IoT-BASED REAL-TIME LANDSLIDE DETECTION USING FUZZY LOGIC

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ABSTRAK

Projek tahun akhir ini memberi tumpuan kepada pembangunan sistem pengesan tanah runtuh pintar yang bertujuan untuk memberikan amaran awal dan strategi pemulihan bagi tanah runtuh. Tanah runtuh membawa ancaman besar kepada nyawa manusia, infrastruktur, dan alam sekitar, memerlukan sistem pemantauan dan pengesan yang berkesan. Projek ini menggunakan teknologi terkini seperti IoT (Internet of Things), analitik data, dan logik kabur untuk mencipta sistem yang kukuh dan pintar. Projek ini bermula dengan kajian literatur yang menyeluruh mengenai teknik pengesan tanah runtuh, sistem dan metodologi sedia ada. Melalui kajian ini, projek mengenal pasti kesenjangan dan batasan sistem semasa dan mencadangkan pendekatan inovatif untuk menangani cabaran ini. Seni bina sistem merangkumi rangkaian sensor, termasuk pengukur hujan, sensor kelembaban tanah, pemercepat, dan sensor kemiringan, yang ditempatkan secara strategik di kawasan berisiko tanah runtuh. Data yang dikumpul dari sensor-sensor tersebut dihantar secara wayarles ke unit kawalan pusat untuk pemantauan dan analisis secara masa nyata. Teknik analitik data yang canggih, termasuk algoritma logik kabur, digunakan untuk memproses data sensor dan memberikan ramalan tanah runtuh yang tepat dan tepat pada waktunya. Sistem ini mengintegrasikan antara muka papan pemuka yang mesra pengguna, membolehkan pihak berkepentingan untuk memvisualisasikan dan menafsirkan data dengan berkesan. Projek ini juga menekankan kepentingan strategi amaran awal dan pemulihan. Apabila tanah runtuh berpotensi dikesan, sistem ini menghasilkan amaran dan pemberitahuan automatik kepada pihak berkuasa yang berkaitan, pasukan tindak balas kecemasan, dan komuniti tempatan. Projek ini bertujuan untuk menyumbang kepada perkembangan ilmu dalam pengesan dan pemulihan tanah runtuh, dengan memberi tumpuan kepada aplikasi IoT, analitik data, dan logik kabur secara menyeluruh dan bersepadu. Keputusan projek ini mempunyai implikasi yang signifikan bagi agensi pengurusan bencana, perancang bandar, dan komuniti yang tinggal di kawasan berisiko tanah runtuh. Sistem yang dibangunkan menyediakan alat yang boleh dipercayai dan cekap untuk pengesan, amaran, dan pemulihan awal tanah runtuh, dengan itu meningkatkan keselamatan awam dan mengurangkan kerosakan yang berpotensi disebabkan oleh bencana semulajadi ini.

ABSTRACT

The goal of this senior project is to create a smart landslide detection system that will provide early warning and landslide mitigating measures. Effective monitoring and detection systems are required because landslides represent a serious hazard to infrastructure, human lives, and the environment. To build a reliable and intelligent system, the project makes use of cutting-edge technology including IoT (Internet of Things), data analytics, and fuzzy logic. The project starts with a thorough assessment of the approaches, technologies, and literature related to landslide detection. The project pinpoints the weaknesses and restrictions of the existing systems through this evaluation and suggests creative solutions to deal with these issues. The system design consists of a network of sensors, strategically placed in landslide-prone locations, including rain gauges, soil moisture sensors, accelerometers, and tilt sensors. The initiative also stresses the value of early warning systems and mitigation plans. The technology automatically informs and notifies the appropriate authorities, emergency response teams, and local populations if a potential landslide is detected. This makes it possible to quickly evacuate and to put mitigation measures in place to lessen the effects of landslides. The results of this study will have a big impact on people living in landslide-prone regions, urban planners, and disaster management organisations. The created system offers a trustworthy and effective instrument for landslip early detection, warning, and mitigation, improving public safety and lowering the potential harm brought on by these natural hazards.

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LIST OF ABBREVIATIONS

IoT	Internet of Things
MQTT	Message Queuing Telemetry Transport
AI	Artificial Intelligence
MATLAB	Matrix Laboratory
MySQL	My Structured Query Language
LED	Light-Emitting Diode
GSM	Global System for Mobiles

CHAPTER 1

INTRODUCTION

1.1 Introduction

A landslide is the term for the downward movement of rock, soil, or debris that is frequently brought on by a natural occurrence or human activity. An abrupt or slow movement of material from higher elevations to lower elevations is what defines this geological phenomena. There are many different types and sizes of landslides, from modest, localized movements to massive, catastrophic catastrophes(Lynn M. Highland, 2008). In Bangladesh, interviews have been made. There are other opinions that influence landslide risk. 208 community members were personally interviewed as part of the inquiry, in addition to 15 key informant interviews, three Focus Group Discussions (FGD), field visits, and observations in southeast Bangladesh. According to the findings, unplanned development projects, excessive population growth, settlement along hill slopes, and ineffective disaster risk reduction initiatives are the main anthropogenic contributors to the increase in landslip occurrence that is being brought on by climate change-induced increased torrential rainfall(Alam, 2020).

In this project, there is an IoT (Internet of Things) Architecture. The structure and arrangement of the systems and components that make up an Internet of Things solution is referred to as IoT architecture. In order to allow IoT features, the architecture specifies how devices, networks, applications, and services connect and collaborate. There are four layers in the architecture which are sensing layer which include microcontroller and sensors, network layer which include network that will be using to send the data, data processing layer include protocols has been used and database and application layer include the data visualization(Sethi, 2017).

The project proposed a system called Smart Landslide Detection, a web application to view and monitor real-time data about landslides. This system is a platform for the head of the village to receive information about real-time landslide data and alert. In short, it is one of the web applications that display real-time landslide data and control the systems connection. This project's goal is to develop and put into use a smart landslide detection system that makes use of sensor technologies including soil moisture, accelerometer, and rainfall sensors to identify probable landslides and send out early warning signals. The previous studies have also used the same sensors with the exception of vibration sensor and soil shift sensor(Suryadi, 2020). Soil moisture sensor probes are continuously deep into soil. If soil moisture increases resistance of the sensor, this is the ADC value of the controller(Garad, 2013). For an accelerometer sensor, it is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration(Garad, 2013). For wetness effect, the study was performed by supplying artificial rainfall to the soil using water spray with a constant number of sprays(Susanto & Budiman, 2019). Thus rain sensors play a significant role and it is considered to be important. Rain sensors play a vital role in detecting rainfall(Niraj Prasad, 2017). To analyze the sensor data and send alerts to stakeholders in real-time, the system will employ fuzzy logic.

In this project, fuzzy logic will be used for AI implementation. A mathematical framework called fuzzy logic helps decision-making processes deal with ambiguity and imprecision. As an extension of traditional (crisp) logic, which holds that a proposition can only be true or false, it was created by Lotfi A. Zadeh in the 1960s. Fuzzy logic, in contrast, allows for a range of values between true and false that indicate different degrees of truth or membership. Then, degrees of membership in a set are assigned to variables in fuzzy logic, and the set is represented by a membership function. The degree to which an element belongs to the set is determined by this function. After that, fuzzy rules are developed to explain how inputs and outputs relate to one another. Typically, these laws are represented as "IF-THEN" statements, where the "IF" part provides the prerequisites and the "THEN" part establishes the outcomes.

Fuzzy logic can be linked with landslide because fuzzy logic can evaluate the current status of the slope and the possibility of a landslide occurrence by using real-time monitoring data from multiple sensors, including accelerometer, soil moisture, and rainfall sensor. Based on the level of landslide risk, fuzzy rules can be created to interpret sensor data and initiate warnings or evacuation procedures. Fuzzy logic may improve the comprehension and management of landslides with its capacity to handle uncertainty and simulate complicated interactions. It enables a more flexible and adaptive approach to risk assessment, hazard zoning, early alerts, and susceptibility assessment, ultimately assisting in reducing the impact of landslides on infrastructure and human life.

IoT protocols that will be used in this project are MQTT and Websocket. A lightweight messaging protocol called MQTT (Message Queuing Telemetry Transport) was created for effective machine-to-machine (M2M) and Internet of Things (IoT) communication between devices. It was created by IBM in the latter part of the 1990s, and it is now an open standard. In the publish-subscribe messaging model used by MQTT, devices connect with one another via a central broker. Next, in Websocket a client and a server can connect to one another using the WebSocket communication protocol to create full-duplex communication channels. It enables two-way, real-time communication between web servers and web browsers (clients). WebSocket utilizes a straightforward, lightweight message-based protocol over a single TCP connection. For delivering and receiving messages between the client and server, it offers a common set of API methods and events. Both binary and text-based data transmission are supported by the protocol.

With the help of this project, landslide detection will be made more affordable and effective in a variety of locations, including residential neighborhoods, railroads, highways, and industrial sites. A holistic approach to disaster risk reduction will be possible with the help of the smart landslip detection system's potential integration with other disaster management systems. This initiative will have a big influence on raising public safety and lessening the toll that natural catastrophes take on local populations. The outcomes of this study will help create efficient and dependable landslip detection systems that can preserve infrastructure and save lives.

1.2 Problem statements

The current issue is that landslide detection and early warning systems are insufficient and ineffective, posing serious dangers to infrastructure and human life. Accuracy, real-time monitoring, and the integration of different data sources are all lacking in the current methodologies. This issue is especially widespread in areas that are prone to landslides, where prompt detection and warnings are essential for reducing the impact of landslides.

The inability to proactively respond to landslide threats and prevent loss of life and property damage is hampered by the lack of a complete smart landslide detection system. In order to improve early detection, prompt warnings, and efficient disaster management strategies, a sophisticated and integrated smart landslip detection system that integrates precise sensor technology, real-time monitoring, and data processing methodologies is urgently needed.

This method will be crucial in reducing the risks brought on by landslides and guaranteeing the security and adaptability of communities in landslide-prone areas. The suggested method by using accelerometer sensor, rainfall sensor and soil moisture sensor intends to dramatically improve the capability to identify, monitor, and react to landslide events by solving these difficulties, hence lowering the terrible effects brought on by landslides.

1.3 Objective

The objectives of this project are:

I. To study the requirement for Iot architecture that provides real-time data for smart landslide detection.

II. To develop a smart landslide detection by using fuzzy logic implementation.

III. To evaluate the effectiveness of smart landslide detection based on fuzzy logic.

1.4 Scope

The scope of the project consists of user, system and development. These scopes are specified below.

User Scope:

I. Pahang State Department of Environment which is responsible for environmental management and protection.

System Scope:

I. Rain sensor, soil moisture sensor and accelerometer have been used in this project to collect real-time data.
II. It will give an alert if there are slopes on the soil and the servo motor will be turned on.
III. Using fuzzy logic from previous studies to do classification from soil moisture and accelerometer sensor reading.
IV. MQTT and Websocket protocol will be used to send data reading to the local database and display on the dashboard.
V. This project will not consider the type of soil that will be used.

Development Scope:

I. The system will be developed using Laravel framework, Visual Studio Code and MySQL, which is a local database to store data.
II. MQTT server will be used to send and receive data, Websocket will be used to retrieve data and visualize on the dashboard and AI server will be used to classify fuzzy logic.

1.5 Thesis Organization

This thesis consists of five chapters which are Chapter 1 shall discuss the introduction to the Smart Landslide Detection. Which includes the introduction, problem statement, objectives, scope, and thesis organization.

Chapter 2 will summarize the literature review which includes the introduction, existing academic journal, comparison of existing academic journal and summary.

Chapter 3 will cover all the designs which include introduction, flowchart, IoT architecture, dashboard design, data collecting and potential use of the proposed solution.

Chapter 4 will cover the implementation in the project which include the details about the system and result and discussion.

Chapter 5 will summarize the conclusion about the IoT-Based Real-time Landslide Detection Using Fuzzy Logic application.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In-depth study of the corpus of research on smart landslide detection is provided in this chapter. It offers a comprehensive analysis of prior research, techniques, tools, and technologies that are relevant to the offered solution. By addressing the "What, Why, and How" of the research, this chapter aims to examine the current state of knowledge, highlight the issue or issues, and identify the gaps that the proposed project seeks to remedy. The literature review will also evaluate the pertinent tools, software, and hardware, compare and contrast at least three current systems, and look at the advantages and disadvantages of the project-based methodology.

2.2 Existing System/Academic Journal

The systems and methods used in the past to identify intelligent landslides will be examined in this part. The main focus of the review will be on comprehending the design, implementation, and performance of these systems. The analysis will take into account data collection techniques, monitoring tactics, data processing algorithms, and decision-making procedures. By examining the benefits and drawbacks of various systems, substantial insights will be gained to improve the suggested solution.

2.2.1 IoT Based Landslide Detection and Monitoring

The application of IoT technology for landslide detection and monitoring is the main topic of this scholarly article. It probably covers how different sensors, data gathering techniques, and communication protocols may be integrated into the IoT framework. The implementation of the system, including sensor installation, data transfer, and analytic methods, may be covered in detail in the article. The data gathering techniques are successfully demonstrated such as the figure below(Pitambar, 2019).

Instrumental Intensity	Acceleration (g)	Velocity (cm/s)	Perceived shaking	Potential damage
I	< 0.0017	< 0.1	Not felt	None
II-III	0.0017 – 0.014	0.1 – 1.1	Weak	None
IV	0.014 – 0.039	1.1 – 3.4	Light	None
V	0.039 – 0.092	3.4 – 8.1	Moderate	Very light
VI	0.092- 0.18	8.1 – 16	Strong	Light
VII	0.18 – 0.34	16 – 31	Very strong	Moderate
VIII	0.34 – 0.65	31 – 60	Severe	Moderate to heavy
IX	0.65 – 1.24	60 - 116	Violent	Heavy
X+	>1.24	>116	Extreme	Very Heavy

Figure 2.1 Data Gathering Techniques

2.2.2 Real-Time Monitoring And Wireless Data Transmission To Predict Rain-Induced Landslides In Critical Slopes.

In order to forecast rain-induced landslides, this scholarly journal emphasises the value of wireless data transfer and real-time monitoring. It probably examines how to monitor important slopes using sensors like soil moisture sensors and rain gauges. In order to promote rapid data gathering and analysis, the article may detail the data transmission techniques used, such as wireless networks or IoT platforms. The value of predictive modelling and analytics in predicting landslide occurrences based on current data and meteorological conditions may be highlighted by this. The prediction has been made from slope inclination and volumetric water content and only five data are successful to be collected due to power failure of the central unit(Abeykoon, 2018)

Figure 2.2 Data Prediction

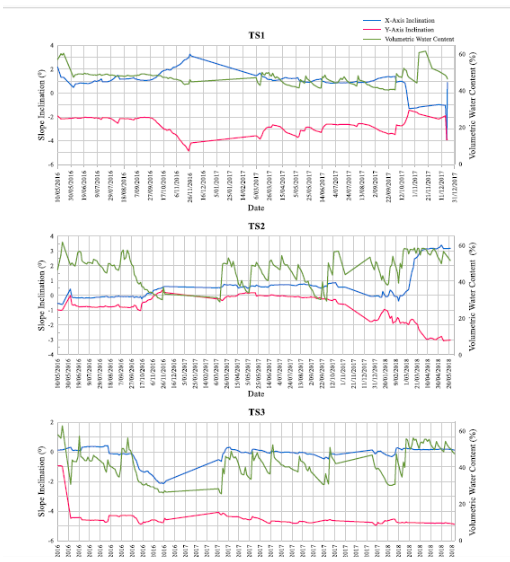
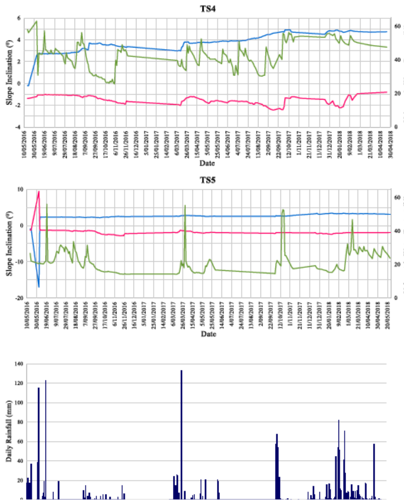


Figure 2.3 Data Prediction



2.2.3 Landslides Early Warning System With Gsm Modem Based On Microcontroller Using Rain, Soil Shift And Accelerometer Sensors

This scholarly publication focuses on the creation of a GSM modem and microcontroller-based early warning system for landslides. It probably refers to the system's incorporation of accelerometer, rain, and soil shift sensors. The GSM modem's function in distributing warnings and notifications to pertinent stakeholders may be included in the paper. The microcontroller-based system's design and implementation details, such as sensor calibration, data processing, and alarm triggering methods, may be presented(Suryadi, 2020)

Table 5 Result of combining rain sensor and soil shift sensor test at 40^0

Angel	S S	R	V	Result
40°	0	0	0	Norm
40°	0	0	0	Norm
40°	0	0	1	Norm
40°	0	0	1	Norm
40°	0	1	0	Crack/Alert
40°	0	1	0	Crack/Alert
40°	0	1	1	Crack/Alert
40°	0	1	1	Crack/Alert
40°	1	0	0	Shift/Danger
40°	1	0	0	Shift/Danger
40°	1	0	1	Shift/Danger
40°	1	0	1	Shift/Danger
40°	1	1	0	Shift/Danger
40°	1	1	0	Shift/Danger
40°	1	1	1	Shift/Danger

Figure 2.4 Data Testing for 40 Degree angle

Table 6 Result of combining rain sensor and soil shift sensor test at 50^0

Angel	S S	R	V	Result
50°	0	0	0	Norm
50°	0	0	0	Norm
50°	0	0	1	Norm
50°	0	0	1	Norm
50°	0	1	0	Crack/Alert
50°	0	1	0	Crack/Alert
50°	0	1	1	Crack/Alert
50°	0	1	1	Shift/Danger
50°	1	0	0	Shift/Danger
50°	1	0	0	Shift/Danger
50°	1	0	1	Shift/Danger
50°	1	0	1	Shift/Danger
50°	1	1	0	Shift/Danger
50°	1	1	0	Shift/Danger
50°	1	1	1	Shift/Danger

Figure 2.5 Data Testing for 50 Degree angle

Table 7 Result of combining rain sensor and soil shift sensor test at 60^0

Angel	S S	R	V	Result
60°	0	0	0	Norm
60°	0	0	0	Crack/Alert
60°	0	0	1	Crack/Alert
60°	0	0	1	Crack/Alert
60°	0	1	0	Crack/Alert
60°	0	1	0	Crack/Alert
60°	0	1	1	Crack/Alert
60°	0	1	1	Crack/Alert
60°	1	0	0	Shift/Danger
60°	1	0	0	Shift/Danger
60°	1	0	1	Shift/Danger
60°	1	0	1	Shift/Danger
60°	1	1	0	Shift/Danger
60°	1	1	0	Shift/Danger
60°	1	1	1	Shift/Danger

Figure 2.6 Data Testing for 60 Degree angle

2.3 Analysis Comparison Of Existing Academic Journal

2.3.1 Analysis of comparison on existing academic journal

Table 2.1 below shows the summary of analysis of comparison on the three existing academic journal which are the IoT Based Landslide Detection and Monitoring, Real-Time Monitoring And Wireless Data Transmission To Predict Rain-Induced Landslides In Critical Slopes and the Landslides Early Warning System With GSM Modem Based On Microcontroller Using Rain, Soil Shift And Accelerometer Sensors. The comparison includes the advantages and disadvantages of the systems, protocols that have been used, sensors that have been used, programming language of the systems and another that is related to the academic journal.

	IoT Based Landslide Detection and Monitoring	**Real-Time Monitoring And Wireless Data Transmission To Predict Rain-Induced Landslides In Critical Slopes.**	**Landslides Early Warning System With GSM Modem Based On Microcontroller Using Rain, Soil Shift And Accelerometer Sensors**
Advantages	- Real-time monitoring - Provide early warning system	- Real-time monitoring - Provide early warning system	- Provide an early warning system - Deliver real-time data
Disadvantages	- Not encircle a large region	- Inadequate electricity supply - Only gather five data	- Not encircle a large region
Programming Language	Python	Python	Python
MLP or Fuzzy Logic	Fuzzy Logic	MLP	Fuzzy Logic

Tools/Technology	Fuzzy logic tool in MATLAB	Prediction real-time data and own collected data	Fuzzy logic by using their own collected data
Sensors	- Soil Moisture - Accelerometer - Geophones	- Tilt - Volumetric soil moisture - temperature	- Soil shift - Vibration - Rainfall
IoT Protocols	MQTT	MQTT	MQTT
Connection	- LoRa - Zigbee - GSM - WiFi	- 4G	- GSM

Table 2.1 Comparison Existing Academic Journal

2.3.2 Relevance of comparison with project title

The comparison allows for the validation and justification of the smart landslip detection technique that was chosen. By examining how it is applied in Malaysia, it is feasible to demonstrate the value of fuzzy logic in landslip detection and control. The comparison helps to discover the top techniques and strategies applied in the present systems. The effectiveness and efficiency of the smart landslip detection are ensured by having a thorough understanding of the technique, methods, and technologies used in the publications.

2.4 Summary

The literature study gives a thorough understanding of the key information required to understand the recommended research's field. The evaluation of the literature identifies best practices from extant systems and can support the chosen strategy. This study enhances the functionality of the system by highlighting its advantages and fixing its shortcomings. And also, the comparative analysis deepens our comprehension of the topic.

CHAPTER 3

METHODOLOGY

This chapter discusses the project's procedure and flow which follows the IoT architecture when it comes to completing the project. The IoT architecture consists of four layers or stages and will be discussed in detail later in this chapter.

3.1 Introduction

In Chapter 3 of this report, methodology that is used for the project is introduced. In this project, the use of the methodology aims to identify and apply the most suitable approach for techniques and procedures in the process of developing the proposed application which is the Smart Landslide Detection. Besides, several other important elements are also included in this chapter of report such as the IoT architecture, dashboard design for the application and AI analytics.

The Smart Landslide Detection is built based on the IoT architecture, which enables the seamless integration of several sensors and devices for real-time data collecting. Critical landslide-related characteristics may be continually monitored by placing a network of sensors, such as soil moisture sensors, rainfall sensor and accelerometers. Wireless transmission of the gathered allows for real-time processing and analysis.

Next, the Smart Landslide Detection dashboard layout is essential for visualising the gathered data and giving insightful information. An intuitive and user-friendly interface will be provided by the dashboard, which will be built with a user-centric perspective. It will provide current data on parameters linked to landslides, historical patterns, and early warning signs. This will make it possible for decision-makers, emergency personnel, and citizens in landslide-prone regions to quickly obtain crucial information and make wise choices.

AI analytics which are fuzzy logic will be used to improve the system's decision-making skills. The inherent uncertainty and imprecision in landslide-related data that characterises natural systems is well-suited for handling by fuzzy logic. Algorithms based on fuzzy logic will be created to find trends and spot warning signals. This will make it possible to take preventative actions and develop quick reaction plans, which will help with successful disaster management and mitigation efforts.

In summary, the goal of this research project is to create a smart landslide detection system that makes use of IoT architecture, a user-friendly dashboard design, and AI analytics. By combining these technologies, the project aims to produce precise classifications, a smart detection system, and pertinent data about the cliff's present state.

3.2 Flowchart

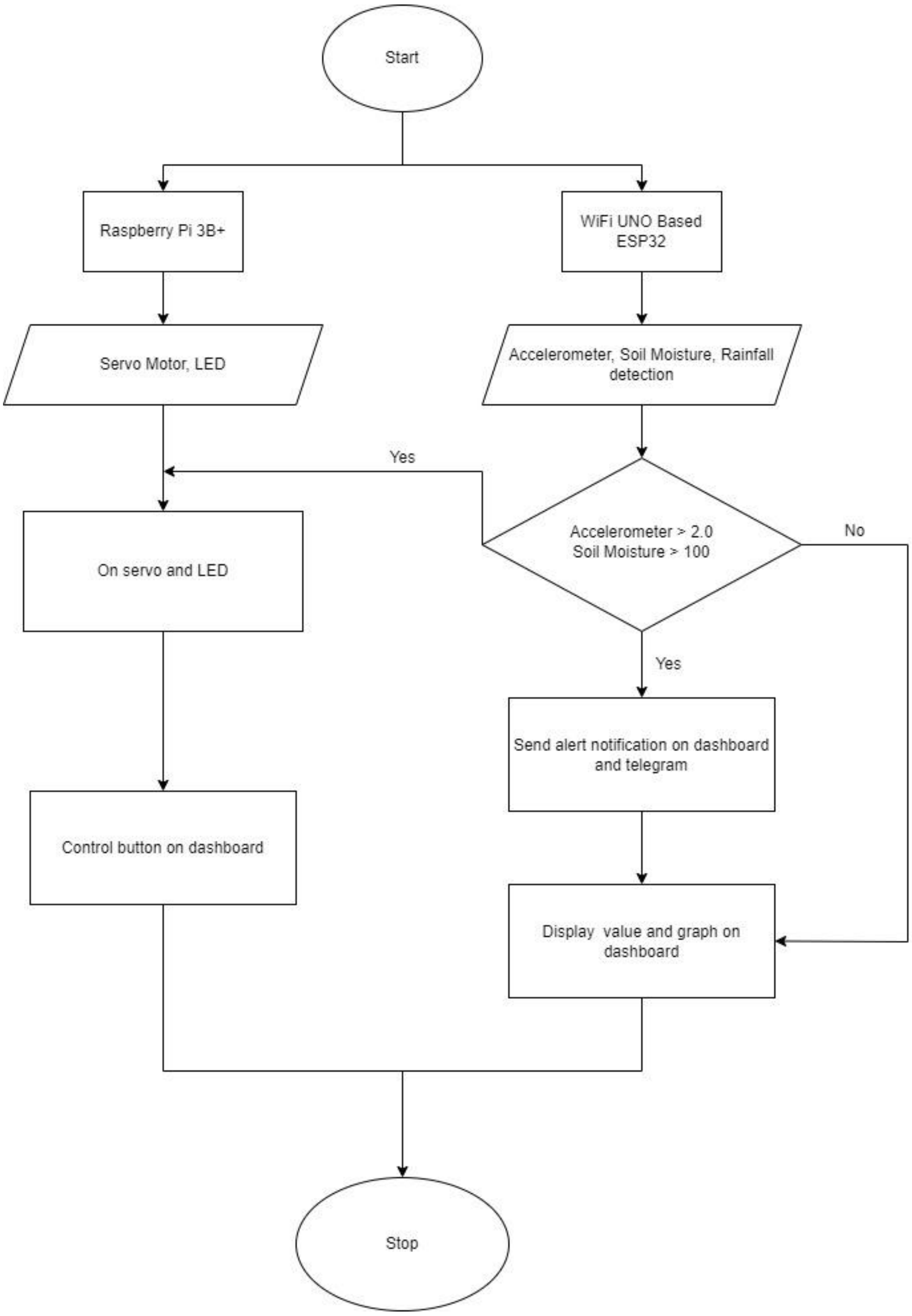


Figure 2.7 Flowchart

The flowchart shows the basic flow for the system. Firstly, there are two microcontrollers which are Raspberry Pi 3B+ and ESP32. Raspberry Pi will be connected with a servo motor and LED. ESP32 will be connected with an accelerometer, soil moisture and rainfall sensor. If the reading of the accelerometer and soil moisture reach the limit, an alert will be sent to telegram and shown on the dashboard then, servo motor and LED will turn on. If the readings are in normal range, it will be shown on the dashboard. Servo motor and LED will be turned on by using a button on the dashboard.

3.3 IoT Architecture

This project will be built based on IoT architecture. IoT architecture was very important in developing a full stack IoT framework. It is because IoT architecture gives a perfect structure to develop effectively(Simmons, 2022). In this project there are four layers of architecture which are sensing layer as the first layer, network layer as the second layer, data processing layer as the third layer and application layer as the fourth or final layer in architecture.

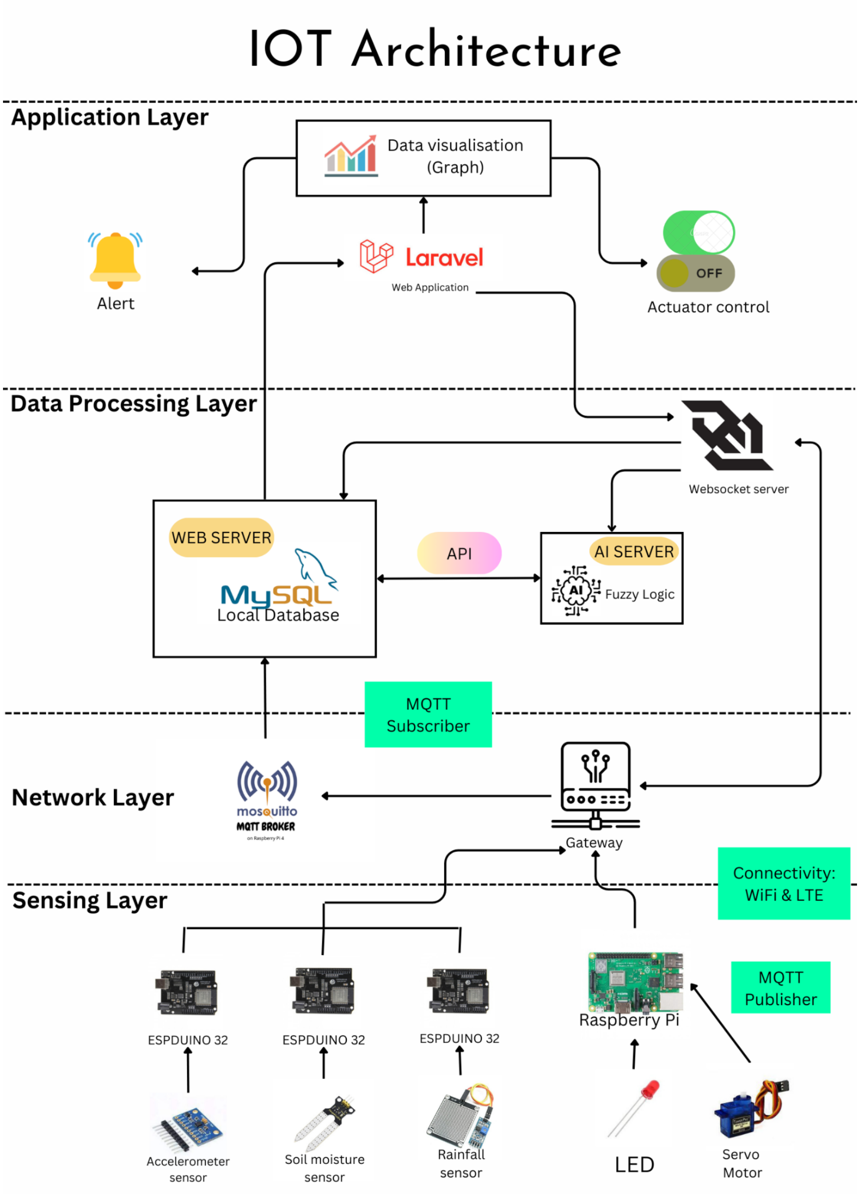


Figure 2.8 IoT Architecture

3.3.1 Sensing Layer

First layer, which is the sensing layer, microcontrollers that have been used are ESPDUINO 32 and Raspberry Pi 3B+. There were three sensors that will be used which are rainfall sensor, soil moisture sensor and accelerometer sensor. The actuator and output device that will be used are servo motor and LED. The three sensors will be connected to three ESPDUINO 32 because all three sensors are analog sensors. On Raspberry Pi 3B+ will be connected with actuator and output devices which are servo motor and LED. Sensors reading will be sent to MQTT broker through gateway by using WiFi connection. ESPDUINO 32 will be the MQTT publisher because ESPDUINO 32 will publish the sensor data.

3.3.2 Network Layer

For the second layer, which is the network layer. ESPDUINO 32 will publish the sensor data to the MQTT broker. Then, the subscriber will subscribe the data from MQTT broker and store it in a local database which is MySQL. In MySQL, there was a database for the project and a few tables to store data such as in this project, there are rainfall data, soil moisture data and accelerometer data.

3.3.3 Data Processing Layer

The third layer is the data processing layer. In the data processing layer, the data collected will be sorted in the local database which is MySQL. Then, the data that was subscribed by the subscriber will be visualised on the dashboard through Websocket server. Next, Websocket will be used as the subscriber to display the data from MySQL through Laravel framework. Data which is stored in the database will be retrieved to build fuzzy rules. To get the data, API connections need to be used because the AI server cannot retrieve the data straight from MySQL for safety. The fuzzy logic result will be displayed on the dashboard using Websocket protocol by listening to the events.

3.3.4 Application Layer

The fourth or final layer is the application layer. In this layer, it will visualise the real-time sensor data in the graph and display the current value of the graph, actuator and output device switch as on and off button and alarm status in the table and also, it will give an alert on Telegram application when the accelerometer reaches the danger value.

To build a full stack IoT framework, IoT architecture is the most important thing to make sure the project will have an effective flow and the project will function as it builds.

3.4 Data Collection

For data collection in this project, fuzzy logic will be used. In this project, the data will be collected from the value of rain sensor, soil moisture sensor and accelerometer and a model will be made to collect some data. The way the data will be collected was by referring to the previous journal or studies(Abeykoon, 2018)(Pitambar, 2019). The previous study collected the data by making their own model and using soil moisture sensor, rain sensor, vibration sensor, soil shift sensor and accelerometer(Abeykoon, 2018)(Pitambar, 2019).

Instrumental Intensity	Acceleration (g)	Velocity (cm/s)	Perceived shaking	Potential damage
I	< 0.0017	< 0.1	Not felt	None
II-III	0.0017 – 0.014	0.1 – 1.1	Weak	None
IV	0.014 – 0.039	1.1 – 3.4	Light	None
V	0.039 – 0.092	3.4 – 8.1	Moderate	Very light
VI	0.092- 0.18	8.1 – 16	Strong	Light
VII	0.18 – 0.34	16 – 31	Very strong	Moderate
VIII	0.34 – 0.65	31 – 60	Severe	Moderate to heavy
IX	0.65 – 1.24	60 - 116	Violent	Heavy
X+	>1.24	>116	Extreme	Very Heavy

Figure 2.9 Data Collection using accelerometer and soil moisture

Rain 40° &50°	ADC	Rain on 60°	ADC
72% - 75%	250 – 279	68% - 75%	235 - 279

Figure 2.10 Value rain sensor

Angle	ADC Data	
	X (%)	Y
40	83	380 – 390
50	83	391 - 396
60	83	397-405

Figure 2.11 Slope angle value

Angel	S S	R	V	Result
40°	0	0	0	Norm
40°	0	0	0	Norm
40°	0	0	1	Norm
40°	0	0	1	Norm
40°	0	1	0	Crack/Alert
40°	0	1	0	Crack/Alert
40°	0	1	1	Crack/Alert
40°	0	1	1	Crack/Alert
40°	1	0	0	Shift/Danger
40°	1	0	0	Shift/Danger
40°	1	0	1	Shift/Danger
40°	1	0	1	Shift/Danger
40°	1	1	0	Shift/Danger
40°	1	1	0	Shift/Danger
40°	1	1	1	Shift/Danger

Figure 2.12 Result on 40 degree angle

Angel	S S	R	V	Result
50°	0	0	0	Norm
50°	0	0	0	Norm
50°	0	0	1	Norm
50°	0	0	1	Norm
50°	0	1	0	Crack/Alert
50°	0	1	0	Crack/Alert
50°	0	1	1	Crack/Alert
50°	0	1	1	Shift/Danger
50°	1	0	0	Shift/Danger
50°	1	0	0	Shift/Danger
50°	1	0	1	Shift/Danger
50°	1	0	1	Shift/Danger
50°	1	1	0	Shift/Danger
50°	1	1	0	Shift/Danger
50°	1	1	1	Shift/Danger

Figure 2.13 Result on 50 degree angle

Angel	S S	R	V	Result
60°	0	0	0	Norm
60°	0	0	0	Crack/Alert
60°	0	0	1	Crack/Alert
60°	0	0	1	Crack/Alert
60°	0	1	0	Crack/Alert
60°	0	1	0	Crack/Alert
60°	0	1	1	Crack/Alert
60°	0	1	1	Crack/Alert
60°	1	0	0	Shift/Danger
60°	1	0	0	Shift/Danger
60°	1	0	1	Shift/Danger
60°	1	0	1	Shift/Danger
60°	1	1	0	Shift/Danger
60°	1	1	0	Shift/Danger
60°	1	1	1	Shift/Danger

Figure 2.14 Result on 60 degree angle

3.5 Dashboard Design

The figure below is the design of the dashboard for this project. The visualization has been compact in one dashboard.

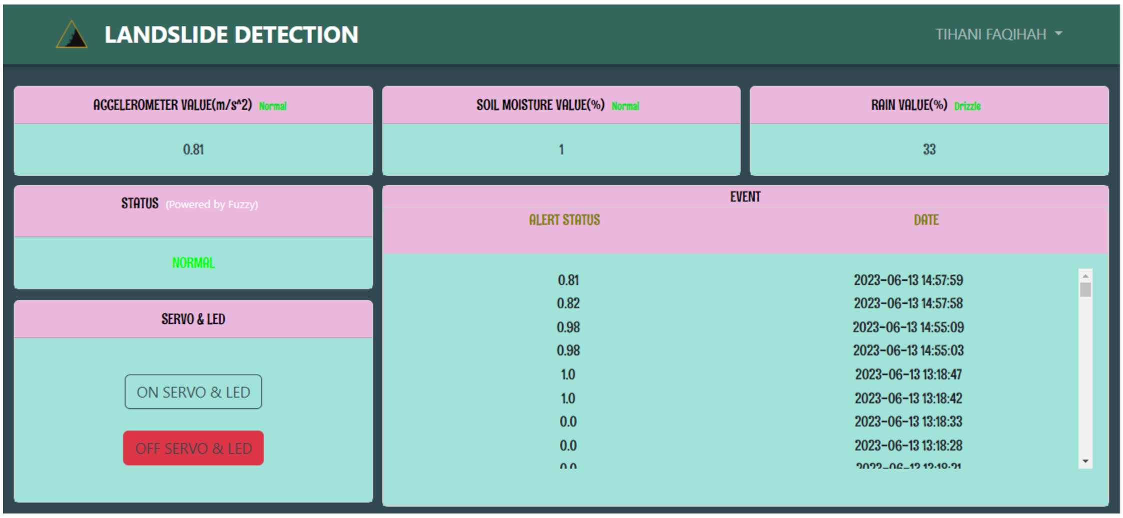


Figure 2.15 Dashboard design

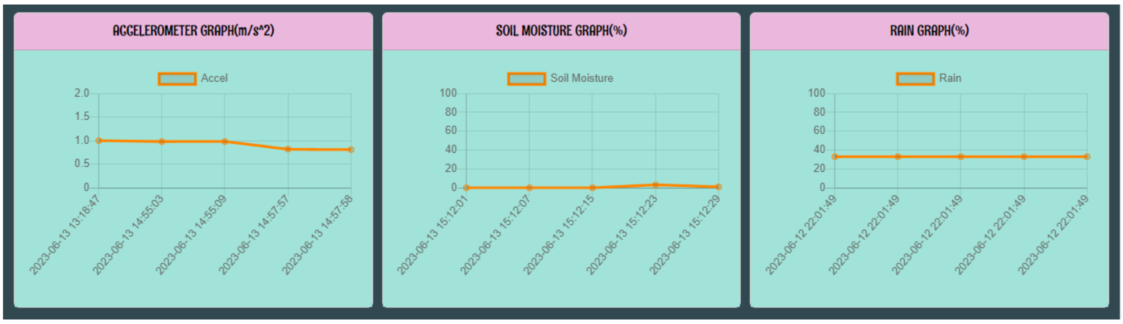


Figure 2.16 Dashboard design

The design above is for the dashboard of the "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system when the application opens. There is the name of the system which is Landslide Detection on the top of the dashboard. It offers a user-friendly interface. It also requires an understandable visual display that provides real-time information on soil moisture, accelerometer and rain value. To make the user not confuse with the graph or chart, the current value of the graph has been provided. There are alarm status that help the user to be aware of the sensor's reading.

Dashboard above shows buttons of actuator and output devices which are servo motor and LED. The button can be used to switch the actuator and output devices on and off. With the help of these features, users can turn the switch on and off from afar.

3.6 Potential Use of Proposed Solution

The suggested real-time "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system has a wide range of applications. It offers continuous, real-time monitoring of rainfall, soil moisture, and accelerometer, enabling the village chief to take prompt action. When problems are discovered, the system may send out alerts and do data analysis to offer early warnings. Furthermore, it allows remote landslide activities. Resource optimization and trend detection are made easier with real-time data visualisation. Overall, the system enhances landslide management efficiency, landslip early warning capabilities, and remote accessibility for quick decision-making.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter four will discuss the implementation, result and discussion of "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system. This chapter's goal is to summarise and assess the system's implementation's outcomes. This chapter provides a full study of the outcomes while delving into the particulars of the developed dashboard and the fuzzy graphs that were generated. At the beginning of the chapter, the characteristics and capabilities of the dashboard are discussed. It displays techniques for data visualisation, user interface layout, and the utilisation of multiple sensors and data gathering devices. Screenshots or other visual representations of the dashboard may be provided to offer readers a thorough understanding of its design and usefulness. We will also look at the result and discussion on the system.

4.2 Implementation, dashboard result and discussion

The following process subchapters will each go into great detail on how each process is carried out during the entire development process of the 'IoT-Based Real-time Landslide Detection Using Fuzzy Logic' system. These processes include the hardware setup, web application development and AI technique implementation respectively.

4.2.1 Hardware Setup

Hardware is the fundamental building block of the "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system. Without it, the system won't have any actuators to control or sensors to gather data from, therefore all the hardware has to be perfectly configured before moving on to other development procedures. The complete hardware configuration is shown in the next figures.

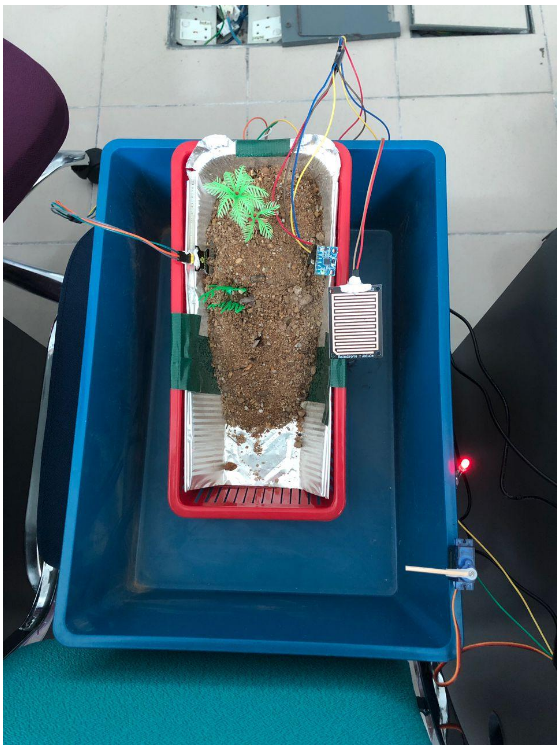


Figure 2.17 Early prototype before improvements

With complete setup, the data needs to be sent to the database which is MySQL by using MQTT protocol. To control the actuators, it can be triggered from the application layer and go back to the sensing layer by using Websocket protocol based on the IoT architecture in Chapter 3.

Then, ESP32 will read the sensor data, and publish the data to the MQTT broker in their own topics because ESP32 has a wifi module. And also, there was a python code in the RaspberryPi to control the actuator. It functions by listening to Websocket events and that will allow it to control it in the system accordingly.

4.2.2 Dashboard result

The figure below shows a dashboard for "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system.

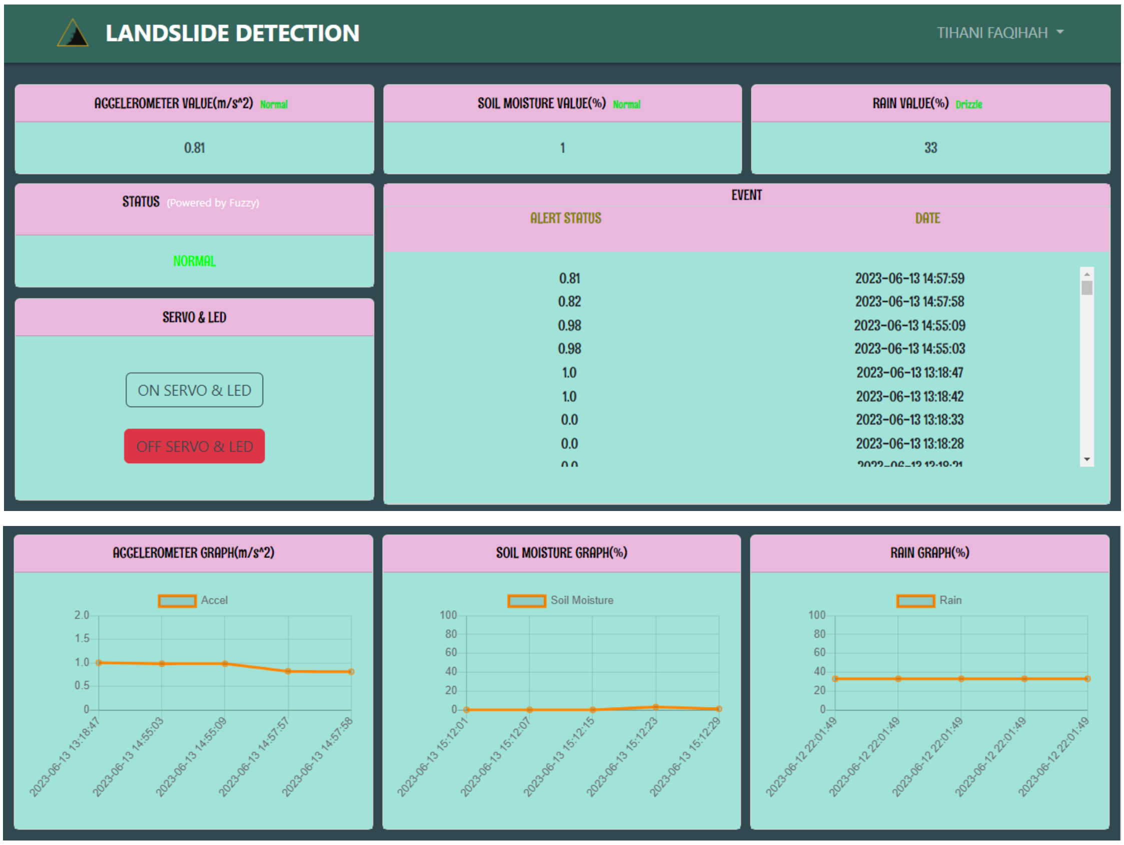


Figure 2.18 Dashboard

The dashboard of "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system provides functional information to the user. Before the dashboard will be displayed, the user needs to login first and for the new user, can be registered because it will make the security tight. Figure above shows that the user can view the data from the sensor in graphs or values. Rain and soil moisture will be in the percentage unit and the accelerometer will be in the meter per second squared (m/s^2).

The rainfall sensor can be read until 100% maximum value. For the soil moisture, the maximum value is 100% then for the accelerometer, the maximum value is 4.0 m/s^2. The unit has been put on the top of the table because it will make it easy for the user to know how to count the value and level.

In the dashboard, there is a status of fuzzy logic. It determines the condition of the landslide based on the data that has been collected. The exact value of fuzzy logic will not be shown on the dashboard because the user will not know the condition of the fuzzy logic that has been created. If the status is normal, it will turn green. If in moderate condition, it will be yellow and if in severe condition, it will show red color.

The alert status table displays the data of the sensors reading if it reaches its threshold. It also shows the date and time to alert the user at what date and time the alert was happening. And also, there is a button to control a servo motor and LED. The servo motor will be stated as a gate and LED symbolizes as a 'danger'.

The dashboard of "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system provides a very good application that functions well. It also provides real-time data of accelerometer, rainfall and soil moisture. All the information provided in the dashboard, will help the user effectively.

4.3 Fuzzy result and discussion

In this project, "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system, fuzzy logic has been used to decide the condition of the landslide based on inputs from the sensors.

Fuzzy logic is used to analyse the accelerometer and soil moisture, two key elements in the smart landslide detection. The system successfully interprets and assesses the sensor data using fuzzy logic, allowing for a more thorough knowledge of the landslide's present condition.

The membership functions, specified rules, and linguistic variables make up the fuzzy logic system. The membership functions used to define the linguistic variables, such as soil moisture and accelerometer, describe the ranges and degrees of membership for each. Based on the measured values of the inputs, the system can classify them as “normal”, “warning” or “danger” using these membership functions.

The links between the input variables and the output variable, which is the state of the landslide, are established by the specified rules in the fuzzy logic system. The rules specify how the system should react to various fusion of the accelerometer and soil moisture, finally identifying the landslide state as “safe”, “warning” or “danger”. For safe conditions, it will be shown from 0% - 30%. Then, for warning conditions, it will be between 31%-60% and for danger conditions will be between 61%-100%.

Fuzzy logic is used to provide prompt and informed decision-making, permitting preemptive steps to reduce hazards and guarantee people's safety. The application of fuzzy logic improves the smart landslide detection's dependability and efficiency, making it a useful tool for risk reduction.

The range for the accelerometer is divided by three ranges which are safe, warning and danger. The range are stated as below in m/s^2 and the membership:

Safe: 0.0 - 0.89(m/s^2)

Warning: 0.90 - 0.99(m/s^2)

Danger: 1.0 - 2.0(m/s^2)

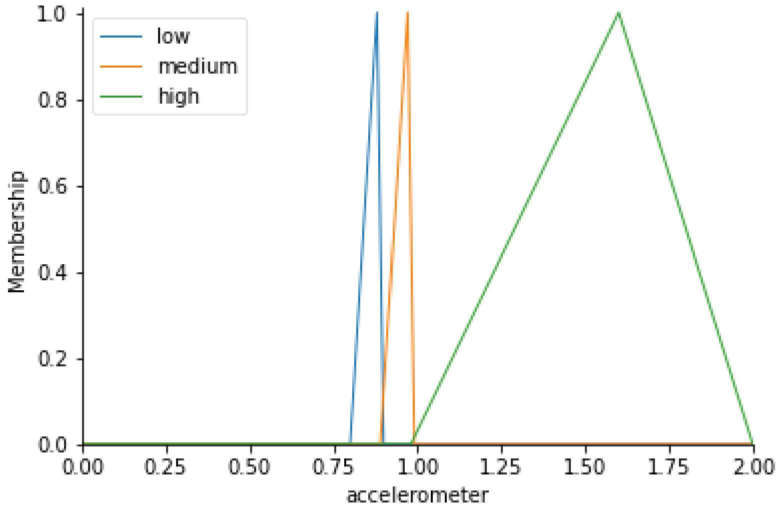


Figure 2.19 Membership function (accelerometer)

The range for soil moisture is divided by three ranges which are dry, normal and wet. The range are stated as below in (%) and the membership:

Dry: 0 - 30(%)

Normal: 31 - 70(%)

Wet: 71 - 100(%)

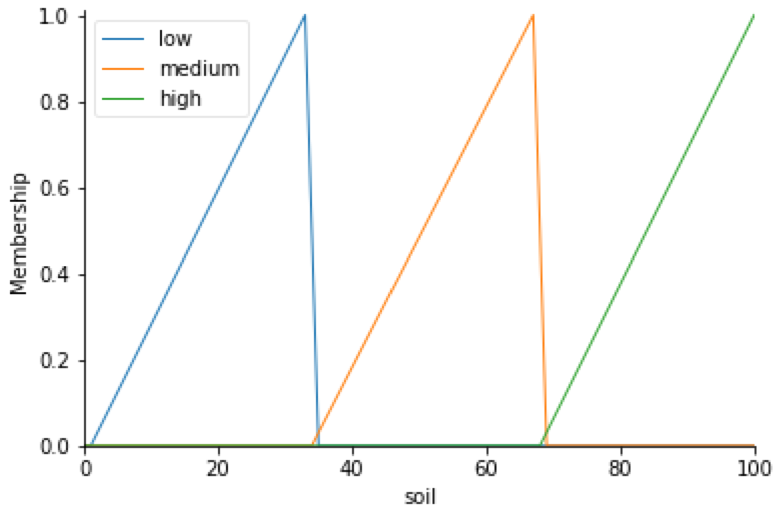


Figure 2.20 Membership function (soil moisture)

From the range above, there was a condition based on accelerometer and soil moisture. The rules are stated as below with the citation range and the membership image:

There are nine rules:

rule1 = ctrl.Rule(accelerometer['high'] & soil['wet'], condition['danger'])

rule2 = ctrl.Rule(accelerometer['medium'] & soil['wet'], condition['danger'])

rule3 = ctrl.Rule(accelerometer['low'] & soil['wet'], condition['danger'])

rule4 = ctrl.Rule(accelerometer['high'] & soil['normal'], condition['warning'])

rule5 = ctrl.Rule(accelerometer['medium'] & soil['normal'], condition['warning'])

rule6 = ctrl.Rule(accelerometer['low'] & soil['normal'], condition['warning'])

rule7 = ctrl.Rule(accelerometer['high'] & soil['dry'], condition['safe'])

rule8 = ctrl.Rule(accelerometer['medium'] & soil['dry'], condition['safe'])

rule9 = ctrl.Rule(accelerometer['low'] & soil['dry'], condition['safe'])

Condition from the accelerometer and soil moisture:

Safe: 0 - 30(%)

Warning: 31 - 60(%)

Danger: 61 - 100(%)

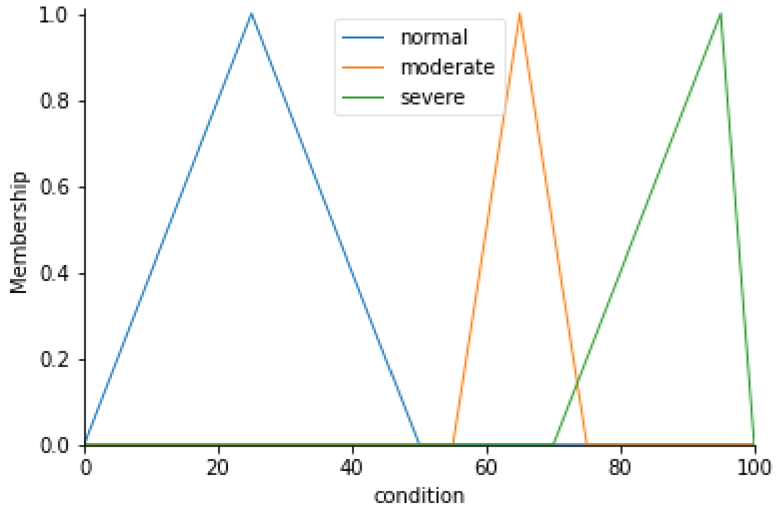


Figure 2.21 Condition (accelerometer and soil moisture)

CHAPTER 5

CONCLUSION

5.1 Introduction

Chapter 5 will discuss the summary of the project that can be used by Pahang State Department of Environment to achieve the objectives and overcome the problems that had been stated earlier. With enhancement in smart landslide detection, it will help a lot of people. To avoid people from being stuck with landslides, this smart landslide detection has been introduced. It also is more efficient because it can be accessed anywhere from afar.

5.2 Conclusion of the project

The ESPDUINO 32 with WiFi connectivity and Raspberry Pi Model 3B+ are two of the microcontrollers that have been successfully incorporated into the smart landslide detection. These microcontrollers have made it possible to record crucial parameters like rainfall, soil moisture, and accelerometer in real-time reading. The system has demonstrated its ability to collect and analyse accurate and reliable data, providing a full understanding of the landslide's current situation.

A key element of the IoT-Based Real-time Landslide Detection Using Fuzzy Logic is the dashboard. It is easy to understand and utilize. The dashboard provides a single platform for visualising and interpreting the obtained data. Important information such as the accelerometer, rainfall, soil moisture and the condition of the landslide are easily accessible to users. The graphical representation of data, which includes charts and color-coded status indications, enhances the system's usability. This makes it easier to make shrewd decisions.

The system's use of fuzzy logic has been significant in assessing the landslide condition. By utilising fuzzy logic approaches, the system is able to handle inaccurate and obscure data, providing a more enlightened evaluation of the landslide situation. The system has been able to classify the condition as "safel", "warning" or "danger" in accordance with the established membership functions and rule base based on the inputs from the accelerometer and soil moisture sensors. This fuzzy logic-based categorization provides meaningful data for assisting in identifying possible dangers and taking appropriate action.

The "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system has potential to fabricate alerts in Telegram. These enterprising alerts will make the user react wisely and fastly when the alerts happen. Then, the alert also will be shown in the dashboard.

In conclusion, "IoT-Based Real-time Landslide Detection Using Fuzzy Logic" system has shown to be a helpful tool for monitoring and assessing the condition of landslides. The incorporation of three sensors, the user-friendly interface, and the implementation of fuzzy logic techniques have improved the accuracy and potency of the landslide detection. The system's ability to produce real-time data, classify landslide conditions, and generate relevant warnings considerably facilitates risk reduction and enterprising decision-making.

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