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An Electric Talempong with Transpose System Based on the Teensy 4.1 Microcontroller

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ABSTRACT

Talempong is a traditional Minangkabau musical instrument that holds significant cultural value and plays a vital role in traditional art performances. However, its application in modern music accompaniment is limited due to a lack of pitch flexibility, as it is generally configured in a fixed base scale such as C=Do. This limitation makes it difficult to integrate talempong into contemporary music arrangements that often require different key scales to suit a singer's vocal range. This research aims to develop an electric talempong equipped with a pitch transposition system based on the Teensy 4.1 microcontroller to enhance its adaptability for modern musical performances.
This study employs an engineering approach by designing an electric talempong system using a Teensy 4.1 microcontroller and piezoelectric sensors for 16 pad inputs. Sound frequency is extracted and analyzed using Audacity software. The base pitch is displayed through an OLED screen, while transposition is controlled using two buttons. Testing procedures include sensor characterization, frequency error analysis, accuracy and precision measurement, and practicality evaluation by professional talempong players. The results show that the system has an average frequency error rate of less than 2%, relative accuracy above 97%, and a precision level of up to 99.72% on the C7 note. The practicality score reached 87 out of 100, indicating the system is user-friendly and functional in practice. Therefore, the developed electric talempong proves to be an effective and adaptable instrument for modern music performances while preserving its traditional sound character.

1. INTRODUCTION

The Talempong is a traditional percussion instrument originating from Minangkabau culture and is commonly performed in traditional cultural performances such as randai [1]. In its conventional form, the Talempong uses a pentatonic tuning system that reflects the musical characteristics of Minangkabau traditional music. In recent years, the instrument has been adapted to use a diatonic major scale to better suit modern musical arrangements [2]. As a result, the Talempong is now often performed alongside contemporary instruments such as electric bass guitars and keyboards in modern musical performances [3].

However, both traditional and modernized Talempong instruments are typically tuned to the C = Do scale, which limits their flexibility when accompanying songs in other keys. In modern music performances, singers frequently change the key of songs to match their vocal range [4]. This situation requires accompanying instruments to be adaptable to different tonal centers. Consequently, the fixed tuning of the Talempong creates limitations when it is used in contemporary musical settings.

Previous research has attempted to address this issue through electronic adaptations of the Talempong instrument. Ulva (2019) developed an electric Talempong using a Raspberry Pi and piezoelectric sensors to detect on the instrument surface. However, the system experienced audio delay and did not include a pitch transposition feature. In [5] later designed an IoT-based Talempong learning system that focused on educational applications rather than live musical performance.

Furthermore, In [6] introduced a dual-tone electric Talempong based on the Teensy 4.1 microcontroller, which achieved high sound accuracy and low latency but remained limited to the C-major scale without key transposition capability. Although Army et al. successfully implemented a low-latency electric Talempong, their system remained static in its basic tone. This research goes beyond static playback by implementing a dynamic tone transposition algorithm that allows real-time key changes without requiring numerous pre-recorded samples, a feature that is crucial for live music accompaniment.

To address these limitations, this study proposes the development of an electric Talempong instrument equipped with an integrated pitch transposition system using the Teensy 4.1 microcontroller. This system allows performers to change the base scale by simply pressing the "up" or "down" button, enabling the instrument to follow different musical keys. The Teensy 4.1 microcontroller was selected due to its high-performance ARM Cortex-M7 processor running at 600 MHz, which supports real-time audio signal processing [7]. In addition, microcontroller-based systems are relatively cost-effective, easily programmable, and highly adaptable for digital audio innovations [8].

Through this approach, the Talempong can adapt to various musical keys without requiring multiple sets of instruments. This capability increases the practicality of the Talempong in modern musical performances. Furthermore, integrating digital technology with traditional instruments can support the preservation and development of Minangkabau musical heritage. Therefore, the proposed system offers a potential solution for maintaining the relevance of Talempong in contemporary music environments.

2. METHOD

This research was conducted at the Electronics and Instrumentation Laboratory of the Department of Physics and at the Tuah Sepakat Art Studio in Lubuk Alung. The research began in March 2025 and was carried out in several stages, including system design, prototype development, performance testing, and final reporting. The type of research used was engineering research, which involves the development of devices based on theoretical understanding and scientific principles to meet specific functional requirements [9]. The research procedure followed the stages of idea formulation, system design, prototype construction, and performance evaluation.

The variables in this study were categorized into three types. The independent variable was the pressure applied to the piezoelectric sensor, the dependent variables included the sensor's voltage output and the frequency of the produced tone, and the control variable consisted of the fixed electronic components used throughout the experiment [10].

The hardware system consisted of piezoelectric sensors as the primary input to detect vibration from strikes, a Teensy 4.1 microcontroller as the central processing unit, a PCM5102 DAC to convert digital signals into analog audio, and an OLED LCD to display the current root note. Push buttons were used to control the transposition system, and a signal conditioning circuit ensured that voltage levels were safe for the microcontroller. The system also utilized the I2S audio protocol to produce clear, low-latency sound output.

The system was designed by first composing a functional block diagram, which illustrated the interconnection between core components, as shown in Figure 1. When the user strikes a pad, the piezoelectric sensor detects the vibration and sends a signal to the Teensy 4.1, which processes the input and determines the corresponding tone. The transposition system allows the user to shift the root note using up/down buttons, and the selected root note is displayed on the OLED screen. The Teensy then sends the audio signal to the PCM5102 module, which converts it to analog form for speaker output.

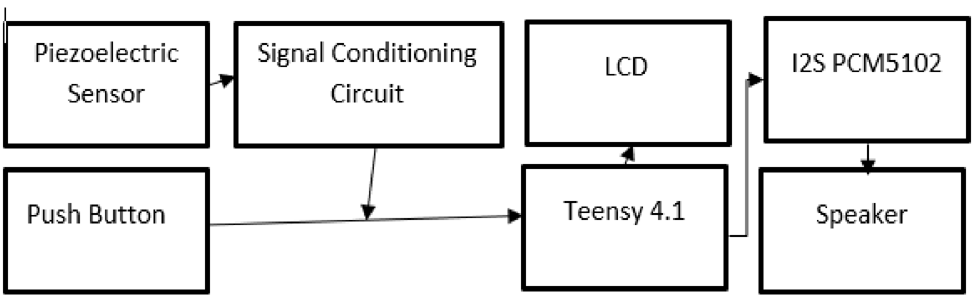

Figure 1. Block Diagram of the Electric Talempong System with Note Transpose Functionality

The physical design of the electric talempong was developed to emulate the form of the traditional instrument while integrating digital technology. As shown in Figure 2, the prototype features a 100 cm × 25 cm × 10 cm frame with 16 circular pads, each 80 mm in diameter, equipped with individual piezoelectric sensors. The microcontroller and other supporting components were neatly integrated within the body of the instrument.

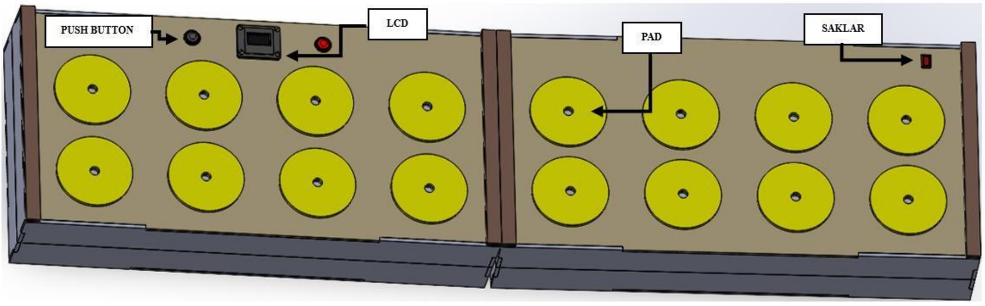

Figure 2. Design of the Electric Talempong

The software was developed using Arduino IDE with C++ programming. The system's logic included component initialization, transpose button detection, strike detection, tone generation based on the selected scale, and audio output via the I2S protocol. The program's workflow is illustrated in Figure 3.

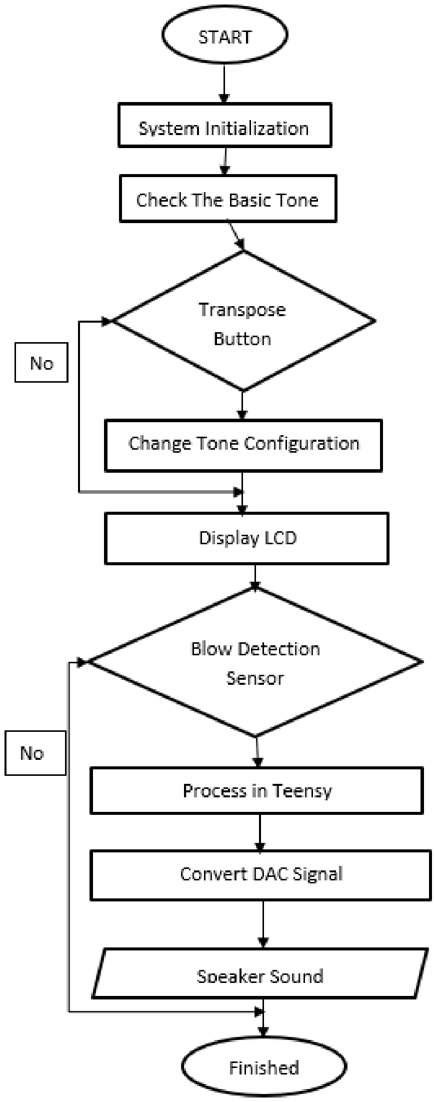

Figure 3. Flowchart of The Electric Talempong System Program

Once the system was fully assembled, a series of tests were conducted to evaluate its performance. Data were collected by measuring the voltage output from the piezoelectric sensors under varying pressure levels. These measurements were based on the physics principle of pressure, expressed as using Equation (1)

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

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

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

The voltage output was digitized by the Teensy 4.1 microcontroller and analyzed to assess the sensor's response to pressure changes. Accuracy was evaluated by comparing the frequencies produced by the electric talempong with reference frequencies from the traditional instrument using Audacity software. Precision was assessed by repeatedly striking the same pad and analyzing the consistency of the resulting frequency. Flexibility of the transpose system was tested by adjusting the scale via the transpose buttons and verifying the output tones against the C=Do diatonic scale.

The collected data were analyzed through error rate, accuracy, and precision metrics. Frequency error was calculated using the Equation 3.

$$\%error = \left|\frac{Yn - Xn}{Yn}\right| \times 100\% \tag{3}$$

where Yn is the reference frequency from the traditional talempong and Xn is the frequency from the electric version. Accuracy was measured by Equation 4.

$$Accuracy = 1 - \left|\frac{Yn - Xn}{Yn}\right| \tag{4}$$

and precision was determined through standard deviation by Equation 5.

$$Precision(\%) = 100\% - \left(\frac{SD}{\bar{X}} \times 100\right) \tag{5}$$

In addition, a practicality test was conducted to assess the instrument's usability, efficiency, and appeal. This involved distributing a questionnaire to ten musicians from the Tuah Sepakat art group. Respondents evaluated five aspects: ease of use, usefulness of the transpose feature, sound response delay, audio quality, and their interest in using the instrument in performances. Responses were scored on a 5-point Likert scale. The final practicality score was calculated as a percentage of total respondent scores relative to the maximum possible score, and interpreted using a standard rubric: very practical (86–100%), practical (76–85%), moderately practical (60–75%), less practical (55–59%), and not feasible (<54%) [11].

3. RESULTS AND DISCUSSION

This study successfully produced a prototype of an Electric Talempong instrument equipped with a transpose tone system based on the Teensy 4.1 microcontroller. A series of tests were conducted to evaluate the system's performance and design specifications, including sensor characterization, frequency accuracy, frequency precision, and practicality assessment.

a. System Performance Specifications

The Electric Talempong system consists of three main components: input, processing, and output. The input section includes piezoelectric sensors that detect vibrations from pad strikes. The signals from the sensors are conditioned through amplifying and filtering circuits, then transmitted to the analog pins of the Teensy 4.1 microcontroller. Within the microcontroller, the analog signals are converted to digital using ADC and processed according to the system's logic. The output signals are sent via the I2S interface to the PCM5102 module, which functions as a digital-to-analog converter (DAC). The resulting analog signal is then outputted through speakers. The complete electronic system is shown in Figure 4.

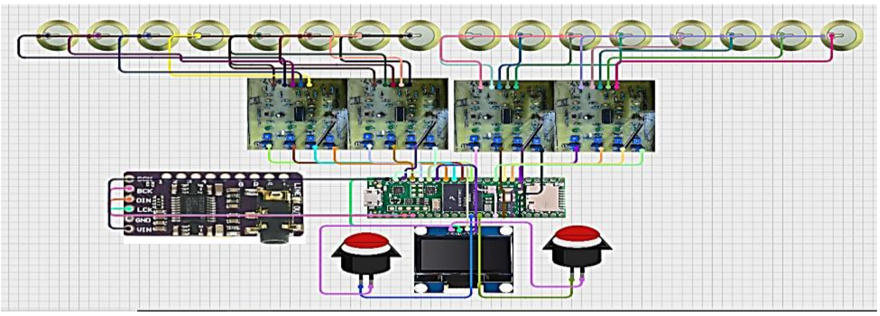

Figure 4. The Complete Electronic System

To produce authentic sounds, original talempong tones were recorded using Audacity software. The recordings were saved in WAV format and converted into .cpp and .h code files using the Teensy audio converter. These files were loaded into the Teensy program so that each pad could reproduce the corresponding tone sample when played. The recording process and spectrum analysis using Audacity are shown in Figures 5 and 6, respectively, illustrating the frequency spectrum of the C5 tone.

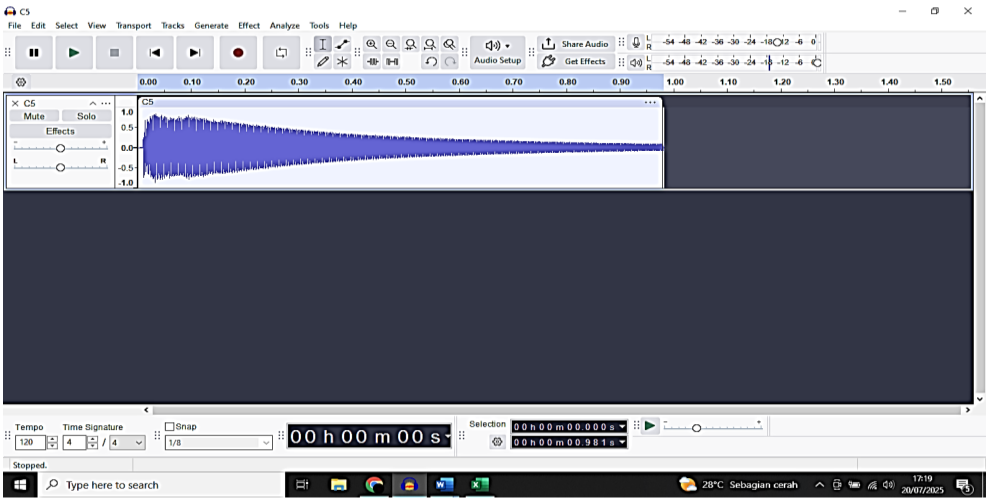

Figure 5. The Complete Electronic System

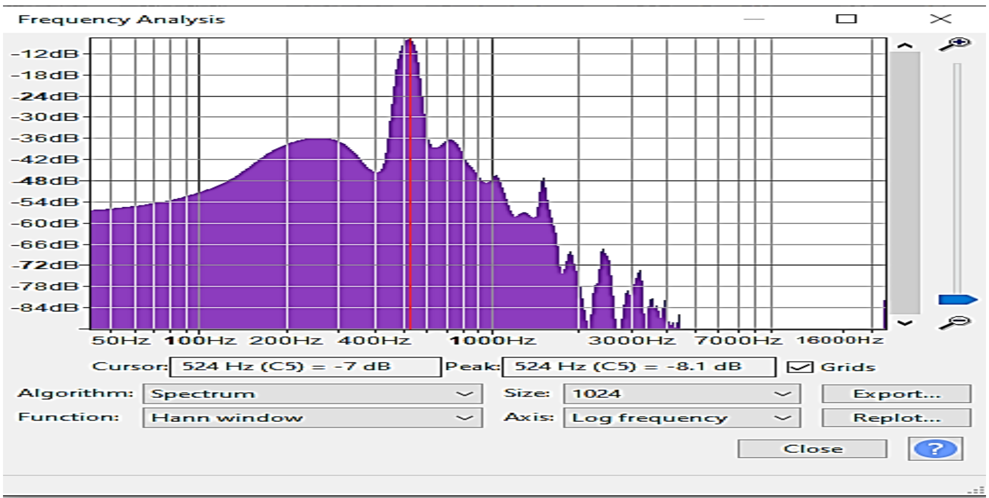

Figure 6. The Complete Electronic System

The mechanical structure of the Electric Talempong was made from 3 mm thick plywood, designed to be foldable and lightweight, with dimensions of 100 cm × 25 cm × 10 cm. Each pad includes a piezoelectric sensor mounted on foam and rubber to enhance player comfort and sensor protection. The complete mechanical design is displayed in Figure 7.

Figure 7. The Complete Mechanical Design

The audio system was designed using the Teensy Audio System Design Tool. Components such as AudioPlayMemory, AudioMixer4, and AudioOutputI2S2 were used to manage the playback and routing of audio signals from the pads to the speaker system. The system design schematic is shown in Figure 8.

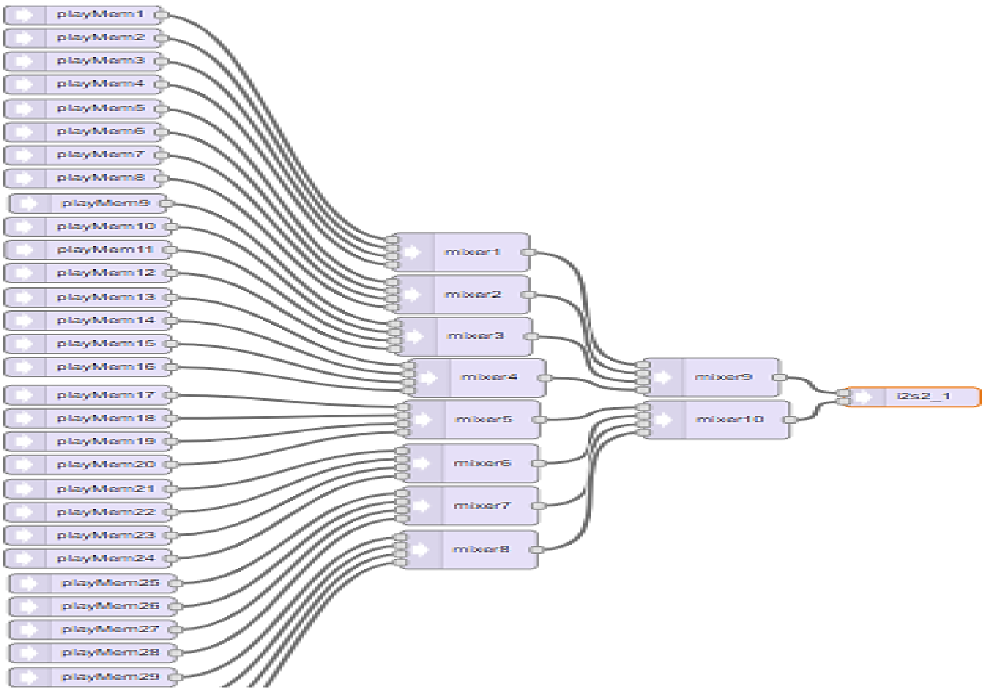

Figure 8. The Audio System Design of The Electric Talempong

Figure 8 shows the audio system design of the electric talempong, which was created using the Teensy Audio System Design Tool. The design begins with the use of the AudioPlayMemory module, which functions to play pre-converted digital sound samples. Each audio signal from the AudioPlayMemory is then routed to interconnected mixers, which manage the mixing of signals from various tone sources.

b. System Design Specifications

The design specifications of the Electric Talempong system were determined based on a series of performance evaluations, including sensor characterization, frequency accuracy, tone precision, and practicality assessment. These evaluations aimed to ensure that the developed system not only functions effectively but also replicate the tonal qualities of traditional talempong instruments with a high degree of fidelity.

The characterization of the piezoelectric sensors was conducted by applying varying levels of mechanical pressure. A 5-gram weight was dropped from different heights ranging from 2 cm to 20 cm onto the sensor surface to simulate different impact intensities. If an object of the same weight is dropped from different heights, it will have different kinetic energies upon impact[12]. Deformation (or pressure) influencing electronic signals remains relevant in piezoelectric systems as pressure sensors[13]. The resulting output voltages were measured using a digital multimeter, while the analog values were recorded through the Teensy 4.1 microcontroller. The results confirmed a linear correlation between the applied pressure and the output voltage, indicating that the sensors are highly responsive and suitable for detecting percussive input. The experimental setup used in this test is illustrated in Figure 9 and the resulting Analog Values-pressure relationship is plotted in Figure 10.

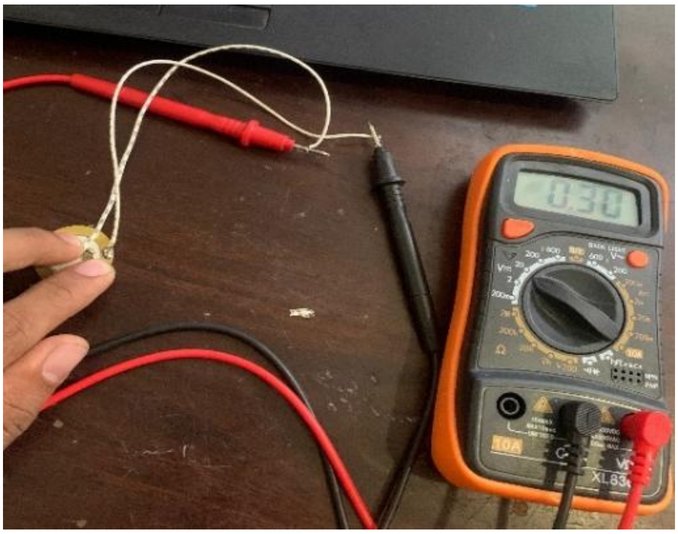

Figure 9. Piezoelectric Sensor Characterization

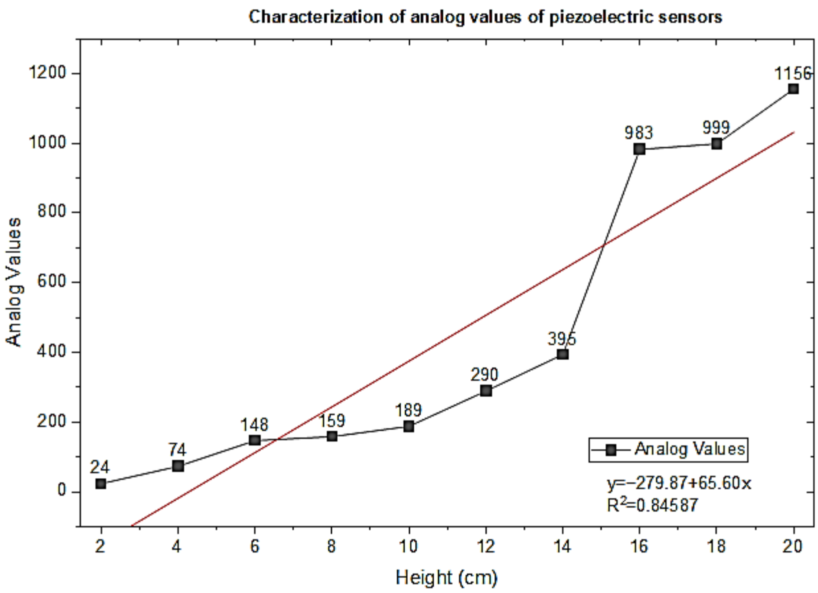

Figure 10. The resulting Analog Values-pressure relationship

To assess frequency accuracy, the tones generated by the Electric Talempong were compared with those produced by a traditional talempong. The measured frequencies from the electric system (Xn) and the reference frequencies from the traditional instrument (Yn) were analyzed to determine the percentage error. The comparison graph, presented in Figure 11, shows that the deviations in frequency are minimal—generally below 3%—demonstrating that the Electric Talempong effectively reproduces traditional tones. The numerical data for this analysis can be found in Table 1.

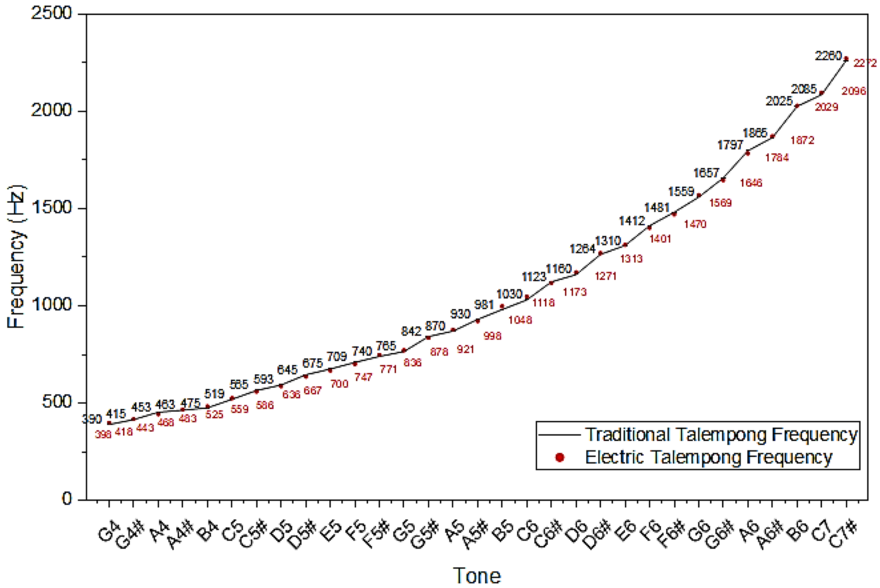

Figure 11. The electric talempong effectively reproduces traditional tones

Table 1. Frequency Comparison Between Traditional Talempong and Electric Talempong

Tone	Traditional Talempong Frequency (Hz) (Yn)	Electric Talempong Frequency (Hz) (Xn)	Error (%)
G4	390	398	2,05
G4#	415	418	0,72
A4	453	443	2,21
A4#	463	468	1,08
B4	475	483	1,68
C5	519	525	1,16
C5#	565	559	1,06
D5	593	586	1,18
D5#	645	636	1,40
E5	675	667	1,19
F5	709	700	1,27
F5#	740	747	0,95
G5	765	771	0,78

G5#	842	836	0,71
A5	870	878	0,92
A5#	930	921	0,97
B5	981	998	1,73
C6	1030	1048	1,75
C6#	1123	1118	0,45
D6	1160	1173	1,12
D6#	1264	1271	0,55
E6	1310	1313	0,23
F6	1412	1401	0,78
F6#	1481	1470	0,74
G6	1559	1569	0,64
G6#	1657	1646	0,66
A6	1797	1784	0,72
A6#	1865	1872	0,38
B6	2025	2029	0,20
C7	2085	2096	0,53
C7#	2260	2272	0,53

Although the frequency deviations observed in Table 1 are relatively small, several technical factors may contribute to these differences between the traditional talempong and the electric talempong system. First, the sensitivity of the piezoelectric sensors can influence the triggering response when detecting pad strikes. Variations in impact force may cause slight differences in the signal amplitude received by the microcontroller. Second, the analog signals from the sensors are converted into digital signals using the analog-to-digital converter (ADC) of the Teensy 4.1 microcontroller. Although the ADC provides high resolution, minor quantization errors may occur during the conversion process, which can slightly affect the timing of audio playback. Third, the sampling rate used during the audio recording process may introduce small frequency shifts when the recorded samples are reproduced. In addition, the digital audio processing and mixing operations within the audio system, such as signal routing through AudioPlayMemory and AudioMixer modules, may introduce minimal latency that can indirectly influence frequency representation. Mechanical factors, including pad elasticity and variations in sensor placement, may also contribute to small differences in the detected strike intensity. Despite these potential sources of deviation, the measured frequency errors remain below 3%, indicating that the developed electric talempong system maintains a high level of tonal fidelity compared with the traditional instrument.

In addition to accuracy, tone precision was also evaluated to determine the stability of the electric talempong system. This test was conducted by striking the same tone ten times for four representative pitches: A4, C5, C6, and C7. The resulting frequencies were recorded and analyzed by calculating the mean value and standard deviation for each tone. The relatively small variations observed across repeated trials indicate that the system produces consistent frequency outputs for the same input. This result demonstrates that the electric talempong has good repeatability and stable tone generation. The detailed precision results are presented in Figure 12. The precision data table can be seen in Table 2-5.

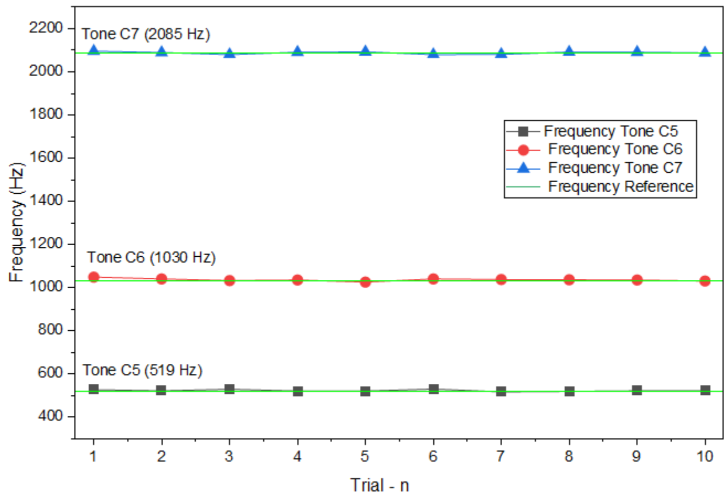

Figure 12. Precision Graph of the electric talempong

Table 2. Repeated Frequency Measurements of Note A4 for Precision Testing

Tone	Trial-n	Frequency (Xn) (Hz)
A4 (453 Hz)	1	443
	2	450
	3	439
	4	440
	5	443
	6	441
	7	446
	8	445
	9	445
	10	443
MEAN (Hz)		443,5 Hz
STANDAR DEVIATION (Hz)		3,01 Hz
ACCURACY (%)		97,90 %

The precision of the electric talempong system was evaluated by performing repeated measurements of the same tone. Table 2 presents the results of ten repeated trials for note A4. The measured frequencies range from 439 Hz to 450 Hz, with an average value of 443.5 Hz and a standard deviation of 3.01 Hz. The relatively small standard deviation indicates that the electric talempong produces stable and consistent frequency outputs when the same tone is repeatedly played. This result demonstrates that the system has good repeatability and reliable tone generation performance.

Table 3. Repeated Frequency Measurements of Note C5 for Precision Testing

Tone	Trial-n	Frequency (Xn) (Hz)
C5 (519 Hz)	1	525
	2	520
	3	527
	4	519
	5	519
	6	528
	7	515
	8	517
	9	520
	10	520
MEAN (Hz)		521 Hz
STANDAR DEVIATION (Hz)		4,06 Hz
ACCURACY (%)		99,61 %

Table 3 presents the results of repeated frequency measurements for note C5 to evaluate the precision of the electric talempong system. The measurements were conducted ten times for the same tone, producing frequencies ranging from 515 Hz to 528 Hz. The calculated mean frequency is 521 Hz with a standard deviation of approximately 4.06 Hz. The relatively small variation between repeated measurements indicates that the system is capable of producing stable and consistent frequencies for the same input tone. In addition, the average frequency is very close to the reference frequency of the traditional talempong (519 Hz), resulting in an accuracy value of approximately 99.61%. These results demonstrate that the electric talempong exhibits good precision and repeatability in generating the C5 tone.

Table 4. Repeated Frequency Measurements of Note C6 for Precision Testing

Tone	Trial-n	Frequency (Xn) (Hz)
C6 (1030 Hz)	1	1048
	2	1040
	3	1032
	4	1035
	5	1025
	6	1040
	7	1037
	8	1036
	9	1035

	10	1030
MEAN (Hz)		1035,8 Hz
STANDAR DEVIATION (Hz)		6,03 Hz
ACCURACY (%)		99,44 %

The precision of the electric talempong for note C6 was evaluated through ten repeated measurements, as shown in Table 4. The measured frequencies range from 1025 Hz to 1048 Hz. The calculated mean frequency is 1035.8 Hz with a standard deviation of approximately 6.03 Hz. The relatively small variation among the repeated measurements indicates that the system produces stable and consistent frequencies for the same tone. Furthermore, the mean frequency is very close to the reference frequency of the traditional talempong (1030 Hz), resulting in an accuracy of approximately 99.44%. This demonstrates that the electric talempong is capable of generating the C6 tone with high precision and reliability.

Table 5. Repeated Frequency Measurements of Note C7 for Precision Testing

Tone	Trial-n	Frequency (Xn) (Hz)
C7 (2085 Hz)	1	2096
	2	2090
	3	2080
	4	2091
	5	2093
	6	2080
	7	2081
	8	2092
	9	2091
	10	2088
MEAN (Hz)		2088,2 Hz
STANDAR DEVIATION (Hz)		5,16 Hz
ACCURACY (%)		99,85 %

Table 5 presents the results of repeated frequency measurements for note C7 to evaluate the precision of the electric talempong at higher frequencies. The measurements were conducted ten times, producing frequency values ranging from 2080 Hz to 2096 Hz. The calculated mean frequency is 2088.2 Hz with a standard deviation of approximately 5.16 Hz. The relatively small variation between repeated trials indicates that the system maintains stable tone generation even at higher frequency ranges. Furthermore, the mean frequency is very close to the reference frequency of the traditional talempong (2085 Hz), resulting in an accuracy value of approximately 99.85%. These results demonstrate that the electric talempong is capable of producing the C7 tone with high precision and consistent performance.

To evaluate user practicality, a validation questionnaire was administered to 11 musicians from Sanggar Tuah Sepakat, Lubuk Alung. These musicians were asked to test the Electric Talempong and assess five aspects of its usability, including ease of play, responsiveness, and the effectiveness of the transpose feature. After collecting their responses, a total practicality score of 87% was obtained, indicating that the instrument was considered "Highly Practical" for real-world performance settings. The results of this questionnaire are summarized in Table 6.

Table 6. Practicality Evaluation Results of the Electric Talempong Instrument

Name	P1	P2	P3	P4	P5	Total
Musicians 1	5	5	5	4	5	24
Musicians 2	4	5	5	5	4	23
Musicians 3	5	5	5	5	4	24
Musicians 4	5	5	5	5	5	25
Musicians 5	5	5	5	5	5	25
Musicians 6	5	5	5	5	5	25
Musicians 7	5	5	5	4	5	24
Musicians 8	5	5	5	5	5	25
Musicians 9	5	4	5	4	5	23
Musicians 10	4	4	4	4	5	21
Number of Respondents Scores						239
Maximum Score						275
Practical Values (%)						87 (Very Good)

Table 6 presents the results of the practicality evaluation conducted with ten musicians who tested the electric talempong instrument. The assessment consisted of five indicators (P1–P5) related to ease of use, sound response, playing comfort, system reliability, and overall usability. The total score obtained from all respondents was 239 out of a maximum possible score of 275. Based on the practicality calculation, the instrument achieved a practicality value of 87%, which falls into the “very good” category. This result indicates that the electric talempong is considered practical and easy to use by musicians, making it suitable for musical performance and practice.These findings indicate that the developed instrument not only reproduces traditional talempong tones with good accuracy but also provides a practical and user-friendly playing experience for musicians.

4. CONCLUSION

This study successfully developed an Electric Talempong instrument equipped with a transpose tone system based on the Teensy 4.1 microcontroller. The performance evaluation shows that the instrument is capable of reproducing traditional talempong tones with high accuracy, where the frequency error ranges from 0.20% to 2.21% across 31 tested tones (G4–C7#). Precision testing through repeated measurements resulted in standard deviation values between 3.01 Hz and 6.03 Hz, indicating stable and consistent tone generation. Furthermore, the practicality evaluation involving ten musicians produced a score of 87%, which falls into the “very good” category. These results demonstrate that the developed electric talempong not only maintains tonal fidelity to the traditional instrument but also provides a practical and reliable digital alternative for musical performance and learning.applications.

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DECLARATIONS

Authorship contribution

Alfadli Jambak: Conceptualization, methodology, formal analysis, software and writing -original draft.
Yohandri, Yulkifli and Riri Jonuarti: Validation, writing –review and editing.

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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