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Development of a Piezoelectric-Based Hand-Pressure Generator for Green Technology Education

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Abstract

This research aims to develop a piezoelectric-based Hand-Pressed Generator as a green technology learning medium in vocational education. This research uses the Research and Development method with the ADDIE model. The prototype is designed to convert mechanical energy from hand pressure into electrical energy using a piezoelectric sensor integrated with a rectifier circuit, boost converter, and a microcontroller-based monitoring system. Functional testing was carried out with pressure frequency variations of 30, 60, 90, and 120 pressures per minute to analyze the resulting output voltage. The test results show that the system is capable of producing an electrical voltage of 0.7 VDC; 1.6 VDC; 2.5 VDC; 3.6 VDC, which indicates a positive relationship between pressure frequency and the resulting voltage. As a learning medium, this prototype was validated by two material experts and two media experts, and tested on a limited basis on 35 students. The validation results obtained a feasibility value of 86.5% and 84.5%, while the user feasibility test obtained a value of 88.25%. These findings indicate that the Hand-Pressed Generator is a new breakthrough in learning media and supports green technology learning in vocational education.

Keywords: *Piezoelectric, Hand-Pressed Generator, Green Technology*

Abstrak

Penelitian ini bertujuan mengembangkan Hand-Pressed Generator berbasis piezoelektrik sebagai media pembelajaran teknologi hijau pada pendidikan vokasional. Penelitian ini menggunakan metode *Research and Development* dengan model ADDIE. Prototipe dirancang untuk mengonversi energi mekanik dari tekanan tangan menjadi energi listrik menggunakan sensor piezoelektrik yang terintegrasi dengan rangkaian penyearah, boost converter, dan sistem monitoring berbasis mikrokontroler. Pengujian fungsional dilakukan dengan variasi frekuensi tekanan sebesar 30, 60, 90, dan 120 tekanan per menit untuk menganalisis tegangan keluaran yang dihasilkan. Hasil pengujian menunjukkan bahwa sistem mampu menghasilkan tegangan listrik sebesar 0,7 VDC; 1,6 VDC; 2,5 VDC; 3,6 VDC, yang menunjukkan adanya hubungan positif antara frekuensi tekanan dan tegangan yang dihasilkan. Sebagai media pembelajaran, prototipe ini divalidasi oleh dua ahli materi dan dua ahli media, serta diujicobakan secara terbatas pada 35 mahasiswa. Hasil validasi memperoleh nilai kelayakan sebesar 86,5% dan 84,5%, sedangkan uji kelayakan pengguna memperoleh nilai sebesar 88,25%. Temuan ini menunjukkan bahwa *Hand-Pressed Generator* merupakan terobosan baru media pembelajaran serta mendukung pembelajaran teknologi hijau pada pendidikan vokasional.

Kata kunci: Piezoelektrik, Generator Tekan Tangan, Teknologi Hijau

Introduction

Global electricity demand is showing a sharp and sustained upward trend. The International Energy Agency's Electricity Market Report 2024[1] projects global electricity consumption to grow by around 3-4% per year until 2026, driven by the electrification of transportation, the expansion of electricity-based industries, increased use of air conditioning due to rising global temperatures, and the growth of data centers and artificial intelligence. This trend is reinforced, which asserts that the surge in electricity demand is a major challenge in achieving global energy transition targets[2].

However, the global energy mix is still dominated by fossil fuels; the[2] reports that around 60% of global electricity production comes from coal and natural gas, which contribute significantly to carbon emissions. In line with this, the Intergovernmental Panel on Climate Change[3] emphasizes that the energy sector accounts for more than one-third of total global greenhouse gas emissions, making the decarbonization of the electricity system a top priority for climate change mitigation. The United Nations also highlights that the increasing frequency and intensity of extreme weather events are a direct consequence of global warming[4], making the transition to a low-carbon, decentralized, and sustainable energy system an urgent necessity. The literature on energy transition shows that the development of distributed energy systems and micro-generation can increase energy security while supporting sustainable development[5],[6],[7], making the exploration of non-conventional renewable energy sources crucial to filling the micro-energy gap in urban areas.

One of the potentials that is beginning to be developed in the context of micro-scale renewable energy is the utilization of mechanical energy from human activities. Daily activities, such as footsteps in public areas, generate mechanical pressure and deformation that are generally wasted as heat or compressive force without further utilization[8]. Recent studies show that human biomechanical energy has significant potential to be converted into electrical energy through piezoelectric and triboelectric transduction mechanisms[9],[10]. The technology capable of capturing this energy is known as a Footstep Generator, which is conceptually part of an energy harvesting system, namely the process of extracting energy from the surrounding environment to convert it into electrical energy[11]. Further studies also show that piezoelectric systems designed for footstep pressure can generate enough power for low-power applications such as wireless sensors and monitoring system[12],[13].

In addition, developments in triboelectric nanogenerator technology have expanded the potential for harvesting energy from low-frequency mechanical pressure, such as human footsteps[14]. Although this system is widely implemented by installing it on floors in high-traffic areas, the principle of mechanical energy conversion can be adapted into more compact, portable units for technical learning in laboratories, allowing for more controlled and experimental observation of voltage, current, and energy conversion efficiency. This technology adaptation on a laboratory scale is realized through the development of a Hand-Pressed Generator as a representation of a micro energy harvesting system. This device works on the principle of converting mechanical energy into electrical energy, as in a footstep generator, but uses a hand-press method to facilitate experimental demonstrations and precise data collection by students. The use of

piezoelectric materials is a key component because these materials generate electrical charges when subjected to mechanical deformation, a phenomenon known as the direct piezoelectric effect[15].

Recent research shows that PZT- and PVDF-based piezoelectric materials have high sensitivity to low-frequency pressure, such as manual human pressure[16],[17]. In addition, the configuration of piezoelectric elements in series and parallel circuits has been proven to significantly increase voltage and current output compared to single configurations, making them optimal for low-power applications[18]. With a controlled design in a laboratory environment, this unit is highly relevant as an experimental device for analyzing voltage, current, power, and conversion efficiency characteristics in manual pressure-based micro energy generation systems.

The application of this technology is in line with the concept of Green Technology Education. Learning media is a very important component in learning activities[19],[20]. In the field of vocational education, green technology emphasizes the mastery of technical competencies in designing equipment that can conserve resources and minimize environmental impact[21]. Green technology education requires students to not only understand environmental theory but also be skilled in creating environmentally friendly technological solutions[22]. Integrating this concept into practical media is crucial for preparing vocational workers who are ready to meet the demands of the future green industry.

At Universitas Negeri Yogyakarta (UNY), particularly in the Electrical Engineering Education Study Program, mastery of renewable energy technology is an integral part of the curriculum. The Electric Power Generation (EPG) course is the main foundation for students to understand the mechanisms of energy conversion. Based on vocational education competency standards, students are required to have practical skills in analyzing power generation systems, ranging from large-scale to micro-generation systems[23]. However, EPG learning is often dominated by simulations or observations of large power plants, so portable practice media are needed to enable students to interact directly with micro energy generation systems.

The development of this piezoelectric-based hand-pressed generator is presented as a learning medium solution that bridges the gap between electrical mechanics theory and green technology implementation. Through a Project-Based Learning approach in the UNY electrical engineering laboratory, students are involved in the design of rectifier systems, power storage management, and analysis of energy efficiency generated from variations in hand pressure frequency. This is in line with the demands of 21st-century vocational education, which emphasizes technical problem-solving skills and appropriate innovation[24].

Therefore, research on the development of Hand-Pressed Generators as a representation of energy harvesting technology is highly relevant to strengthening Green Technology literacy among Electrical Engineering students at UNY. By incorporating the piezoelectric phenomenon into the EPG course practicum, students can observe energy conversion in real life and internalize the values of sustainability. This research is expected to produce a valid and effective educational prototype that can improve the

professional competence of future educators and electrical engineering practitioners.

Method

This research is a type of research and development using the ADDIE development model[25]. The research procedure was carried out in stages to produce a valid and feasible prototype of a Hand-Pressed Piezoelectric Generator for learning purposes. The ADDIE research process is shown in Figure 1.



Figure 1. The ADDIE research process

a. Analysis

This stage aims to identify gaps between learning needs and the availability of practical media. Curriculum Analysis: Reviewing the Semester Learning Plan (RPS) for the Electric Power Generation (EPG) course in Electrical Engineering Education at UNY, particularly in terms of learning outcomes related to renewable energy and micro-generation. Student Needs Analysis: Identifying the need for portable, hands-on teaching aids to explain the concept of energy harvesting without relying solely on software simulations. Technical Analysis: Analyzing the amount of mechanical energy generated by the average human hand pressure to determine the number of piezoelectric sensors needed.

b. Design

The design stage includes creating a blueprint for the device, both mechanically and electrically. Electrical Design: Designing a circuit diagram consisting of several main components, shown in Table 1.

Table 1. Components of Piezoelectric-Based Hand-Pressure Generators

No	Components	Specifications	Qty
1	Arduino	Microcontroller: ATmega328P Operating voltage: 5V Input voltage (recommended): 7–12V Digital I/O pins: 14 (6 PWM) Analog input pins: 6 Clock speed: 16 MHz Flash memory: 32 KB	1

No	Components	Specifications	Qty
		SRAM: 2 KB EEPROM: 1 KB	
2	RFID	Operating frequency: 13.56 MHz Interface: SPI (Serial Peripheral Interface) Operating voltage: 3.3V Maximum read distance: ±5 cm Current consumption: ±13–26 mA Module dimensions: ±40 x 60 mm	1
3	DC Relay	Coil voltage: 5V DC Activation current: 70–100 mA Contact capacity: 10A 250VAC or 10A 30VDC Output type: NO (Normally Open) and NC (Normally Closed)	1
4	Piezoelectric	Maximum output voltage: ±1–5V (depending on pressure) Type: Ceramic piezo disc Resonance frequency: 4–6 kHz Material: PZT (Lead Zirconate Titanate)	6
5	DC Voltmeter	Input voltage: DC 0–25V Operating voltage: 0–25V DC	1
6	DC Amperemeter	Current Range: 0-5A	1
7	DC M/F Socket	Type: DC barrel jack Standard size: 5.5 mm (outer) / 2.1 mm (inner) Maximum voltage: 12–24V DC Maximum current: 2–5 A	2
8	Accu/Battery	Nominal voltage: 12V DC Capacity: 4 Ah (depending on battery type) Type: VRLA (Valve Regulated Lead Acid) / MF (Maintenance Free)	1
9	DC-DC boost converter XL6009	Main IC: XL6009 Input voltage: 3–32V DC Output voltage: 5–35V DC (adjustable) Maximum output current: 2A (stable), 3A (maximum momentary)	2
10	Charging Module	Input Voltage: DC 6-24V Output Voltage: 5.1-5.2V Output Current: 3A	2
11	I2C	Operating voltage: 3.3V – 5V Protocol: I2C (SDA, SCL) Default I2C address: 0x27 or 0x3F Communication speed: 100 kHz (standard), 400 kHz (fast mode)	1
12	Bridge rectifier	100V 2A	2

Mechanical Design: Designing a portable casing with a spring system that allows the sensor to obtain optimal pressure from the hand while remaining protected from overpressure. The block diagram of the Hand-Pressed Piezoelectric Energy Harvesting System is shown in Figure 2.

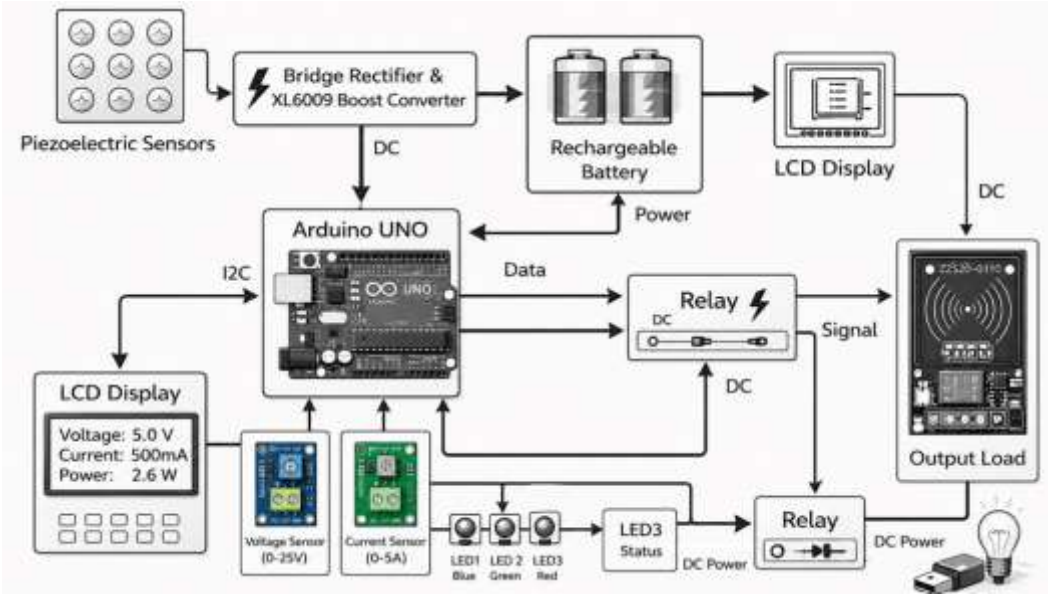


Figure 2. The block diagram of the Hand-Pressed Piezoelectric Energy Harvesting System

The system block diagram depicts the design of the Hand-Pressed Piezoelectric Energy Harvesting System, comprising several main components integrated. The piezoelectric circuit consists of six pieces, each with a maximum output voltage of up to 5V, depending on the pressure intensity. Mechanical energy from hand pressure is captured by a piezoelectric sensor and converted into an AC electrical signal, which is then rectified through a bridge rectifier and stabilized using an XL6009 boost converter module to produce the appropriate DC voltage. This DC energy is then stored in a rechargeable battery as a temporary storage medium and power source for the system. The battery used has a capacity of 4 Ah. An ammeter (current sensor) is used to measure the current, and a voltmeter (voltage sensor) is used to measure the voltage. The voltage measurement results are displayed on the LCD. Arduino Uno functions as a control center that monitors and processes voltage data and controls output components, with an I2C-based LCD used to display system parameters such as voltage, current, and power. An Arduino controls the relay module to connect or disconnect the load under programmed conditions, thereby enabling the system to automatically regulate power distribution to the load. Overall, this diagram illustrates the flow of mechanical energy into controlled, monitored DC electrical energy within an integrated piezoelectric-based micro power generation system.

The next step is to develop research instruments. Research instruments consist of functional testing instruments, validation instruments, and user response instruments. The functional testing instrument is used to determine the functionality of the developed prototype. The validation instrument involves media experts and material experts to assess the prototype's feasibility from an expert perspective. Two material experts and two media experts were involved in this study. The user response instrument is designed to assess the prototype's feasibility from the user's perspective.

c. Development

This stage involves realizing the design as a physical product. The focus at this stage is on integrating technical components. Components are selected using piezoelectric

sensors. The sensors are arranged in a series-parallel configuration inside the Hand-Pressed unit. Precision soldering techniques are used to ensure connectivity between sensors is maintained under repeated pressure. Laboratory testing is conducted by calibrating the device with an oscilloscope to verify that the output waveform conforms to the theory of mechanical-to-electrical energy conversion.

d. Implementation

The prototype has been implemented on a limited scale in the laboratory. User trials involve UNY Electrical Engineering students in independent practicum sessions. There were 35 students involved in this activity. Students were asked to vary the pressure applied by their hands (fast and slow) and to record the voltage measured with a multimeter. Students were then asked to assess the suitability of the media using a suitability questionnaire. During the practicum, students gained an understanding of the principles of Green Technology, whereby energy that is typically wasted (e.g., hand/foot pressure) can be harnessed as an alternative resource. The results of the expert validation and user feasibility responses were then categorized into four categories: poor, fair, good, and very good. The detailed classification of the expert validation and user feasibility responses is shown in Table 2.

Table 2. Media Eligibility Category

Percentages	Categories
$0 < X \leq 25$	poor
$25 < X \leq 50$	fair
$50 < X \leq 75$	good
$75 < X \leq 100$	very good

e. Evaluation

Evaluations are conducted at each stage of the ADDIE model. Evaluations are conducted to assess the product's quality and suitability for green technology education.

Result and Discussion

a. Results of Hand-Pressed Generator Prototype Development

Piezoelectric-based hand-pressure generators were assembled in accordance with the specified design. In general, this prototype consists of a control box, a piezoelectric sensor, a battery, and an output. Figure 3 shows the assembly of the piezoelectric-based Hand-Pressed Generator.



Figure 3. The assembly of the Piezoelectric-based Hand-Pressed Generator

After assembly of the piezoelectric system was completed, testing was conducted to observe the output voltage response under repeated mechanical pressure. The test results showed that the system successfully generated a voltage that varied with the magnitude and frequency of hand pressure. Figure 4 shows the assembled device in its physical form, ready for testing.



Figure 4. Final appearance of Piezoelectric-Based Hand-Pressure Generators

b. Technical Performance Analysis of Power Generation

After assembly and integration of the piezoelectric system and supporting components (Arduino, RFID reader, relay, LCD, and boost converter) are completed, the next step is functional testing and collection of output voltage data. Testing is conducted by applying repeated mechanical pressure to the piezoelectric surface assembled in series using direct hand pressure. To obtain measurable results, pressure was applied at four quantitatively defined rates: 30, 60, 90, and 120 pressure units/min. The system's output voltage was measured using a digital voltmeter integrated into the circuit. The data obtained show that the higher the pressure, the greater the electrical voltage produced, indicating a linear relationship between pressure and output voltage. The test results are summarized in Table 3.

Table 3. Output Voltage Results Based on Pressure Frequency

No	Pressure Frequency	Duration (seconds)	Output Voltage (VDC)
1	30	60	0.7
2	60	60	1.6
3	90	60	2.5
4	120	60	3.6

From these results, it can be proven that the piezoelectric principle of generating electrical energy through pressure works well. However, the energy capacity generated is still relatively small, so the use of this system is still limited to low-power devices. The average current produced is quite low, with a maximum of only 500 mA, and it generates 2.6 W of electrical power. This is because the piezoelectric used has a low voltage specification and is in small quantities. Nevertheless, this prototype can at least function well.

The success of the system in generating voltage shows that the piezoelectric effect works according to theory. However, there are several limitations, including sensitivity to dynamic signals (high frequencies) and fluctuating output. This is consistent with the

literature, which states that piezoelectricity is highly effective for time-varying mechanical signals but is not ideal for constant loads or static pressure. This is consistent with the results of studies by[26],[27], which indicate that piezoelectricity is highly effective for time-varying mechanical signals but is not ideal for constant loads or static pressure. Technical discussions indicate that the higher the pressure applied, the faster the accumulation of electrical charge. This demonstrates the fundamental principle of the Electric Power Generation course: the relationship between mechanical energy input and electrical energy output.

c. Suitability as a Medium for Green Technology Education

Validation was conducted by two subject-matter experts and two media experts from the Electrical Engineering Education Department at UNY, as well as learning media experts. The validation was conducted by two media experts and two subject matter experts. The validation results showed an average score of 85.5% (Very Good). Next, a feasibility test was conducted based on the opinions of Electrical Engineering Education students at UNY as respondents. The respondents involved in the reliability test consisted of 35 students. The subject matter and media aspects were demonstrated by the tool/prototype's ability to visualize the abstract concept of energy harvesting as a measurable phenomenon. Students can observe the conversion of AC to DC using the provided test points. The vocational aspect is demonstrated using the Hand-Pressed method, which enables students to conduct repeated experiments independently, whereas the floor model (footstep) requires a large space. The validation results and respondent test are shown in Figure 5.

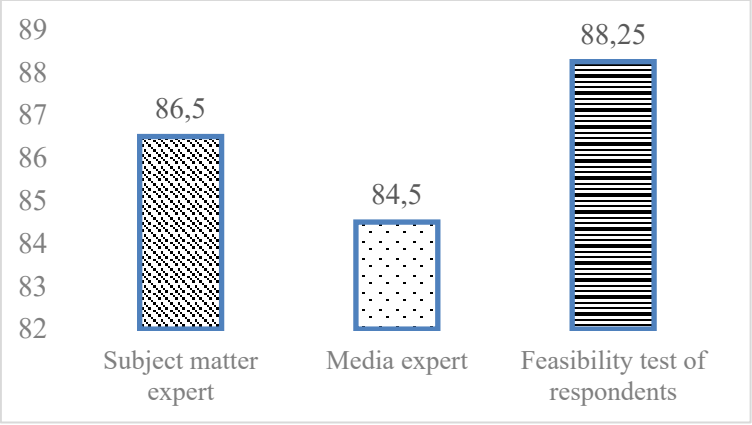


Figure 5. Suitability as a Medium for Green Technology Education

Based on the results of expert validation and user feasibility, the average percentages were 86.5% for expert validation, 84.5% for media experts, and 88.25% for user feasibility. Based on the results of content expert validation, media expert validation, and user feasibility testing, this learning material falls into the “very good” category.

d. Discussion on the Integration of Vocational Education and Green Technology

In the context of vocational education, this Hand-Pressed Generator has successfully changed the conventional EPG learning paradigm. Students are not only consumers of technology but also analysts who evaluate energy-conversion efficiency. The concept of Green Technology Education is internalized when students realize that

static mechanical energy from human activities can be converted into functional electrical energy. This strengthens students' "Green Skills," namely the ability to design technical solutions that minimize carbon footprints by utilizing waste energy. The implementation of this tool in the UNY Electrical Laboratory proves that simple piezoelectric-based innovations have a significant educational impact in shaping the sustainable mindset of prospective vocational graduates. This is in line with the opinion of [28], who explains that vocational education graduates must be competent and have sustainable competencies.

Conclusion

This study successfully developed a prototype of a piezoelectric-based Hand-Pressed Generator as an innovative Green Technology educational medium through the ADDIE development model. The results of the study show that the device's portable, ergonomic design is highly effective for use as an independent practicum in the Electric Power Generation course in the Electrical Engineering Education program at UNY, bridging theoretical understanding of kinetic energy conversion to functional electrical energy. Technically, the optimization of the series-parallel circuit and the use of appropriate rectifier components were capable of producing a voltage accumulation above 3.5 VDC at high pressure frequencies, as visually demonstrated by indicators and multimeter measurements. Based on the results of expert validation and user feasibility, the average percentages were 86.5% for expert validation, 84.5% for media experts, and 88.25% for user feasibility. This tool is well-suited as a vocational learning medium that not only improves students' technical skills in analysing micro-generation systems but also instils values of green technology and sustainability. Thus, the development of this unit makes a real contribution to preparing vocational graduates who are adaptive to renewable energy innovations and future green industry challenges.

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