by debris; and insufficient land coverage in upstream areas (Saputro et al., 2022). While floods cannot be entirely prevented, their impact and resulting losses can be mitigated through effective control measures (Findayani Aprilia, 2018). A flood is the increased discharge of river water, relative to normal, caused by continuous rainfall upstream or in a specific location. This excess water cannot be contained by the existing river channel, resulting in an overflow that inundates the surrounding area (Taryana et al., 2022).

Hence, there is a necessity for tools and systems that enable homeowners and officials to streamline access to information through the establishment of a monitoring system. This system would empower them to conduct real-time measurements of water levels and rainfall intensity, facilitating proactive measures in response to potential flood threats (Hadramy et al., 2023). The study involved creating a flood monitoring tool utilizing an HC-SR04 ultrasonic sensor, Tipping Bucket, and a buzzer employed for alert purposes.

For early flood detection, sensors capable of monitoring water levels are essential. Water level monitoring can be achieved using the HC-SR04 sensor, which operates based on sound waves reflecting off objects and returning to the ultrasonic sensor. With an error rate of approximately 1 cm, this sensor offers reliable accuracy, making it suitable for water level monitoring. Rainfall stands as a primary factor contributing to rising water levels. Rain consists of water particles with a diameter of 0.5 mm or more, known as hydrometeors. Rain that reaches the ground is simply referred to as rain, while precipitation that evaporates before reaching the ground is termed Virga (Masturoh & Anggita, 2018). Continuous rainfall and inadequate water drainage systems can exacerbate flooding. Consequently, a rainfall sensor is necessary to gather rainfall data (Wandi & Ashari, 2023).

Rainfall intensity refers to the quantity of precipitation measured as the height or volume of rain per unit of time, typically occurring during a concentrated period of rainfall (Juleha et al., 2016). The intensity of rainfall is influenced by both the duration and magnitude of the rain. Longer durations of rain tend to result in higher intensity, whereas shorter durations lead to lower intensity. Additionally, intensity assessed based on recurrence is directly proportional; longer recurrence times correspond to higher intensities. High-intensity rainfall typically occurs over a brief period and affects a relatively small area (Hendri, 2015).

Fuzzy logic is a constituent of soft computing (Nilawati & Nusa Mandiri Jakarta, 2018). Fuzzy logic is a component of artificial intelligence utilized to address uncertainties in problem causality (Jufriadi et al., 2020). Fuzzy logic serves as an effective tool for managing uncertainty in data-driven decision-making processes (Siskandar et al., 2023). The concept of Fuzzy logic was introduced by Prof. Lotfi A. Zadeh in 1965. Fuzzy logic is utilized as a problem-solving approach for controlling systems, which can be applied to various types of systems, ranging from straightforward and compact systems to embedded systems, computer networks, data acquisition systems based on workstations, and control systems with multiple channels. This approach can be implemented in hardware, software, or a combination thereof. Classical logic operates on a binary basis, meaning it only acknowledges two possibilities such as "Yes or No," "True or False," "Good or Bad," among others, assigning a membership value of either 0 or 1. However, in Fuzzy logic, the membership value typically falls between 0 and 1. Consequently, a situation can exhibit both "Yes or No," "True or False," "Good or Bad" simultaneously, with the magnitude of the value contingent upon its membership weight (Puspitasari et al., 2019). In fuzzy set theory, the significance of membership degrees as indicators of the presence of elements within a set is paramount. The membership value, also known as degree of membership or membership function, serves as the primary characteristic in reasoning with fuzzy logic (Nasyuha et al., 2019). Fuzzy logic is renowned for its flexibility and ability to accommodate existing data with a certain degree of tolerance (Arifah et al., 2017). Fuzzy logic is characterized by a structured approach involving distinct stages. Among the various models within fuzzy logic used for addressing diverse problems, the fuzzy Mamdani model stands out as one of the most widely applied (Triwinanto et al., 2023)

The Mamdani model is a type of fuzzy relational model characterized by IF-THEN relationships, where both antecedents and consequent propositions are fuzzy propositions, also known as linguistic models. Fuzzy logic systems typically encompass four core mechanisms: fuzzified inference, a knowledge base (also referred to as a rule base or database), decision-making (also known as an inference engine or inference mechanism), and defuzzification (Salim & Rahman, 2022).

In this research, fuzzy logic calculations for predicting water levels were conducted both manually and using MATLAB software. The manual calculation method entails determining rules, membership degrees, defuzzification calculations, and analyzing results manually. On the other hand, utilizing MATLAB software enables a more efficient and straightforward fuzzy logic calculation process through computer programming.

MATLAB, short for Matrix Laboratory, is software utilized for programming, analysis, and matrix-based technical and mathematical computing. The initial version of MATLAB was released in 1970 by Cleve Moler. Initially, MATLAB was primarily employed to address issues concerning linear algebraic equations. Over time, the functionality and computational performance of the MATLAB system have continuously expanded and evolved (Febrianti & Harahap, 2021). The MATLAB software, developed by MathWorks Inc., is designed for performing numerical analysis and computation. It utilizes an advanced mathematical programming language that is based on the manipulation of matrix properties and forms (Astutik & Fitriatien, 2019). Matlab employs a straightforward matrix format that facilitates ease of use. It is a high-level programming language tailored for technical computing, visualization, and programming tasks such as mathematical computation, data analysis, algorithm development, simulation and modeling, and plotting graphs (Atina, 2019). The underlying programming language of Matlab is primarily C. The application finds extensive application across various fields including physics, mathematics, statistics, and many others (Noor & Fitrian, 2020). This program can be employed to enhance speed and accuracy in various computations (Cahyono, 2016). Furthermore, MATLAB can assist in conducting mathematical calculations, analyzing data, developing algorithms, performing simulations and modeling, and presenting results in graphical formats (Puji Astuti, 2020).

Figure 1. Arduino Uno

The Arduino Uno is a microcontroller board that utilizes the ATmega328 microcontroller. It offers 14 input/output pins, with 6 pins capable of functioning as PWM (Pulse Width Modulation) outputs, and 6 analog inputs. Additionally, it features a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Arduino Uno supports microcontrollers and can be connected to a computer using a USB cable (Syam et al., 2022). A microcontroller serves as the brain of a digital electronic system, where its operation is governed by a program written in the programming language used (Tri Wahyudiningsih et al., 2022). The primary purpose of programming a microcontroller is to enable an electronic circuit to read input, process it, and produce the desired output. Microcontrollers serve as the "brains" that control the input, processing, and output functions of an electronic circuit. Arduino has gained widespread popularity worldwide. The programming language used in Arduino is not the relatively complex assembler language, but rather the C language, which tends to be easier to understand. Unlike some other microcontrollers, which require a separate loader circuit, Arduino can be programmed directly from a computer (Nahnu Afrianto, 2019). Once the block diagram has been designed and the algorithm flow is considered correct, the program code can be created using the C language within the Arduino IDE software (Farras Fauzan et al., 2021).

Figure 2. Arduino IDE

The *Integrated Development Environment* (IDE) for Arduino is a comprehensive application designed for Arduino programming. It includes editors, compilers, and upload tools, providing a complete solution for developing Arduino projects. The Arduino IDE supports all series of Arduino family modules, making it versatile and widely used among Arduino enthusiasts (Firdaus et al., 2018). Arduino is made using C ++ language and has been simplified through libraries, this is suitable for beginners who may not have a basic programming language (Syam et al., 2022). Arduino utilizes the Arduino Software (IDE), which is used for writing programs and uploading them into Arduino boards. The Arduino IDE is based on the Processing Software, which is a combination of C++ and Java programming languages. The Arduino IDE can be installed on various operating systems including Linux, Mac OS, and Windows. It serves as a comprehensive development tool, combining hardware, programming languages, and a sophisticated Integrated Development Environment (IDE). The IDE allows users to write programs, compile them into binary code, and upload them into the memory of the microcontroller (Arifin et al., 2016).

The Arduino IDE software comprises three main components:

1. Program editor, used for writing and modifying programs written in processing languages. The program listing in Arduino is referred to as a sketch.
2. Compiler, a module responsible for translating processing language (program code) into binary code, as binary code is the sole programming language comprehensible by the microcontroller.
3. Uploader, a module tasked with inserting binary code into the memory of the microcontroller.

Figure 3. Sensor Ultrasonic

Ultrasonic sensors are electronic devices capable of converting electrical energy into mechanical energy in the form of ultrasonic sound waves. The HC-SR04 sensor is a popular ultrasonic sensor used for object distance monitoring. It comprises ultrasonic transmitters, also known as emitters, and ultrasonic receivers (Purwanto, H., 2019). The HC-SR04 ultrasonic proximity sensor is capable of non-contact distance measurements ranging from 2 cm to 400 cm, with an accuracy of approximately 3 mm. This module consists of an ultrasonic transmitter, a receiver, and a control circuit. The HC-SR04 sensor is equipped with 4 pins: VCC, Trigger, Echo, and GND. One of the advantages of the HC-SR04 ultrasonic sensor is its ability to rapidly reflect sound waves during operation, with minimal delay, as the trigger pulse (Trigger) and echo pulse (Echo) are accessed through different ports (Hidayanto & Winarno, 2016). One of the advantages of the HC-SR04 ultrasonic sensor is its ability to rapidly reflect sound waves during operation with minimal delay. This is facilitated by accessing the trigger pulse (Trigger) and echo pulse (Echo) through different ports, ensuring efficient and timely detection of objects (Musthofa & Winarno, 2015).

Figure 4. Buzzer

A buzzer is an electronic transducer component that converts electrical vibrations into sound vibrations. Its operation is similar to that of a loudspeaker, as it consists of a coil attached to a diaphragm. Buzzers are often utilized as indicators to signal the completion of a process or the occurrence of an error in a device (Fani et al., 2020). Ordinary buzzers also serve as signal alarms and are commonly used in research projects as indicators of specific conditions (Normah et al., 2022). A buzzer is an output device utilized to provide notifications in response to a command. When used in conjunction with a microcontroller, the buzzer can be programmed to produce specific sounds according to the software stored in the microcontroller (Arifianto et al., 2022).

Figure 5. Tipping Bucket Rain Sensor

A tipping bucket rain gauge is a device used for measuring rainfall. It operates based on the principle of collecting rainwater in a bucket or receptacle, which then tips or empties when a certain amount of water is accumulated. The tipping action is detected and recorded, allowing for the measurement of rainfall. The device is equipped with a measuring scale, known as a pias, which has been determined through testing and calibration to accurately measure the amount of rainfall collected (Laksono & Nurgiyatna, 2020). In a tipping bucket rain gauge system, when water fills a holding vessel equivalent to 0.1, 0.2, or 0.5 mm of rainfall, the vessel tips over, releasing the water. There are typically two vessels that alternate to collect rainwater. Each movement of the tipping vessel is mechanically recorded on the measuring scale (pias) or through a counter mechanism. The recorded signals are then processed to convert into rainfall data, typically measured in millimeters (Jaelani Hidayat et al., 2017). With the proposed monitoring tools developed in this study, local governments, disaster monitoring agencies, and communities can enhance preparedness and response to flood threats in the following ways:

1. Enhancement of Early Warning Systems:
   The monitoring tools utilized in this research enable real-time measurements of water levels and rainfall intensity. The gathered information can be utilized to establish more effective early warning systems. These early notifications provide communities with extended time to take preventive actions, such as evacuating or relocating valuable belongings.

2. Urban Development Planning:
   With improved understanding of rainfall patterns and river water levels, local governments can plan safer urban development. For instance, they can avoid construction in flood-prone areas or reinforce drainage systems to manage excessive rainfall.
3. Development of Adaptive Infrastructure:
   Findings from this research can serve as a foundation for the development of better adaptive infrastructure. This may include the construction of more efficient levees or floodgates, as well as the optimization of irrigation systems to mitigate flood impacts and utilize rainwater efficiently.

By implementing the findings of this research, it is expected that the effectiveness of flood mitigation can be significantly enhanced, consequently reducing both human and material losses caused by floods overall. Thus, this study holds clear and beneficial implications for both communities and the field of disaster mitigation studies.

METHODS

Research on Prediction of Flood Depth Detection System from Rainfall with Normal Level, Alert, and Hazard Based on Fuzzy Logic Using the Mamdani Method. The Mamdani method is one of the commonly used approaches in fuzzy logic to overcome uncertainty in decision making. The method was first introduced by Professor Lotfi Zadeh in 1975 and named after the founder of fuzzy logic, Professor Ebrahim Mamdani. The first step of the Mamdani method is fuzzification, where crisp input variables are converted into fuzzy variables using membership functions. This allows for a more flexible representation of input variables, which are not only limited to a single value, but also take into account uncertainty and ambiguity in the data. Once an input variable is converted into a fuzzy variable, fuzzy rules are created to link the fuzzy input to the fuzzy output. These rules take the form of the proposition "If... then..." and is usually expressed in natural language or linguistic terms. For example, "If the water depth is normal and rainfall is high, then the result is alert". After that it performs fuzzy inference which is used to determine how strongly each rule applies and its implications for fuzzy output variables. This is done by combining fuzzy rules using fuzzy logic operators such as AND, OR, and NOT. The result is a fuzzy set representing the relative contribution of each rule to a fuzzy output variable. The final step is defuzzification, where the fuzzy set generated from fuzzy inference is converted into crisp values using the corresponding membership function. It produces understandable outputs in numerical or linguistic form, which can be used for further decision making.

The research was conducted on March 5, 2024, at Jalan Pemuda 2 No.32 Sindangrasa, RT.04/RW.19, Katulampa, Bogor Timur District, Bogor City, West Java. The location was chosen due to its frequent fluctuations in river water levels and significant rainfall. The primary method used for data collection was interviews with Mr. Andi, the relevant party at the research site. Interviews were used to gain an in-depth understanding of the range of water levels along with their levels and rainfall ranges in the study area. In addition to interviews, this study also utilizes the results of literature studies from several relevant sources, including journals, theses, and final project reports. One of the journals that became a reference was "Implementation of a flood detection system in Kp. Kojan RW 06 Kalideres West Jakarta based on the internet of things" written by Saputro et al. and published in "PUNDIMASKOT: Abdimas Computer and Technology Publications" in 2022. Literature studies are conducted to strengthen the data needed in this study, as well as to gain a broader understanding of the systems built. Data collected through interviews and literature studies were analyzed qualitatively to identify ranges of river water levels and rainfall at the study site. Data analysis also includes an evaluation of information obtained from various sources to ensure the accuracy and reliability of the data.

Based on interviews and literature studies that have been obtained, the system to be created is a system that can:

1. Water Level Measurement:
   Water level measurement is carried out using ultrasonic sensors. This sensor works on the principle of reflected ultrasonic waves emitted by the transmitter and received by the receiver after being reflected by the water surface. The travel time of ultrasonic waves from transmitter to receiver is used to calculate the distance between the sensor and the surface of the water. By taking into account the travel time and speed of ultrasonic waves in the air, water height can be accurately estimated.

2. Rainfall Measurement:
Rainfall measurements are made using bucket tipping sensors. This sensor operates on the principle of a bucket that receives rainwater and calculates the amount of rain falling. Each turn of the bucket filled to the brim with rainwater is recorded as one unit of precipitation. The bucket tipping sensor is equipped with an electronic mechanism to calculate the number of revolutions of the bucket, which is then converted into precipitation units such as millimeters or inches.

This water level and rainfall measurement system is integrated into a wider system for real-time data capture and recording. The data collected by these two sensors can be used for flood hazard analysis.

RESULTS AND DISCUSSION

This study evaluates the use of fuzzy Mamdani approach to detect water levels with the aim of mitigating flood risk in the Katulampa Dam area, Bogor. This study used an application developed using Matlab software. In this study, there were two input variables analyzed, namely water height and rainfall. The unit for water depth is in centimeters (cm), and the unit for precipitation is in millimeters (mm). Flood warnings, which consist of three levels of Normal, Alert, and Hazard, are determined using Mamdani's fuzzy logic approach. This process involves several stages, ranging from determining the degree of membership, making rules, to the last stage, namely defuzification. Both variables are then converted into fuzzy form with membership function graphs as part of the analysis process as follows:

1. Variable Water Level
Based on the interview results, water level variables (KA) were grouped into three fuzzy sets, namely low with a range of 50-150 cm with a peak point of 25 cm, medium with a range of 150-200 cm with a peak point of 175 cm and high with a range of 200-250 cm with a peak point of 225 cm.

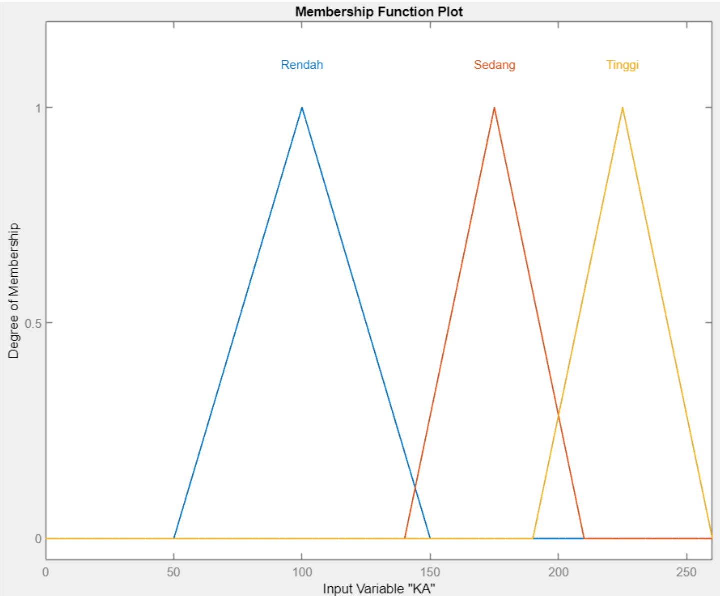

Figure 6. Triangular membership function graph for the variable input "Water Level"

2. Variable Rainfall
From the results of the data obtained during the interview, the rainfall variable (CR) was divided into three fuzzy sets, namely light with a range of 0-50 mm with a peak point of 25 mm, medium with a range of 50-70 mm with a peak point of 55 mm, and dense with a range of 70-100 mm with a peak point of 85 mm.

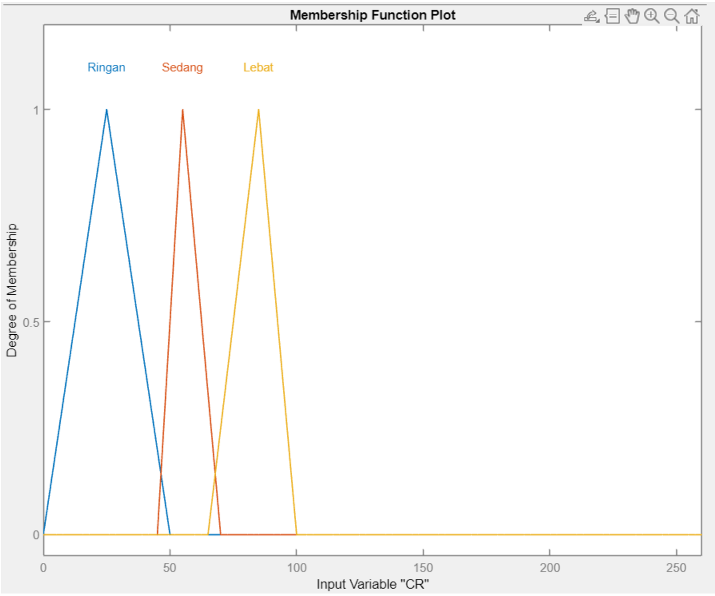

Figure 7. Triangular membership function graph for the variable input "Rainfall Intensity"

3. Warning Variables
   The warning variable (P) is broken down into three fuzzy groups, namely normal with a range of 50-150 centimeters (cm) and its peak point at 100 centimeters (cm), alert with a range of 150-200 centimeters (cm) and its peak point at 175 centimeters (cm), and danger with a range of 200-250 centimeters (cm) and its peak point at 225 centimeters (cm).

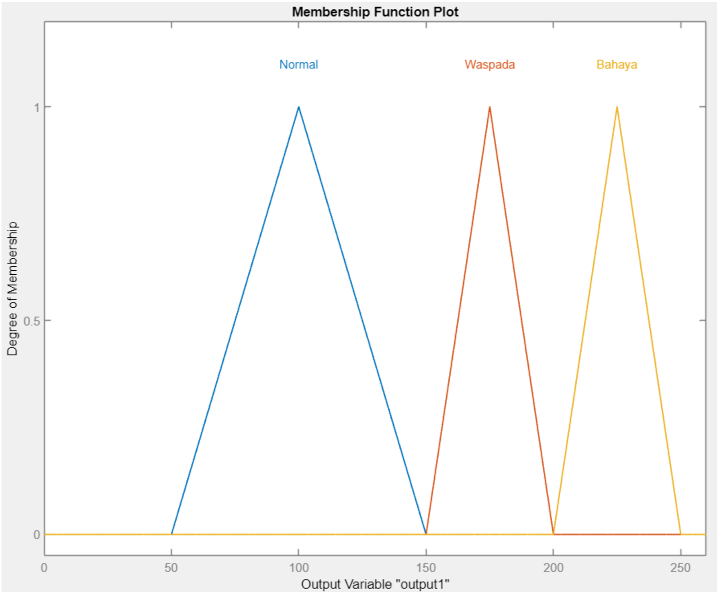

Figure 8. Triangular membership function graph for the variable output "Warning Level."

Membership Association

This set of input membership is developed based on the results of interviews and adjusted to graphs compiled using the Matlab application. This graph will play a role in the flood warning calculation process, where each parameter has a certain range that is used to determine the value of its membership degree (μx). Here is data about the membership set function of that input variable, which has been adjusted and integrated:

Information:
KA = Water Depth
CR = Rainfall
P = Warning

$$f(x,a,b,c) = \begin{cases} 0 & ; x \le a \\ \frac{x-a}{b-a} & ; a \le x \le b \\ \frac{c-x}{c-b} & ; b \le x \le c \\ 0 & ; c \le x \end{cases}$$

Variable Water Depth:

$$\mu_{KA_{Rendah}} = \begin{cases} 0 & ; x \le 50 \\ \frac{x-50}{100-50} & ; 50 \le x \le 100 \\ \frac{150-x}{150-100} & ; 100 \le x \le 150 \\ 0 & ; 150 \le x \end{cases} = \begin{cases} 0 & ; x \le 50 \\ \frac{x-50}{50} & ; 50 \le x \le 100 \\ \frac{200-x}{50} & ; 100 \le x \le 150 \\ 0 & ; 150 \le x \end{cases}$$

$$\mu_{KA_{Sedang}} = \begin{cases} 0 & ; x \le 140 \\ \frac{x-140}{175-140} & ; 140 \le x \le 175 \\ \frac{210-x}{210-175} & ; 175 \le x \le 200 \\ 0 & ; 210 \le x \end{cases} = \begin{cases} 0 & ; x \le 140 \\ \frac{x-140}{35} & ; 140 \le x \le 175 \\ \frac{200-x}{35} & ; 175 \le x \le 200 \\ 0 & ; 210 \le x \end{cases}$$

$$\mu_{KA_{Tinggi}} = \begin{cases} 0 & ; x \le 190 \\ \frac{x-190}{225-190} & ; 190 \le x \le 225 \\ \frac{260-x}{260-225} & ; 225 \le x \le 260 \\ 0 & ; 260 \le x \end{cases} = \begin{cases} 0 & ; x \le 190 \\ \frac{x-190}{35} & ; 190 \le x \le 225 \\ \frac{260-x}{35} & ; 225 \le x \le 260 \\ 0 & ; 260 \le x \end{cases}$$

Precipitation Variables:

$$\mu_{CR_{Ringan}} = \begin{cases} 0 & ; x \le 0 \\ \frac{x-0}{25-0} & ; 0 \le x \le 25 \\ \frac{50-x}{50-25} & ; 25 \le x \le 50 \\ 0 & ; 50 \le x \end{cases} = \begin{cases} 0 & ; x \le 0 \\ \frac{x-0}{25} & ; 0 \le x \le 25 \\ \frac{50-x}{25} & ; 25 \le x \le 50 \\ 0 & ; 50 \le x \end{cases}$$

$$\mu_{CR_{Sedang}} = \begin{cases} 0 & ; x \le 45 \\ \frac{x-45}{55-45} & ; 45 \le x \le 55 \\ \frac{70-x}{70-55} & ; 55 \le x \le 70 \\ 0 & ; 70 \le x \end{cases} = \begin{cases} 0 & ; x \le 45 \\ \frac{x-45}{10} & ; 45 \le x \le 55 \\ \frac{70-x}{15} & ; 55 \le x \le 70 \\ 0 & ; 70 \le x \end{cases}$$

$$\mu_{CR_{Lebat}} = \begin{cases} 0 & ; x \le 65 \\ \frac{x-65}{85-65} & ; 65 \le x \le 85 \\ \frac{100-x}{100-85} & ; 85 \le x \le 100 \\ 0 & ; 100 \le x \end{cases} = \begin{cases} 0 & ; x \le 65 \\ \frac{x-70}{20} & ; 65 \le x \le 85 \\ \frac{100-x}{15} & ; 85 \le x \le 100 \\ 0 & ; 100 \le x \end{cases}$$

Based on the membership set data presented earlier, we have performed calculations to determine flood warnings using water levels of 100 centimeters (cm), which are in the low water level range, and rainfall of 60 millimeters (mm), which are in the moderate rainfall range. The results of the experiment show that the degree of membership (µx) of the water level of 100 centimeters (cm) is 1, because the value is in the middle of the range and is the highest point in the membership chart. While the membership degree (µx) of 60 millimeters (mm) of precipitation is 0.66.

$\mu_{KA_{Rendah}} = 100 = 1$

$\mu_{CR_{Sedang}} = \dfrac{70 - x}{15} = \dfrac{70 - 60}{15} = \dfrac{10}{15} = 0{,}66$

After that the next step is to create rules that will be used in the process towards defuzification. These rules are created by considering the combination of two or more input variables. Each input variable has three parameters, so the total rules that can be created are 9 rules. Here are the rules that we have defined based on the input variable data and the output variable:

	Rule
1	If KA is Rendah and CR is Ringan then output1 is Normal
2	If KA is Sedang and CR is Ringan then output1 is Normal
3	If KA is Tinggi and CR is Ringan then output1 is Waspada
4	If KA is Rendah and CR is Sedang then output1 is Normal
5	If KA is Sedang and CR is Sedang then output1 is Waspada
6	If KA is Tinggi and CR is Sedang then output1 is Bahaya
7	If KA is Rendah and CR is Lebat then output1 is Waspada
8	If KA is Sedang and CR is Lebat then output1 is Bahaya
9	If KA is Tinggi and CR is Lebat then output1 is Bahaya

Figure 9. Rules

Based on previous calculations, where the water level (KA) is 100 centimeters (cm) and rainfall (CR) is 60 millimeters (mm), these two values fall under the 4th rule: "If the water level is low and the rainfall is moderate, then the flood warning level is normal."Thus, from the rule, the following formula can be obtained:

$$\alpha_2 = \min\left(\mu_{KA_{Normal}}[1], \mu_{CR_{Sedang}}[0.66]\right) = \min(1, 0.66) = 0{,}66\ (karena\ diambil\ yang\ terkecil\ kecil)$$

In this experiment, we apply the AND logical operator to combine the membership degree values of both input variables. The value of the selected membership degree is the smallest of the two, which is used to calculate the value of the output variable. The next step is to use the calculated membership degree values to determine the positions of x_1 dan x_2 on the output graph, as well as to determine the relevant membership sets of the output variables. Additionally, we calculate the area under the curve of the output membership sets and apply the moment equation to determine the final defuzzification value.

Defuzzyfication

In the defuzzification stage, the first step is to determine the values of x_1 and x_2 that were previously calculated. These values are obtained from the output variable graph based on the predefined rules. In this calculation, the values of x_1 and x_2 are taken from the "Normal" parameter range on the graph. After the calculation, the value of x_1 is found to be 83 and the value of x_2 is found to be 117, in accordance with the established procedure and based on the following calculation:

Left side

$\alpha_2 left = \dfrac{x_1 - a}{b - a}$

$0{,}66 = \dfrac{x_1 - 50}{100 - 50} = \dfrac{x_1 - 50}{50}$

$0{,}66\ x\ 50 = x_1 - 50$

$33 = x_1 - 50$

$33 + 50 = x_1$

$83 = x_1$

Right side

$\alpha_2 right = \dfrac{c - x_2}{c - b}$

$0{,}66 = \dfrac{150 - x_2}{150 - 100} = \dfrac{150 - x_2}{50}$

$0{,}66\ x\ 50 = 150 - x_2$

$33 = 150 - x_2$

$x_2 = 150 - 33$

$x_2 = 117$

After obtaining the values of x_1 and x_2, the next step is to calculate the area under the curve of the membership function on the output variable. This process is done using the previously determined values of x_1 and x_2, which represent the boundaries of the relevant area within the "Normal" membership function of the output variable. Subsequently, the area between the values of x_1 and x_2 is calculated to form the membership function on the output variable.

The area under the curve:

$$LD_1 = \frac{a\ x\ t}{2}$$
$$LD_1 = \frac{(x_1 - 50)\ x\ 0{,}66}{2}$$
$$LD_1 = \frac{(83 - 50)\ x\ 0{,}66}{2}$$
$$LD_1 = \frac{33\ x\ 0{,}66}{2}$$
$$LD_1 = \frac{21{,}78}{2} = \mathbf{10{,}89}$$

$$LD_3 = \frac{a\ x\ t}{2}$$
$$LD_3 = \frac{(150 - x_2)\ x\ 0{,}66}{2}$$
$$LD_3 = \frac{(150 - 117)\ x\ 0{,}66}{2}$$
$$LD_3 = \frac{33\ x\ 0{,}66}{2}$$
$$LD_3 = \frac{21{,}78}{2} = \mathbf{10{,}89}$$

$$LD_2 = p\ x\ l$$
$$LD_2 = 0{,}66\ x\ (x_2 - x_1)$$
$$LD_2 = 0{,}66\ x\ (117 - 83)$$
$$LD_2 = 0{,}66\ x\ 33 = \mathbf{22{,}44}$$

In the above calculation, we obtained three values, each representing the area under the curve of the output variable's membership function. We used the formula for the area of a triangle for LD_1 and LD_3, and the formula for the area of a rectangle for LD_2. The variables x_1 and x_2 were used to determine the relevant boundaries under the curve. The results of the calculations provide concrete values that depict the respective areas, with LD_1 and LD_3 both having a value of 10.89, while LD_2 is calculated as 22.44.

Normal Output Function Membership Set

$$\mu_{TA_{Normal}} = \begin{cases} x < 50 & 0 \\ \mathbf{50 \le x \le 83} & \dfrac{x - \mathbf{50}}{\mathbf{100 - 50}} \\ 83 \le x \le 117 & 0{,}66 \\ 117 \le x \le 150 & \dfrac{150 - x}{150 - 100} \\ x > 150 & 0 \end{cases}$$

Counting Moments

Himpunana momen

$$= \frac{x - 50}{100 - 50} = \frac{x - 50}{50} = \mathbf{0{,}02x - 1}\ \ (for\ set\ 1)$$
$$= \mathbf{0{,}66}\ (for\ set\ 2)$$
$$= \frac{150 - x}{150 - 100} = \frac{150 - x}{50} = \mathbf{3 - 0{,}02x}\ (for\ set\ 3)$$

Moment of set 1

$$\int_a^b F(x)x.dx \rightarrow \int_{50}^{83} (0{,}02x - 1)x\ .dx$$

Derived

$$\int_{50}^{83}(0{,}02x^2 - 1x)\,.\,dx \;\rightarrow \int_{50}^{83}\frac{0{,}02x^3}{3} - \frac{1x^2}{2}.\,dx \;\rightarrow \int_{50}^{83}(0{,}0066x^3 - 0{,}5x^2)\,.\,dx$$

$$= [\ (0{,}0066(83)^3\ - 0{,}5(83)^2)\ -\ (0{,}0066(50)^3\ - 0{,}5(50)^2)\ ]$$
$$= \mathbf{754{,}29}$$

Moment of set 2

$$\int_a^b F(x)x.\,dx \rightarrow \int_{83}^{117} 0{,}66x\,.\ dx \;\rightarrow \int_{83}^{117}\frac{0{,}66x^2}{2}\ .\ dx \;\rightarrow \int_{83}^{117} 0{,}33x^2\,.\ dx$$

$$= [(0{,}33(117)^2 - 0{,}33(83)^2)] = \ \mathbf{2.244}$$

Moment of set 3

$$\int_a^b F(x)x.\,dx \rightarrow \int_{117}^{150}(3 - 0{,}02x)x\,.\,dx$$

Derived

$$\int_{117}^{150}(3x - 0{,}02x^2)\,.\,dx \;\rightarrow \int_{50}^{83}\frac{3x^2}{2} - \frac{0{,}02x^3}{3} -.\,dx \;\rightarrow \int_{117}^{150}(1{,}5x^2 - 0{,}0066x^3)\,.\,dx$$

$$= [(1{,}5(150)^2 -\ (0{,}0066(150)^3\ )\ - (1{,}5(117)^2 -\ (0{,}0066(117)^3\ )\ ]$$
$$= \mathbf{1.512{,}14}$$

After obtaining all the data from the previous calculations, such as the area under the membership set curve and the moment, the next stage is defuzzyfication. At this stage, the total moment is divided by the total area to get the final defuzzyfication value. This is done to generate a single value that represents the output of a fuzzy logic system based on predefined calculations and rules.

Calculating the center point or Centroid

$$= \frac{\sum Moment}{\sum Area\ Size}$$

$$= \frac{754{,}29 + 2.244 +\ 1512{,}14}{11{,}22 + 22{,}11 + 11{,}22} = \frac{4510{,}43}{44{,}55} = \mathbf{101{,}2}$$

From the results of the defuzzyfication process, the final value obtained is 101.2, which represents the percentage for the "Normal" alert level with a margin of error of 1.2%. This shows that the calculations have been carried out in accordance with the pre-established rule, namely "If the water level is low and the rainfall is moderate, then the flood warning level is normal." Trials conducted on the Matlab application with an input of 100 cm water level and 60 mm rainfall also produced an output in accordance with the calculations that had been done, with an output value of 100. This shows that the calculations that have been carried out are reliable and fairly accurate in determining flood warning levels based on given water level and rainfall conditions.

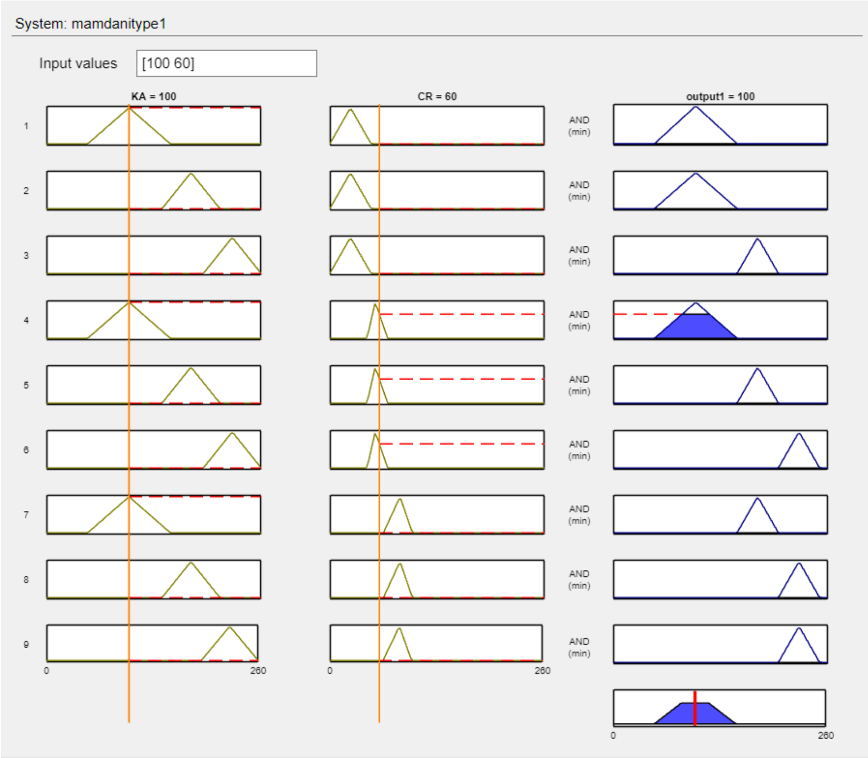

Figure 10. Output results in matlab application 1

CONCLUSION

The conclusion of the research conducted is that a fuzzy logic-based water depth detection system using Arduino as a microcontroller has been successfully developed. The system can detect water levels using ultrasonic sensors and precipitation using a Tipping Bucket. The main purpose of this research is to build a system that can provide early warning of potential floods through alarms. The result of this study is the implementation of an Arduino Uno-based flood detection system that can help users to monitor water levels and anticipate floods. This study also considers safety aspects by utilizing fuzzy logic technology to predict flood potential based on water level and rainfall data. The use of fuzzy logic allows the system to overcome uncertainty and vagueness in data, thus providing more accurate and reliable early warnings.

The study also shows that Mamdani's fuzzy logic approach has proven effective and accurate in detecting flood warning levels based on water levels and rainfall. The results of the experiment show that the calculations and rules that have been set are able to provide consistent output and in accordance with expectations. In addition, trials on the Matlab application also validate the results of calculations carried out manually. Thus, it can be concluded that Mamdani's fuzzy logic approach can be used as a useful tool in flood risk mitigation by providing precise warnings based on existing water level and rainfall conditions.

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