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Development of Anthropomorphic Musical Performance Robots: From Understanding the Nature of Music Performance to Its Application to Entertainment Robotics

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Abstract—**During several decades, the research at Waseda University has been focused on developing anthropomorphic robots able of performing musical instruments. More recently, the authors have succeeded in developing a human-like robot able of playing the alto saxophone. As a result of our research efforts, the Waseda Flutist Robot WF-4RIV and the Waseda Saxophonist Robot WAS-1 have been designed to reproduce the human player performance. Therefore, as a long-term goal, we are proposing to enable the interaction between musical performance robots (i.e. robots orchestra). Such approach may enable us not only to propose new ways of musical expression, but also we may contribute to the better understanding of some of the mechanisms that enable the communication of humans in musical terms. In general terms, the communication of humans within an orchestra is a special case of conventional human social behavior. Rhythm, harmony and timbre of the music played represent the emotional states of the musicians. Of course, we are not considering a musical performance robot (MPR) just as a mere sophisticated MIDI instrument. Instead, its human-like design and the integration of perceptual capabilities may enable to act on its own autonomous initiative based on models which consider its own physical constrains. Due to the complexity of our long-term goal, in this paper, we are presenting our first steps towards enabling the interaction between musical performance robots. In particular, the details of the musical performance control systems are detailed. Thanks to the use of MIDI data, we performed preliminary experiments to enable a duet performance between the WF-4RIV and the WAS-1. We expect in the future; as a result of our research, we may enable a single anthropomorphic robot to perform different kinds of woodwind instruments as well as enable to interact at with level of perceptual capabilities (like human does).**

I. Introduction

THE relation between art and robots has a long history dating since the golden area of automata. As a result from the great efforts from researchers from both musical engineering and biomechanical engineering fields, nowadays we may distinguish to basic research approaches: developing human-like robots and developing robotic musical instruments [1-2].

The first approach, formally named Musical Performance Robots, is based on the idea of developing anthropomorphic robots able of displaying musical skills similar to human (from the point of view of intelligence and dexterity). The first attempt of developing an anthropomorphic musical robot was done by Waseda University in 1984. In particular, the WABOT-2 was able of playing a concert organ. Then, in 1985, the WASUBOT built also by Waseda, could read a musical score and play a repertoire of 16 tunes on a keyboard instrument [3]. Prof. Kato argued that the artistic activity such as playing a keyboard instrument would require human-like intelligence and dexterity. Other examples can be found in [5-8].

From the second research approach, a robotic musical instrument is a sound-making device that automatically creates music with the use of mechanical parts, such as motors, solenoids and gears. By implanting algorithms of Musical Information Retrieval (MIR), the robotic musical instruments are simple mechanisms designed to embed sensors to analyze the human behavior and to provide physical responses on the actuated musical instrument. In other words, this approach may facilitate the introduction of novel ways of musical expression that cannot be conceived through conventional methodologies. A number of engineers and artist have made headway in this area. The art of building musical robots has been explored and developed by musicians and scientists such as [9-12].

More recently, few researchers have been focused on integrating basic perceptual modules to the musical performance robots in order to interact with human musicians. In particular, Singer et al. [13] has been developed the GuitarBot, TibetBot, etc; which it has been designed to create new ways of musical expression. In particular, their approach is based in developing robotic instruments that can play in way that humans can't or generally don't play. The instruments provide composers with an immediacy of feedback, similar to composing on synthesizers. However, as opposed to synthesizers, physical instruments resonate, project and interact with sound spaces in richer, more complex ways. All robotic instruments are controlled by custom developed MIDI hardware and software, based around PIC microcontrollers. Another example is the Haile

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developed by Weinberg et al. [14]; which is a robot designed to utilize autonomous behaviors that support expressive collaboration with human musicians. Haile is composed by a robotic arm that can hit the drumhead in different locations, speeds and strengths. The mechanism of the arm is reproduced by a sliding mechanism controlled by a solenoid. From the musical perceptual level, different Musical Information Retrieval algorithms have been implemented to modify the performance of Haile.

Even that both GuitarBot and Haile are able to interact with musicians; their mechanism design is too simple; which facilitates the implementation of conventional MIR algorithms. However, if we want to understand in more detail the human while interacting in a musical way, we may require to increase the complexity of the mechanism of the musical performance robots as well as enhancing the perceptual capabilities of the robot (not only to process aural information but also visual, etc.) while considering physical constrains (such as breathing points, etc.).

Since 1990 at Waseda University we have been performing the research on musical performance robots. As a result, we have been developing an anthropomorphic robot that is able of producing the flute sound similar to an intermediate player. In order to add expressiveness to the flute performance, we have implemented musical performance rules based on Neural Networks so that the robot can extract the musical content of the human player before doing the interaction. However, when we tried to perform experiment where the robot interacting in real-time with a human musician (band context), still the robot lacks of cognitive capabilities to process the coming musical information from the performance of the partner.

Up to now, several researchers have been providing advanced techniques for the analysis of human musical performance. However, in our case, we are talking about not just analyzing the human performance, but also we are required to map those musical parameters into control parameters of the robot. This means that we are also required to take into account the physical constraints of the robot. Due to the complexity of doing this task, we have proposed to continue our research based on two approaches: enhancing the cognitive capabilities of the Waseda Flutist Robot to process visual/aural information and developing a new musical performance robot such as a Waseda Saxophonist Robot. Therefore, as a long-term goal, we would like to enable the interaction between human-like performance robots that are able to interact at the same level of perception as humans. From this, we may understand more in detail, from a scientific point of view, how humans can interact in musical terms. This may also contribute in finding new ways of musical expression that have been hidden behind the rubric of musical intuition.

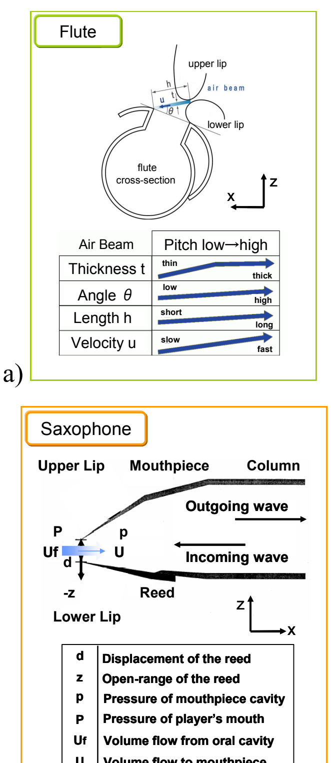
In this paper we provide an overview of the current research achievements on the Waseda Flutist Robot WF-4RIV and the Waseda Saxophist Robot WAS-1. Then, a preliminary experiment is proposed to analyze the possibilities of interacting between both robots through the MIDI communication. The reason why we have choose two different robots is that up to now, there isn't any anthropomorphic musical robot able of playing two different musical instruments with changing any mechanical component. As we will describe latter, the principle of sound production differs among both wind instruments. This may also provide us more knowledge about the required skills to play different kind of wind instruments. This issue could be as well as an important factor towards enriching the entertainment capabilities of MPRs.

II. Development of Anthropomorphic Performance Robots Able of Playing Flute and Saxophone

In order to develop human-like performance robots, we are required to understand in detail the principle of sound production of the instrument as well as the mechanism of humans to control different kinds of properties of the sound. In particular, in this section, we will provide a general overview of the differences on the principles of sound production between the flute and the saxophone. The flute is an air reed woodwind which only takes into consideration the width, thickness, angle, velocity of the air beam due to the absence of a reed (Figure 1a). Slight changes of any of these parameters are reflected in the pitch, volume, and tone of the flute sound.

On the other hand, in the case of the saxophone, the sound is produced by controlling the differential pressure before the mouth piece (Uf) and after it (U). Such a differential pressure produces a vibration on the reed located inside the mouth piece so that a sound is produced (Figure 1b). Depending on the frequency of the vibration, the correct pitch of the sound is produced. Therefore, the pressure of the lips on the reed and

a)



b)

Fig. 1. a) Principle of flute sound production [15]; b) Principle of saxophone sound production (single-reed) proposed by Schumacher [16].

the air beam coming from the lungs are important in order to control the pressure inside the mouth.

Humans are capable of performing impressive variety of movements that range from simple movements, such as looking at an object of interest by turning the head and eyes, to complex and intricate series of movements, such as executing a triple axel on ice. These movements are improved over an extensive period of practice. This iterative process, known as motor learning involves executing movements, identifying errors, and correcting those errors in subsequent movements. From the musical performance point of view, human players are not only required to accurately control and synchronize the movements of each of the organs required. In fact, they are able of improving their musical skills by practicing scores. For this purpose, human players perform several times a score. For each single note, humans listen and evaluate its quality. If the quality is not acceptable, they adjust some parameters (i.e. lips shape, etc.) until the produced sound is acceptable.

As we will describe later on, thanks to our experience on the development of the anthropomorphic flutist robot, we were able of implementing a bio-inspired auditory feedback system so that the robot may improve its performance after several trials. However, this is still not the case for the anthropomorphic saxophonist robot. As it was previously described, the principle of the sound production differs between the flute and the saxophone. Therefore, in this paper, we presented a preliminary musical performance control system that enables the saxophonist robot to reproduce some basic technical skills.

As one of our long term goals, we are aiming into implementing an auditory feedback system designed to enable musical performance robots to imitate the musical intelligence of musicians as well as reproduce the motor dexterities in order to play different kinds of wind instruments.

III. Musical Control Performance of the WF-4RIV

The research on the anthropomorphic Waseda Flutist Robot has been focused on mechanically reproducing the anatomy and physiology of the human organs involved during the flute playing [4]. In addition, we have focused on enabling the interaction with humans at the emotional level of perception. As a result of this research, in [5], the WF-4RIV has enhanced its musical performance thanks to the improvements on reproducing the lips and tonguing mechanisms (Figure 2). The WF-4RIV is composed by a total of 41-DOFs; which mechanically simulate the human organs involved during the flute playing. The WF-4RIV mechanically reproduces the anatomy and physiology of the following organs: lips (3-DOFs), neck (4-DOFs), lungs and valve mechanism (2-DOFs and 1-DOF respectively), fingers (12-DOFs), throat (1-DOF), tonguing (1-DOF), two arms (each with 7-DOFs) and eyes (3-DOFs).

In addition, research efforts have been done in order to enable the robot to enhance its expressiveness during the flute playing by implementing expressive performance rules by using Neural Networks. Moreover, an auditory feedback system (AFS) has been implemented on the WF-4RIV. The AFS enables the WF-4RIV to autonomously detect incorrect sounds produced during a performance and correct them. In particular, the proposed auditory feedback system is composed by three main modules (Figure 3): Expressive Music Generator (ExMG), Feed Forward Air Pressure Control System (FFAiPC) and Pitch Evaluation System (PiES).

The *ExMG* uses as an input the musical parameters from the performance of a professional flutist. Those parameters are analyzed and extracted by using our FFT tool [4]. As an output, a set of musical performance rules (which defines the deviations introduced by the performer) are produced. The process of modeling the expressiveness features of the flute performance is done by using Neural Networks. The *FFAiPC* was implemented by a feed-forward control system to control the air pressure coming out from the lungs. Such an improvement is related to enable the robot to produce an attack time of the note more similar to the human. For this purpose, we compute the inverse model of the lung system to control the air pressure during the attack time. The inverse model was computed by the feedback error learning. The feedback error learning is a computational theory of supervised motor learning proposed by Kawato [17]; which is inspired by the way the central nervous system works at. The *PiES* has been designed to detect both the pitch of the flute sound as well evaluation its quality. As a first approach, we have implemented the Cepstrum method. The Cepstrum is calculated by taking the Fourier transform (STFT) of the log of the magnitude spectrum of sound frame. In order to assure the accuracy of the pitch detection, the MIDI-data of the score was used to provide information to the pitch detection

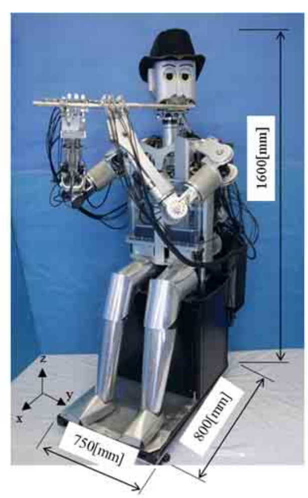


Fig. 2. The Waseda Flutist Robot No.4 Refined IV (WF-4RIV)

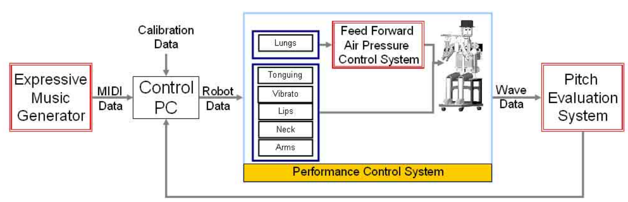


Fig. 3. Diagram of the proposed Auditory Feedback System.

algorithm about where the pitch is supposed to be located. By tracing the peaks, we are able of identifying the pitch of the note. After the detection of the pitch, we are then able of evaluating the quality of the sound. Basically, the quality of the sound is determined, based on Ando's experimental results [15], by considering the relation among the harmonics structure content (Eq. 1).

$$Eval = \frac{(M - H) + (L_e - L_o)}{Volume} \quad (1)$$

M: Harmonic level [dB] *H*: Semi-Harmonics level [dB]
L_e: Even-harmonics level [dB] L_o: Odd-harmonics level [dB]
Volume: Volume level [dB]

IV. MUSICAL CONTROL PERFORMANCE OF THE WAS-1

In this year; we have developed the WAseda Saxophonist No.1 (WAS-1) which is composed by 15-DOFs required to play an alto saxophone (Figure 4). The reason why we chose an alto saxophone, instead of the tenor saxophone, is due to its physical properties. In particular, the lips (1-DOF's lower lip), tongue (1-DOF), oral cavity, artificial lungs (1-DOF's air pump and 1-DOF's air flow valve) and fingers (11-DOFs) were developed.

The mouth of WAS-1 has been designed with 1-DOF that controls the motion of the lower lips. The actuation of the lower lips enables the control of the threshold pressure and the production of vibrato. The lower lip is then connected to the artificial lips made of Septon; which is a thermoplastic rubber. The artificial lips have been modeled by using Septon (Kuraray Co. Ltd.) which is an elastomer with high elasticity, high stiffness thermoplastic [19]. Such properties make possible the design of an artificial lip similar to the human lips in terms of shape and elasticity. In order to reproduce the motion of the lower lips, a T-shaped metallic pin (artificial tooth) has been embedded into the septon. In contrast, even that a metallic pin has been embedded into the upper lips.

The oral cavity of WAS-1 has been also designed by using the septon. In addition, the strength of the oral cavity has been modelled to support pressures upper to 8kPa [20]. On the other hand, the motion of the tongue tip is controlled by a DC motor which is connected to a link attached to the motor axis. Thanks to this tonguing mechanism of the WAS-1, the attack and release of the note can be reproduced. Regarding the air source of WAS-1, a DC servo motor has been used to control the motion of the diaphragm of the air pump. By changing the rotational speed of the motor axis, the air flow quantity can be accurately controlled by measuring it with a flow meter (Figure 4). Moreover, a DC servo motor has been designed to control the motion of an air valve so that the delivered air by the air pump is effectively rectified. In order to enable the WAS-1 to play from C3 to C#5 (two octave fingering), 11-DOFs have been implemented.

Inspired on the development of the WF-4RIV; as a first approach, the performance control system of WAS-1 is composed of a PC Control and a PC Sequencer (Figure 5). The PC Control is used to acquire and process the information from each of the degrees of freedom of the saxophonist robot as well as controlling the air flow/pressure to produce the desired sound. Similar to the flutist robot, the PC Control has as inputs the MIDI data and Music Pattern Generator (calibration data). The MIDI data is generated by means of the PC Sequencer (*Note On*, *Vibrato*, *Tonguing*, *Breathing Points*, etc.); in which the timing clock signal is used to synchronize the entire musical performance of WAS-1. The Music Pattern Generator is designed to output the calibration parameters required in order to produce the desired

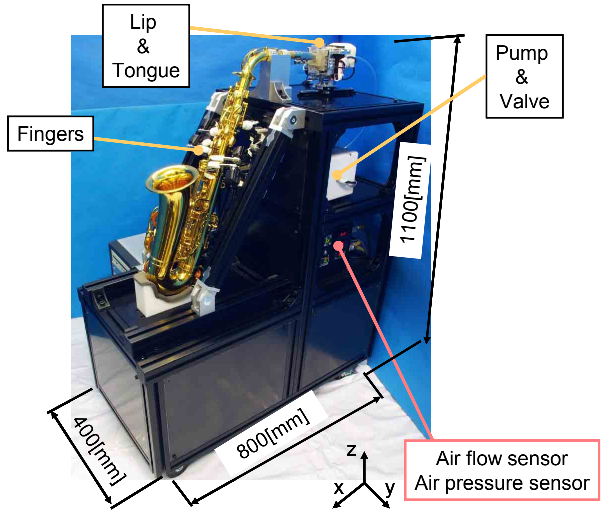


Figure 4. a) The WAseda Saxophonist Robot No.1 (WAS-1) was designed to play an alto saxophone. The WAS-1 is composed by artificial lungs, fingers and mouth mechanism.

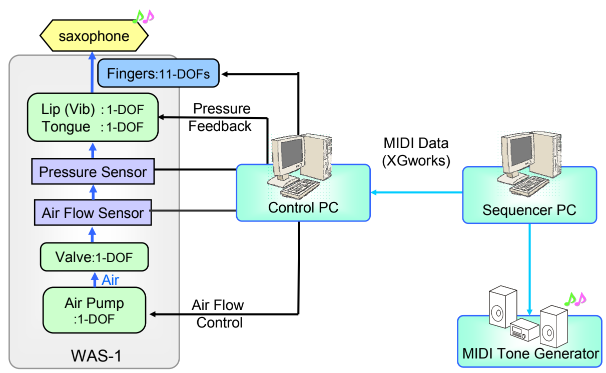


Figure 5. Musical performance control system of WAS-1

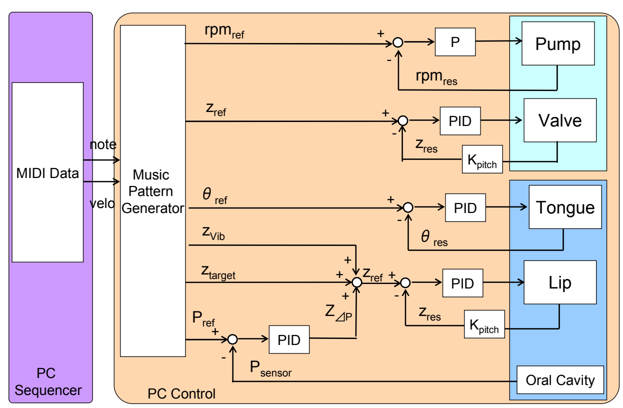


Fig. 6. Block diagram of the control system implemented on the WAS-1. In order to assure the production of sound on the alto saxophone, an air pressure feedback control was proposed.

saxophone sound. Inspired on the principle of sound production of single-reed instruments, the WAS-1 requires the control of the following parameters: lower lip's position, valve closing rate, air flow and pressure. In particular, the lower lip position (1-DOF) is controlled to exert pressure on the reed along the Z axis. For each single note, the position of the lower lip should be pre-defined before the performance. The valve closing rate is controlled to regulate the quantity of air flow to produce the saxophone sound. Finally, the air flow and air pressure are pre-defined during the calibration procedure. Those parameters depend on the requirements of each single note.

The block diagram of the proposed control system of the WAS-1 is shown in Fig. 6. In particular, during the saxophone performance, it is required to assure the accurate control of the lower lip's position and air pressure. For that purpose, the lips position is controlled by means of a PID controller. Due to the relation between the air pressure and the lower lip's position, the pressure information obtained from the attached sensor on the oral cavity is used to feedback the signal (P_{sensor}). The measured pressure signal is then compared with the reference pressure output (P_{ref}) from the Music Pattern Generator. As a result, the lower lip's position is compensated by (2); where P_e is the pressure error computed as (3). The proportional, derivative and integral coefficients have been experimentally determined (K_p: 15, K_d: 30, K_i: 1).

$$Z_{\Delta P}(t) = K_p P_e(t) + K_d \frac{dP_e}{dt} + K_i \int_0^t P_e(t)dt \quad (2)$$

$$P_e = P_{ref} - P_{sensor} \quad (3)$$

V. Experiments & Results

In this paper, we have focused in comparing the performance of the flutist and saxophonist robot with the performance of human players. In the first case, we have based our analysis by means of the proposed evaluation function (1). Regarding the second case, we have compared by means of analyzing the pitch and volume. It is worth to mention that in this experiment we couldn't use the evaluation function (1) to evaluate the performance of the saxophonist robot WAS-1. Finally, we have carried out a preliminary experiment to enable a duet performance between the WF-4RIV and WAS-1 by synchronizing their performance using the timing clock signal (MIDI data). In this experiment, it is worth to mention that we are not aiming in enabling the duet performance by simple developing sophisticated MIDI-based performance robots. Instead, we are doing basic research on enabling the perceptual interaction between anthropomorphic musical performance robots. At the moment, the WAS-1 is not equipped with vision//aural sensors, but we are implementing interaction and cognitive modules on the WF-4RIV [18].

Regarding the WF-4RIV, we have analyzed the flute sound compared with that produced by a professional flutist. For this purpose, we have used the Eq. (1) to compare their quality. The results are shown in Fig. 7. As we may observe,

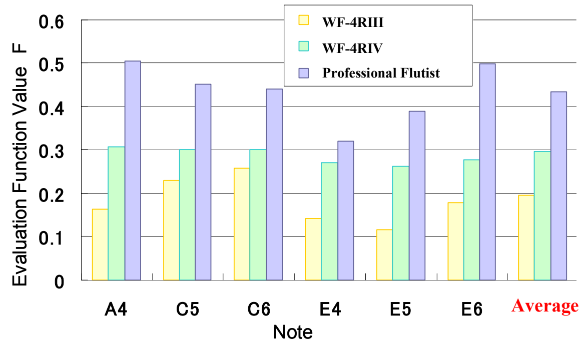


Figure 7. Experimental results while comparing the quality of the flute sound between the WF-4RIV and a professional flutist (the previous version of the flutist robot WF-4RIII is also analyzed).

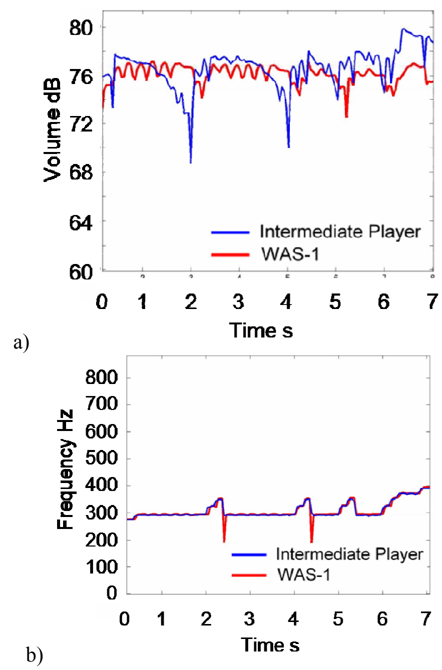


Figure 8. Experimental results while comparing the both performances: volume and pitch.

the flute sound quality of the WF-4RIV has been improved thanks to the mechanical improvements as well as the proposed auditory feedback system. In average, a 52% of improvement of the evaluation score was found while comparing the previous version of the flutist robot and the WF-4RIV.

Regarding the WAS-1, we have compared the pitch and volume produced by the WAS-1 and the intermediate level player. The experimental results are shown in Fig. 8. As we may observe the produced pitch by WAS-1 was quite similar to the human player (Fig. 8a); however, further improvements are still required to improve dynamic transitions between notes (Fig. 8b).

Finally, in this preliminary experiment, we have focused in verifying the possibility of performing a duet between the WAS-1 (main voice) and the WF-4RIV (second voice). For this purpose, we have programmed both robots to perform the *Trois Duos de Mendelssohn et Lachner* composed by Felix Mendelssohn Bartholdy. In order to achieve the duet performance, as a preliminary approach, we have synchronized the performance of both robots by means of MIDI signal. In this performance, we have recorded the performance of each robot separately by using two microphones. The recorded data was then analyzed by means of SSUM developed by Sturm et al. [21]. The SSUM is a tool to demonstrate essential principles and concepts of media signal processing to students.

The experimental results are shown in Fig. 9, where the pitch and volume of each performance during the duo are shown. As we may observe, both performance were synchronized and it is clearly observable the differences between the main and second voice by comparing the volume of the performance as well as the pitch pattern. However, in both cases still some difficulties are found while doing the dynamic transitions between notes, particularly during the breathing points of the robot. From these results, we may confirm the possibility of enabling the musical interaction between musical performance robots. In the near future, we hope we can enable a more natural interaction between both robots by means of processing not only the MIDI signal, but also the exchanged perceptual information among them.

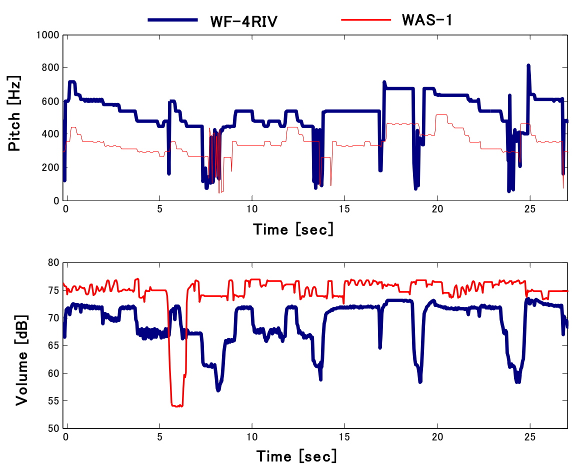


Figure 9. Experimental results while analyzing the duet performance of the WF-4RIV and WAS-1.

VI. Conclusions & Future Work

In this paper, an overview of the research carried out at Waseda University towards enabling the interaction between musical performance robots has been detailed. In particular, the developments of the Waseda Flutist Robot WF-4RIV and the Waseda Saxophonist Robot WAS-1 have been detailed. Thanks to the human-like design of the mechanical simulated organs on each of the robots, we were able of demonstrating their capabilities to perform the flute and the saxophone respectively. Moreover, thanks to the use of MIDI data on the musical performance control systems implemented on both robots, preliminary experiments were carried out to enable a musical duet.

As a long-term goal, we are aiming in enabling the musical interaction between robots in terms of perceptual and dexterity capabilities. From this research approach, we may not only understand better the nature of musical performance, but novel ways of musical expression can be conceived. Currently, we are implementing cognitive capabilities on the flutist robot (vision and aural processing).

References

[1] A. Kapur, "A History of Robotic Musical Instruments," in Proc. of the International Computer Music Conference, pp. 21-28, 2005.
[2] Solis, J., Takanishi, A. “An overview of the research approaches on Musical Performance Robots,” in Proc of the International Computer Music Conference, pp. 356-359, 2007.
[3] Sugano, S., Kato, I., "WABOT-2: autonomous robot with dexterous finger-arm coordination control in keyboard performance: in Proc. of the Int. Conference on Robotics and Automation, pp. 90-97, 1987
[4] Solis, J., Takanishi, A., et al. “The development of the anthropomorphic flutist robot at Waseda University,” International Journal of Humanoid Robots, Vol. 3(2), pp. 127-151, 2006
[5] Solis, J., Ninomiya, T., Yamamoto, T., Klaus, P., Takanishi, A., The Mechanical Improvements of the Waseda Flutist RobotWF-4RIV and the Implementation of a New Performance Control System, in Proc. of the 17th CISM-IFToMM Symposium on Robot Design, Dynamics, and Control, pp. , 2008.
[6] Takashima, S., Miyawaki, T., "Control of an automatic performance robot of saxophone: Performance control using standard MIDI files," in Proc. of the IROS Workshop on Musical Performance Robots and Its Applications, pp. 30-35, 2006.
[7] Shibuya, K., “Toward developing a violin playing robot: bowing by anthropomorphic robot arm and sound analysis,” in Proc. of ROMAN, pp. 763-768, 2007.
[8] Kuwabara, H., Shimojo, M., et al., “The development of a violin musician robot,” in IROS06 Workshop on Musical Performance Robots and Its Applications, pp. 18-23, 2006.
[9] Kapur A., Singer E., Benning, M, Tzanetakis G., Integrating HyperInstruments, Musical Robots & Machine Musicianship for North Indian Classical Music,” in Proc. of the New Interfaces for Musical Expression, pp. 238-241, 2007.
[10] Dannenberg, R.B., Brown, B., Zeglin, G., and R. Lupish, “McBlare: A Robotic Bagpipe Player”, In Proc. of the NIME2005, Vancouver, 2005.
[11] Beilharz, K. “Interactively Determined Generative Sound Design for Sensate Environments: Extending Cyborg Control”, Y. Pisan (eds), Interactive Entertainment, pp. 11-18. 2004.
[12] Hayashi, E., “Development of an automatic piano that produce appropriate: touch for the accurate expression of a soft tone,” in Proc. of IROS Workshop on Musical Performance Robots and Its App., pp. 7-12, 2006.
[13] E. Singer, et al., “LEMUR’s musical robots,” in Proc. Of the Conference on New Interfaces for Musical Expression, pp. 183-184, 2004.
[14] Weinberg, G., Driscoll, S., Parry, M., Musical interactions with a perceptual robotic percussionist,” in Proc. of the 16th Int. Symposium on Robot and Human Interactive Communication, pp. 456-461, 2007.
[15] Ando Y., “Drive conditions of the flute and their influence upon harmonic structure of generated tone”, Journal of the Acoustical Society of Japan (in Japanese), pp. 297-305, 1970.
[16] Schumacher, R. T., "Ab Initio Calculations of the Oscillations of a Clarinet," Acustica, 48(2), 1981, pp. 71-85.
[17] Kawato M., Furukawa K., Suzuki R., “A hierarchical neural network model for control and learning of voluntary movement,” Byological Cybernetics, vol. 57, pp. 169-185, 1987.
[18] Petersen, K., Solis, J., Takanishi, A., “Towards enabling a natural interaction between human musicians and musical performance robots: Implementation of a real-time gestural interface,” in Proc. of the 17th Int. Symposium on Robot and Human Interactive Communication, pp. 340-345.2008
[19] http://www.septon.info/en/septon/what_septon.html.
[20] Fuks L & Sundberg J ,’Blowing pressures in reed woodwind instruments’, KTH TMH-QPSR 3/1996, Stockholm, pp. 41-56, 1996.
[21] Sturm, B. L., and J. Gibson, Signals and Systems Using MATLAB: An Effective Application for Teaching Media Signal Processing to Artists and Engineers,” in Proc. of the International Computer Music Conference, pp. 645–649, 2004