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The Dual-Tone Electric Talempong Using Piezoelectric Based on Teensy 4.1

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ABSTRACT

The Minangkabau tribe has a traditional percussion instrument called Talempong. Talempong is one of the cultural heritages that is rarely used by today's young generation. Due to the expensive price of Talempong, the size of the Talempong base reaches 140x35 cm, heavy enough that 2-3 people are needed to lift it. Therefore, this research aims to create and design a dual tone electric Talempong system using piezoelectric sensors based on teensy 4.1 as a new innovation for traditional Talempong that is lighter, and minimalist. This research method is engineering research that explains the performance specifications that explain the performance of the electric Talempong system and the design specifications explain the accuracy and precision of the electric Talempong sound. Based on the objectives of the research, the results of the performance specifications of the tool were obtained, namely the characterisation of piezoelectric sensors, signal control circuits, Talempong sound recordings, and Talempong elektik mechanics. While the results of the design specifications are the results of the analysis of the average accuracy of the original Talempong sound with the electric Talempong getting accuracy data of 99.8%. The average error in the frequency accuracy data of the original Talempong with the electric Talempong is 0.24%. The accuracy data obtained for tone C is 99.9%, tone G 99.9%, and tone C 'observance at 100%. The average practicalisation data for electric talempog musical instruments is 94% with very practical criteria.

1. INTRODUCTION

Talempong is a type of percussion instrument crafted from materials like metal, bronze, stone, and brass, played by striking it directly with two wooden sticks. The Talempong has a circular shape with a diameter ranging from 15 to 17.5 cm. It features a knob (pencon) approximately 5 cm in diameter on its upper part and an opening at the bottom (Nengsih & Syeilendra, 2019). In Minangkabau, the Talempong is employed to accompany traditional dances, as well as in cultural rituals and social events within the Minangkabau community (Indrawati & Marzam, 2022). The Talempong instrument is categorized into two genres: one that employs interlocking techniques known as Talempong Pacik, and another that is played melodically, referred to as Talempong Duduak. Both genres are integral to traditional music ensembles across various parts of Minangkabau.(Wimbrayardi & Parmadi, 2021). Melodic Talempong is composed of two sets of accompanying Talempong, with each set containing four notes. The notes are sequenced as 1, 2, 3, 4 for the low-pitched Talempong, corresponding to do, re, mi, fa, and 5, 6, 7, i for the high-pitched Talempong, corresponding to sol, la, si, do' (Wulandari, 2015).

Technology in the modern world has progressed at a remarkable pace (Sudiantini et al., 2023). The musical instruments available today have become more advanced, which has impacted traditional instruments. Talempong is one of the cultural heritages that is becoming less common among the younger generation. This is largely due to the high cost of a Talempong set, the base size measuring up to 140x35 cm, and its weight, which necessitates 2-3 people to lift it. Furthermore, it requires a significant amount of space for setup. As a result, modern innovations are needed to simplify the operation of Talempong, with a focus on developing a lighter, more affordable, and uniquely designed electric version.

In previous research, a study was conducted on Electric Gamelan: An Easy Solution to Introduce Javanese Gamelan to the Younger Generation (Sutyasadi, 2019). The electric Gamelan system was developed using piezoelectric sensors paired with an Arduino UNO microcontroller to process data and generate Gamelan sounds. The research revealed that the system experienced a latency of 14.5 ms. To mitigate latency issues in musical instruments, a microcontroller with superior data processing performance is necessary, such as the Teensy microcontroller, which offers data processing speeds of up to 600MHz.

To enhance the prior research, this study will focus on developing a dual-tone electric Talempong using the Teensy microcontroller. The Teensy is a 32-bit microcontroller module designed by Paul Stoffregen, co-founder of PJRC, the company that developed the module. (Hidayat, n.d.). The hardware support of the Teensy 4.1, along with the Teensyduino software, is engineered to allow dynamic adjustments in timing functions, ensuring smooth data transmission without interruptions (Amirul Haq et al., 2019). The Teensy 4.1 microcontroller is equipped with 18 analog pins and 55 digital pins. It is capable of real-time audio conversion, which helps to mitigate delays in electric musical instruments. Furthermore, it can more precisely detect latency issues in microcontroller performance (Martínez et al., 2022). The Teensy 4.1 improves the effectiveness of delay correction. Utilizing the Teensy 4.1's speed and capacity helps minimize latency, allowing for efficient data processing (Aris Saputra et al., 2019).

This research employs piezoelectric sensors, which are highly sensitive to pressure and convert it into voltage. This characteristic makes them ideal for use in musical instruments like the electric Talempong (Rizki et al., 2018). The sensor transforms each applied pressure into an electrical signal, with the voltage generated increasing in proportion to the intensity of the pressure (Putra & Antara, 2022). Piezoelectric sensors are classified as active sensors because the electrical energy produced by the piezoelectric material in response to mechanical force can be sensed without requiring external power. (Ompusunggu et al., 2020). A piezoelectric sensor operates by converting mechanical pressure into an electrical signal. When pressure is applied to a sensor composed of dielectric material, the piezoelectric crystals within it deform. This deformation causes atomic shifts in the crystal, which generates an electric field. As the electric field moves through the material, it causes polarization of the molecules, thereby producing an electrical signal that can be measured (Hartono, 2017).

The system incorporates an Analog-to-Digital Converter (A/D) and audio processor, which use the Inter-Integrated Circuit Sound (I2S) synchronous serial protocol for data transmission. The I2S UDA1334A chip facilitates communication between the microcontroller and the UDA1334A chip, converting digital data into sound. Furthermore, I2S is employed as an audio output amplifier module that needs a low voltage power supply, and it is utilized for audio output with the UDA1334A decoder, which requires a supply voltage of 3.3 to 5 volts (Vizvari et al., 2020). This research aims to offer new solutions to the problems found in earlier studies and contribute to the development of a lighter, more unique, and modern electric musical instrument by integrating sensors and microcontrollers into traditional musical instruments.

2. METHOD

This research takes place in the Electronics and Instrumentation Laboratory within the Department of Physics at the Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang. The project commenced in March 2024 and is divided into several phases: preparation, execution, and final report writing. The preparation phase encompasses drafting the research proposal, designing the system, assembling components, collecting data, processing data, and analyzing data. This study is classified as engineering research, involving non-routine design activities that contribute new elements, whether in process or through the development of new products or prototypes (Sugandi et al., 2020).

In this study, variables are categorized into three groups. The independent variables include the pressure readings from the piezoelectric sensor and the hexadecimal values in the Talempong tone data array within the software. The dependent variables are the output voltage from the piezoelectric sensor and the frequency of the Talempong tones. The control variables are the values of the electronic components utilized in the research.

The electric Talempong system is composed of a piezoelectric sensor, signal conditioning circuitry, a Teensy 4.1 microcontroller, an I2S UDA1334A, an LCD, a power supply, and a speaker. The system's block diagram is illustrated in Figure 1.

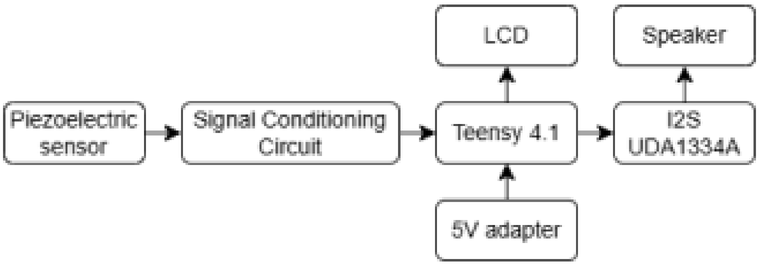

Figure 1. System block diagram for the electric Talempong

According to Figure 5, in the dual-tone electric Talempong system, the piezoelectric sensor detects the pressure from the player's strikes and converts this pressure into an electrical signal. This signal is amplified by the IC LM324 circuit to ensure that the output can be handled by the Teensy 4.1 microcontroller, which operates with a 3.3-volt input. The Teensy 4.1 processes the sensor signals using C++ programming, managing the entire system including I2S configuration, power supply control, and LCD display settings. The I2S (Inter-IC Sound) interface connects the Teensy 4.1 to the speaker, transmitting the audio signal generated by the Teensy 4.1 and producing sound based on the sensor input. The LCD serves as a visual interface controlled by the Teensy 4.1, enabling the display of notes or settings for the electric Talempong.

The mechanical design of the electric Talempong includes 8 pads on the top and 8 pads on the bottom, mimicking the traditional Talempong shape. Each pad has a primary tone and a variation, and is fitted with a piezoelectric sensor that generates an output voltage when struck. This output voltage is processed by the Teensy 4.1, which serves as the signal processor for the Talempong. The hardware design is illustrated in Figure 2.

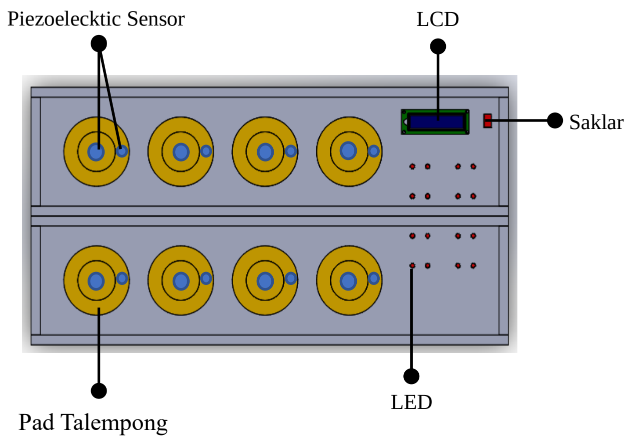

Figure 2. Mechanical design of the electric Talempong

According to Figure 2, the mechanical design of the electric Talempong features a piezoelectric sensor on each pad, an LCD display positioned in the top right corner to facilitate easy viewing of the notes or pads being struck, and LEDs that serve as indicators for note selection. For example, when the C note is struck, the C LED will illuminate. A switch is included to power the device on or off when the adapter is connected to the electrical source. The electric Talempong is controlled using Teensy 4.1, programmed in C++ via the Arduino IDE, which provides instructions for the correct operation of the Teensy 4.1. The flowchart for the microcontroller design is depicted in Figure 3.

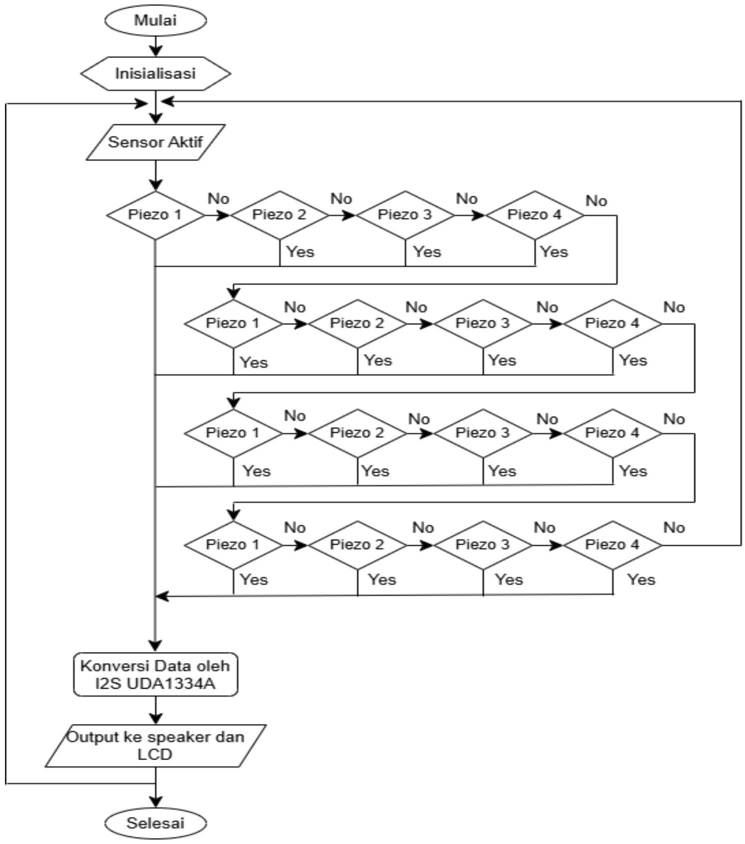

Figure 3. Flowchart of the microcontroller design

Figure 3 shows the microcontroller software system workflow. The design employs the Arduino IDE, starting with the initialization of the device to set up the pins and prepare the necessary components. The system then gathers data from 16 piezoelectric sensors using the Teensy 4.1, which involves reading the values from each sensor to detect taps or strikes. The input data process checks whether the sensors or the Talempong are being played. When any activity or pressure is detected, sound is produced through the speaker via I2S. The microcontroller processes this data, and the resulting sounds or tones from the piezoelectric sensors are displayed on the LCD.

Data for this research is gathered by measuring sensor pressure, program variations, accuracy, and precision. The data collection utilizes the free fall motion equation to analyze sensor output. By dropping a weight from a certain height, data can be collected from the piezoelectric sensors using Equation (1).

$$\mathrm{P} = \frac{F}{\mathrm{A}} \tag{1}$$

To calculate the force exerted when pressing the piezoelectric sensor, you can use Equation (2).

$$F = m.g \tag{2}$$

In the electric Talempong, the relationship between pressure (P) and force (F) is influenced by the pressure applied to it. Other factors, such as the cross-sectional area (A), mass (Kg), and gravitational acceleration (m/s^2), also impact the force resulting from the pressure when the piezoelectric sensor is hit. The piezoelectric sensor is capable of measuring variations in force and pressure within the electric Talempong.

The analysis of data for the electric Talempong involves evaluating error percentages, measurement accuracy, and the precision of the Talempong tones. Error is defined as the percentage difference between the measured values and the actual values. The percentage error can be computed using Equation (3).

$$Error = \left| \frac{Y_n - X_n}{Y_n} \right| \times 100\% \tag{3}$$

In this context, Yn represents the true value of the original Talempong, while Xn denotes the voltage measured by the piezoelectric sensor. Accuracy refers to how closely the measurement results align with the actual values or data (Kania Nisa Fauziah et al., 2022). The accuracy of a measurement can be determined using Equation (4).

$$Accuracy = \left(1 - \left| \frac{Y_n - X_n}{Y_n} \right| \right) \times 100\% \tag{4}$$

In the dual-tone electric Talempong, Yn denotes the true value of the original Talempong, while Xn is the voltage read by the piezoelectric sensor. The outcome of this analysis is the accuracy of the sensor's measurements. Precision can be calculated using Equation (5).

$$precision = \left(1 - \left| \frac{X_n - \overline{X}_n}{\overline{X}_n} \right| \right) \times 100\% \tag{5}$$

Xn is the value of the n-th measurement, n is the total number of measurements, and the average of these measurements is used in the calculation.

3. RESULTS AND DISCUSSION

3.1. RPM Testing on DC Motor Encoder

After completing the development of the dual-tone electric Talempong system with a piezoelectric sensor and Teensy 4.1, a device has been created that fulfills the research goals. The research details the specifications of the components used. Data analysis covers both system performance and design specifications, presented in tables and graphs. Accuracy is assessed by comparing the frequencies of the original Talempong with those of the electric Talempong. Precision is determined by recording the frequency of the electric Talempong tone struck 10 times.

The characteristics of the piezoelectric sensor are measured using two methods: a multimeter and the Teensy 4.1 program as a voltage measurement tool for the output of the piezoelectric sensor. The characterization data obtained from the device is the output voltage of the piezoelectric sensor. Data on the characterization of the piezoelectric sensor using Teensy 4.1 can be seen in Figure 6.

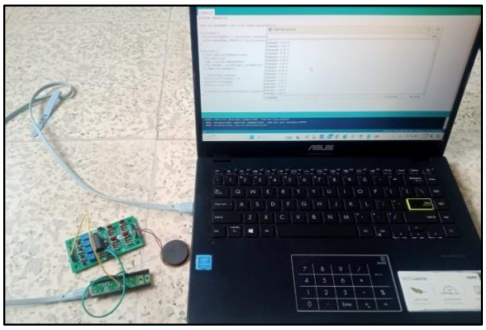

Figure 4. Data acquisition for piezoelectric sensor characterization using Teensy 4.1.

Figure 4 displays the characterization data of the piezoelectric sensor with Teensy 4.1. For data collection, a load was dropped onto the sensor, which was shielded with a 4 mm thick foam. This foam protects the sensor from damage due to the falling load and helps keep the load in place on the sensor to generate electrical voltage. The analog output from the piezoelectric sensor is converted into voltage, with different force levels applied to produce corresponding voltage changes. The impact of force on the output voltage of the piezoelectric sensor, as measured with Teensy, is detailed in Table 1.

Table 1. Data on the characterization of the piezoelectric sensor using Teensy 4.1

Force **(N)**	Voltage **(V)**
0.1	0.118
0.2	0.212
0.3	0.304
0.4	0.435
0.5	0.557
0.6	0.644
0.7	0.713
0.8	0.869
0.9	0.981
1	1.215

Table 1 indicates that the output voltage of the piezoelectric sensor increases in direct proportion to the applied force. The greater the force applied, the higher the sensor's output voltage. This relationship between force and the piezoelectric sensor's output is illustrated in a graph shown in Figure 5.

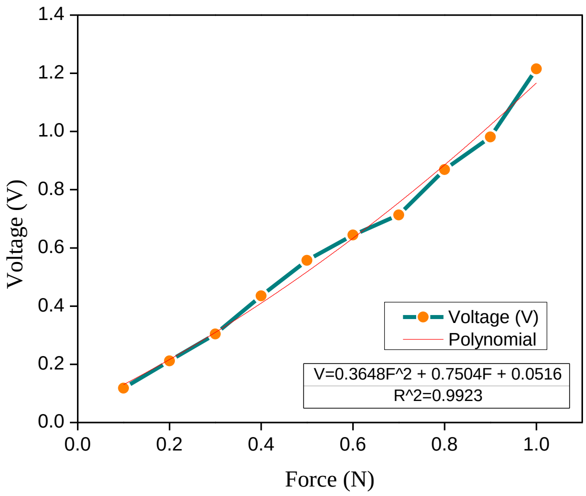

Figure 5. The effect of force on the output of the piezoelectric sensor

Figure 5 illustrates that the relationship between force and the output voltage of the sensor is linear. The graph shows that the sensor's output voltage increases with the applied force; higher forces result in higher output voltages. The obtained linear equation is V = 0.3648F2 + 0.7504F + 0. where the constant is 0.0516, he coefficient for a is 0.3648, nd the coefficient for b is 0.7504. The coefficient of determination is 0.9923, indicating a value close to 1.

The design specifications are assessed by evaluating the accuracy and precision of the electric Talempong. Accuracy is determined by comparing the frequency of the electric Talempong with that of the original Talempong, analyzed using Audacity software. The electric Talempong is deemed accurate if its frequency is the same as or very close to that of the original Talempong. Data comparing the frequencies of the original Talempong and the electric Talempong can be found in Table 2.

Table 2. Accuracy data of the original Talempong compared to the electric Talempong

Note	Frequency of Original Talempong (Hz)	Frequency of Electric Talempong (Hz)	Error Percentage (%)	Relative Accuracy	Relative Accuracy (%)
C	528	527	0.19	0.998	99.8
C2	533	527	1.13	0.989	98.9
D	586	585	0.17	0.998	99.8
D2	585	584	0.17	0.998	99.8
E	659	657	0.30	0.997	99.7
E2	659	656	0.46	0.995	99.5
F	695	692	0.43	0.996	99.6
F2	694	695	0.14	0.999	99.9
G	782	782	0.00	1.000	100.0
G2	783	783	0.00	1.000	100.0
A	872	873	0.11	0.999	99.9
A2	873	873	0.00	1.000	100.0
B	1000	1002	0.20	0.998	99.8
B2	1000	1002	0.20	0.998	99.8
C’	1042	1045	0.29	0.997	99.7
C’2	1043	1044	0.10	0.999	99.9
	Average		**0.24**	**0.998**	**99.8**

According to Table 2, the frequencies of the original Talempong and the electric Talempong are very similar, showing a minimal error percentage and accuracy nearing 1. This data is illustrated in a graph, as shown in Figure 6.

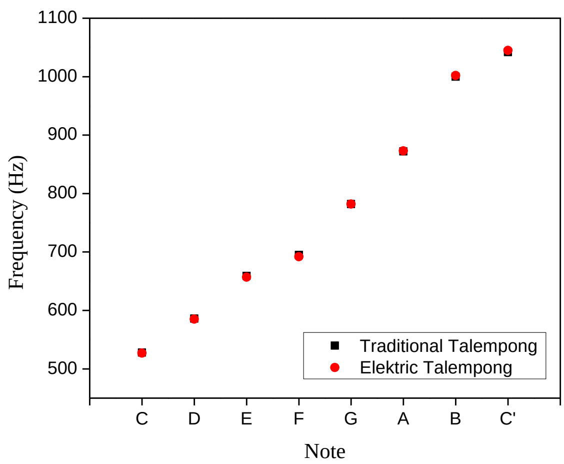

Figure 6. Accuracy of the frequency of the original Talempong compared to the electric Talempong

Figure 6 illustrates the accuracy of the electric Talempong's frequency in comparison to the original Talempong. The graph indicates that the frequency of the electric Talempong closely matches that of the original. Next, the precision of the electric Talempong's notes is examined by hitting each pad on the instrument 10 times. These strikes are recorded with Audacity software to analyze the frequencies of the notes produced. The recordings from this precision testing are shown in Figure 7.

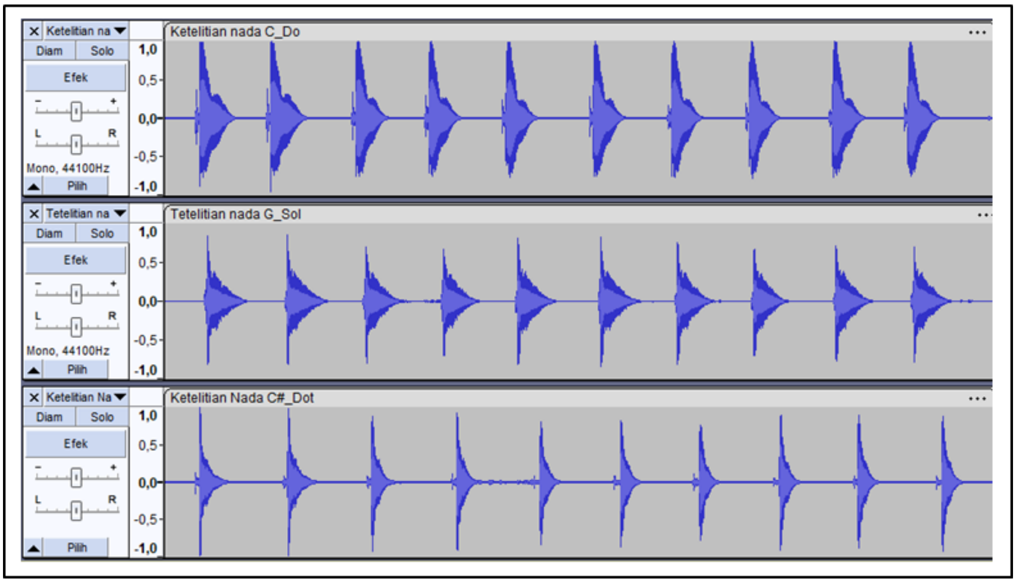

Figure 7. Recording the pitch accuracy of the electric Talempong using Audacity software

Figure 7 displays the recordings of notes C, G, and C’ from 10 consecutive hits on each note. It is expected that when a pad is struck repeatedly 10 times, the sound produced should remain consistent, and the frequencies should align with those of the original Talempong. The precision of the electric Talempong's sound is illustrated in Figure 8, shown in the graph.

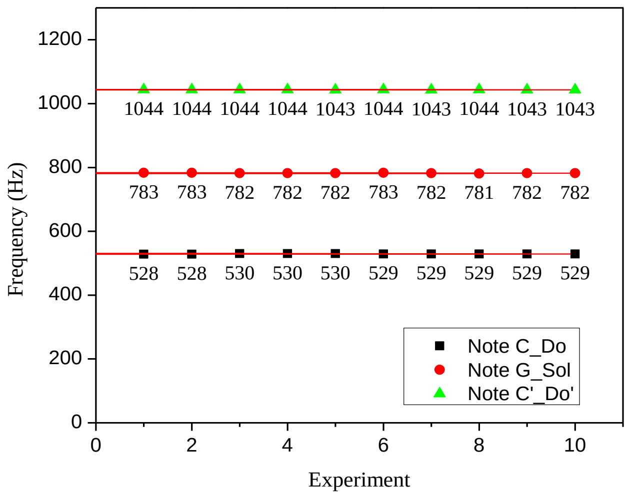

Figure 8. The precision of the electric Talempong's sound for the notes C, G, and C’

Figure 8 presents the results of the sound precision test for the electric Talempong. The testing involved three note samples: note C for low pitches, note G for mid pitches, and note C’ for high pitches. The graph illustrates that the frequencies produced by the electric Talempong remain relatively stable even after multiple strikes or taps.

From the analysis conducted, including data from graphs and statistical computations, the research has met its objectives. The study has resulted in two key outcomes: the performance specifications and the design specifications of the dual-tone electric Talempong utilizing piezoelectric sensors with Teensy 4.1. The performance specifications were determined by examining the role of each component in the system. In contrast, the design specifications were derived from the measurements and data analyses performed. Together, these aspects offer a thorough understanding of both the functionality and design of the electric Talempong system.

The primary outcome of this study is the performance specification of the piezoelectric sensor characteristics and the use of the Teensy program. The measurement process involved connecting the positive pin of the sensor to the signal conditioning circuit, with the circuit's output connected to an analog pin on the Teensy 4.1. This setup allowed for the assessment of how force applied to the piezoelectric sensor affects its output voltage. The data obtained from this characterization revealed that the changes in electrical energy produced by the piezoelectric sensor, measured either with a multimeter or through Teensy 4.1 programming, are directly proportional to the output voltage of the sensor. This finding is consistent with the operational principle of piezoelectric sensors, where the electrical energy change on the sensor surface directly corresponds to the output when force is applied (Mu'aliman et al., 2023).

The second outcome related to performance specification involves collecting output data from the piezoelectric sensor using Teensy 4.1, with the addition of a signal conditioning circuit. This circuit is crucial for interfacing the piezoelectric sensor with the Teensy 4.1, ensuring that the sensor's output voltage does not exceed the 3.3-volt maximum input limit of the Teensy 4.1 microcontroller. The signal conditioning circuit was constructed using a 100kΩ resistor and a 1N4148 diode, forming a voltage divider to reduce the sensor's output voltage to a safe level below 3.3 volts (Diniardi et al., 2018). The LM324A IC functions as an operational amplifier in the circuit, amplifying the signal from the piezoelectric sensor so that it can be properly read by the Teensy 4.1. The circuit's role is to ensure that the sensor's output voltage stays within the safe input range of the Teensy. When the sensor is struck, the amplified signal is fed into the analog pin of the Teensy 4.1. The Teensy 4.1 then processes this input, triggering the corresponding pre-set tone for each pad. The sound from the struck pad is played through the speaker. Additionally, an LCD and LEDs are used to visually indicate the selected tone sequence, facilitating the use of the electric Talempong during play.

The third result in performance specifications involves using Audacity software to record the Talempong sound. Audacity visualizes the sound waveform, which is then analyzed with the spectrum plot feature to determine the frequency of the Talempong sound (Pebriani et al., 2023). The recorded sound is saved as a WAV file and used as a reference tone for the electric Talempong. This recorded sound is converted into C/C++ arrays with wav2sketch for integration into the Teensy program. After covering performance specifications, the discussion shifts to the results of design specifications.

The design specifications results encompass data on accuracy, precision, and the practicality of the Talempong electric sound. Accuracy is evaluated by comparing the frequency of the original Talempong with that of the electric Talempong, showing an accuracy rate of 99.8%, meaning the electric Talempong's sound closely matches that of the original. Precision is tested by repeatedly striking the Talempong electric pad 10 times on tones C, G, and C', which are three out of eight possible tones. The precision results are 99.9% for tone C, 99.9% for tone G, and 100% for tone C'. Practicality is assessed with a 94% score, indicating the instrument is very practical.

The development of the electric Talempong presents both strengths and limitations. The dual-tone electric Talempong, utilizing a piezoelectric sensor and Teensy 4.1, effectively addresses the issues of the original Talempong's heavy weight, high cost, and large size. It is designed to weigh 1.4 kg and has dimensions of 50x12x7 cm to solve these issues. Nonetheless, there are several drawbacks.

First, only 8 Talempong tones (pentatonic scale) are used for 16 piezoelectric sensors due to the limited number of analog pins on the Teensy microcontroller. Second, the HC-05 Bluetooth module is not ideal because it lacks the necessary input pins to connect I2S to Bluetooth. Third, the placement of the LED indicators for tone selection is less optimal. Fourth, the small circle placed on top of the large circle is not centered on the Talempong body, unlike the original Talempong where the pencon is centered.

4. CONCLUSION

The performance specifications of the electric Talempong encompass its electronic circuitry and mechanical design. The electronic system includes piezoelectric sensors, a signal conditioning circuit, the Teensy 4.1 microcontroller, the I2S UDA1334A audio interface, and a speaker. When a Talempong pad is struck, the piezoelectric sensor sends an analog signal to the Teensy 4.1, which converts it to digital. The I2S UDA1334A then transforms this digital signal into sound that replicates the Talempong tones. The speaker outputs the sound, while the LCD displays the tone. Design specifications involve accuracy, precision, and practicality: the accuracy, based on comparing frequencies between the original and electric Talempong, averages a 0.24% error with a 99.8% accuracy rate; precision is evaluated through 10 strikes per tone, achieving 99.9% for tone C and G, and 100% for tone C', practicality assesses the overall functionality and usability of the device.

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DECLARATIONS

Authorship contribution

Annisa Aulia Army: Conceptualization, methodology, formal analysis, software and writing -original draft, **Asrizal and Mairizwan**: Validation, review and editing. **Mohd Effindi Samsuddin**: Validation and review.

Competing Interest

The authors **declare** no conflict of interest in this study.

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Ethical Clearance

There are no human subjects in this manuscript, and informed consent is not applicable.

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