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Laboratory Model Landslide Monitoring System Using Internet of Things (IoT) Technology

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Abstract

A landslide disaster is one of the natural disasters that has a detrimental impact on society. This impact can be avoided if the community knows the signs of landslides and gets a warning that a landslide will occur. Therefore, this study aims to design an laboratory landslide warning monitoring system based on Internet of Things (IoT) technology. Landslide monitoring using a tilt sensor connected to a web communication network. Before data testing, IoT sensor calibration was carried out. The calibration results showed a coefficient of determination (R^2 = 0.9967), so that this sensor system can be used as a smart sensor in monitoring landslides. In the data acquisition process, the IoT system sends data in real time which is received by the computer via the internet network. The web communication network displays the results in the form of a 2D profile in real time, namely a graph of the slope angle against time. To confirm the web monitoring data, a computer programming language is used to display a 3D profile of the slip plane. The study results show that IoT technology can monitor landslides and the presence of artificial rain in real time with a reading of the soil displacement sensor of 32.4 °. At this angle, a landslide occurs until it deposits under the foot of the slope, with a landslide mass deposition rate of 0.0012 m^3/s. The designed IoT system is portable and permanent and can monitor landslides. This system can be developed more widely in areas prone to landslides for smart communities and can be used as a disaster prevention and mitigation movement in arranging spatial planning based on disaster mitigation. This research can advance our understanding of landslide monitoring dynamics using web-based IoT systems, providing important insights for mitigation strategies and future research.

Introduction

A landslide disaster is one of the natural disasters that has a detrimental impact on humans. The losses incurred can be in the form of material and non-material losses, even to the point of loss of life. Landslides are also the disasters that cause the most deaths, displacement, infrastructure, and environmental damage [1,2], and the number continues to increase every year. Sometimes landslides are caused by human activities [3]. Landslides are found in almost every region in Indonesia, especially in Ambon City when entering the rainy season [4] and when an earthquake occurs [5]. Generally, in the rainy season, the frequency of landslides increases so that landslides are often associated with rain [6]. However, landslides do not always occur during heavy rain, but when it has stopped (only drizzle) for several hours, landslides will occur. Landslides will occur during or after rain if the infiltration of rainwater has been sufficient to saturate the soil and there is a sliding plane, this is what causes the soil to collapse and slide along the slope and out of the slope [7-9]. Rainwater infiltration will move into the soil through the surface vertically [10] in the soil profile as a result of capillary force (water movement in a lateral direction) and gravity (water movement in a vertical direction). This is caused by the driving force being greater than the slope retaining force.

This landslide event usually occurs naturally, and no one knows when the landslide will occur [5]. Therefore, direct research in the field is difficult to do when landslides occur. So, landslides cannot be predicted in advance during the sliding time, especially when calculating slope stability [10]. Therefore, this study uses an laboratory slope model or laboratory model to observe the mechanism of landslides directly. In the laboratory model, residual soil material from the Ambon volcanic formation in the form of sandy clay taken from natural landslides in areas prone to landslides was included. The mechanism of landslide occurrence using a laboratory scale shows the process of landslide dynamics using a loamy sandbox design. As a result, it can be observed that the slope cover soil is destroyed and moves out of the slope and slides along the slope until it settles at the foot of the slope. Many researchers have created laboratory models to understand landslide movements such as Cerbus et al. [11].

Landslide disasters can be avoided if people know the signs of landslides and receive early warning of landslides. Therefore, an early detection tool for landslide disasters is needed that can be monitored in real-time to save human lives and property [12]. Current methods and techniques for landslide monitoring have many limitations and weaknesses [13]. Therefore, various landslide early warning system (LEWS) designs are needed which have been built by various institutions in Indonesia, but this prototype has not been built in Maluku, especially in Ambon City. The designed LEWS uses a slope sensor using an ESP32 microcontroller that will send signals to applications in the cloud using the internet [14], and this system is called Internet of Things (IoT) technology [15-19]. ESP32 is a microcontroller produced by Espressif Systems which has the advantages of resolution of up to 12 bits, smaller size, and cheaper price [20,21]. The IoT system design in this study aims to monitor landslide movements on laboratory slope models. The difference between the designed IoT system and similar system designs that have been carried out lies in the placement of the IoT system on the surface of a plane that has the potential for landslides and data information is sent via web monitoring in real-time in the form of slope angles against the time of landslide mass movement. In this study, LEWS was designed to estimate the level of landslide probability using IoT technology as a means of communication-based on web monitoring that provides data information in real-time and is verified with application software that can process data information in three dimensions (3D), so that mitigation efforts can be made to reduce the effects of disasters when the disaster occurs. Assuming that when the slope angle changes from large to small, the slope cover is ready to move, and in this condition, the IoT system provides a warning signal, and the enumeration continues until the landslide mass is deposited. Determining the level of landslide disaster at this time is still not fast and accurate enough, so technology is needed to support intelligent decision-making. As a result, the development of the IoT system as a new breakthrough is used to monitor landslides in real time, then transformed into a 3D profile of the slip plane.

Research Method

Research design

Laboratory slope model research was conducted to determine the occurrence of landslide-type landslides, and the results of sandy clay material. The research stages began with designing a landslide model in the form of an acrylic box containing sandy clay material (loamy sandbox), preparation of tools and materials, and checking the tools. The following stages in the design of the IoT system use several main components and supporting components.

a. Internet of Things (IoT) system design

The IoT system design combines several components to facilitate the work of the Data Acquisition System (DAS) see Figure 1. This system combines LM2596 as a supply voltage to the MPU6050 sensor component, MUX 1 to 8, and ESP32. The MPU6050 sensor is used to detect the slope of the slope surface, and this sensor is connected to the ESP32 microcontroller. From the SAD above, there is an MPU6050 sensor connected to the ESP32 with the help of the I2C Multiplexer digital component. The MUX receives signals from the MPU6050 sensor and sends data to the ESP32 microcontroller. ESP32 is an IoT system that is then packaged in the form of IoT technology. IoT technology is developed to collect data from sensors, analyze the collected data, and display data on web monitoring [13].

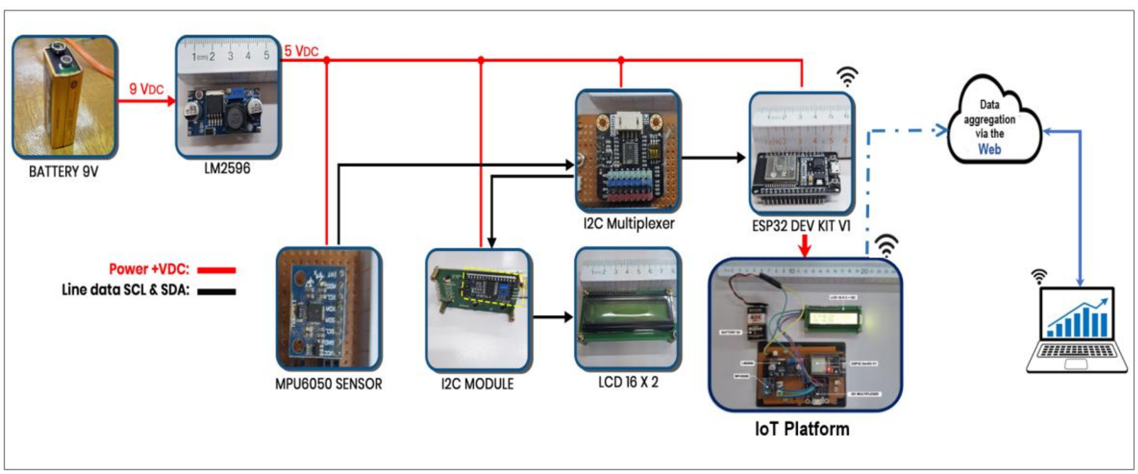

Figure 1. IoT Component and Communication Integration Scheme.

b. Laboratory slope model design

The laboratory model as a research medium is made of acrylic material in the form of a box with dimensions of 80 cm long, 45 cm wide, and 50 cm high, filled with sandy clay material as high as 40 cm as the parent rock, arranged as in Figure 2. (a). Sandy loam soil was inserted into the laboratory model, then an artificial slope was created with an angle of 38.3 degrees, and served as a research object. The soil type and slope are set to be the same as those on the field.

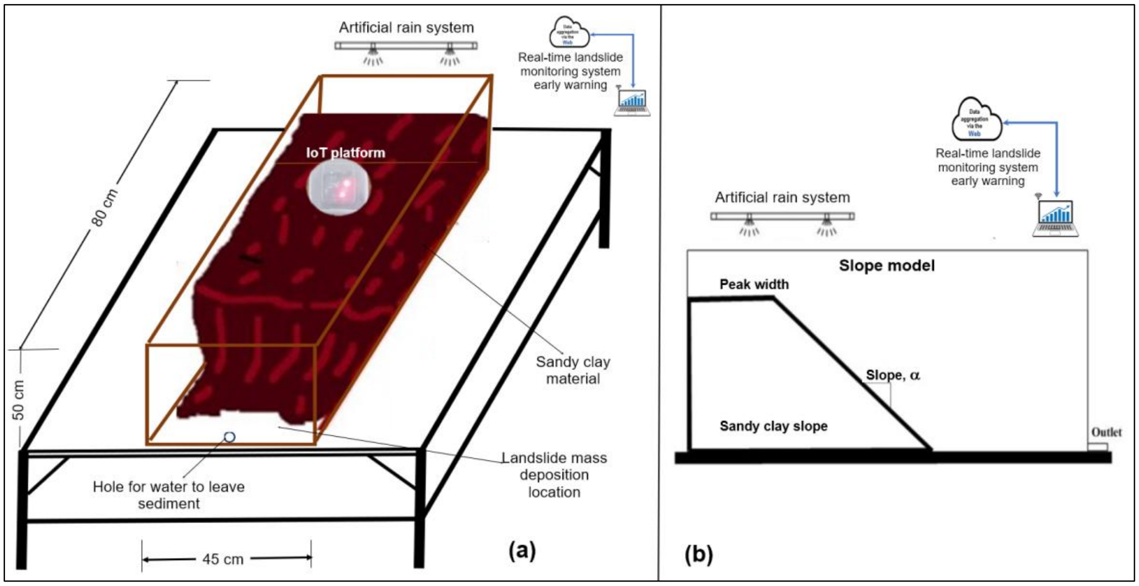

Figure 2. (a) Dimensions of the analog slope model and IoT platform, (b) Side view of the analog slope model.

Research set-up

The equipment used for the study (Figure 2. (a)) consists of a rectangular box made of acrylic material to be used as a visual observation of the infiltration and triggering process. The acrylic box is 80 cm long, 45 cm wide, and 50 cm high. To ensure equal friction between soil particles and the bottom of the channel (flume). A waterproof barrier is installed in front of the artificial slope to contain the soil mass after the landslide occurs, while the IoT system is used to monitor the landslide in real time, destroying the slope cover until it settles below the slope. Spray nozzles are properly placed on the artificial slope to create artificial rainfall with a raindrop size distribution and impact energy consistent with the analog slope model. Artificial rainfall falls at a constant velocity.

This research used an laboratory slope angle of 38.3°. The magnitude of this landslide slope angle usually occurs in Ambon City [10]. After the analog slope design is made, the IoT system is placed in the middle position of the slope plane to observe the slipping process throughout the analog slope model. At the bottom of the slope, a small hole is made for the water to exit leaving the sediment (Figure 2. (a)).

Data acquisition

Data collection through laboratory model research activities begins with:

a. The model used as an investigation field has an area below the laboratory slope of 80x45 cm^2 (Figure 2. (a)). The distance between the bottom of the slope and the barrier is 25 cm with a slope angle of 38.3°, and stable artificial rain is provided from the nozzle.
b. Data acquisition before and during the process of slope surface destruction until the landslide mass settles using IoT technology. IoT technology will track and send data in real-time received by the computer via web monitoring.

c. To determine the speed of landslide mass deposition, measurements were made of soil mass (m_t), water mass (m_a), landslide material deposition mass (m_d), soil moisture (h_t), volumetric water content (θ_v), volume during the deposition process (V_d), and the time of landslide mass movement until it settles (t_d).

Data processing

Data processing steps are carried out based on the results of laboratory slope model measurements as follows:

a. During the experiment process, the IoT system will send real-time data received by the computer via web monitoring. Web monitoring will display the measurement results in the form of graphs in real-time, namely changes in surface slope that change with landslide run time. To verify web data, a computer application program is used to display three-dimensional (3D) graphs both before the landslide event and after the landslide occurs.

b. The determination of the friction coefficient is calculated by involving the variables of slope height (H), landslide reach distance (R), and the time of landslide mass movement until it settles (t_d). Thus, the landslide mass velocity as a function of time is calculated using the equation [1,4]:

$$\Delta v = g \sin\alpha \left(1 - \frac{\tan\phi}{\tan\alpha}\right)\Delta t_{\mathrm{d}} \quad (1)$$

with g = gravitational acceleration, (= 9.81 m/s2), α = slope angle (°), ϕ = internal friction angle (°), and Δt_d = change in the run time of landslide mass deposition.

c. To determine the concentration of landslide mass sedimentation (cs), a volume of 0.25 liters of landslide mass sedimentation was taken, and the mass of filter paper and sediment was weighed so that the results could be used to determine $c_s = \frac{m_{tf} - m_f}{V_{\mathrm{d}}}$, (mg/liter). Next, the landslide mass deposition speed is calculated using the formula: $Q_s = Q \times c_s$ [22]. Plot the graph between landslide mass velocity and landslide mass deposition rate.

Result and Discussion

Working principle of data acquisition system with IoT technology

After the IoT system is designed, the system is calibrated. The calibration results showed a coefficient of determination (R^2 = 0.9967) as in Figure 3 (top left), so that this sensor system can be used as a smart sensor in monitoring landslides. The IoT system is placed in the middle of the analog slope field so that the calibrated slope surface slope sensor can detect the destruction of the slope cover and move along the slope until it settles at the foot of the slope. In the process of destruction, the IoT system will send sensor data online which is received by the computer through a real-time web monitoring system in the form of an angle versus time graph, and computer application software is also used to verify data information in the form of 3D graphics.

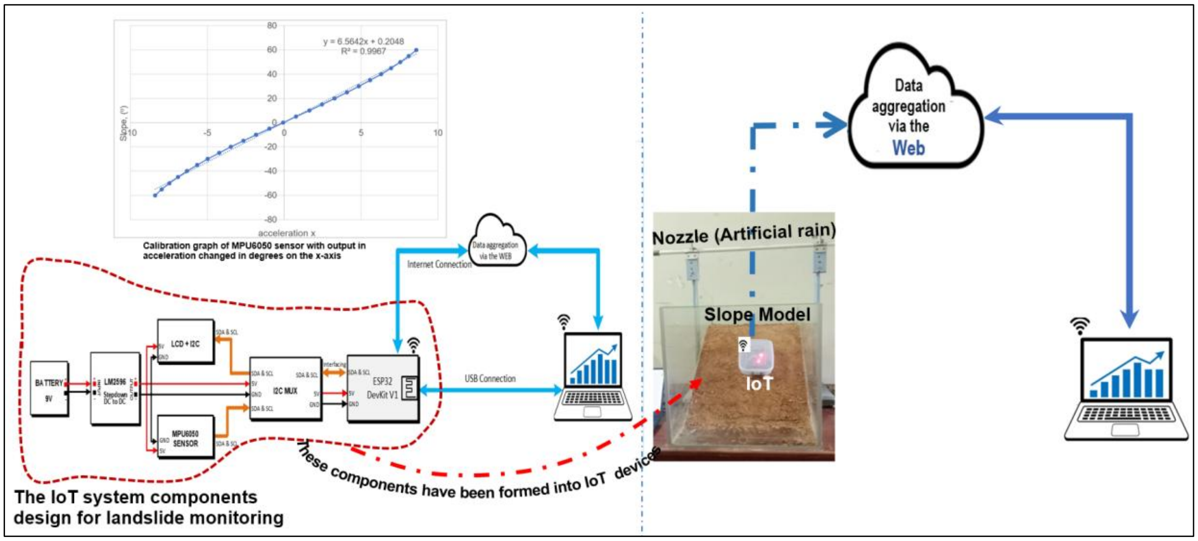

Figure 3. Data acquisition system network with IoT technology

Laboratory slope model land movement using IoT technology

This section describes the results of real-time monitoring of laboratory slope model landslides, warning systems using IoT, and calculations of landslide mass deposition rates.

a. The IoT system is placed on a plane surface

The IoT system is placed on a flat surface or the crown of the slope (Figure 4 bottom left), then the web monitoring will display the measurement results in the form of a 2D graph in real-time (Figure 4. (c)). This graph shows the change in average surface slope over time. On the other hand, a computer application program is used to display three-dimensional (3D) graphs as in Figure (4. (a), (b), (c)). The measurement results (Figure 4. (a), (b)) using a computer application program show a slope angle in the horizontal direction (x-axis) of 1.5° and in the vertical direction (y-axis) of 1.7°, and the 3D graphic display (Figure 4. (c)) shows a slope angle of 1.5°. 1.5°. Meanwhile, data information from web monitoring produces changes in slope angle over time in real-time (1.47 – 1.62)°. This means that the measurement results between web monitoring and computer application programs are almost the same so that the next process can be used for calculations and graphing.

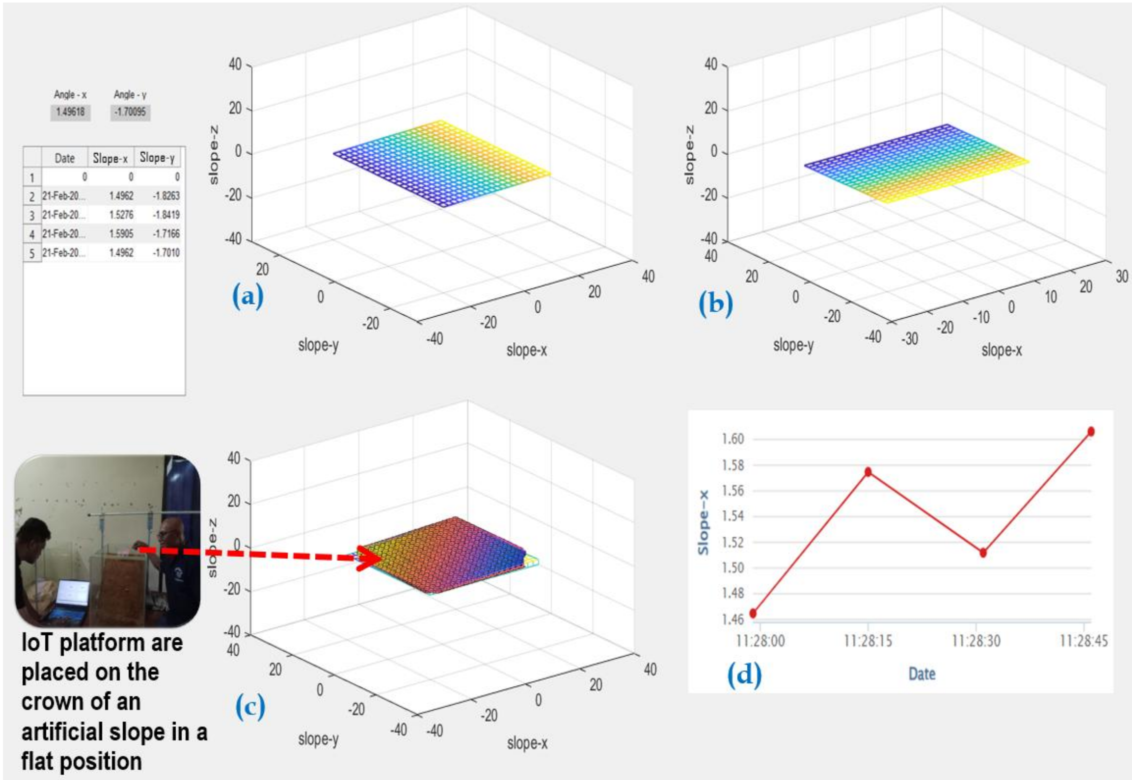

Figure 4. Before the research was conducted, the IoT platform was placed on a laboratory slope model on top of the sloped crown. (a) View of the slope model in a flat plane direction, (b) view of the slope model in a vertical plane direction, (c) view of the slope model on a flat plane with a slope of 1.5°, and (d) real-time view for research preparation.

b. The IoT system is placed on an inclined plane

The IoT system is placed in the middle of an inclined plane (laboratory slope) as shown in Figure 5 on the bottom left. The measurement results using real-time web monitoring (Figure 5. (d)) obtained a constant slope angle over time of 38.3°. While the measurement results (Figure 5. (a), (b)) using a computer application program show a slope angle in the horizontal direction (x-axis) of 38.3°, and in the vertical direction (y-axis) of 3.2°, and the 3D graphic display (Figure 5. (c)) shows a slope angle of 38.3°. This shows that the measurement results between web monitoring and computer application programs are the same at a slope angle of 38.3 degrees. Therefore, this laboratory slope angle is used as a landslide monitoring process.

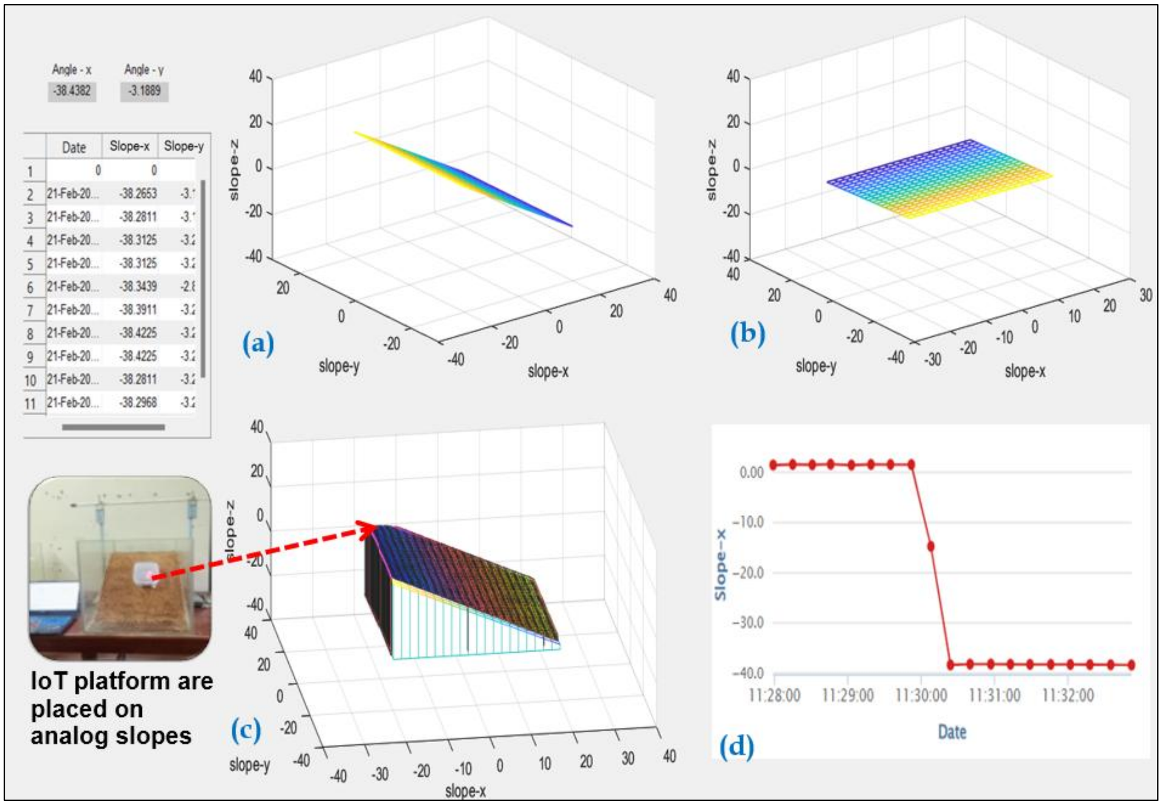

Figure 5. Before the research was conducted, the IoT system was placed on the landslide area. (a) Display of the slope gradient in the direction of the landslide area, (b) display of the slope gradient in the direction of the vertical landslide area, (c) display of the laboratory model slope with a slope of 38.3°, and (d) real-time display for research preparation with a slope angle of 38.3°.

c. Landslide monitoring using IoT technology

The IoT system is placed in the middle of an inclined plane as shown in Figure 6 on the bottom left. Furthermore, artificial rain is given from the nozzle continuously with a falling velocity of 1.02 m/s until the slope cover soil is saturated with water and destroyed moving down the slope due to gravity and settling at the foot of the slope.

Next, web monitoring will display the measurement results in the form of a 2D graph in real-time (Figure 6. (d)) which starts with a constant angle of 38.3°, and when the slope angle reaches 32.4° the slope cover soil is destroyed and moves down the slope, and ends the enumeration. While monitoring land movement with a computer application program, a 3D graph is displayed as in Figure (5. (a), (b), (c)). The measurement results (Figure 5. (a), (b)) using a computer application program show a slope angle in the horizontal direction (x-axis) of 32.4° and in the vertical direction (y-axis) of 3.2°, and the 3D graphic display (Figure 6. (c)) shows a slope angle of 32.4°. This means that the measurement results between web monitoring and the computer application program in real-time are the same as the slope angle of 32.4°. As a result, the laboratory slope cover soil is destroyed and moves along the slope with an angle reaching 32.4°, and shows a shift in the slope surface slope. According to [23], the real-time prediction method makes landslide warnings more accurate, and timely as internal mechanical vibrations of landslide slope failure, from landslide slope displacement data. Why use a laboratory slope angle of 38.3°, and the slope angle decreases to 32.4° when a landslide occurs? When the slope cover is in a stable state (angle 38.3°) artificial rain is given to the slope surface, then the slope begins to be saturated with water. The destroyed slope cover will slowly move down the slope so that the slope surface angle at the destroyed part slowly decreases, and the slope sensor also shifts down the slope together with the sliding of the landslide mass until it reaches the foot of the slope.

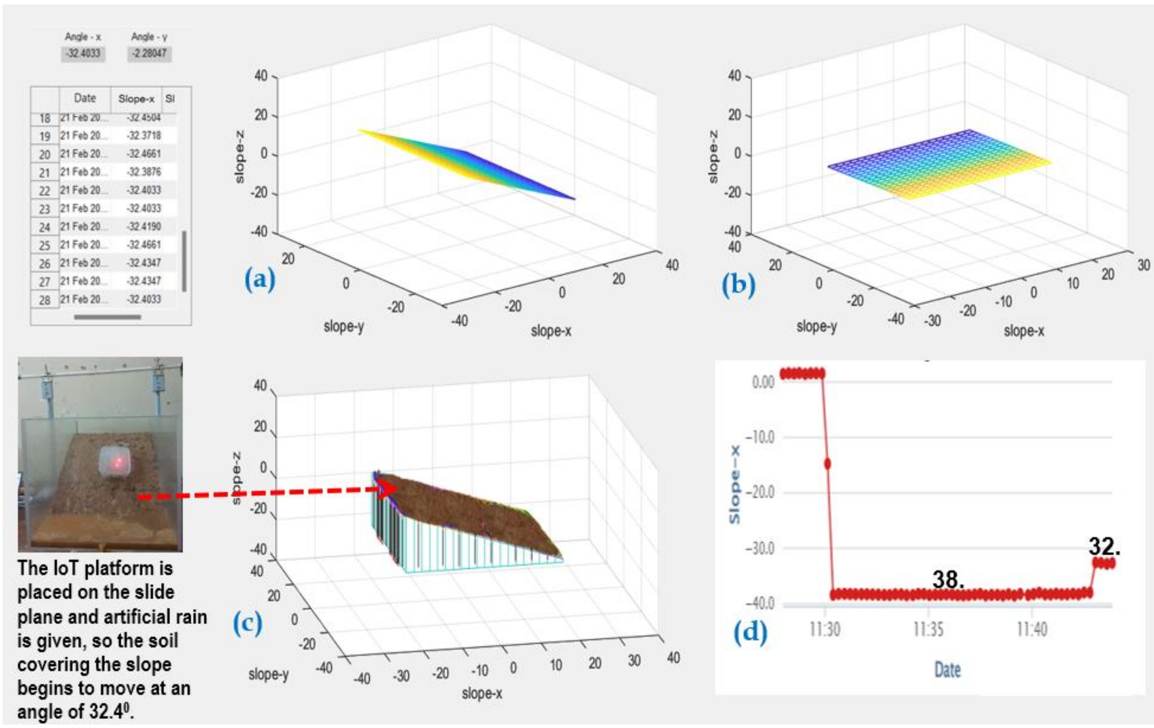

Figure 6. Research process, the IoT system is placed on the laboratory model slope plane. (a) Display of the slope gradient in the direction of the landslide plane, (b) display of the slope gradient in the direction of the vertical landslide plane, (c) display of the laboratory model slope when the overburden is destroyed with a slope of 32.4° and moves along the slope, and (d) Real-time display when the research is carried out until the slope is in a critical condition and moves at an angle of 32.4°.

Determination of landslide mass runoff velocity and deposition rate

Based on the infographics (Figures 7 and 8), it shows that the magnitude of the landslide mass deposition rate is very significant, depending on the shift of the landslide mass against the landslide run time and the slope angle. From the study, it was found that the analog slope model can indicate landslide events. The presence of rainwater causes the slope to crack. As time passes, the cracks get bigger, and the water-saturated slope cover mass moves outward following the slope so that the slope equilibrium is exceeded [4].

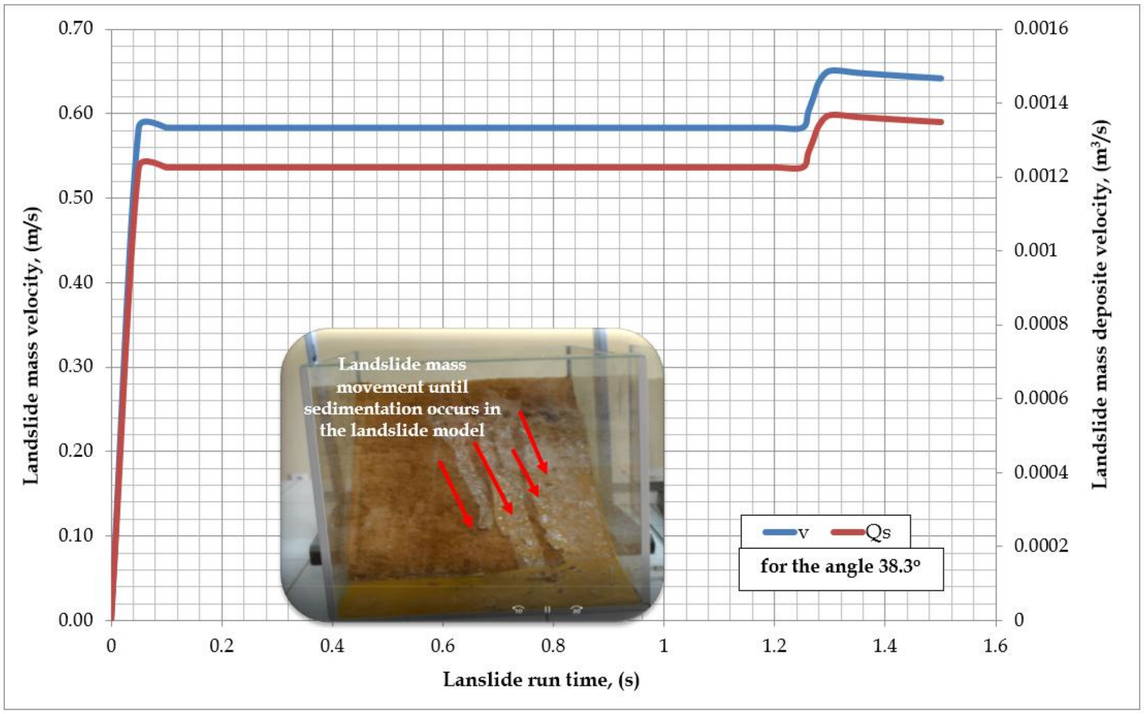

Figure 7. Landslide mass runoff velocity and deposition rate as a function of landslide runoff time for a slope angle of 38.3°.

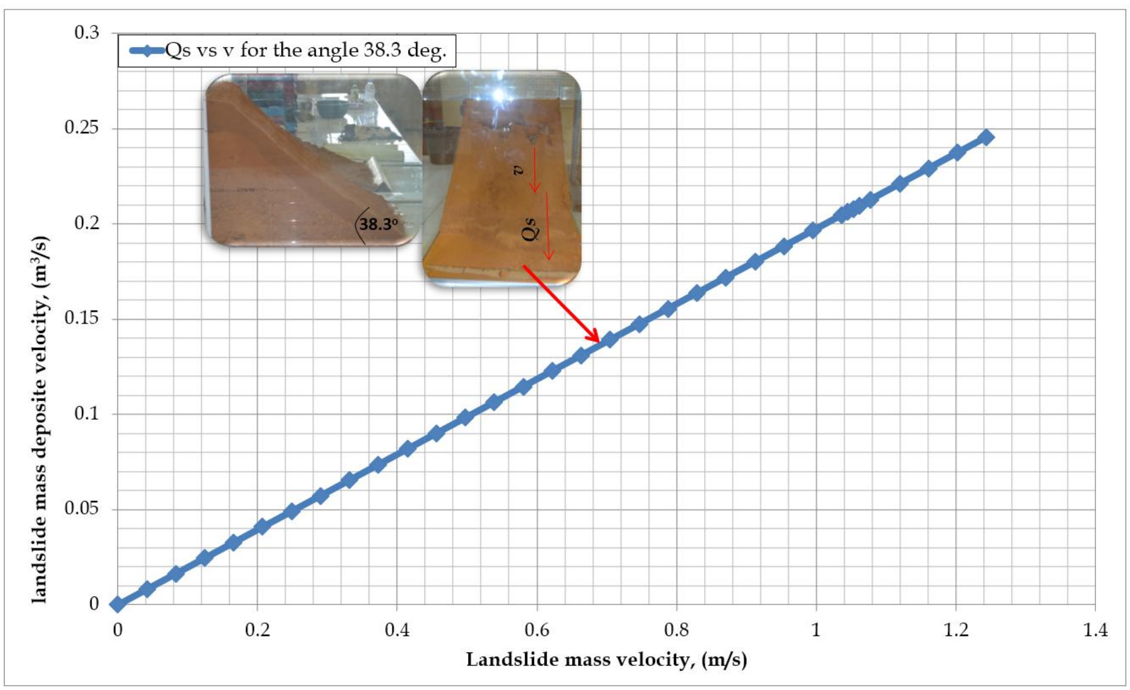

Figure 8. Landslide mass deposition rate as a function of landslide runoff velocity.

Based on the results of the study of landslide mass movement in a laboratory model using IoT technology, it shows that at a slope of < 38.3°, the mass of the slope cover begins to move, and until the slope reaches 34.5°, the slope is in a critical state, and until the slope reaches 32.4° the mass of the slope cover is released and moves along the slope until it is deposited under the foot of the hillside (Figure 6). Based on the laboratory slope angle of 38.3°, it shows that the landslide speed reaches a maximum and constant value of 0.58 m/s occurring at an initial counting time of 0.05 seconds to 1.25 seconds (Figure 7). It provides a landslide mass deposition rate of 0.0012 m^3/s. Thus, when the landslide movement process follows the slope and settles, the process is the same as in the field. When the soil covering the slope is saturated with water and destroyed, it will move down the slope, and then settle under the hillside. Meanwhile, for LEWS monitoring using IoT technology and calculating the predicted rate of landslide mass sedimentation obtained in the laboratory model is a prototype that can be tested and developed widely in areas prone to landslides by adding several sensors to the Arduino or sensor network [24]. The landslide movement process that occurs on the laboratory slope can be observed directly and in real time, but the landslide event process in the field cannot be observed directly [23]. It is hoped that the existence of an early detection device system for landslide disasters using laboratory models of IoT technology, can be a basis for further research using slope reinforcement on the prototype of landslides, and then applied to areas prone to landslides.

For the application of IoT systems in areas prone to landslides, the IoT system is developed by adding several sensors such as soil sensors, soil moisture, soil conductivity, and temperature. The design of these future IoT sensors is integrated with a cloud communication network for real-time landslide monitoring. Landslide warning system through the integration of IoT devices and cloud communication that has high sensitivity, relatively short information delivery and analysis time, low cost [25], and is environmentally friendly. The IoT smart device developed is portable and permanent, which can monitor landslides using a smartphone or laptop, and if a landslide occurs, the IoT protocol provides a warning signal, then disseminated to the public via smartphones as an effort to mitigate the risk of landslide disasters due to climate change. This research can advance our understanding of landslide monitoring dynamics using web-based IoT systems, providing important insights for mitigation strategies and future research.

Conclusion

A study has been conducted on the design of a landslide monitoring system on a laboratory slope model using IoT technology. Based on the research results, the IoT system can monitor landslides and the presence of artificial rain in real time with a ground displacement sensor reading of 32.4°. At this angle, a landslide occurs until it deposits under the foot of the slope, with a landslide mass deposition rate of 0.0012 m^3/s.

The proposed IoT-based landslide monitoring system design is both portable and permanent. This system also has high sensitivity, relatively short information delivery and analysis time, low cost, and is environmentally friendly. To conduct further research in the natural environment or landslide-prone areas, it is necessary to develop smart IoT devices by adding several IoT sensors such as soil sensors, soil moisture, soil conductivity, and temperature, and equipped with solar panels. Thus, the IoT system can detect and monitor landslide-prone areas to be disseminated to the community and can be used as a disaster prevention and mitigation movement in preparing disaster mitigation-based spatial planning.

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