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Piezoelectric-Based Staircase Lighting System with IoT Monitoring

James Tulende[1*], Lusia Rakhmawati[2], Unit Three Kartini[3], Miftahur Rohman[4]
[1,2,3,4]Universitas Negeri Surabaya
jamestulende.21001@mhs.unesa.ac.id

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Abstract

Renewable energy plays an important role in overcoming the negative environmental impact of fossil fuel-based energy consumption. One of the renewable energies is piezoelectric technology that can convert mechanical stress into electrical energy. In this research, piezoelectricity is used to convert energy from human movement on stairs into electricity that can be used for lighting and monitored by IoT. Monitoring is done through the Arduino IoT Cloud Remote application on a smartphone in real-time. Tests were carried out with 15 steps on the prototype stairs, both up and down, to measure the voltage generated. Test results show that the voltage when body weight >75 kg can reach 3V when climbing stairs, while when descending stairs body weight >44 kg can reach a voltage of 3V.

Keywords: Piezoelectric, ESP32, Internet of Things.

Abstrak

Energi terbarukan berperan penting dalam mengatasi dampak negatif lingkungan dari konsumsi energi berbasis bahan bakar fosil. Salah satu energi terbarukan adalah teknologi piezoelektrik dapat mengubah tekanan mekanik menjadi energi listrik. Dalam penelitian ini, piezoelektrik digunakan untuk mengonversi energi dari pergerakan manusia pada tangga menjadi listrik yang dapat digunakan untuk penerangan dan dimonitoring secara IoT. Pemantauan dilakukan melalui aplikasi aplikasi Arduino IoT Cloud Remote pada smartphone secara real-time. Pengujian dilakukan dengan 15 kali pijakan pada prototipe anak tangga, baik saat naik maupun turun, untuk mengukur tegangan yang dihasilkan. Hasil Pengujian menunjukkan bahwa tegangan ketika berat badan >75 kg dapat mencapai 3V pada saat naik tangga, sedangkan pada saat turun tangga berat badan >44 kg dapat mencapai tegangan 3V.

Kata kunci: Piezoelektrik, ESP32, Internet of Things.

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INTRODUCTION

Energy is a vital element that supports the sustainability of human life on earth. The need for humans to find new energy sources is increasingly driven by global conditions that show that fossil energy reserves are decreasing due to their non-renewable nature (Almanda et al., 2015). The use of renewable energy resources, such as the latest harvesting technologies, has an important role in reducing dependence on fossil fuels (Sih Setyono et al., 2019). One such technology is piezoelectric energy harvesters (PEH), which convert energy from mechanical vibrations into electrical energy (Abedanzadeh et al., 2023) (Wakshume & Płaczek, 2024)) (Li et al., 2023.

Piezoelectricity is one of the environmentally friendly renewable energy source options. This environmentally friendly electrical energy can be generated from resources that are wasted without realizing it. Utilization of the pressure generated by human steps in locations with high mobility. Piezoelectricity can be integrated in shoes, stairs, roofs (Boby et al., 2014) (Alfraidila et al., 2022) (Zebua et al., 2019).Research on energy harvesting using piezoelectricity has been carried out by a number of researchers. Research conducted by Raja Hendry (Ade, 2020). In this study, a prototype tool for stairs using 12 piezoelectrics will produce voltage, current and power which are measured using a digital multimeter. However, this research still does not use Internet of Things (IoT) technology.

In this research, a prototype of a lighting system on stairs that utilizes piezoelectricity with Internet of Things (IoT) based monitoring will be designed and made. This research presents an innovation by integrating IoT technology into a piezoelectric-based staircase prototype as an interface for monitoring. The INA219 sensor is used to measure the voltage generated by the piezoelectric circuit. The ESP32 microcontroller serves as the main controller connected to the IoT platform. Data from the INA219 sensor is processed by ESP32, then sent to the internet to be displayed through the Arduino Cloud web server and the Arduino IoT Cloud Remote application. This tool can operate automatically and will send notifications to the Arduino IoT Cloud Remote application when the device is active, as well as monitoring voltage remotely through the website and Android application in real-time.

Piezoelectric

Piezoelectricity is a material that can produce electrical energy when mechanically stressed and stretched and vice versa. Piezoelectric energy harvesting technology is able to collect and use various vibrational energies, which are always present in the human environment (Muhsinin et al., 2022) (Edlund & Ramakrishnan, 2019).

Figure 1. Piezoelectricity

Diode Bridge

When piezoelectric elements are stressed, they produce an AC voltage. A diode bridge converts this voltage to DC, so it can be used to charge batteries or capacitors (Ketut Hariyawati Dharmi et al., 2021).

NodeMCU ESP32

The NodeMCU ESP32 integrates the ESP32 chip, which is a 32-bit microcontroller with Wi-Fi and Bluetooth capabilities. This chip has a dual-core architecture with a clock rate of up to 240 MHz, and is equipped with various features such as ADC (Analog to Digital Converter), DAC (Digital to Analog Converter), and various GPIO (General Purpose

Input/Output) pins for interfacing with other devices. ESP32 is widely utilized for connection purposes in IoT implementation (Adeagbo, 2024).

Figure 2. ESP32

INA219 Sensor

The INA219 is a sensor module that can monitor voltage and current in an electrical circuit. This module is equipped with an I2C interface or SMBUS compatible, which allows monitoring of shunt voltage and bus voltage supply, and is equipped with program time conversion and filtering. This sensor works by calculating the value of the current flowing through the series connection of the Vin+ and Vin- terminal blocks (Tri Monda & Santi Rudati, 2018) (Wicaksono et al., 2023).

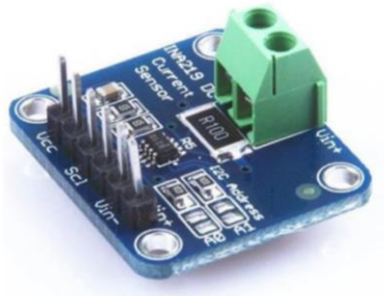

Figure 3. INA219 sensor

Internet Of Things

IoT is a network of sensors connected via the internet or intranet, allowing communication between machines or servers without the need for human intervention. Each device in this network has a unique internet protocol (IP) address. IoT operates by utilizing programming instructions, where each command can generate a language that is understood by other connected devices automatically, even over great distances (Yomeldi, 2020))(Selay et al., 2022.

Arduino IoT Cloud Remote

Arduino IoT Cloud IDE is used to program microcontrollers to perform IoT functions, and provides various libraries that can be utilized in the development process (Yohan Husnira, 2023).

Figure 4 shows the block diagram of the piezoelectric-based lighting monitoring system with IoT. This system operates through a series of components that are integrated with each other. First, the INA219 Sensor is used to acquire data from the connected piezoelectric circuit to measure the voltage generated. This data is then controlled by the NODEMCU ESP32, which serves as the brain of the system and runs the program to process the information. Furthermore, the Relay acts as an electromechanical switch controlled by electrical signals from the NODEMCU ESP32, enabling the control of electricity flow to the LEDs. Users can monitor and control the system through the Arduino IoT Cloud Remote App, which provides a user interface to view the data collected from the sensors. Finally, the LEDs serve as visual indicators to show the status of the system, providing immediate feedback to the user regarding the operation of the controlled lighting.

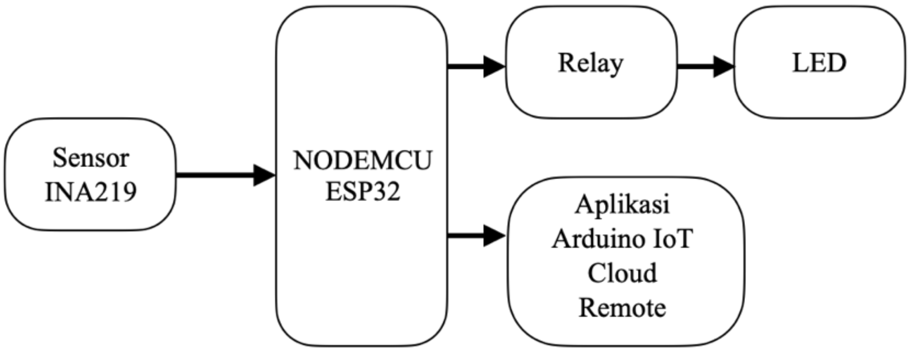

Figure 4. System Block Diagram

In Figure 5, the prototype specifications have a height of 15 cm, a width of 30 cm, and a length of 40 cm to match the stairs in Building A8 FT Engineering Surabaya State University. In the installation of 15 piezoelectrics, the positive part of one piezo element is connected to the negative part of the next piezo element, and likewise the positive part of the next piezo element is connected to the negative part of the next piezo element, with this process repeating sequentially. While Figure 6(b) shows a series of 15 piezoelectrics in parallel, all the positive parts of each piezoelectric element are connected into a common point, and all the negative parts of each piezoelectric element are connected into a common point.

Figure 5. Prototype Stair Step

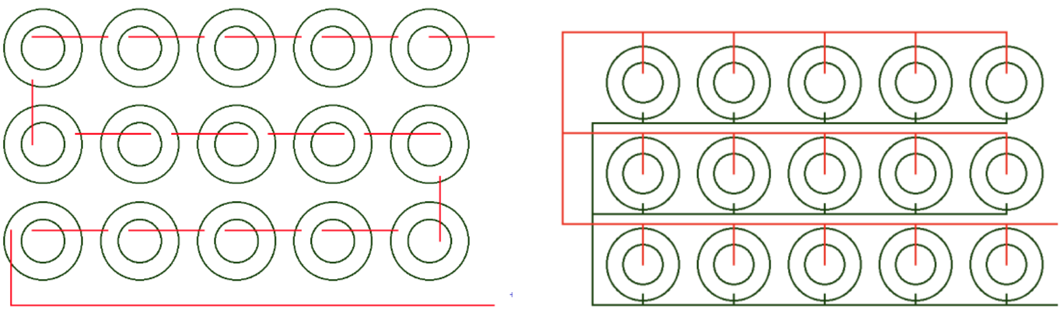

Figure 6. (a) Series Piezoelectric circuit, (b) Parallel Piezoelectric circuit

Figure 7 shows the Piezoelectric Hardware Wiring produces AC voltage and current output, so a diode bridge or rectifier circuit is needed to convert the output into DC voltage and current. The rectifier circuit will be assembled on a PCB using four diodes to convert the AC voltage generated by the piezoelectric into a DC voltage. The output of the rectifier circuit is then connected to a 25V capacitor for temporary storage. After that, the voltage detected by the INA219 sensor is sent to the NodeMCU ESP32 as a microcontroller, which then sends the data to the Arduino IoT Cloud Remote application. When the voltage reaches 3V, the system will read and send a signal to the relay to turn on the LED.

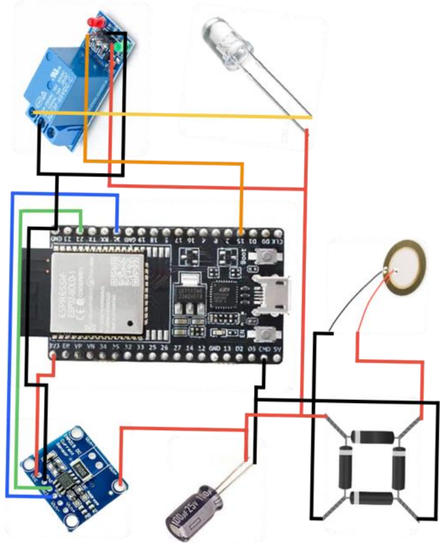

Figure 7. Wiring Hardware

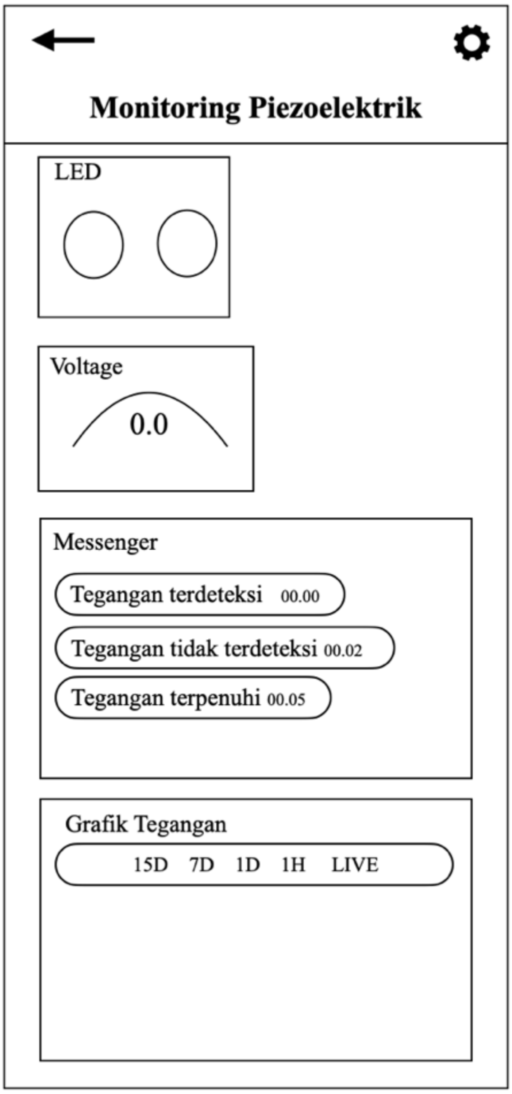

Figure 8. Sketch of Monitoring in the Application

In Figure 8 is a sketch of the monitoring system in the Arduino IoT Cloud Remote application where the value displayed is Voltage, . In addition to displaying the value, the Arduino IoT Cloud Remote made has a notification if the Voltage value has three different conditions. Where the first condition if the voltage read by the sensor < 1 V message displayed voltage is not detected, while the voltage read by the sensor > 1 V message displayed is the voltage detected, and if > 3 V message displayed is the voltage is met and lights the LED. The application display also shows a graph of the voltage that has been generated in the prototype in real time.

RESULTS AND DISCUSSION

Piezoelectric Series Circuit Prototype Testing

Table 1. (a) Testing by Climbing Stairs, (b) Testing by Descending Stairs

Weight (Kg)	Voltage (V)	Current (m)A	Power (m)W
32	1,32	0,04	0,052
36	1,36	0,05	0,068
40	1,39	0,05	0,069
44	1,45	0,07	0,101
50	1,48	0,08	0,134
55	1,52	0,09	0,136
58	1,55	0,13	0.201
60	1,57	0,16	0.251
62	1,58	0,18	0.284
65	1,61	0,22	0.354
67	1,63	0,24	0.391
70	1,66	0,28	0.464
75	1,69	0,31	0.523
80	1,72	0,33	0.567
108	1,77	0,34	0.601

Weight (Kg)	Voltage (V)	Current (m)A	Power (m)W
32	1,38	0,06	0,082
36	1,40	0,07	0,098
40	1,45	0,08	0,116
44	1,48	0,08	0,118
50	1,53	0,09	0,137
55	1,54	0,10	0,154
58	1,58	0,18	0,2844
60	1,63	0,24	0,3912
62	1,65	0,27	0,4455
65	1,69	0,31	0,5239
67	1,70	0,32	0,544
70	1,73	0,35	0,6055
75	1,75	0,38	0,665
80	1,77	0,41	0,7257
108	1,80	0,45	0,81

In testing the prototype of the piezoelectric series circuit by climbing stairs, the average of 15 steps can be seen in table 1 (a) The power generated is calculated using the formula P = V x I. At a weight of 32 kg, the power generated was 0.052 mW, and at a weight of 108 kg, the power generated increased to 0.601 mW. Testing the prototype of the piezoelectric series circuit by going down the stairs in Table 1(b) The voltage and current generated increase with the increase in the weight of the person doing the footing. At a weight of 32 kg, the generated power is 0.082 mW, and at a weight of 108 kg, the generated power reaches 0.810 mW.

Piezoelectric Parallel Circuit Prototype Testing

Table 2. (a) Testing with Stairs Up, (b) Testing with Stairs Down

Weight (Kg)	Voltage (V)	Current (mA)	Power (m)W
32	1,46	0,32	0,467
36	1,52	0,37	0,562
40	1,57	0,40	0,628
44	1,61	0,45	0,724
50	1,65	0,47	0,775
55	1,68	0,51	0,856
58	1,70	0,55	0,935
60	1,71	0,58	0,991
62	1,72	0,60	1,032
65	1,73	0,61	1,055
67	1,74	0,62	1,078
70	1,74	0,62	1,078
75	1,76	0,63	1,108
80	1,78	0,66	1,174
108	1,79	0,69	1,235

Weight (Kg)	Voltage (V)	Current (mA)	Power (m)W
32	1,54	0,40	0,616
36	1,57	0,44	0,690
40	1,63	0,48	0,782
44	1,65	0,52	0,957
50	1,68	0,58	0,974
55	1,72	0,60	1,032
58	1,76	0,63	1,108
60	1,77	0,65	1,150
62	1,78	0,66	1,174
65	1,78	0,66	1,174
67	1,79	0,69	1,235
70	1,79	0,69	1,235
75	1,81	0,71	1,285
80	1,83	0,72	1,317
108	1,86	0,74	1,376

In testing the prototype of the piezoelectric parallel circuit by climbing stairs, the average of 15 times the footing, can be seen in table 2 (a) The power generated is calculated using the formula P = V x I. At a weight of 32 kg, the power generated was 0.467 mW, and at a weight of 108 kg, the power generated increased to 1.235 mW. Testing the piezoelectric parallel circuit prototype by going down the stairs in Table 2(b) The voltage and current generated increase with the increase in the weight of the person doing the footing. At a weight of 32 kg, the power generated was 0.616 mW, and at a weight of 108 kg, the power generated reached 1.376 mW.

Comparison of Series and Parallel Circuit Prototypes

Graph of stress rise against weight

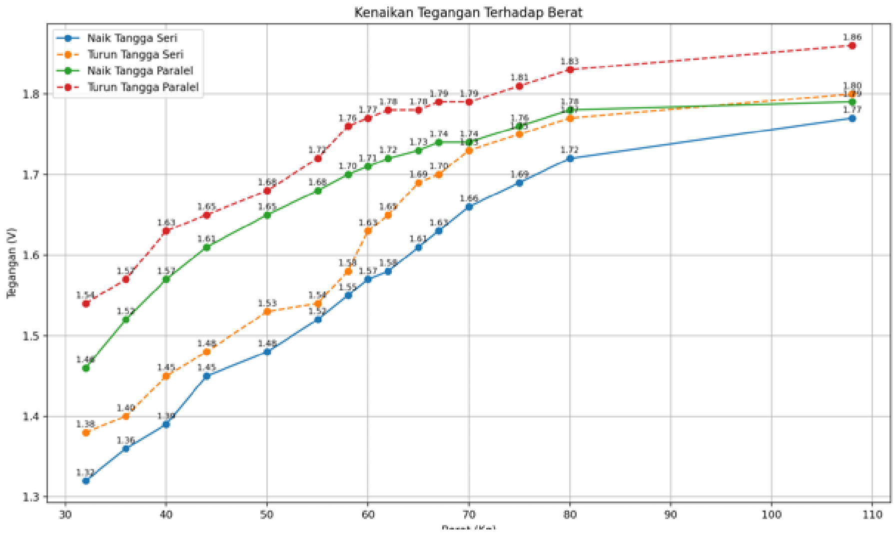

Figure 9. Graph of Voltage Increase with Weight

Figure 9 shows a graph of the voltage increase against weight. In the series circuit, the resulting voltage ranges from 1.32 V to 1.77 V when going up the stairs, while when going down the stairs, the voltage ranges from 1.38 V to 1.80 V. In contrast, in the parallel circuit, the voltage ranged from 1.46 V to 1.79 V when ascending the stairs and 1.54 V to 1.86 V when descending the stairs. Although the voltage range in the parallel circuit is slightly higher than that in the series circuit, the difference is not too large, but still shows better performance in the parallel configuration.

Graph of power gain against weight

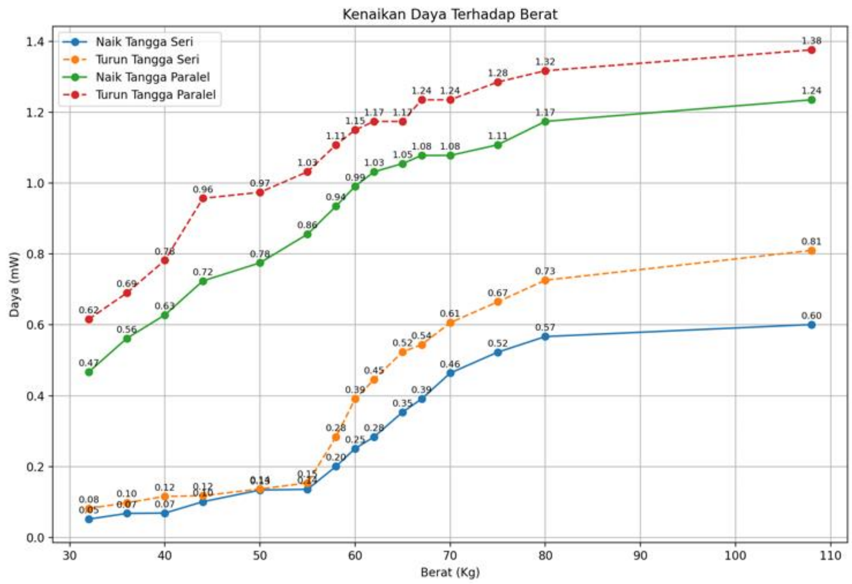

Figure 10. Graph of Power Increase against Weight

Figure 10 shows the gradual increase in power with respect to weight. In the series circuit, the power generated ranges from 0.05 V to 0.60 V when climbing the stairs, while during the descent, the voltage ranges from 0.08 V to 0.81 V. In contrast, in the parallel circuit, the power generated ranged from 0.47 V to 1.24 V when ascending the stairs and 0.62 V to 1.38 V when descending the stairs. Although the power range in the parallel circuit is slightly higher than that in the series circuit, the difference is not too large, but it still shows better performance in the parallel configuration.

Testing Lighting System with IOT Monitoring System

The lighting system test aims to evaluate the effectiveness of the parallel piezoelectric prototype in generating enough electrical energy to power a 3mm LED and monitor the system performance in real-time using Internet of Things (IoT) technology. In the test, 15 times the step up and down were carried out, then the 15th voltage data was taken.

Table 3. Testing the Lighting System with the IoT Monitoring System Up the Stairs

Body Weight	Display Voltage	Display LED	Display Messeger
32	2,34	Blackout	Voltage Detected
36	2,39	Blackout	Voltage Detected
40	2,43	Blackout	Voltage Detected
44	2,48	Blackout	Voltage Detected
50	2,52	Blackout	Voltage Detected
55	2,56	Blackout	Voltage Detected
58	2,60	Blackout	Voltage Detected
60	2,65	Blackout	Voltage Detected
62	2,70	Blackout	Voltage Detected
65	2,81	Blackout	Voltage Detected
67	2,86	Blackout	Voltage Detected
70	2,89	Blackout	Voltage Detected
75	3,04	Light up	Voltage Fulfilled
80	3,08	Light up	Voltage Fulfilled
108	3,30	Light up	Voltage Fulfilled

In the stair climbing test in Table 3, the voltage generated varied depending on body weight, ranging from 2.34V to 3.30V. At body weight below 75 kg, the voltage generated is still less than 3V, so the LED does not light up even though the messenger display shows the message "Voltage Detected," indicating that the system recognizes the presence of voltage, but not enough to light up the LED. When the body weight reaches 75 kg or more, the voltage generated exceeds 3V, which activates the relay and turns on the LED, and the messenger display shows the message "Voltage Met."

Testing by descending stairs

Testing down the stairs in Table 4 shows different results, where the voltage generated is higher than when going up the stairs, starting from 2.60V and reaching 3.89V. At a body weight of 44 kg, the voltage has reached 3V, so the LED lights up and the body weight above it can also turn on the LED because the voltage generated is more than 3V and sends a message on the messeger display that is "voltage met".

Table 4. Testing the Lighting System with the IoT Monitoring System Down the Stairs

Body Weight	Display Voltage	Display LED	Display Messeger
32	2,60	Blackout	Voltage Detected
36	2,64	Blackout	Voltage Detected
40	2,67	Blackout	Voltage Detected
44	3,00	Light up	Voltage Fulfilled
50	3,05	Light up	Voltage Fulfilled
55	3,10	Light up	Voltage Fulfilled
58	3,15	Light up	Voltage Fulfilled

60	3,25	Light up	Voltage Fulfilled
62	3,29	Light up	Voltage Fulfilled
65	3,30	Light up	Voltage Fulfilled
67	3,34	Light up	Voltage Fulfilled
70	3,35	Light up	Voltage Fulfilled
75	3,38	Light up	Voltage Fulfilled
80	3,42	Light up	Voltage Fulfilled
108	3,89	Light up	Voltage Fulfilled

Monitoring with Arduino IoT Cloud Remote App

Figure 11 shows the display of the Arduino IoT Cloud Remote application that can monitor the voltage generated from the prototype of the Piezoelectric-Based Staircase Lighting System. There are four displays, namely led display, voltage, messenger and voltage graph.

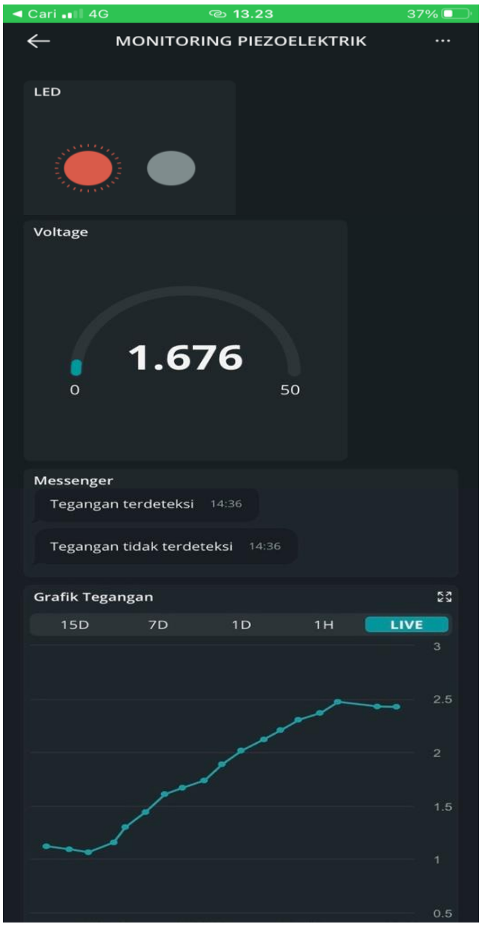

Figure 11. Monitoring of Arduino IoT Cloud Remote Application

CONCLUSION

The results of the voltage test on the piezoelectric-based lighting system with IoT monitoring show that this design is able to generate enough voltage to turn on the 3mm led lighting on the prototype stairs. The test results show that the voltage generated varies depending on the weight given and the way up and down the stairs. When body weight >75 kg can reach 3V when climbing stairs, while when descending stairs body weight >44 kg can reach a voltage of 3V. The resulting voltage can be monitored in real time with the Arduino IoT Cloud Remote platform. This research has limitations, namely the use of piezoelectricity which is still small. This research can be further developed by adding piezoelectrics so that the resulting voltage can be compared.

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