ORIGINAL ARTICLE

Offline Sound Volume Feedback Algorithm for a Violin-Playing Robot

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Abstract: This paper proposes an offline sound volume feedback algorithm for a violin-playing robot and shows the validity of the algorithm. We built a 7 D.O.F. violin-playing robot and investigated the relationship between bow speed and sound volume. We found from experiments that the sound volume can be approximated by a third-order polynomial of the bow speed. Based on this relationship, we proposed an algorithm for sound volume feedback. We implemented the proposed algorithm onto the robot to clarify its effects. The result confirmed the validity of the proposed algorithm.

Keywords: *Violin-playing robot, Sound volume feedback, Bow speed*

1. INTRODUCTION

Recently, many robot researchers have focused on communication between humans and robots. For example, Kobayashi et al. built a humanoid robot with facial and gestural expressions [1]. Also, Ogata et al. built a robot that can communicate with humans using primitive language [2]. The goal of those studies was to establish smooth communication between humans and robots.

We focus on musical instrument playing because it is greatly affected by *kansei*. Many musical robots have been developed up to now [3-5]. Among various musical instruments, we focus on the violin. Violin playing is a very difficult task for robots because they must control many parameters such as position, speed and force of the bow. Although a few violin-playing robots have been developed, such research has not focused on *kansei* [3, 6, 7]. Therefore, the final goal of this study is to develop a violin-playing robot capable of expressing *kansei* by producing expressive sounds.

In this paper, we focus on the offline feedback process of violin playing. Usually when practicing, human violinists listen to the produced sounds, and alter bowing parameters and fingerings in the next performance to produce much better sounds. This process is an offline feedback process, so to speak. The process is also very important for robots because, in communication with humans, they have to recognize the results of their behaviors, and alter their behaviors according to the results for the next communication. In violin playing, a robot must be able to evaluate the produced sounds and alter bowing parameters to produce much better sounds.

As the first step of this study, we focused on sound volume, and the goal of this paper is to construct an offline sound volume feedback algorithm. In this paper, first, we describe the relationship between *kansei* and violin play-

ing. Then, the violin playing robot we built is introduced. Also, the experiments conducted for investigating the relationship between bow speed and sound volume are explained. Finally, we propose an algorithm for offline sound volume feedback and its evaluation.

2. KANSEI AND VIOLIN PLAYING

2.1 Violin

Figure 1 shows the names of each part of a violin and a bow. A violin has four strings: G, D, A and E. The ends of each string are connected to a peg and a tail piece, and the strings are supported by the bridge. Violinists usually put their chin on the chin rest and pin the violin between their chin and shoulder.

A bow consists of three parts: stick, hair and frog. The hair is made of horse hair. The tension of the hair can be adjusted by rotating the screw, which changes the position of the frog. To regulate friction between hair and strings, an appropriate quantity of resin must be applied to the hair.

Violin playing can be divided into three tasks: bowing, fingering and holding a violin. Bowing and fingering are much more important than holding because those tasks affect sounds directly. In bowing, bow force, bow speed and sounding point are significant parameters that determine the parameters of produced sounds, such as volume and timbre. The sounding point is the position at which the bow touches a string. Also, there are two types of bowing: Down bow and Up bow. Down bow is bowing starting from near the frog to the tip. Up bow is vice versa.

2.2 Kansei in Violin Playing

Before explaining details of the robot and the experiments, we will explain our concept of the role of *kansei* in violin playing. Figure 2 shows the information flow of

Figure 1: Names of each part of a violin

musical instrument playing proposed in this study. Images of the sounds are derived from musical notes. Then, the image is transferred to sound information such as pitch, length, volume, and timbre. Next, the playing parameters such as bow force, bow speed, and fingering positions are derived from the sound information. All those processes go through *kansei* and can be considered task planning. The motions to achieve the derived playing parameters are produced in the motion planning process in Fig. 2. Violinists listen to the produced sound and adjust playing parameters to produce much better sounds when practicing. This can be considered an offline feedback process. Of course, this feedback process works in real time when playing.

We analyzed playing parameters and timbre in human violinists [8]. Then, we become interested in the offline feedback process because it seems to be greatly affected by human *kansei*. Therefore, in this paper, the offline feedback of sound volume is focused on and used to construct a sound volume feedback algorithm using a violin-playing robot.

3. VIOLIN PLAYING ROBOT

Figure 3 shows a robot built for violin playing [9]. The robot arm is anthropomorphic because violin playing is a

Figure 2: Information flow of violin playing

highly sophisticated task for humans, and the human arm seems to be best suited for it. The robot arm has seven joints (three in the shoulder, one in the elbow, and three in the wrist, see Fig.4). Each of the joints is actuated by a D.C. servo motor whose angle and angular speed are controlled by a P.C. In addition, a hand is attached to the end of the arm (Fig. 5). This hand grasps the frog of the bow and pushes the stick, as humans do.

The length between the shoulder joint and elbow joint is approximately 262 mm and 304 mm between the elbow and wrist joints, which is close to the length of a human arm. The trajectory of the hand is a straight line orthogonal to the string when the arm performs bowing. Angles of each joint are calculated by inverse kinematics. Then, velocity patterns are also calculated from the angle patterns. From the P.C., the velocity patterns are sent to the servo amplifiers. Also, position data from the each joint are obtained through the encoders attached to the all the motors to control the angles. Therefore, angular velocity and angles of each joint are controlled in this robot.

Figure 6 shows the photograph of the robot playing the violin. In this photograph, the hand is a previous version.

4. RELATIONSHIP BETWEEN SOUND VOLUME AND BOW SPEED

In the offline feedback process, sounds have to be evaluated as to whether they are desirable. Then, playing

Figure 3: Photograph of violin playing robot

Figure 4: Link model of the robot

parameters should be altered according to the evaluation. Therefore, we have to know the relationship between sound volume and playing parameters such as bow force, bow speed and sounding point. In this paper, we focus on the relationship between bow speed and sound volume. To ascertain that relationship, we conducted the following experiment.

4.1 Recording Sound and Calculation of Sound Volume

Sounds of the “A” string without fingerings are produced by the robot as explained in Section 3. Both acceleration and deceleration time of the bow are 0.5 sec and the time of constant bow speed is approximately 1.0 sec. We use bow speed every 0.025m/s from 0.025 to 0.25m/s. The sounds were produced three times for each experimental condition. The sound was recorded through a microphone and

(a) front view

(b) side view

Figure 5: Photograph of hand for grasping bow

Figure 6: Photograph of the robot playing the violin with previous version of a hand

sound card of a PC as a WAV file. The sampling frequency was 48 kHz, and the quantum bit number was 16.

The frequency of the “G” string is 196 Hz, which is the lowest pitch for a violin. A period of the sound wave is $1/196.00 \approx 0.0051$ s, thus the biggest and smallest sound pressure in one period must be contained in every 0.01 s of data. Therefore, we calculate sound volume every 0.01 s.

Usually, sound volume L_p is defined as the following equation (1):

$$L_p = 10 \times \log \left(\frac{p}{p_0} \right)^2 = 20 \times \log \frac{p}{p_0}, \quad (1)$$

where p is the amplitude of sound pressure that can be obtained by subtracting the smallest sound pressure from the biggest sound pressure during one 0.01 s of data and p_0 is standard sound pressure. For simplicity, we assumed $p_0 = 1$.

4.2 Experimental Result

Figure 7 shows an example of calculated sound volume of a down bow. The period is divided into three parts: acceleration, constant, and deceleration periods in bow speed. We use averaged sound volumes in the constant bow speed period shown in Fig. 7.

We conducted experiments using the robot to investigate

Figure 7: Example of sound volume in one playing

average sound volume and bow speed. We selected two strings: “A” and “D.” Also, the robot plays the violin near the bridge and fingerboard. Therefore, there are four experimental conditions. Figure 8 shows the results. Plots represent calculated sound volumes, the curves of each figure are fitted lines. We fitted the plots by third-degree polynomial functions and they fitted to the plots very well. Therefore, we concluded that sound volume has a close relation to bow speed and the relationships between them can be approximated by third-degree polynomial functions.

5. OFFLINE SOUND VOLUME FEEDBACK ALGORITHM

Based on the relationships between bow speed and sound volume described in the last section, we constructed a sound volume feedback algorithm. In this algorithm, other bowing parameters (bow force and sounding point) are considered fixed. Also bow speed is considered to affect timbre. But in this algorithm timbre is ignored.

First, all the robot joints are moved to the initial position. Then, joint movements are calculated from the straight line trajectory of the hand movement using inverse kinematics. Then, the robot plays the violin and the sound is recorded through a microphone and the sound card in a PC. The average volume of recorded sound in the constant bow speed period is calculated as described in Section 4.1. Then, the volume is fed back and compared with the desired volume, and the bow speed is altered for producing the desired volume.

The offline sound volume feedback is achieved by the following method. Figure 8 shows a schematic diagram of the algorithm. First, the robot plays the violin two times at different bow speeds. The two plots are obtained in a sound volume versus bow speed graph, and by connecting them with a straight line. We can obtain the first-order polynomial of the relationship between sound volume and bow

Figure 8: Relationships between bow speed and volume

speed (Fig. 9 (a)). From an intersection point of the line with the target sound volume, we can approximate the next bow speed for producing a target sound volume. Then, the robot plays the violin again at the bow speed. We can calculate the volume and obtain three plots in the graph of bow speed versus sound volume. Those data are approximated in a second-degree polynomial (Fig. 9 (b)). From an intersection point of the polynomial line with the target sound volume, the next bow speed can be determined. The robot again plays the violin at the bow speed. Then, we can calculate the volume and obtain four plots in the graph and a third-degree polynomial (Fig. 9 (c)). The next bow speed is determined from the graph and the robot again plays the violin at the bow speed. The sound volume is calculated

(a) after two playings

(b) after three playings

(c) after four playings

Figure 9: Schematic diagrams of offline volume feedback algorithm

and the third-degree polynomial is modified according to the obtained data. Then, the process is repeated.

The relationship between volume and bow speed is not simple monotone function (see Fig. 8 (c)), the algorithm should be use third-degree polynomial functions as described Section 4.2.

6. EXPERIMENTS

We conducted the experiments based on the algorithm described above. We use “A” string near the bridge. The target volumes are 74, 75, 76, and 77 dB. Figure 10 shows the results. The vertical and horizontal axes represent sound volume and number of performances, respectively. The plots $\blacklozenge$, $\blacksquare$ and $\blacktriangle$ in Fig. 10 mean first, second, and third trials in each target volume, respectively. In all the targets, the sound volume goes to the target volume after four or five performances.

7. DISCUSSION

It is difficult to prove the existence of solution in this algorithm theoretically. But in Fig.10, we can see that the algorithm finally reach the target volume. The robot can play the violin at the target sound volume after four or five performances. Therefore, we considered that it is proved experimentally that the proposed algorithm reaches reasonable solution.

Because a violin has its own characteristics of sound volume, human violinists need to play the violin a few times and determine the characteristics by trial and error. The proposed algorithm simulates that process. Also, other parameters such as quantities of resin on the hair of the bow affected volume. By using the algorithm, a robot can acquire the characteristics of sound volume, even if those parameters are changed.

8. CONCLUSION

This paper proposed an offline sound volume feedback algorithm for a violin-playing robot. First, we found that sound volume can be estimated by third degree polynomial functions. Based on the result, we constructed an algorithm of offline volume feed back system. Then, we concluded that the algorithm works very well based on the experimental results.

Investigating influences of other parameters such as bow force on sound volume is the future work. The next step in this research is an offline timbre feedback system. Because timbre is evaluated by *kansei*, feedback loop in Fig.2 should consider timbre. Also, creating a real-time feedback system remains a challenge for the future.

Figure 10: Experimental results of offline volume feedback algorithm

REFERENCES

1. Takuya Hashimoto, Sachio Hiramatsu, Toshiaki Tsuji and Hiroshi Kobayashi, "Development of the Face Robot SAYA for Rich Facial Expressions," *SICE-ICASE International Joint Conference 2006*, pp.5423-5428 (2006).
2. Tetsuya OGATA, Yoshihiro MATSUYAMA and Shigeki SUGANO, "Acquisition of internal representation in robots -toward human-robot communication

using primitive language," *Advanced Robotics*, 14(4), pp.277-291, (2000).

3. M. Kajitani, "Development of Musician Robots," *Journal of Robotics and Mechatronics*, 1(3), pp.254-255 (1989).
4. Kato, I.: "The robot musician WABOT-2," *Robotics*, Vol. 3(2), pp.143-155,(1978).
5. Jorge Solis, Koichi Taniguchi, Takeshi Ninomiya, and Atsuo Takanishi, "Towards an expressive performance of the Waseda Flutist Robot: Production of Vibrato," *Proc. 16th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN2007)*, (2007).
6. H. Kuwabara, H. Seki, Y. Sasada, M. Aiguo, and M. Shimojo, "The development of a violin musician robot," *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2006) Work-shop: Musical Performance Robots and Its Applications*, pp.18-23, (2006).
7. Tarek M. Sobh, and Bei Wang, "Experimental Robot Musicians," *Journal of Intelligent and Robotic Systems*, 38, pp.197-212, (2003).
8. Koji SHIBUYA, Takaharu KOYAMA, Shigeki SUGANO, "The Relationship between KANSEI and Bowing Parameters in the Scale Playing on the Violin," *Proceedings of 1999 IEEE International Conference on Systems, Man and Cybernetics (SMC '99)*, pp.IV305-310, (1999).
9. Koji Shibuya, Shoji Matsuda, and Akira Takahara, "Toward Developing a Violin Playing Robot - Bowing by Anthropomorphic Robot Arm and Sound Analysis -," *Proc. 16th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN2007)*, pp.763-768, (2007).

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