Fuzzy-Controlled Multi-Valve Pneumatic Soprano Recorder Auto-Playing and Score Recognition System

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Abstract

This study introduces advanced improvements to previous methods for automated score recognition and soprano recorder performance, addressing limitations in playback speed, accuracy, and sound quality. The score recognition system now employs an enhanced method for identifying and removing staff lines, which improves the distinction of musical symbols. In addition, a refined approach is used to classify notes by their placement on the staff, supporting accurate pitch assignment and musical sequencing. The playback mechanism has also been upgraded by replacing traditional motor-driven finger actuators with a solenoid-based multi-valve system, which optimizes performance speed and reduces mechanical noise. The recorder's pitch control now incorporates a 9-valve configuration, offering more precise air pressure regulation across an extended range from bass to treble, thereby addressing pitch stability and tonal accuracy issues. Further, automated tuning is achieved through advanced fuzzy control, which significantly enhances tuning speed and fidelity. Experimental results confirm that these refinements enable substantial improvements in tonal precision and overall performance quality for automated soprano recorder systems.

Keywords: Fuzzy-controlled multi-valve pneumatic, Soprano recorder auto-playing, Enhanced music score recognition, Automated tuning

1. Introduction

With the continuous advancement of robotic technology, its applications have gradually expanded from industrial and military fields to music and arts. The development of automated performance technology, particularly in automatic piano playing, has reached a level comparable to human performance, demonstrating the potential of robots in the arts and music domains. This study aims to develop a multi-valve pneumatic recorder automatic performance and music score recognition system based on fuzzy control to enhance the performance of the existing platform. In the system design, traditional pen-type pneumatic cylinders were replaced with reciprocating electromagnets to reduce noise in the pressing mechanism. Simultaneously, the number of pneumatic valves was increased from three to nine, integrated with fuzzy control technology for automatic adjustment. Furthermore, the system introduced more precise air pressure regulation and multi-phase note classification techniques to address challenges in pitch stability and tuning accuracy, aiming to achieve human-level automation in recorder performance.

In recent years, the application of robotic systems in music has continued to grow. In 2007, Lee W.C. and colleagues proposed a dual-wheel robot capable of autonomously reading music scores and singing using voice, although its score recognition was limited to Arabic numeral formats [1]. In 2016, Hong M.J. developed a mixed media technique applying hand-drawn styles to portrait generation; however, the use of only five colors led to a color-matching error of about 10% [2]. In 2015, Zhang Yonghui et al. adopted Optical Music Recognition (OMR) technology, which, although capable of identifying music symbols, relied on a symbol database, making it prone to errors from minor discrepancies [3]. In 2019, Xiao Zhe studied a real-time OMR system for dulcimer-playing robots, but the decomposition of notes into only three basic elements limited the accuracy of note recognition [4]. Additionally, in 2014, Wang B.R. proposed an iOS-based music score recognition system that required manual assistance, making full automation unachievable [5].

Addressing the shortcomings of the aforementioned studies, C.C. Wang guided students to develop a recorder-playing robot. Initial efforts focused on designing a mechanism capable of replacing human fingers for hole pressing. After completing the initial design, the development of an automatic music score recognition program followed, along with improvements to the pressing mechanism. Lastly, a controller for the blowing component was planned and designed to ensure the machine could produce soft and precise airflow, thereby playing melodious music. However, the first-generation recorder-playing robot encountered issues with insufficient pressing speed and air leakage. Servo motors could not switch pressing actions quickly enough to meet the performance rhythm, while silicone pressing components had inadequate coverage, leading to air leaks due to tolerance issues.

To address these deficiencies, C.C. Wang proposed a pen-type pneumatic cylinder-based pressing mechanism in 2020, incorporating sponge and electric cloth as cushioning elements to effectively reduce air leakage and pressing speed issues [6]. However, the noise generated during pressing by pen-type pneumatic cylinders continued to interfere with performance. Additionally, although the scale classification pneumatic valves were improved to low, medium, and high sections, inaccuracies in scale airflow still resulted in tone-breaking issues. In 2022, C.C. Wang introduced a nine-valve pneumatic system based on fuzzy control to further enhance the precision of scale control, although there remained room for optimization in the fuzzy controller design [7].

Building on the above background and issues, this study, referencing related works [7][8][9], proposes a novel automatic tuning fuzzy control inference for the pneumatic valve control of recorder-playing robots. The goal is to improve the overall performance of automated recorder playing and provide new directions and technical support for future research in music robotics.

2. Soprano recorder auto-playing vehicle

2.1. *Reciprocating electromagnet pressing system*

This study replaces the pen-type pneumatic cylinder with a reciprocating electromagnet, significantly enhancing air pressure stability, reducing air leakage noise, and improving music quality. Additionally, the module's more compact size contributes to streamlined system design and overall stability. Figure 1 shows the soprano recorder auto-playing vehicle, and Figure 2 depicts the reciprocating electromagnet pressing system.

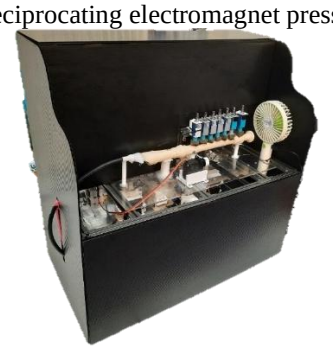

Fig. 1. Soprano recorder auto-playing vehicle

Fig. 2. Reciprocating electromagnet pressing system

2.2. *Scale-classified air valve*

In the section on pitch-classified air valves, the number of pneumatic solenoid valves was increased, resulting in more precise air pressure, reduced risk of note detuning, and enhanced system stability. However, this also increased module space requirements and tuning time, making the operation slightly more complex. Figure 3 illustrates the connection diagram of the third-generation tuning pneumatic valves.

Fig. 3. The connection diagram of the third-generation tuning pneumatic valves

2.3. *Pneumatic valve automatic tuning system*

In the improvement of the pneumatic valve automatic tuning system, 3D-printed connectors were used to integrate the manual pressure adjustment valve with the SAVOX SC-0251 MG servo motor, enabling automatic control and precise adjustments. This enhancement

significantly improves the system's accuracy and operational efficiency, while simplifying the user interface. As shown in Figures 4 and 5, the diagrams illustrate the structure of the pneumatic valve automatic tuning system and the playing range divided into nine intervals.

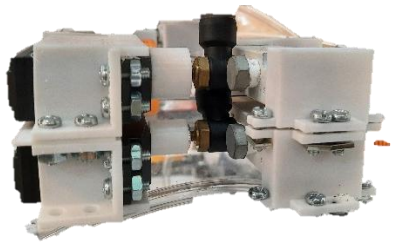

Fig. 4. Pneumatic valve automatic tuning system

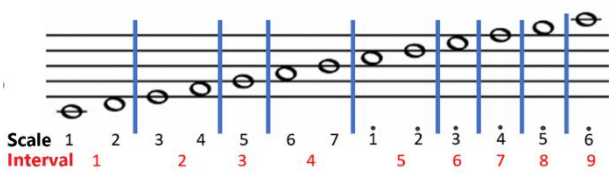

Fig. 5. The playing range divided into nine intervals

2.4. *Manual tuning*

To ensure the accuracy of the automatic tuning, manual tuning is first performed to determine the frequency values corresponding to each scale. Using the Acquire Sound module in LabVIEW, the audio is converted into waveforms, and frequency and amplitude data are obtained through the Tone Measurements module. Figure 6 shows the human-machine interface for sound recognition. This process provides crucial frequency reference data, ensuring the accuracy of the pitch in the automatic flute-playing system, which is essential for maintaining high music quality.

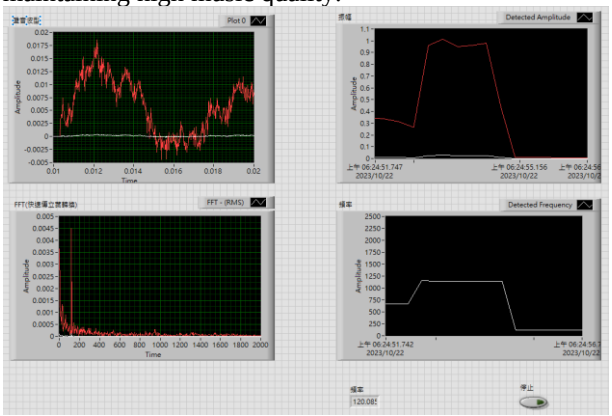

Fig 6. Human-machine interface for sound recognition.

3. Fuzzy-controlled automatic scale tuning method for multi-valve pneumatic systems

3.1. *Fuzzy control*

To enhance the accuracy of musical performance, this work utilizes nine electromagnetic pneumatic valves, each equipped with independent control of the opening degree to meet the airflow demands of different pitch ranges. Each valve is assigned a dedicated fuzzy controller, which takes pitch frequency as input and outputs a correction value for adjusting the valve's opening degree. The fuzzy controller infers the corrected angle, combines it with the preset opening angle, and determines the final opening degree of the valve. For example, if the preset opening angle is 60 degrees and the correction angle is -8 degrees, the final angle would be 52 degrees. This project defines terms such as pitch frequency (e.g., Do = R1) and corrected angle (CorAngl) and designs specific fuzzy rule bases for each pitch range to improve valve control accuracy and musical performance. Figure 7 shows the fuzzy inference for range i, where $i = 1{\sim}9$. The variables and fuzzy rule base for pitch interval 1 are shown in Figures 8 and 9, while the variables and fuzzy rule bases for other intervals follow the same methodology.

If R_i=NB, Then CorAngl=NB

If R_i=NS, Then CorAngl=Z

If R_i=Z, Then CorAngl=NS

If R_i=PS, Then CorAngl=PB

If R_i=PB, Then CorAngl=PS

Fig 7. Fuzzy inference

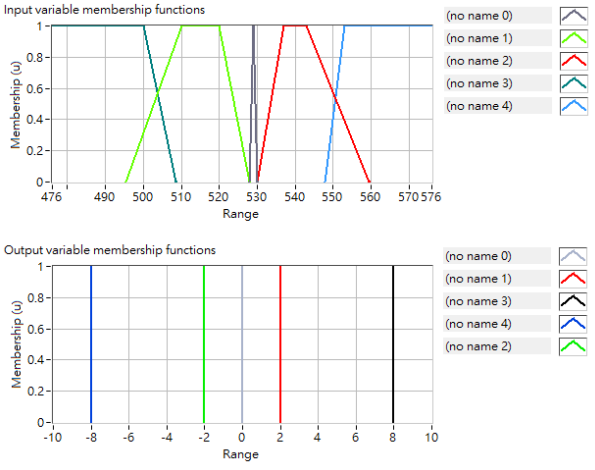

Fig 8. Variables for Range 1

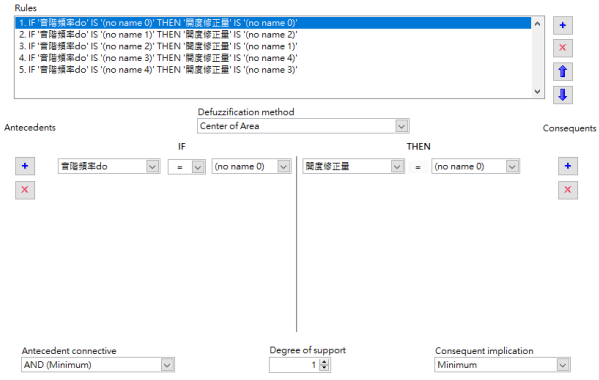

Fig 9. Fuzzy Rule Base for Range 1

3.2. *Automatic scale tuning method*

In the automatic tuning experiment, the tuning tests for nine pneumatic valves were successfully completed, with the results shown in Figure 10. Taking Section 1 as an example, the frequency range for the note was set to 528–530 Hz, and the measured frequency was 528.33 Hz. The servo motor's final angle was 58 degrees, with a correction angle of 0 degrees. Other sections similarly achieved the required frequency range with precision. The experimental results demonstrate that the automatic tuning function performs excellently across all note sections, significantly enhancing the system's musical performance and accuracy.

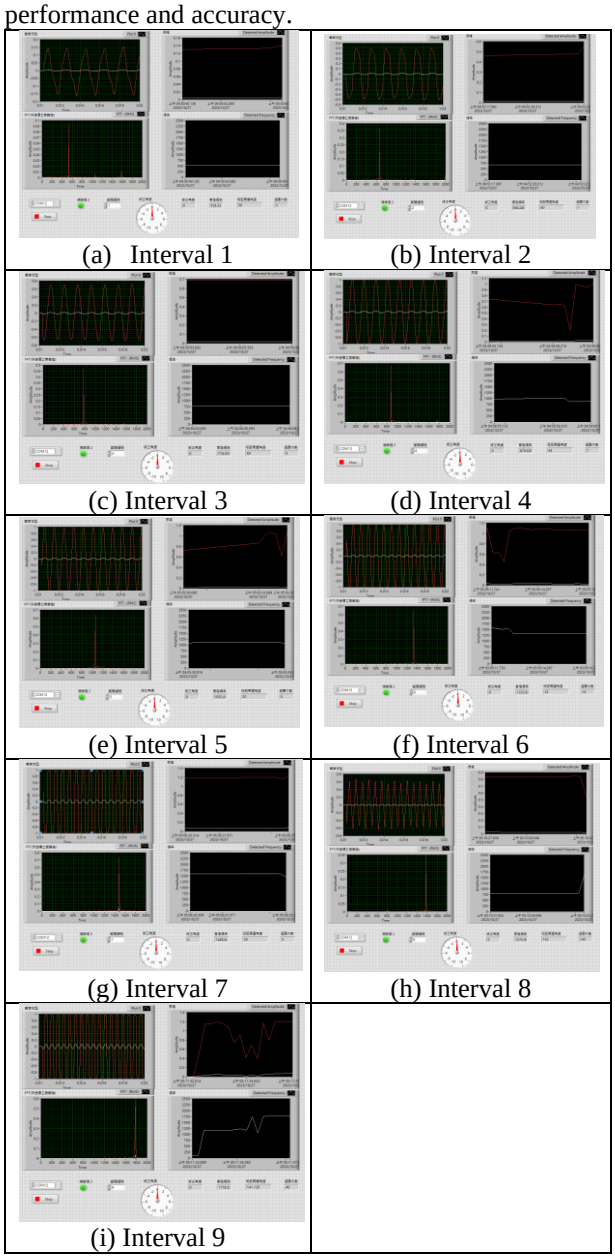

Fig 10. Automatic tuning results of the 9 pneumatic valves

4. Experimental results

Since the topic of this research is "Fuzzy-Controlled Multi-Valve Pneumatic Soprano Recorder Auto-Playing and Score Recognition System," the experimental results will be presented in the form of a video, demonstrating an improved playing performance compared to previous systems.

5. Conclusion

This study improves the automated score recognition and soprano recorder performance system, enhancing playback speed, accuracy, and sound quality. Optimized recognition and classification methods improve pitch assignment. The solenoid-based multi-valve system enhances performance, while the 9-valve setup and fuzzy control significantly improve pitch stability and tuning speed. Experimental results confirm that these refinements greatly enhance tonal precision and overall system performance.

Acknowledgment

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