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APPLICATION OF PIEZOELECTRICITY ON RUNNING TRACKS: A PROTOTYPE FOR THE REALIZATION OF SUSTAINABLE AND EFFICIENT ENERGY

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ABSTRACT

Electrical energy has become a basic necessity today. As the population increases, the amount of electricity demand is also increasing. Therefore, many innovations are needed to meet these needs. One of the innovations in energy harvesting systems is the use of piezoelectricity. This research aims to create a piezoelectric-based running track prototype to produce environmentally friendly electrical energy. The arrangement of piezoelectric sensors used in this research is a parallel circuit. The research method used is the Research and Development method. The test results on the physical activities of walking, running, and jumping show that the prototype system that has been made has worked well and produces a fairly stable electric voltage even though it is still in a small amount. the difference in activity and body weight that presses the prototype produces different electric voltages. For walking activity, the prototype is able to produce a maximum voltage output of 0.83V, running activity has a maximum output of 5.83V and the maximum voltage output of jumping activity is 7.88V. The use of energy is done by storing the energy obtained from the piezoelectric in the battery, which can later be monitored directly by the voltage sensor, bluetooth module, HC-05, and RTC module the data will be sent to the cell phone so that the piezoelectric output voltage can be recorded and monitored. The electrical energy output generated by the piezoelectric is able to charge the battery and switch on the LED light at 2.5 V.

KEYWORDS *Piezoelectrics, Running Tracks, Renewable Energy, Electrical Voltage, Batteries, Bluetooth*

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INTRODUCTION

Electrical energy consumption in Indonesia continues to increase every year in line with increasing economic growth. It is estimated that electricity demand will increase by around 6.5% per year until 2020. The large electricity consumption in Indonesia could become a problem if domestic supply cannot meet demand. The policies taken by the State Electricity Company (PLN) as the electricity provider for State-Owned Enterprises (BUMN) increasingly show that PLN is no longer able to meet national electricity needs (Muchlis & Permana, 202;(Prasetyo & Pradistia, 2022a). Meanwhile, the main raw material in the process of providing electrical energy in Indonesia is still focused on fossil fuels(Sabubu, 2020). State Electricity Company (PLN) reports that in 2021 around 75% of their electricity production will be coal-fired (Surjadi, 2023). The use of non-renewable fossil energy will certainly cause a crisis if there is no balance between demand and availability of raw materials (Prasetyo & Pradistia, 2022a);(Rahmawati et al., 2021);(Rinaldi et al., 2018). Based on existing problems, renewable energy is very necessary and many researchers are trying to develop electrical energy sources from renewable energy (Prasetyo & Pradistia, 2022a);(Kim et al., 2015). Some examples of environmentally friendly energy harvesting devices that already exist and have been widely implemented include solar panels, wind turbines and water wheels.(Gunawan et al., 2021); (Nurdiyanto & Harduyo, 2020); (Pangestu & Nurwijayanti, 2021).

One of the developments in renewable energy is to utilize piezoelectric sensors as a renewable energy source that can be used to produce electricity. Piezoelectricity is one of the many that can be applied to harvest energy, the way it works is by converting mechanical energy produced from human stepping into electrical energy (Yuandhana, Lisdiana, Ghifari, et al., 2021); (Hakim et al., 2020). The amount of electrical energy produced from this piezoelectric varies depending on the amount of pressure to suppress the piezoelectric (Prasetyo & Pradistia, 2022a). Over several periods, piezoelectricity has given rise to a wide variety of applications in various fields, from basic measurement techniques to advanced technologies such as ultrasonic sensors (Ghemari et al., 2024).

Prasetyo in his research revealed that the use of piezoelectric sensors as an energy source by modeling stairs showed positive results. The results of the trials show that the system created has worked well with the largest energy produced being 5.80V(Prasetyo & Pradistia, 2022a). As for Yuandhana et al. conducted research on the use of piezoelectricity as an alternative energy source for ringing doorbells. The experiments carried out show that the piezoelectric device can be optimally utilized as an energy producer to ring the doorbell after being exposed to pressure or footing for 12 hours. This is indicated by the sound of the bell reaching its maximum magnitude (Yuandhana, Lisdiana, Ghifari, et al., 2021).

Other research shows the use of piezoelectricity in speed bumps, research conducted by Yulia et al. shows that piezoelectric speed bumps are capable of producing electrical power with an input of 60 times the speed of a motorized vehicle of 2,166mWh with an efficiency of 2.87% compared to manual input(Yulia et al., 2016). Meanwhile, the application of piezoelectricity to speed bumps in other research succeeded in producing a power plant with an electrical power of 6.97

Watts (Sidiq et al., 2021). uses GA techniques to increase the amount of power harvested from traffic vibrations by piezoelectric energy harvesters (Ye & Soga, 2014). There is also research that describes more specific uses such as installing street lights with an energy harvesting system from piezoelectric integrated speed bumps that can produce energy of 13,772V (Afif & Rini, 2017).

A review article on the utilization of piezoelectric-based shunt damping in 2018 stated that connecting piezoelectric transducers integrated in structures to electrical or electronic circuits, is a promising alternative for use in small and medium scale structural components (Gripp & Rade, 2018). However, as shown by the large number of research papers published in the last 20 years, the number of reported piezoelectric applications and registered patents is, so far, less significant (Kim et al., 2015); (Gripp & Rade, 2018). This seems to indicate that further efforts should be made to increase the maturity level of piezoelectric technology towards real-world industrial applications. However, the use of piezoelectric sensors is still limited to uses as mentioned, while for larger scale uses such as running tracks, no one has implemented them yet. Seeing the existing problems, a research study was carried out regarding the application of piezoelectricity on running tracks which was designed as a prototype with a piezoelectric layer which can produce electrical energy when used in human activities while on the running track field.

The running track is a sports facility that is widely used by people to exercise, the running track field is routinely a favorite place for the general public, various age groups from children to adults can relax their bodies while unwinding from daily activities and participating in sport activities. The presence of extensive running tracks in these fields creates a need for adequate lighting which in turn results in high expenditure in terms of electricity costs (Sya'ban & Pratiwi, Novita, 2021). Apart from this significant cost aspect, this problem also has a negative impact on environmental conservation efforts that need to be considered. However, conventional running tracks are less environmentally friendly because they use electricity from fossil energy plants. Therefore, a solution is needed so that running tracks can produce their own energy sustainably and efficiently. One solution is to utilize the piezoelectric principle, where mechanical energy is converted into electrical energy. Piezoelectricity is an electrical effect produced by certain materials when subjected to mechanical pressure (Sidiq et al., 2021).

RESEARCH METHOD

This research includes Research and Development (R&D) research. According to Sugiyono, Research and Development (R&D) is a research method used to produce certain products and test the effectiveness of these products (Sugiyono, 2015). This method is shown to develop a piezoelectric prototype as an energy harvester to reduce the use and cost of electricity consumption with efforts to preserve the environment then obtain the voltage results that will be connected to the battery for charging (Kuang et al., 2016), and will later be channelled to a small LED lamp as a running track lighting prototype to get an overview of the resulting output and also as an alternative source of electrical energy and also as an innovation in the field of public infrastructure as a step towards sustainable living in order to obtain clean and environmentally friendly energy. (Kuang et al., 2016).

At the tool testing stage, testing is carried out on hardware and software. In hardware testing, data samples were taken with different body weights including 55 kg, 60 kg, 65 kg, 70 kg, 75 kg by testing human activities when on running tracks such as running, walking, and jumping to be compared. Testing on the software is shown by monitoring how many volts enter the battery by monitoring via an android device in real-time using a bluetooth-based application. In this study, monitoring the volt meter generated by piezoelectric in real time using a bluetooth serial monitor application connected to HC-05 and RTC Modules, with this application the author can easily find out how many volt meters are generated by piezoelectric for battery charging.

System planning

The process of designing the system to be tested which consists of hardware and software. Hardware is the required tools and components used in this research. The software is software that supports the tools and components in this research to monitor the voltage at the piezoelectric output.

Hardware

The main hardware used is a piezoelectric sensor. Piezoelectric sensors are a type of transducer that converts mechanical vibrations or pressure changes into electrical signals (Ghemari et al., 2024). Seen in Figure 1. This is a block diagram of the process of changing mechanical energy into electrical energy when the piezoelectric sensor is subjected to pressure or vibration (Prasetyo & Pradistia, 2022b; Yuandhana, Lisdiana, Zulhaisa, et al., 2021). piezoelectric sensor produces an alternating voltage (AC) so that the voltage must become a direct voltage (DC) via a bridge rectifier circuit. In this study, 6 piezoelectrics were used in parallel so that the voltage generated by each piezoelectric can be accumulated. As most of the prisoners are assembled in parallel circuits, the total resistance of the circuit decreases, therefore the total current is greater (Rosman et al., 2019). In addition, the author adds a Zener diode so that the voltage that has been directed becomes stable when the voltage is connected to the battery and voltage sensor module which will be processed through a microcontroller, namely Arduino Uno. The battery as a voltage energy source from the piezoelectric sensor is then connected to a small LED light of 2.5V. The RTC module then sends accurate real-time time information signals to the microcontroller. The microcontroller will read voltage data and sampling time from the voltage sensor module and RTC module, the voltage produced by piezoelectricity is then sent to the Android device and can be monitored via the HC-05 Bluetooth module and I2C Liquid Crystal Display (LCD).

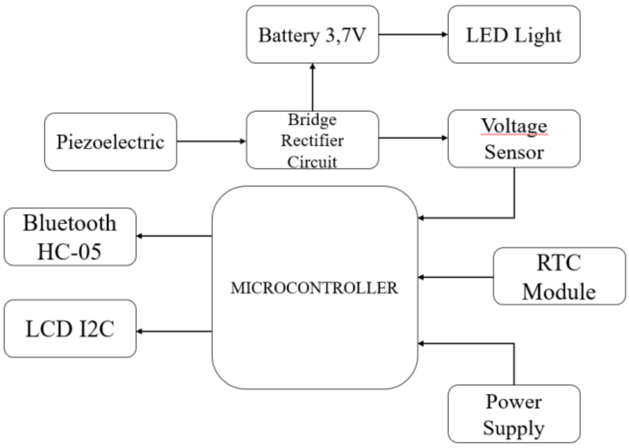

Figure 1. System Block Diagram

The hardware in Figure 2 is a series of hardware design for the entire tool component consisting of an I2C LCD, microcontroller, RTC module, HC-05 Bluetooth module, voltage sensor connected to the bridge rectifier circuit, 3.7V battery, and piezoelectric sensor.

Figure 2. System Hardware

The I2C LCD has a function as a real-time display and also functions as monitoring the voltage produced by the piezoelectric sensor. The microcontroller will play the role of processing piezoelectric sensor voltage input and real-time time from the RTC module which will continue to the HC-05 bluetooth module and I2C LCD. The RTC module sends signals in real-time and continuously with the current time and date, even when the device is turned off or loses power. Apart from that, there is an HC-05 module that functions as a wireless communication device using a Bluetooth signal that can connect to an Android device and can monitor how much voltage is entering the battery. Then the battery will be connected to a small LED lamp as the energy utilisation of the battery whose voltage energy is generated by the piezoelectric sensor.

Figure 3 shows a complete wiring diagram for the prototype that was assembled in this research.

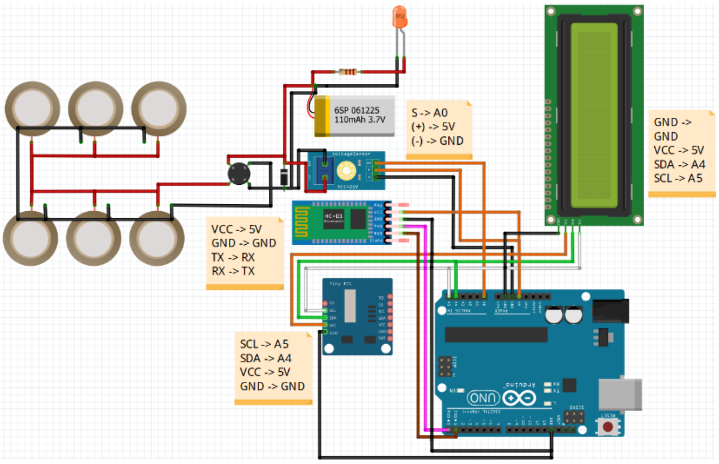

Figure 3. Wiring diagram

The hardware design that has been made in Figure 4 is a refinement and complement to previous research. In designing the prototype, the wooden board used is harbot wood or particle board with dimensions L × W × H = 50cm × 16cm × 2cm, besides the cheap price, the material is harbot woodlighter so that voltage measurements are more accurate when tested. Then there are bolt nuts measuring 4.6 and 9cm long with a wrench diameter of 13 as an adhesive to connect the harbot wood.

Apart from that, by adding polyfoam to the top and bottom of the board as seen in Figure 5. to avoid damage to the piezoelectric due to direct impact with hard objects such as boards so that the piezoelectric can be used for long periods of time without reducing the sensitivity of the piezoelectric sensor and to optimize and maximize the vibrations produced in the piezoelectricity.

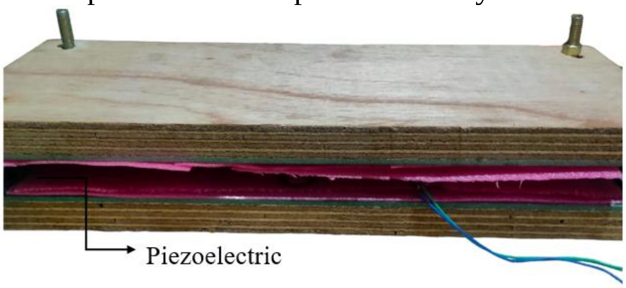

Figure 4. Hardware Design

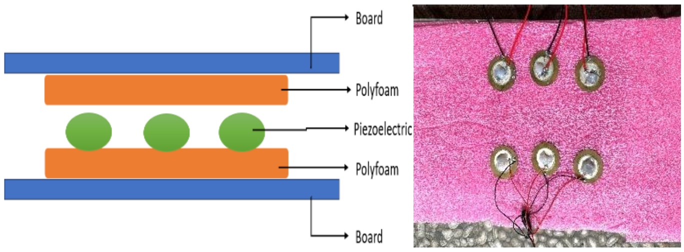

Figure 5. Piezoelectric Mechanical Design

Software

The software used to monitor the voltage entering the battery in this research is an applicationBluetooth serial monitor, the application can be connected to the HC-05 module with a Bluetooth network. This application can be downloaded via Play Store.

RESULTS AND DISCUSSION

The system testing process will consist of hardware and software. Hardware testing will sample human activity data when on running tracks such as running, walking, and jumping, to then be measured and flowed into the battery connected to the LED lamp. While software testing can be shown by monitoring how many volts enter the battery through a bluetooth-based application.

Hardware Testing

Tension Experiment during Running

The experimental data in Table 1 is experimental data on activity while running, taken from 5 trials. In the first experiment, a person weighing 55 kg had a measurement value of 4.12 V, while a person weighing 75 kg had the highest measurement value, namely 5.81 V, the measurement value in the second experiment showed an increase with increasing body weight, with The highest value of 5.83 V was obtained by someone weighing 75 kg. In the third experiment, there was a fairly consistent trend of increasing measurement values along with increasing body weight, where the highest value was obtained by someone weighing 75 kg, namely 5 .87 V, when the fourth trial was carried out with a body weight of 70 kg, the highest measurement value was obtained in the fourth trial, namely 5.62 V, while the lowest value was obtained by someone with a body weight of 55 kg, namely 3.87 V, in the fifth trial, The highest measured value was obtained by someone weighing 70 kg, namely 5.78 V, while the lowest value was obtained by someone weighing 55 kg, namely 4.04 V. Overall, the data in the table shows a consistent trend towards increasing measured values as well as an increase in body weight in each experiment carried out.

Table 1. Running Voltage Results

No	Weight (KG)	Test First (V)	Test Second (V)	Test Third (V)	Test Fourth (V)	Test Fifth (V)
1	55	4.12	3.9	3.84	3.87	4.04
2	60	4.56	4.36	4.48	4.39	4.41
3	65	5.51	5.39	4.9	5.1	5.05
4	70	5.66	5.75	5.54	5.62	5.78
5	75	5.81	5.83	5.87	5.74	5.8

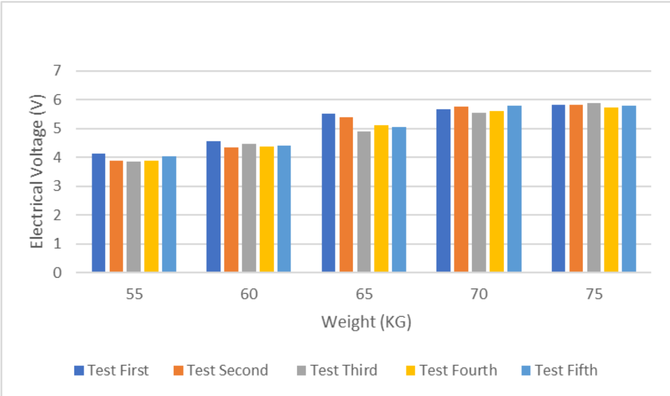

Figure 6. Running Activity Graph

Based on the graphic data seen in Figure 6, it can be concluded that there is a strong positive correlation between body weight and the measured values in all experiments carried out. Specifically, the graph shows that the higher a person's weight, the higher the measurement value obtained in each test, starting from the first test to the fifth test. The increasing trend in these values appeared consistent and significant as body weight increased, with small changes at some points.

Tension Experiment during Walking

There are also experiments carried out when humans walk which can be seen in Table 3. In the first experiment, a person weighing 55 kg had a measurement value of 0.58 V, while a person weighing 75 kg had the highest measurement value, namely 0.81 V , the highest measurement value in the second experiment was obtained by someone weighing 70 kg, namely 0.78 V, while the lowest value was obtained by someone weighing 60 kg, namely 0.7 V,in the third experiment, there was a tendency for the measurement value to increase as body weight increased, where the highest value was obtained by a body weight of 75 kg, namely 0.8 V, the experiment with a body weight of 75 kg obtained the highest measurement value in the fourth experiment, namely 0.83 V, while the lowest value was obtained by someone weighing 60 kg, namely 0.69 V, in the fifth experiment, the highest measurement value was obtained by someone weighing 75 kg, namely 0.82 V, while the lowest value was obtained by someone weighing 60 kg, namely 0.71 V. Just like in the running experiment, the data in the walking experiment table shows a consistent trend towards increasing measured values and increasing body weight in each experiment with a smaller voltage input scale.

Table 2. Voltage Readings while Running

No	Weight (KG)	Test First (V)	Test Second (V)	Test Third (V)	Test Fourth (V)	Test Fifth (V)
1	55	0.58	0.63	0.66	0.6	0.64
2	60	0.73	0.7	0.72	0.69	0.71
3	65	0.71	0.73	0.77	0.76	0.75
4	70	0.76	0.78	0.75	0.8	0.78
5	75	0.81	0.79	0.8	0.83	0.82

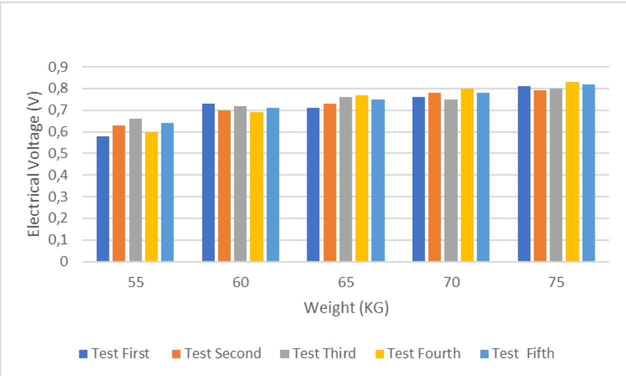

Figure 7. Walking Activity Graph

Based on the graph in Figure 7, it can be concluded that there is a positive correlation between body weight and the measurement values obtained in each experiment. The graph shows a fairly consistent increase in measurement values as body weight increases, seen in all trials (first, second, third, fourth, and fifth). Although there were small fluctuations in some data points, the general pattern that was seen was that the measurement values tended to increase as body weight increased.

Tension Experiment during Jumping

In the experimental data which can be seen in Table 2. In the first experiment, a person weighing 55 kg had a measurement value of 6.15 V, while a person weighing 75 kg had the highest measurement value, namely 7.76 V, the highest measurement value in The second experiment was obtained by someone weighing 75 kg, namely 7.88 V, while the lowest value was obtained by someone weighing 55 kg, namely 5.36 V. In the third experiment, the highest measurement value was obtained by someone weighing 65 V. kg and 70 kg, respectively 6.61 V, while the lowest value was obtained by someone with a body weight of 55 kg, namely 5.58 V, the experimenter with a body weight of 70 kg obtained the highest measurement value in the fourth experiment, namely 6.62 V, while the lowest value was obtained by someone weighing 55 kg, namely 5.39 V, in the fifth experiment, the highest measurement value was obtained by someone weighing 70 kg, namely 6.78 V, while the lowest value was obtained by someone weighing body 75 kg, namely 7.22 V. This is also continuous in running and walking experiments where there is a tendency for the measured value to increase with increasing body weight.

Table 3. Voltage Readings during Jumping

NO	Weight (KG)	Test First (V)	Test Second (V)	Test Third (V)	Test Fourth (V)	Test Fifth (V)
1	55	6.15	5.36	5.58	5.39	5.51
2	60	6.53	6.39	5.9	6.1	6.06
3	65	6.61	6.5	6.61	6.57	6.39
4	70	6.66	6.76	6.65	6.62	6.78
5	75	7.76	7.88	7.6	7.83	7.22

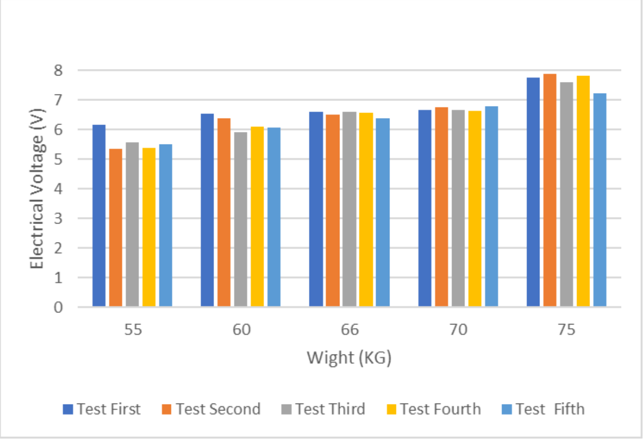

Figure 8. Jumping Activity Graph

Based on graphic analysis in Figure 8, it was found that there was a significant positive correlation between body weight and the measured voltage value in each experiment.

Comparison of Average Electrical Voltage between Running, Walking, and Jumping

It can be seen in Table 4. Running and jumping activities produce much higher electrical voltage than walking activities. In walking activities, the average maximum electrical voltage that can be generated is around 0.81V, in contrast to running and jumping activities where the maximum electrical voltage can reach a maximum of 5.81V and 7.658V. The following details the average voltage produced by the three activities tested and the weight of the different samples.

Table 4. Average Stress Readings for Running, Walking, and Jumping

NO	Body Weight (KG)	Run	Walk	Jump
1	55	3,954	0.622	5,598
2	60	4.44	0.71	6,196
3	65	5.19	0.744	6,536
4	70	5.67	0.774	6,694
5	75	5.81	0.81	7,658

Furthermore, a graph of the relationship between body weight and the average electrical voltage produced is described in Figure 9. This graph shows the correlation between weight and piezoelectricity. We can see that this is in line with the ideas of Afif et al. which states that the greater the frequency of an object's weight hitting a piezoelectric material, the greater the electric voltage will be (Afif & Rini, 2017). Apart from that, it was also concluded that jumping activities produce the highest electrical voltage compared to running and walking activities. This could be caused by body weight pressure and a more intense pounding frequency compared to other activities. This shows that the characteristics of the movement and load received by the piezoelectric material can influence the amount of electric voltage produced.

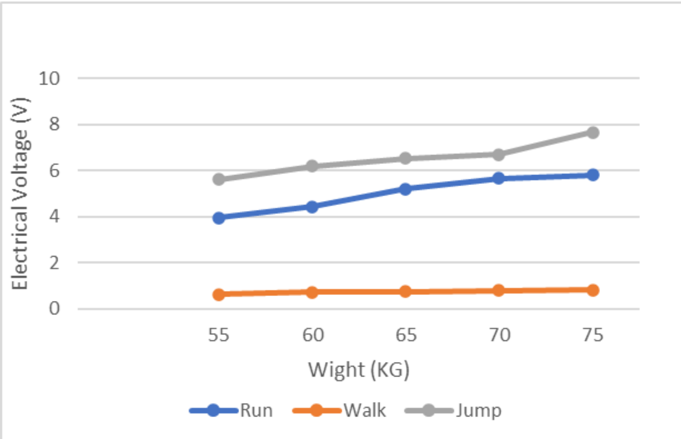

Figure 9. Average graph of running, walking and jumping

Software Testing

The software testing process in Figure 10 is carried out by connecting a Bluetooth-based application using a Bluetooth serial monitor application which acts as a monitoring system for voltage readings entering the battery. When testing the voltage reader, it includes data acquisition from the voltage sensor, then the time of data acquisition is recorded by the RTC module and the data is sent via the HC-05 Bluetooth module. This circuit is designed to read the voltage produced by the piezoelectric after passing through the rectifier circuit. When data collection is carried out, make sure the Android device is connected to the HC-05 module. This can be proven that the testing and monitoring system via an Android device using the HC-05 Bluetooth module was successfully implemented, the data was successfully obtained and the voltage produced by the piezoelectric can be read by the device via the Bluetooth serial monitor application.

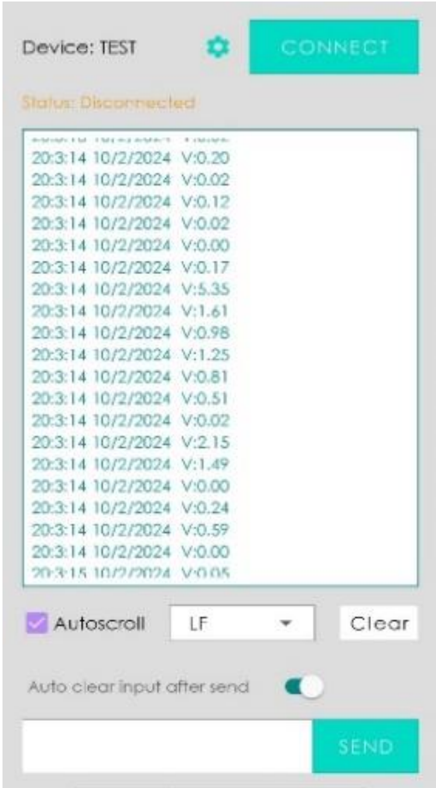

Figure 10. Voltage Monitoring via Android Device

CONCLUSION

The piezoelectric-based running track prototype that has been designed consists of hardware, namely the mechanical system of the running track and the energy harvesting system, while the software consists of android software that is integrated with bluetooth that is able to generate electrical energy with pressure input from human body weight and shows stable results. Experimental results show that the voltage generated is stable at 5V -7.6V in running and jumping activities. On the one hand, the addition of zener diode components to the device helps maximise and stabilise the voltage. The electrical output generated by 6 piezoelectrics is able to charge the battery and turn on the LED lamp of 2.5 V with the assumption that the more piezoelectrics used and the more load on the piezo, of course, can turn on the lamp with a greater voltage as well. The experiments that have been carried out show that the use of piezoelectrics to support lighting on running tracks is possible to be realised. In addition, the results presented provide a solid foundation for further development in this field. Further research can be refined to make a more developed prototype to produce more accurate calculations and can be realised directly.

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