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*Original Article*

# Automatic Thai Phiang or Flute-Playing Robot Reading Notes with Image Processing Technology

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***Abstract*** *- This research aimed to study the characteristics of flute playing and note-reading techniques with image processing technology. The concept involved integrating robot technology with Thai music to preserve Thai culture by designing a robot structured similar to a human flute-playing position along with simulating the head of the "Ngo Pa" (an ethnic Ngo person) character in line with the theme from the Thai song "Rojana-uey" by controlling the opening-closing of the flute holes with a pneumatic system employing a raspberry pi board as the central processor that works with a webcam, touch screen monitor, 8-channel relay, 24-volt power supply, and air-controlled solenoid valves. The findings revealed that: 1. Reading notes with image processing technology is most effective when using the Adobe Thai font in bold and italics for Thai, which was 100% accurate, while English note reading was 100% accurate in almost all font types and character styles, except for the LilyUPC font, which had a lower accuracy; 2. Airspeed testing revealed that the speed suitable for Thai Phiang Or flute-playing is 1.14 meters/second; 3. The analysis of the airflow inside the Thai Phiang Or flute by Computational Fluid Dynamics (CFD) revealed values between 0 and 0.948 meters per second; 4. Sound similarity testing comparing the spectrum values between human-blown and robot-blown sounds found that the Fa note had the most significant similarity at 98.27%, followed by the Me note at 97.20% and the Sol note at 94.23%. The lowest similarity was at 56.56%.*

***Keywords*** *- Phiang or flute, Image processing, Robotics technology, Computational fluid dynamics.*

## 1. Introduction

Thailand's civilization and cultural heritage have developed over a long period until they have become unique. In particular, Thai dance and music reflect Thai life [1]. Thai music is considered unique to the ethnic group and linked to the spirit of the Thai people. It has evolved in line with social contexts, showing Thailand's ancestral artistic subtleties and knowledge. [2]. Nevertheless, Thai music's popularity is declining due to social changes and lifestyles that differ from the past. Furthermore, the integration of art and culture in contemporary music has played a key role in reviving interest in Thai music, as evident in the work of Professor Dr. Thanis Sriklindee, National Artist, who has created a significant phenomenon in combining Thai music with international music through outstanding works such as the song, "Duean Phen" (Full Moon) and the song "Rojana-uey" adapted from the literature "Ngo Pa" [3].

Based on preserving and developing Thai music, the researcher presents an innovative project integrating robot technology with Thai music by developing a Phiang Or flute-playing robot system controlled by pneumatics and image processing technology. This invention has a working principle with two parts: the pneumatic air control part precisely controls the opening and closing of the flute holes, and the image processing part can read and convert musical notes. This invention is not only a preservation of cultural heritage but can also be integrated with contemporary music. However, despite its potential, existing efforts have rarely explored integrating robotics with Thai music performance, leaving a gap in accessible, modern tools that enhance cultural preservation and music education. This research addresses this gap by bridging tradition with technology, offering an innovative platform that promotes Thai music in a contemporary, interactive, and engaging manner.

## 2. Relevant Literature

Developing an automatic control system for Thai Phiang Or flute playing involves three main components: 1) Thai Phiang Or flute, 2) image processing technology, and 3) a pneumatic system. The details of the operation are as follows:

The Thai Phiang Or flute is a Thai wind instrument regarded as the king of Thai wind instruments. Characterized by a hollow tube about 45 to 46 centimeters long, the Thai flute is bamboo with 7 holes in the front and 1 hole in the back, with a flute mouthpiece made of ultra-thin bamboo [4]. The Thai Phiang Or flute can generate beautiful, lilting flute sounds and functions by providing the main melody in groups of stringed instruments, which is used to make music for singers in Thai orchestras. Learning and practising the Thai Phiang Or flute requires many basic techniques, such as breathing control, correct finger placement, and proper finger positioning, as shown in Figure 1, with volume control and various special techniques that require constant practice [5]. The Thai Phiang Or flute is currently being developed for contemporary music mixed with international music to create unique songs [6]. In addition, technology and innovation have been developed to help students learn and inherit the art of Thai Phiang Or flute playing so it can survive and reach more of the younger generation.

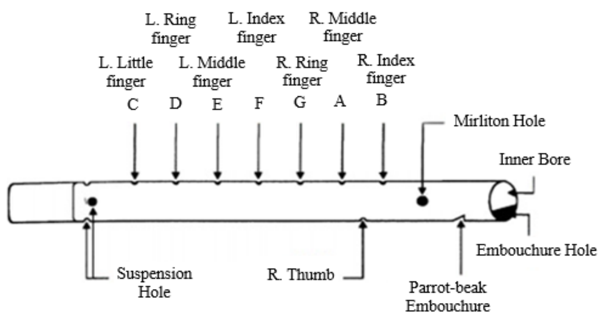



**Fig. 1 Components of the thai phiang or flute and finger placement**

Optical Character Recognition (OCR) is a technology that converts text images into digital text. Thai and English have similar basic processes, from importing images via OpenCV for conversion to grayscale images. Noise disturbance is reduced with Gaussian Blur and adjustments in density [7]. E. Gouillart et al. efficiently analyzed microtomographic data using scikit-image and Python [8]. Additionally, a practical approach for connected handwritten character segmentation was published by V. Rajput et al. [9]. Additionally, a novel offline corrosive handwritten word segmentation technique was introduced by A. Choudhary et al. [10].

Tesseract-OCR or Deep Learning models are preferred for character recognition in both languages [11, 12], as shown in Figure 2. In particular, CNN's [13] English generally uses a model that practices with MNIST [14] or EMNIST [15] data with other options such as EasyOCR. The main difference is that English has less complexity because the letters are not connected, and the type is clear. The main challenges are dealing with various fonts, italicized letters, bold letters, thin letters and differing light conditions [16]. At the same time, the Thai language has additional challenges due to its complex structure with vowels and tone marks that require specific placement [17]. Although both languages use the same basic techniques, models and parameters must be tailored to the characteristics of each language for optimal performance in letter recognition.

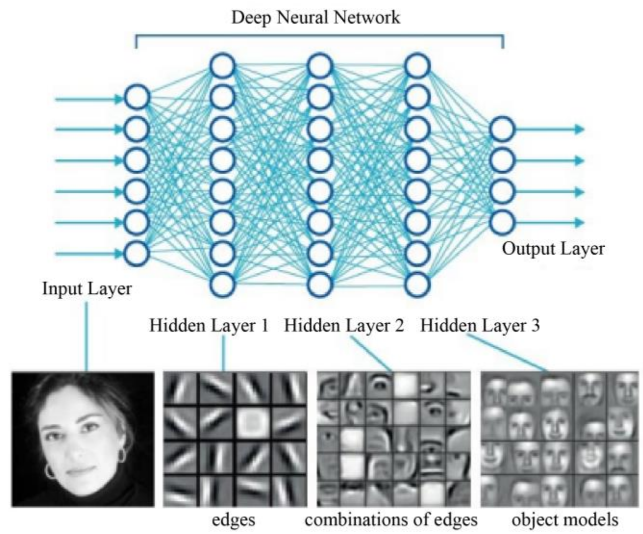



**Fig. 2 Deep neural network architecture**

Pneumatic systems use energy from compressed air [18] and consist of a directional control valve that controls the flow of compressed air, pneumatic cylinders that convert wind energy into linear motion, a pneumatic handle, as shown in Figure 3, and an air motor that converts wind energy into rotation. [19].

Pneumatic systems have the advantage of being highly safe because there is no risk of sparks. They can work in high- or low-temperature environments and have a high response speed. However, pneumatic systems have limitations in terms of lower efficiency than hydraulic systems and noisy air venting [20]. Nowadays, pneumatic systems are widely used in industries like automated manufacturing.

E. Richer and Y. Hurmuzlu suggested a nonlinear controller for high-performance pneumatic actuators that increases tracking stability and accuracy. Ikpe, A. E., & Ekanem, I. I. [21] suggested an intelligent hydraulic system as a crucial element of Industry 4.0. A. E. Ikpe and I. I. Ekanem [22] suggested methods for process maintenance, performance enhancement, and downtime reduction in the automotive sector. [23],

In the automobile sector, in order to increase reliability without the need for electrical components, S. Hoang et al. presented a pneumatically driven logic circuit that allows real-time fault detection in pneumatic systems [24]. A pneumatic sensor for non-invasive arterial pressure monitoring is presented by V. Antsiperov et al. [25], providing real-time pulse waveform analysis for contemporary medical home care systems. [26] Pneumatic systems are used in highly precise agriculture to regulate the flow rate of granular fertilizers, improving resource utilization efficiency and increasing agricultural fertilizer application precision. Z. Talha [27].

**Fig. 3 Air Gripper and pneumatic cylinder**

Most pneumatic systems require air pressure in the system, which can be calculated with Equation (1) as follows:

$$F = P \, x \, A \tag{1}$$

When F is the force in Newtons (N), P is the pressure in Pascals or N/m², and A is the cross-sectional area in square meters (m²), the operating pressure of pneumatic systems usually ranges from 6 to 10 bars or 0.6 to 1.0 MPa.

In addition to calculating the air pressure in pneumatic systems, the flow rate of the air needs to be calculated in pneumatic systems, which can be calculated by Equation (2) as follows:

$$Q = V \, x \, A \tag{2}$$

When Q is the flow rate measured in cubic meters per second (m³/s), V is the air speed measured in meters per second (m/s), and A is the cross-sectional area of the pipe measured in square meters (m2).

## 3. Design and Development of Automatic Thai Phiang Or Flute-Playing Robot

The proposed system is the development of a Thai Phiang Or flute player robot that integrates artificial intelligence technology, robot technology and image processing to create a robot capable of imitating a human Thai flute player. The development was divided into three main parts: 1. robot structure with a mouthpiece that mimics a human; 2. inflatable control system; and 3. finger mechanisms that can be precisely opened-closed. The aim was to create a robot that could play the Thai Phiang Or flute, which would help solve the problem of Thai musician shortages with just a few inches, which will help solve the shortage of Thai musicians and promote the learning of Thai music through modern technology. The shape and figure of the robot Thai Phiang Or flute player were designed to have the head of "Ngo Pa", and the structure was made of a lightweight aluminium profile, as shown in Figure 4.

The design of 3D parts for use as the components of the robot was based on designing with a 3D design program (Design Spark Mechanical), which designed the following four parts: 1. finger opening-closing parts; flute holes; 2. silicone covers for wearing on the fingers to open-close flute holes; 3. parts for pneumatic equipment and 4. Thai Phiang Or flute grippers, as shown in Figure 5.

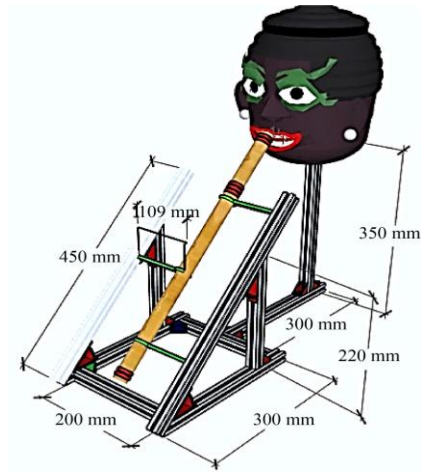
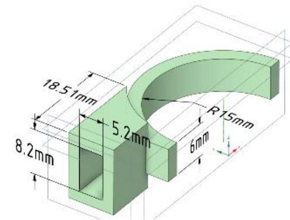
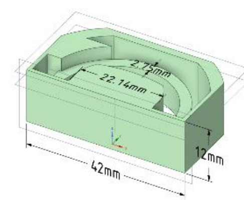


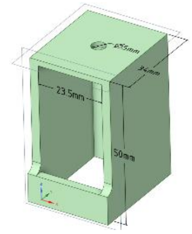

**Fig. 4 Phiang or flute-playing robot model**



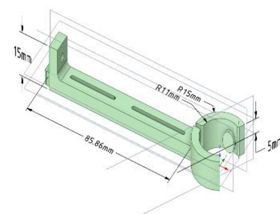

**(a) Flute opening and closing finger parts**




**(b) Silicone casting block**




**(c) Parts for pneumatic equipment clamping**




**(d) Parts for flute holder only**

**Fig. 5 3D part type**

Hardware connection and automatic Phiang Or flute-playing robot control system, which consists of a Raspberry Pi board, a webcam and a touch screen monitor with 8-channel relay, 24-volt power supply and 24-volt air-controlled Solenoid Valves (SV), as shown in Figure 6.

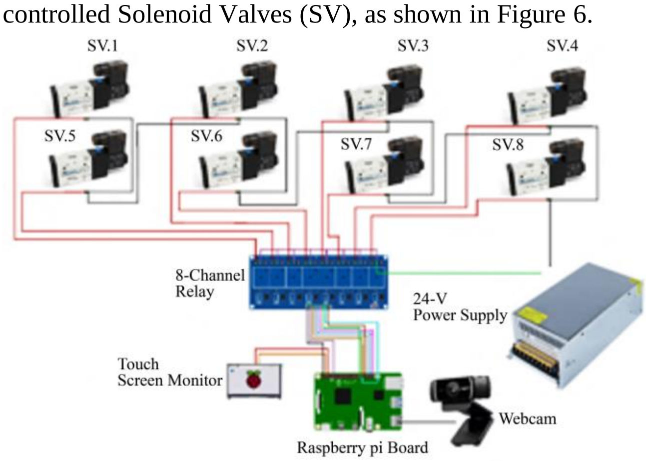



**Fig. 6 Hardware connection of the automatic flute-playing robot**

Operation diagram of the automatic flute-playing robot, which starts from the beginning, receiving the musical notes captured from the webcam, then processing the images of the notes and storing them in an array of variables. When the button is pressed to play music with control of the relay, the system will check whether the current note is the last in order. If it is not the last note, the system will loop back to replay the music. However, if it is the last note, the system will end the operation at the end, as shown in Figure 7.

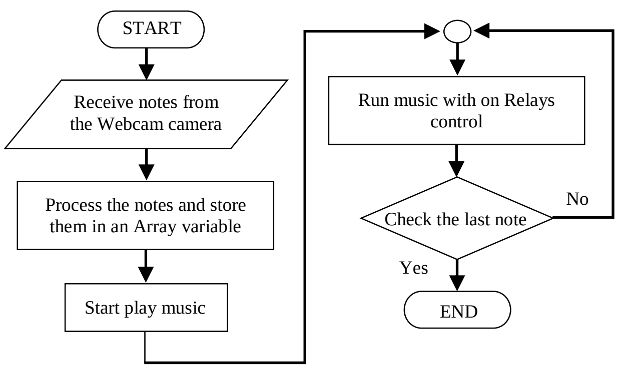



**Fig. 7 Software structure flow**

The sequence of operating the pneumatic device for opening and closing the Thai flute holes to create the 8 notes by ordering the pneumatic device through the operation of a relay to control the air control solenoid valve to order the hand to grip the flute's opening-closing holes by ordering the sequence of operations of the pneumonic of the hand grippers, as shown in Tabel 1.

**Table 1. A sequence of pneumatic device commands for opening and closing flute holes to create all 8 notes**

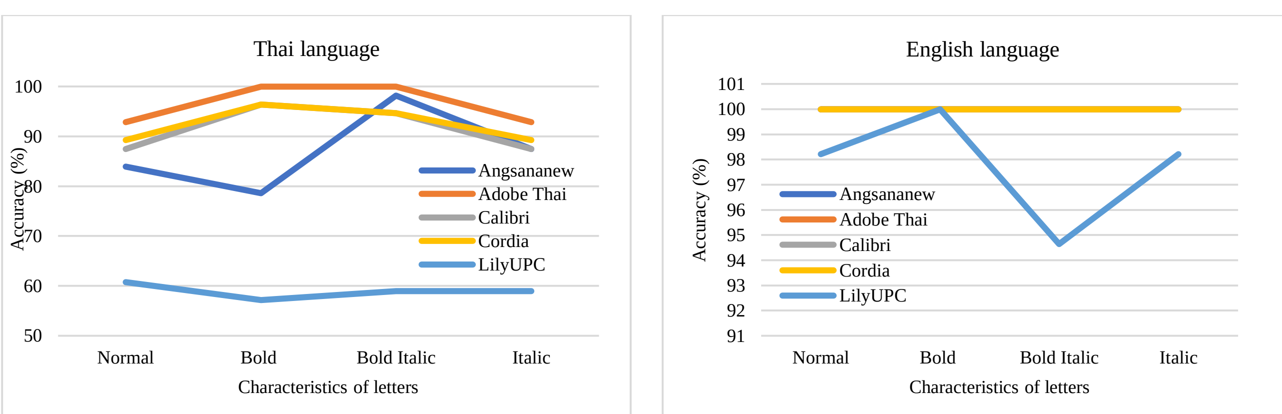
| No. | Note | R1, GPIO 12 | R2, GPIO 16 | R3, GPIO 20 | R4, GPIO 21 | R5, GPIO 5 | R6, GPIO 6 | R7, GPIO 13 | R7, GPIO 26 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | C | √ | √ | √ | √ | √ | √ | √ | √ |
| 2 | D | | √ | √ | √ | √ | √ | √ | √ |
| 3 | E | | | √ | √ | √ | √ | √ | √ |
| 4 | F | | | | √ | √ | √ | √ | √ |
| 5 | G | | | | | √ | √ | √ | √ |
| 6 | A | | | | | | √ | √ | √ |
| 7 | B | | | | | | | √ | √ |
| 8 | C# | | | | | | | | √ |

## 4. Test Results of the Automatic Flute-Playing Robot

The results of the note reading test using image processing technology, which is a test for reading a total of 5 Thai and English fonts, including Angsana New, Adobe Thai, Calibri, Cordia, LilyUPC and 4 Characteristics of letters including regular, bold, bold italics, italics. The testing was conducted 10 times to find the mean accuracy of the reading of the notes, which is shown in Table 2 and Figure 8.

**Table 2. Thai and English note reading test**

| Font Type | Characteristics of Letters (Thai language) | | | | Characteristics of Letters (English) | | | |
|---|---|---|---|---|---|---|---|---|
| | Normal | Bold | Bold Italic | Italic | Normal | Bold | Bold Italic | Italic |
| **Angsananew** | 83.93 | 78.57 | 98.21 | 87.5 | 100 | 100 | 100 | 100 |
| **Adobe Thai** | 92.86 | 100 | 100 | 93.86 | 100 | 100 | 100 | 100 |
| **Calibri** | 87.5 | 96.43 | 94.64 | 87.5 | 100 | 100 | 100 | 100 |
| **Cordia** | 89.29 | 96.43 | 94.64 | 89.29 | 100 | 100 | 100 | 100 |
| **LilyUPC** | 60.71 | 57.14 | 58.93 | 58.93 | 98.21 | 100 | 94.643 | 98.21 |



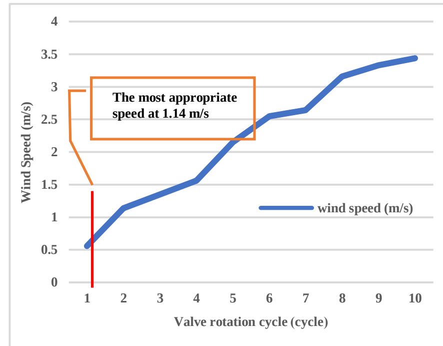

**(a)** **(b)**

**Fig. 8 Percentage of reading Thai and English notes using image processing**

In Table 2 and Figure 8, Reading Thai and English Notes by Image Processing, it can be seen that the most suitable font and letter type for processing Thai characters is Adobe Thai in bold, italics and bold italics at 100% accuracy, while the most suitable font and letter type to be used to process English characters is Adobe Thai in regular, bold, bold italics, and italics at 100% accuracy.

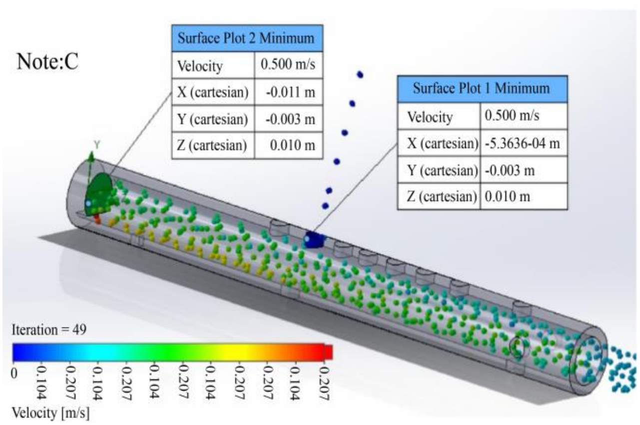
The results from testing the suitability of air speed for the Thai phiang or flute-playing robot were obtained by testing the air blown from an air pump through the air volume control valve. Next, the air speed was measured with a standard EXTECH brand AN200 model gauge, as shown in Figure 9(a). The results of considering the appropriate airspeed for robot flute-playing were 1.14 m/s, as shown in Figure 9(b).

The flute air flow test results were obtained with CFD, which involved simulating the airflow behavior inside the flute's sound tube, starting with the air being blown through the blowing tube. This caused air flow and swirling at the edge of the mouthpiece. The computational fluid dynamics simulation calculated air oscillations' pressure, velocity, and frequency changes, as shown in Figure 10.

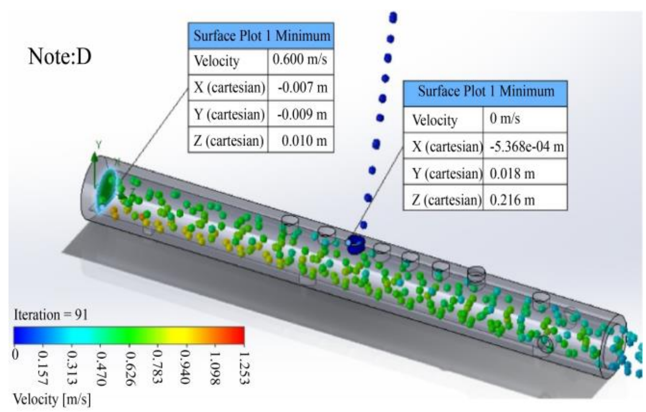



(a) (b)

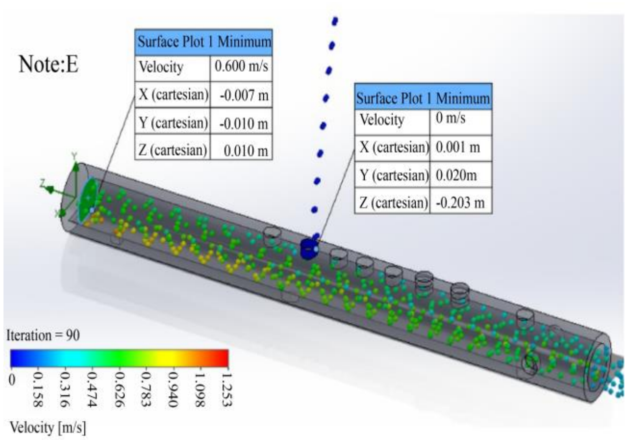
**Fig. 9 Testing and optimum speed for the flute-playing robot.**



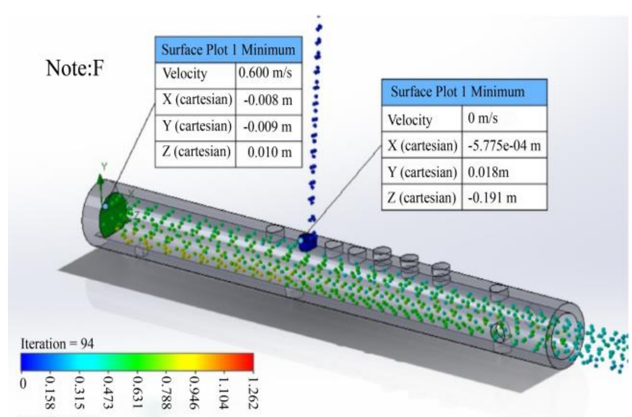

**(a) Note C**



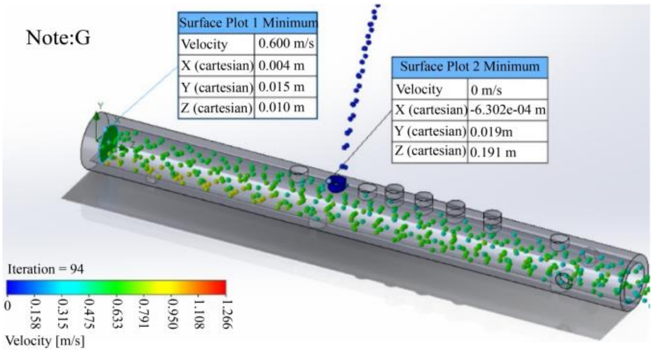

**(b) Note D**



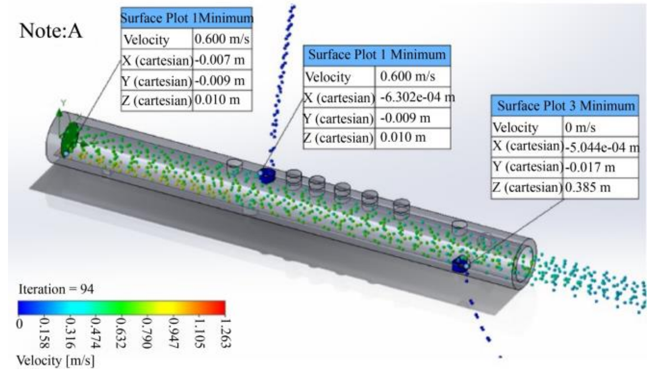

**(c) Note E**



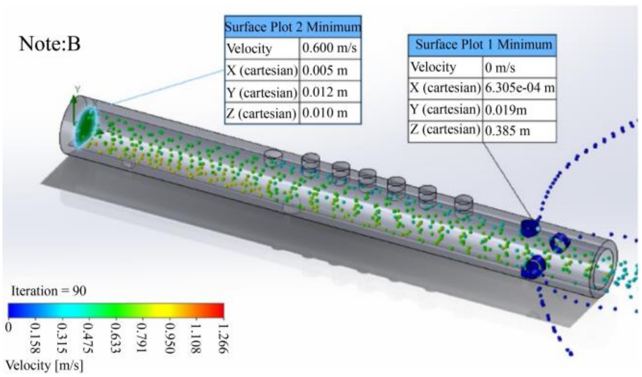

**(d) Note F**



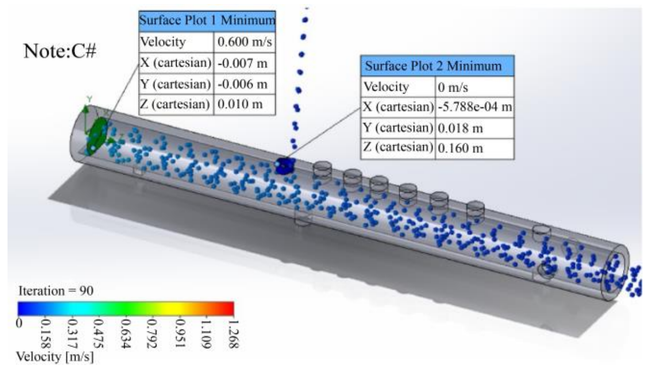

**(e) Note G**




**(f) Note A**




**(g) Note B**




**(h) Note C#**

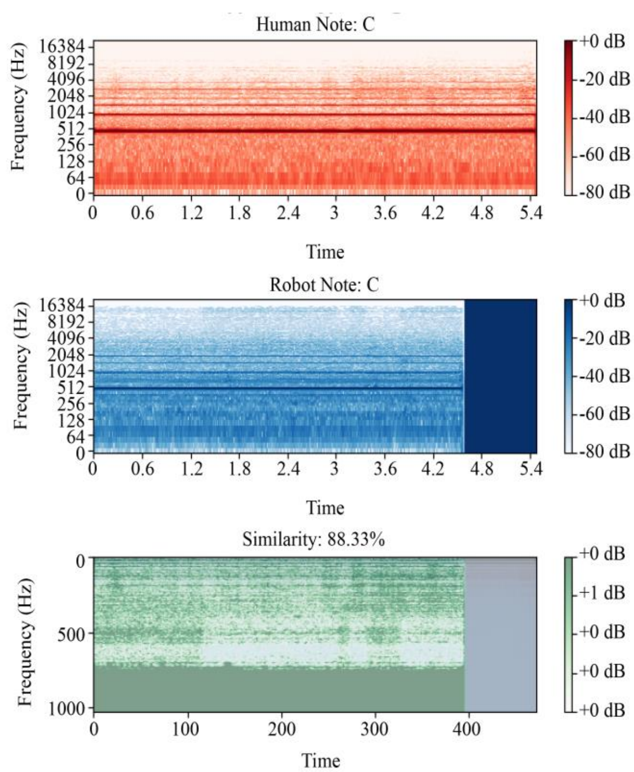
**Fig. 10 Airflow of notes inside the flute for all 8 notes**

**Table 3. Minimum/maximum wind speed from airflow model of 8 notes**

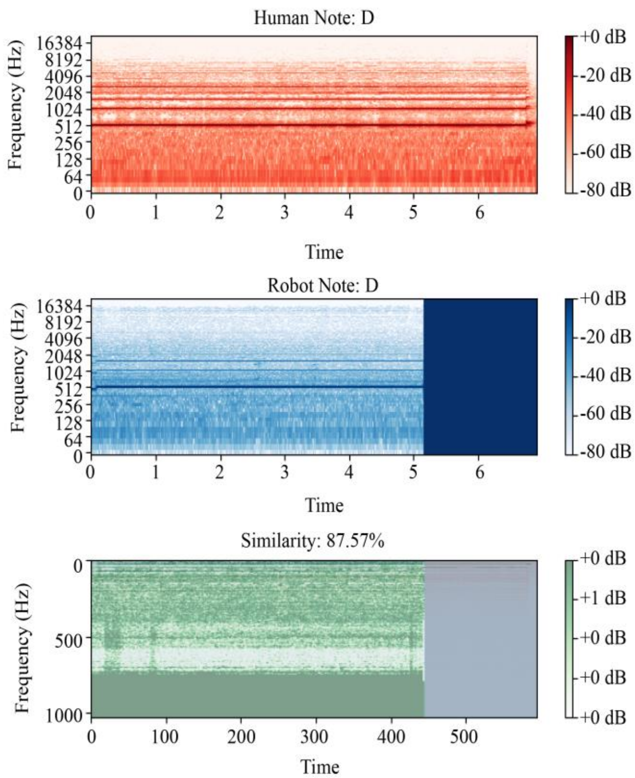
| Notes | Minimum wind speed (m/s) | Maximum wind speed (m/s) | Notes | Minimum wind speed (m/s) | Maximum wind speed (m/s) |
|---|---|---|---|---|---|
| C | 0 | 0.869 | G | 0 | 0.791 |
| D | 0 | 0.940 | A | 0 | 0.790 |
| E | 0 | 0.948 | B | 0 | 0.466 |
| F | 0 | 0.788 | C# | 0 | 0.158 |

In Figure 10, the results of the flute airflow test are based on the computational fluid dynamics of all 8 notes, as shown in Table 3.

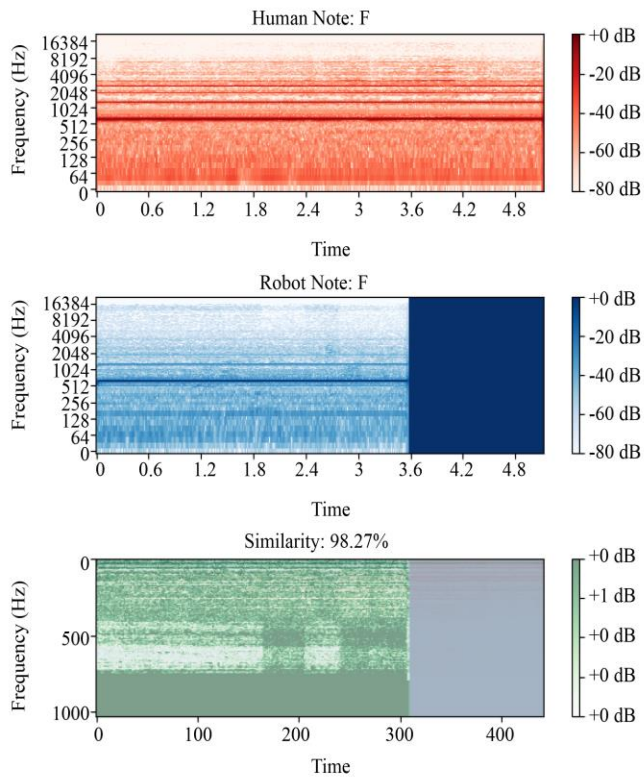
The results of the sound measurement test and comparison of the sound values of the 8 notes were obtained by measuring and recording the sound obtained from blowing the flute with a human mouth and blowing with a robot, then comparing the similarity of the measured sound values of all 8 notes. The sound comparison converted the sound value into a spectrum format and compared the values on the Pycham program, as shown in Figure 11.




**(a) Note C**




**(b) Note D**

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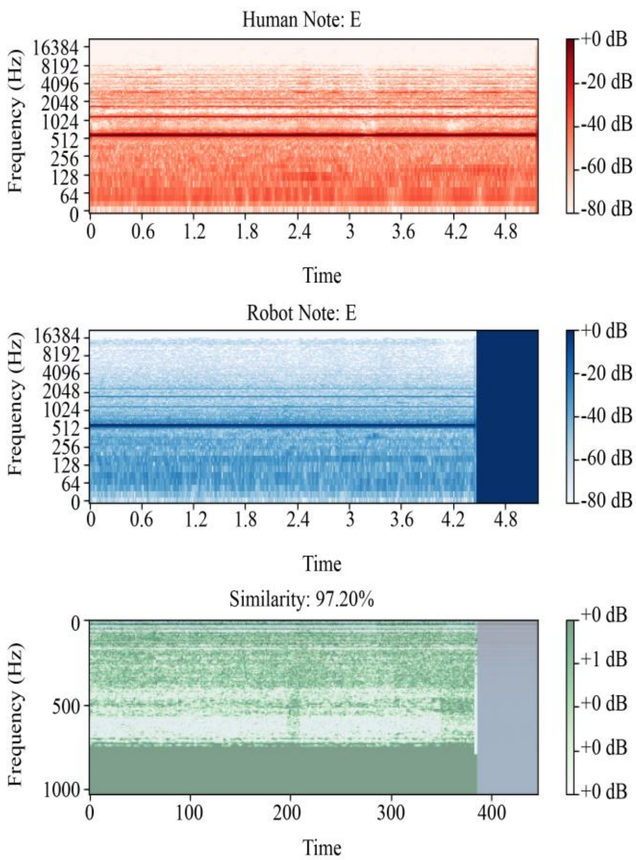
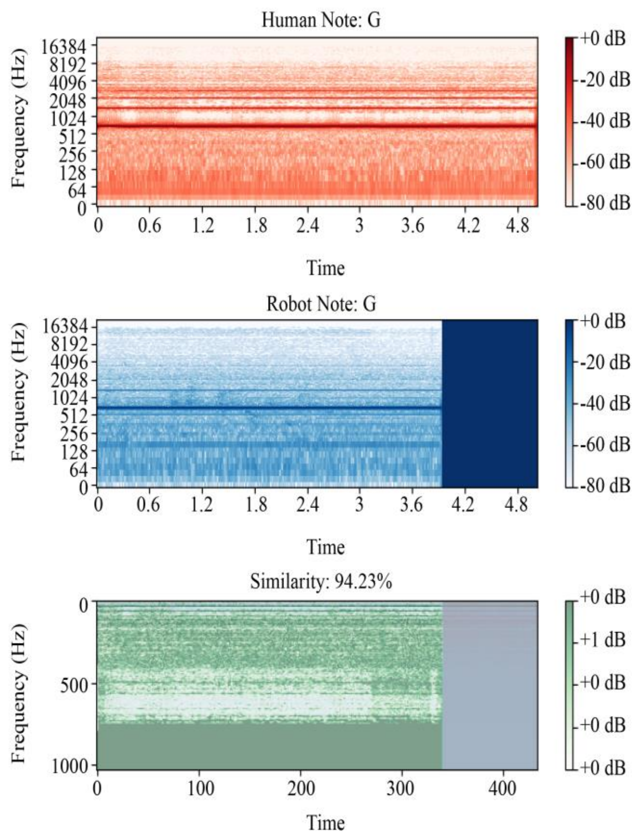
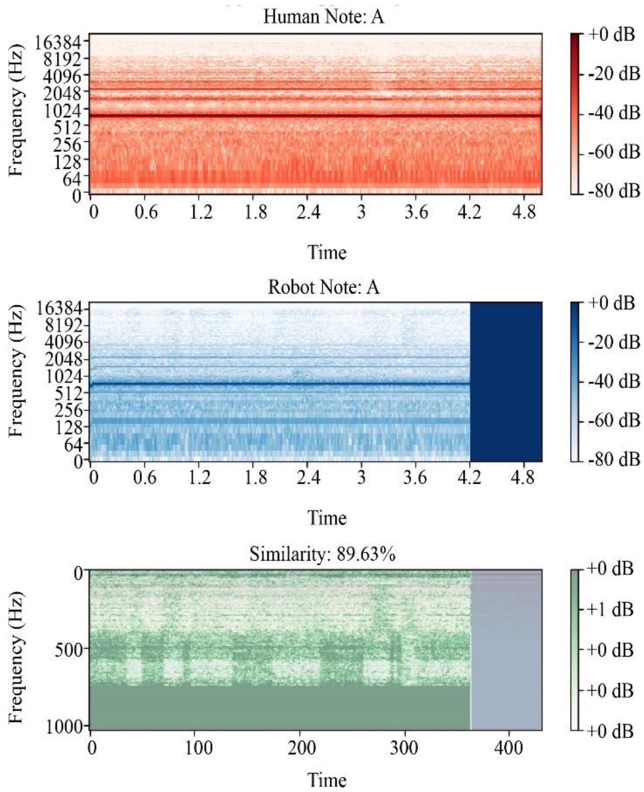


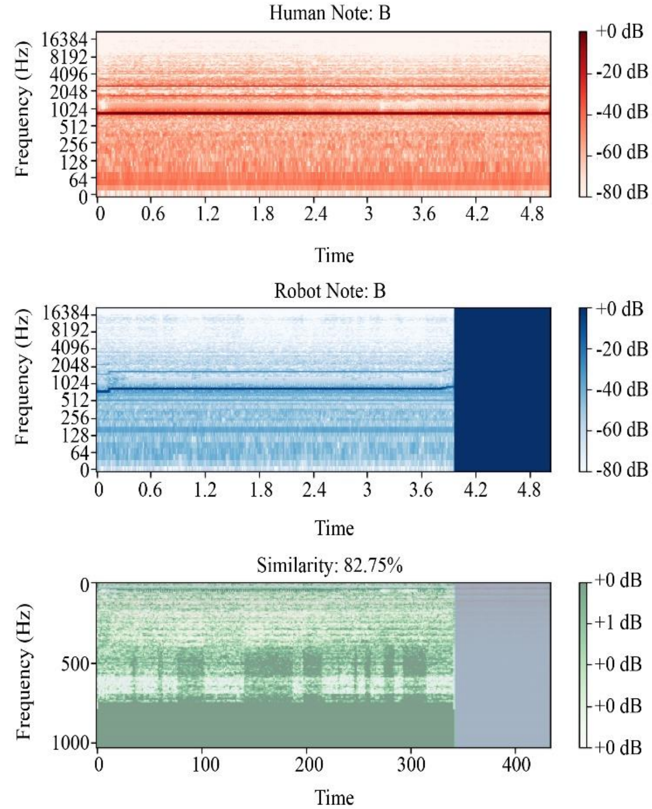

**(c) Note E**



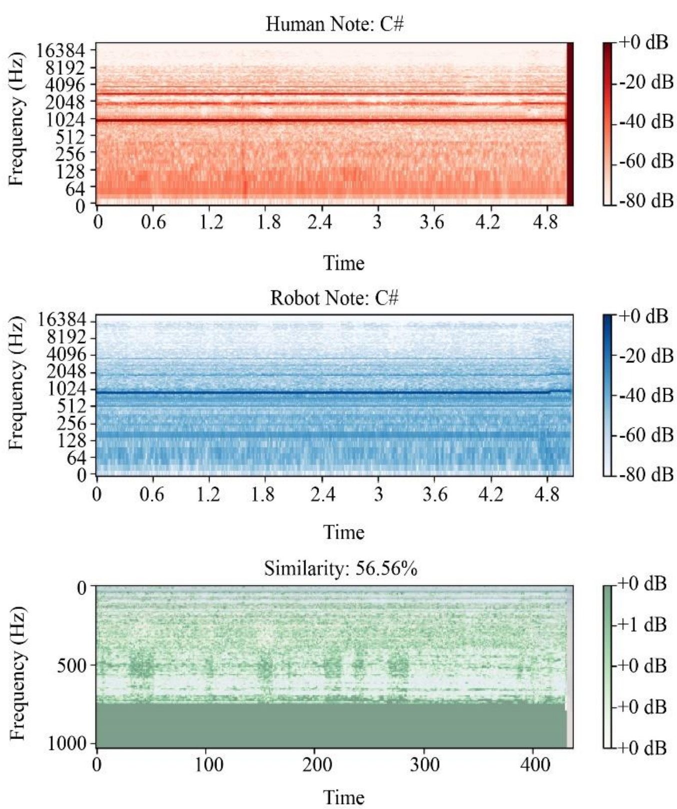

**(e) Note G**




**(f) Note A**




**(g) Note B**




**(h) Note C#**

**Fig. 11 Comparison of the spectrum values of the 8 notes**

Figure 11 shows the Spectrum Comparison Test Results of all 8 notes in Figure 4.

**Table 4. Comparison of the spectrum values of the 8 notes**

| Notes. | Percentage of similarity (%) | Notes | Percentage of similarity (%) |
|---|---|---|---|
| C | 88.33 | G | 94.23 |
| D | 87.57 | A | 89.63 |
| E | 97.20 | B | 82.75 |
| F | 98.27 | C# | 56.56 |

## 5. Discussion of the Test Results

According to the test results on the use of the automatic phiang or flute-playing robot reading notes with image processing technology developed according to the procedures carried out in both theoretical and related research, the results are that the automatic flute-playing robot can play the instrument similar to a human Thai flute player. The test results can be discussed as follows:

- Reading the Notes: It was found that the Adobe Thai font could read notes in Thai with the most accurate image processing at 100%. The font types are bold and bold italics, while LilyUPC had the lowest accuracy at only 57-60%. Reading English notes with image processing was more accurate than Thai, particularly in the Adobe Thai, Angsana New, Calibri and Cordia fonts, with accuracy at 100% In all letter styles.
- Airspeed control is a key factor that affects the sound quality of the Thai Phiang Or flute. According to the testing, the air speed of 1.14 meters per second was optimal, as it produced beautiful, clear, and well-controlled sound, while the testing at a low air speed of 0.7 meters per second made the resulting sound unclear. Using airspeed exceeding 3 meters per second resulted in an overly sharp sound. The results of this testing are also consistent with the CFD analysis, showing that an air speed of 1.14 meters per second produces a balanced and optimal wind distribution for creating the notes of the Thai Phiang Or flute.
- Analyzing Thai Phiang Or flute airflow with CFD showed a different flow pattern for each note. Musical notes requiring more holes open, such as low-pitched notes, were found to have more complex and diverse patterns of air speed distribution because there are more ways for air to pass through. At the same time, notes with more open holes, such as high-pitched notes, have a simpler flow pattern but a higher spot velocity with the air speeds out of the hole from 0 to 0.948 meters per second, depending on the location and number of holes opened. This distribution of different air speeds directly affects the sound generation and quality that occurs with each note.
- Comparison of the spectrum of sound to find similarities by comparing the spectrum values of all 8 notes made by a flute played by a human mouth compared to a flute played by a robot in all 8 notes. The similarity in the notes ranged from 56.56 to 98.27%.

## 6. Conclusion

According to the findings, the font affects the accuracy of reading, whereby the Adobe Thai font produces the highest accuracy for Thai at 100%, while the English notes were more accurate overall. Regarding airspeed control, it was found that 1.14 meters per second was the optimal speed, producing a beautiful and clear sound, which is also consistent with the results of the CFD analysis. Studies of airflow patterns also found that low-pitched notes (many holes open) had a more complex pattern of airspeed distribution than high-pitched notes (many closed holes). The comparison of sound quality between human and robot playing showed similarity from 56.56% to 98.27%, indicating that the robot could play the Thai flute like a human player. Compared to Vinay Kumar Pamula's studies [28], the Automated Digital Wind Instrument (ADWI) system's primary issue is noise interference from the air blower and servo motors, whereas the Phiang Or flute robot struggles with real-time airflow management and note accuracy. Noise remains a significant barrier to performance quality in both systems, though both require automation precision improvements. For future development, efforts should focus on enhancing image processing efficiency for Thai notes and implementing adaptive airspeed adjustment techniques tailored to each note, enabling the robot to create more nuanced melodies that closely emulate a human performer on the Thai bamboo flute.

## Acknowledgments

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