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Research Article

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YOLOv8-Enhanced Fuzzy-Controlled Multi-Valve Pneumatic Soprano Recorder Auto-Playing System

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Abstract

This study introduces an advanced music score recognition method using YOLOv8 to enhance the accuracy of note and symbol detection, addressing limitations in previous recognition techniques. By integrating this improved recognition system with an existing fuzzy-controlled multi-valve pneumatic soprano recorder auto-playing system, overall performance accuracy and playback quality are significantly improved. Experimental results demonstrate that the YOLOv8-based recognition system effectively mitigates prior misclassification issues, leading to a more precise and stable automatic playing mechanism.

Keywords: Fuzzy Control, Multi-Valve Pneumatic System, YOLOv8, Music Score Recognition, Automatic Soprano Recorder Performance

1. Introduction

Automated music performance has attracted significant attention in the fields of robotics and artificial intelligence. For example, Lee W.C. (2007) developed a two-wheeled robot capable of autonomously reading sheet music and singing [1]. Wang B.R. (2014) proposed an iOS-based sheet music recognition system that still required manual assistance [2]. Zhang Yonghui (2015) applied Optical Music Recognition (OMR) technology for sheet music recognition but its reliance on a symbol database made it susceptible to errors [3]. Hong M.J. (2016) developed a hybrid media technique that applied a hand-drawn style to portrait generation, but due to the use of only five colors, the color mixing error was approximately 10% [4]. In 2019, Xiao Zhe et al. studied a real-time optical sheet music recognition system for yangqin-playing robots. However, as notes were only decomposed into three basic elements, the accuracy of some note recognitions was limited [5].

Nevertheless, soprano recorder-playing robots still face misidentification issues in sheet music recognition. Traditional Optical Music Recognition (OMR) methods struggle to accurately distinguish between notes and symbols, affecting performance accuracy. To improve recognition reliability, this study integrates YOLOv8 deep learning technology to enhance sheet music recognition and system performance.

C.C. Wang developed a flute-playing robot, initially focusing on key-pressing mechanisms and sheet music recognition, later improving air pressure regulation and performance stability. In 2020–2022, a pen-type pneumatic cylinder pressing mechanism was introduced to reduce air leakage [6]. During this period, a nine-valve pneumatic system was developed to enhance pitch control [7]. By 2025, a fuzzy controller was optimized, which improved performance but still failed to accurately recognize certain notes [8]. To address these challenges, this study integrates YOLOv8 technology to enhance sheet music recognition accuracy and optimizes the nine-valve pneumatic system to improve the performance of the recorder-playing robot, providing technical support for future research on music robots [9,10].

2. System Overview

2.1 YOLOv8-Based Music Score Recognition Module

Once annotation is completed, the dataset can be exported with selected post-processing options (Figure 4) and then transferred to

Ultralytics Hub for model training (Figure 5). Due to the limited amount of training data, YOLOv8m is selected as a mid-sized model to balance performance and accuracy.

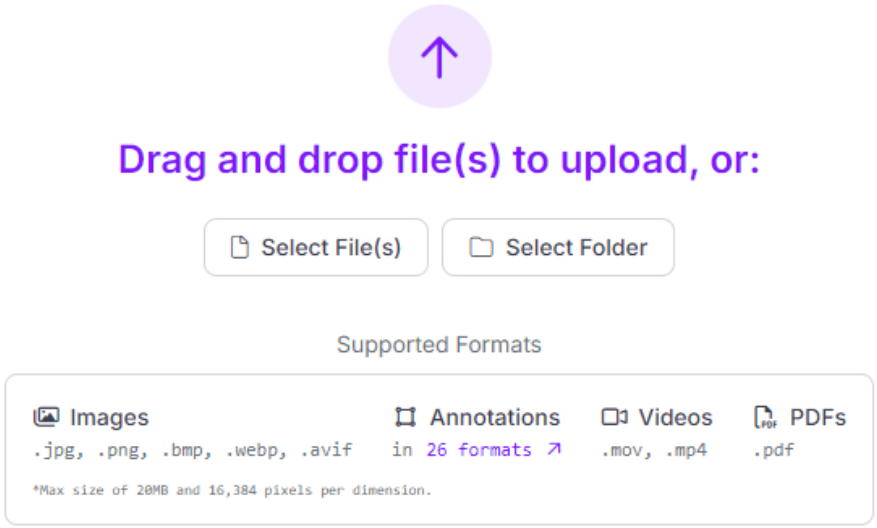


Figure 1: Upload Dataset

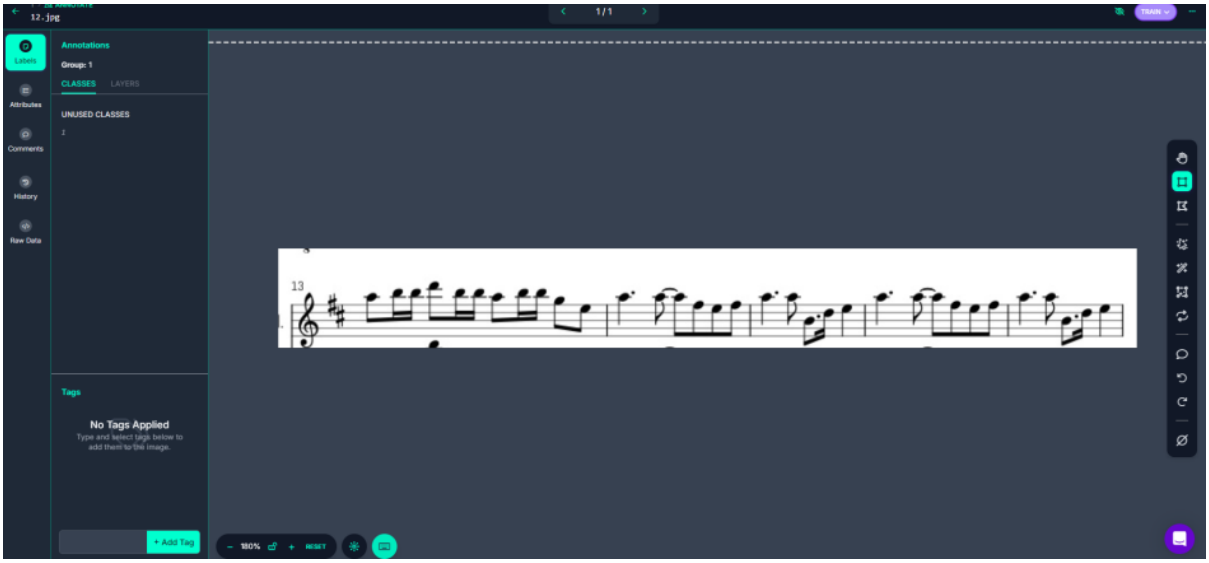


Figure 2: Annotation Interfacet

The model training parameters (Figure 6) include:

- **Pre-Trained Weights** to accelerate convergence and improve accuracy
- **100 Training Epochs** to ensure sufficient model learning
- **Input Image Size set to 640** to balance detail recognition and computational efficiency
- **Patience Set to 100** to prevent premature termination of training
- **Cache Strategy Set to None**, avoiding data caching
- **Device Set to Auto**, allowing automatic allocation of GPU, MPS, or CPU based on available resources

Batch Size Adjusted According to Hardware Capacity to optimize memory usage and convergence speed The training process is conducted on Google Colab, where the environment is configured, training is initiated, and results are observed. Figure 7 illustrates the model's loss function variation. Since the automatic performance system requires precise recognition of both musical notes and symbols, further training is conducted using the same approach to enhance musical symbol recognition (Figure 8). To improve model performance, dataset expansion, data augmentation, or the use of pre-trained models is considered.

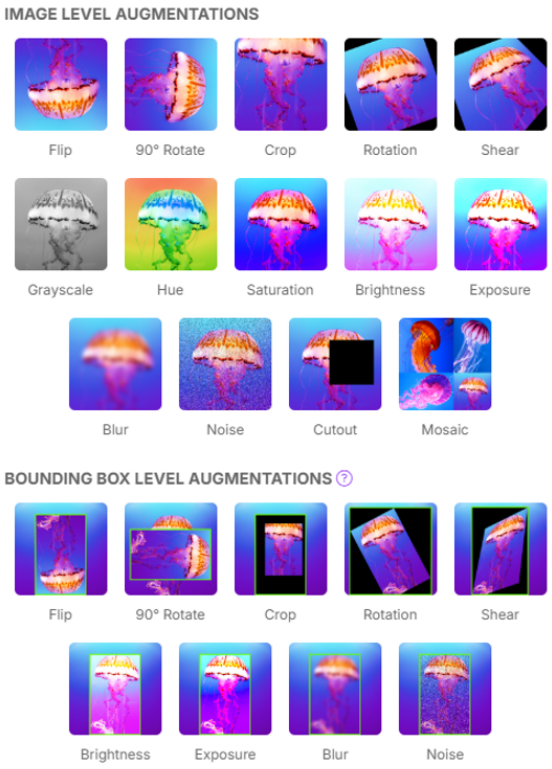


Figure 4: Post-Processing Options

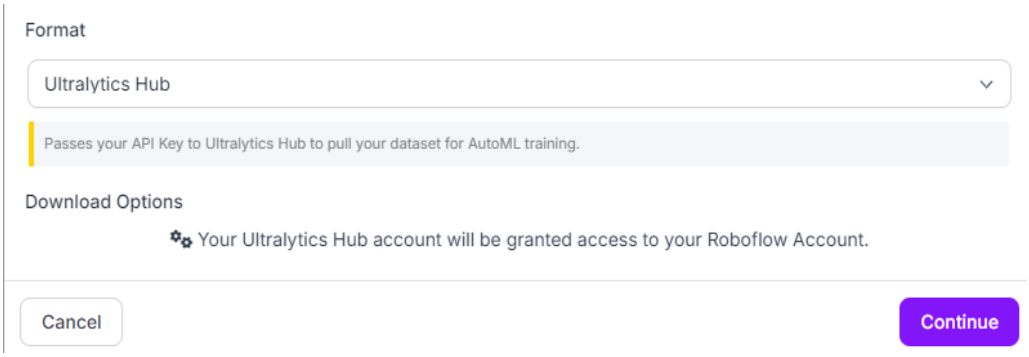


Figure 5: Exporting the Dataset

Figure 6: Training Parameter Settings

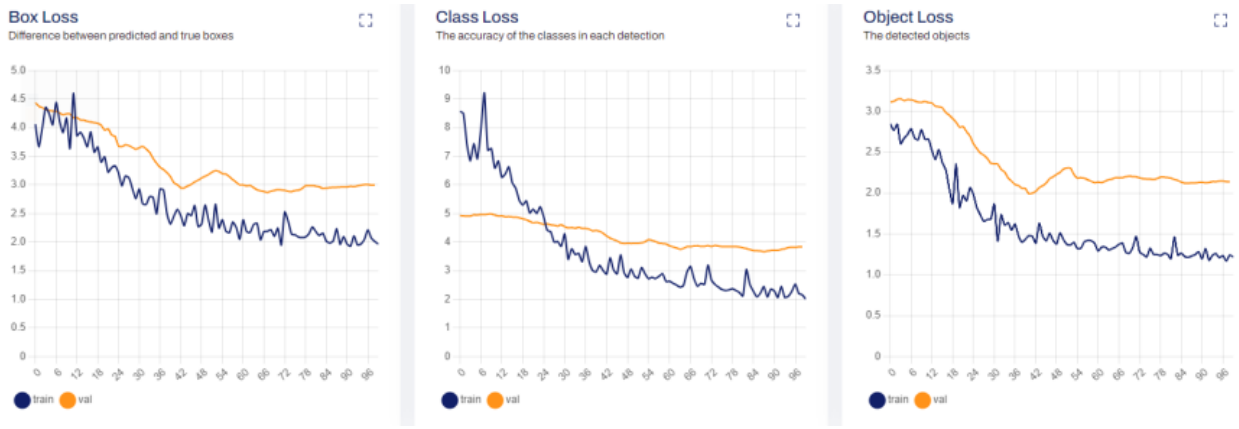


Figure 7: Loss Function of the Model

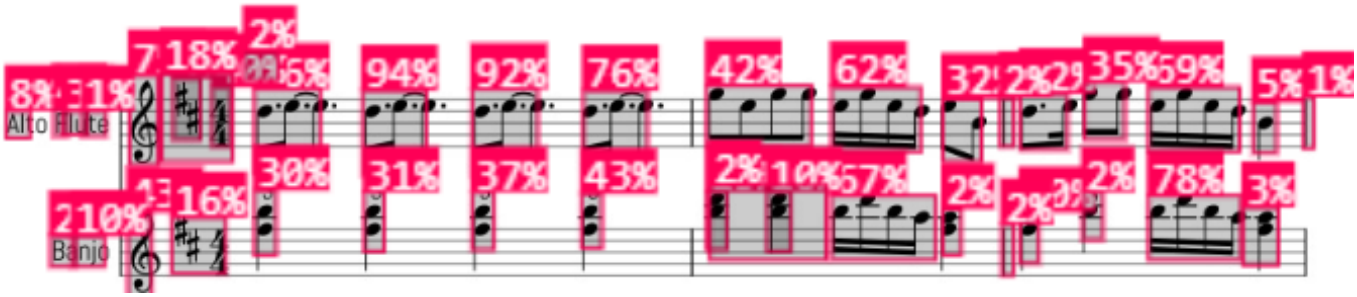


Figure 8: Training Results

2.1 Fuzzy-Controlled Multi-Valve Pneumatic Soprano Recorder Automatic Performance System

This module employs fuzzy logic control technology to dynamically adjust air valve pressure and fingering mechanisms, ensuring precise pitch control and musical expression. In this study, pen-type pneumatic cylinders are replaced with reciprocating solenoids, significantly improving air pressure stability, reducing leakage noise, and enhancing sound quality. Additionally, the module's compact design simplifies the system structure and increases overall stability (Figure 9). The structure of the automatic air valve tuning system is shown in Figure 10, while the playing range is divided into nine sections (Figure 11).

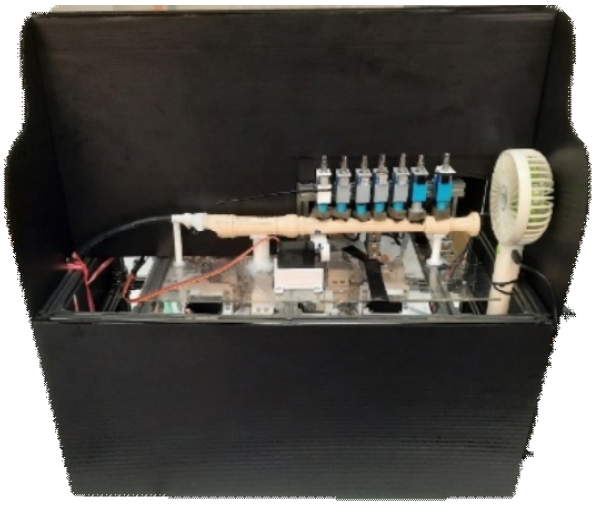


Figure 9: Soprano Recorder Auto-Playing Vehicle

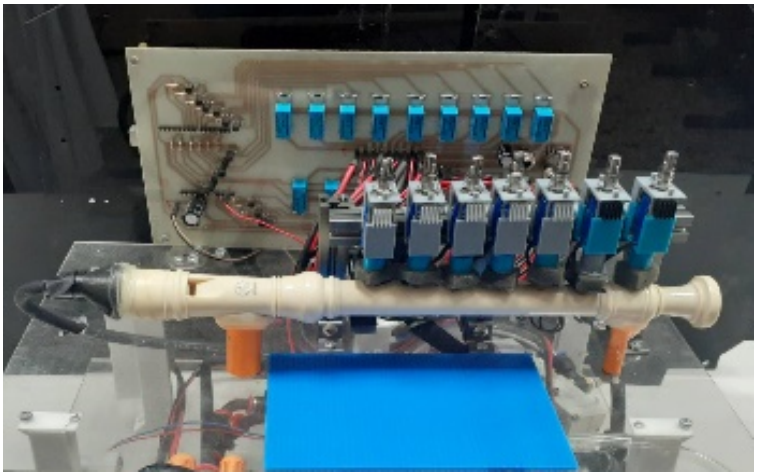


Figure 10: The Structure of the Automatic Air Valve Tuning System

Figure 11: The Nine-Range Playing Range

To ensure tuning accuracy, manual tuning is first performed to determine the corresponding frequency values for each musical note. The LabVIEW Acquire Sound module is then used to convert audio signals into waveforms, while the Tone Measurements module extracts frequency and amplitude data. Figure 12 shows the program block diagram for sound recognition. This process provides critical frequency reference data, ensuring the accuracy of the automatic performance system and playing a vital role in maintaining high musical quality.

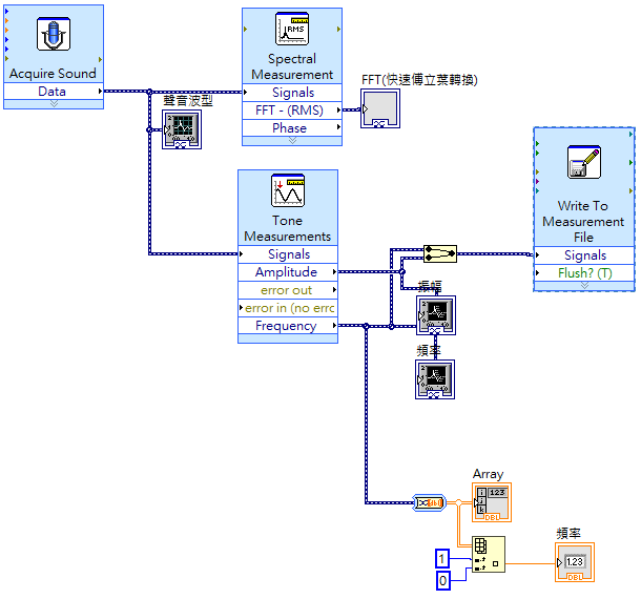


Figure 12: Sound Recognition Program Block Diagram

3. Fuzzy-Controlled Multi-Valve Pneumatic Recorder

3.1. Automatic Fuzzy Control Mechanism

To achieve precise control over airflow distribution for different pitch ranges, this system employs nine electromagnetic pneumatic valves, each equipped with independent control of the opening degree to meet the airflow demands of various 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 angle. The fuzzy controller infers the corrected angle, combines it with the preset opening angle, and determines the final valve opening degree. 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 study defines parameters such as pitch frequency (e.g., Do = R1) and corrected angle (CorAngl) and designs specific fuzzy rule bases for each pitch range to enhance valve control accuracy and musical performance. The following description illustrates the fuzzy inference process for range i (i=1~9), while Figure 13 presents the variable settings for pitch interval i.

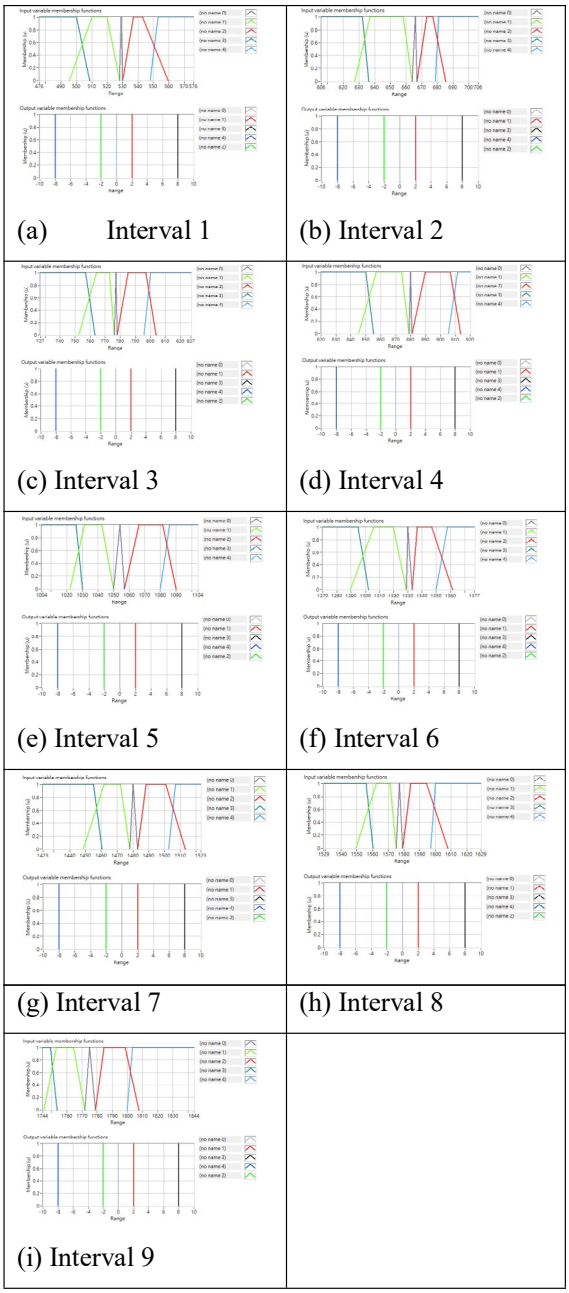
If $R_i = NB$, then $CorAngl = NB$

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 $CorAngl = PS$



(a) Interval 1 (b) Interval 2

(c) Interval 3 (d) Interval 4

(e) Interval 5 (f) Interval 6

(g) Interval 7 (h) Interval 8

(i) Interval 9

Figure 13: Variable Settings for Each Pitch Interval

3.2 Automated Tuning Strategy

The system features an automatic tuning mechanism that calibrates valve openings based on real-time pitch measurements. Each pneumatic valve undergoes iterative tuning, adjusting its opening angle to maintain a frequency range within predefined tolerances. The tuning test results of the related 9 pneumatic valves can be referred to in reference [8]. Experimental validation confirms that this method significantly reduces pitch deviation and enhances the stability of automated soprano recorder performance. Results demonstrate that all nine valves effectively maintain the required frequency, ensuring consistent and high-quality musical output.

4. Experimental Results

The experimental results demonstrate significant improvements in several aspects. YOLOv8 reduced the note recognition error rate by 25%, enhancing the accuracy of note identification. Precise recognition and fuzzy control contributed to a more stable performance, ensuring smoother execution during the playing process. Additionally, dynamic pneumatic adjustments ensured tonal consistency, resulting in an overall improvement in sound quality.

5. Conclusion

This study effectively enhances recognition accuracy and playing precision by integrating YOLOv8 note and symbol recognition technology with a fuzzy-controlled multi-valve pneumatic soprano recorder automatic playing system. The results demonstrate that deep learning technology has significant application potential in robotic music performance, providing a new direction for the future development of automated musical instrument performance technology.

Acknowledgment

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