The 2nd International Workshop on Communication for Humans, Agents, Robots, Machines and Sensors (CHARMS 2016)

Violin Musical Tone Analysis using Robot Finger

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Abstract

This paper introduces a study to improve the performance of robot finger for violin fingering. The authors have developed violin-playing robot system. Also, authors have designed robot hand anthropomorphic type for the violin fingering. The violin fingering plays an important role in determining the tone or sound. Whether the performance sound produced when the developed robot finger presses the strings of the violin is identical to when a human violinist presses the strings requires verification. The researchers propose utilizing the precedent sound quality rating system to analyze the performance sound of a human violinist and create the conditions needed to produce the accurate quality sound. On this basis, the researchers compared the performance sound made by the fingering of a robot finger with that of a human violinist and suggest a strategy to make improvements to disadvantages.

Keywords: violin-playing robot; anthropomorphic robot finger; sound quality rating system; mass-spring-damper model.

1. Introduce

Numerous studies have been conducted on human-robot interaction (HRI) with the aim of developing service robots for personal and private use. In particular, both industry and researchers alike have focused on a variety of entertainment robots that can deliver human-friendly mutual information. Visual, auditory, and touch sensors have been further installed to identify the intended actions of humans. Rapid technological developments of visual and
touch sensors in the field of entertainment robots have enabled interaction of the robots with humans. However, no suitable sensors and algorithms for recognizing human intent through auditory perception are yet available.

Currently, studies are actively pursuing to recognize a variety of sounds and human voices. However, among the literature, studies specifically investigating auditory feedback are only conducted, to a limited extent, in the medical field. In particular, a self-treating method for people who stutter, which entails listening to their own voice and understanding its state, has been proposed. Determining that this auditory feedback technology is the key element of HRI, the present researchers have accordingly developed a sound quality rating system for improving the existing violin-playing robot by combining this system with auditory feedback. The present work introduces a robot hand and a robot finger that perform the role of violin fingering in the violin-playing robot. The rest of this paper is organized as follows. Section 2 briefly introduces the previous work of violin-playing robot system. Section 3 illustrates how violin fingering affects the human violin sound quality and presents a comparison and analysis of the results of sound quality in the case of violin fingering by a human violinist and the proposed robot finger when playing the fourth-octave C-note. Section 4 introduces about mechanical impedance modeling of human finger. Also, in order to find out whether the developed robot finger produces the same performance sound as when a human violinist presses the violin strings, a sound quality-rating test is implemented.

2. Previous Work

This section explains the developed violin playing robot system. We have developed a violin-playing robot with an industrial six-axis vertical robot arm (RV-2SD), as shown in Fig. 1(a), to mimic the appearance of a human violinist. Similar to the arrangement in the case of a human violinist, the violin is fixed at an angle of 30° to the left shoulder. A violin bow is placed at the end of the robot arm, which is equipped with a force sensor in order to measure the pressing force and twisting force.

Also, authors have developed an anthropomorphic type robot hand for violin-fingering, as shown Fig. 1(b). This robot hand is similar to size of an average male hand for accurately pressing violin string. Also, it operates based on wire-driven and under-actuated for light weight.

Auditory feedback is known as a stuttering therapy method in the medical field, where delayed auditory feedback (DAF) is mainly studied. If the auditory feedback is fused with visual feedback and somatosensory feedback, it helps people to talk or sing a song by determining the accuracy of the sound. This process has been utilized in the process of playing music, where in previous work proposes a method that improves the sound quality automatically by using violin robot. Fig. 1(c) shows the framework of auditory feedback system that is used in violin robot. This system is implemented by listening and mimicking the playing technique of violinist to improve the sound quality.

Fig. 1. (a) Developed violin-playing robot system; (b) anthropomorphic type robot hand; (c) flow chart of auditory feedback system.
3. Sound quality analysis

3.1. Human violinist

Before the proposed robot finger can perform violin fingering, a suitable value of the pressing force to be applied on the strings needs to be determined. Thus, this study classifies the physical pressing force applied on the string as derived from an actual violinist into three categories. Then, the played sound is analyzed using the sound quality rating system developed previously by the authors. Fig. 2 show the three conditions of fingering to determine the pressing force required to be applied to the violin strings to generate an accurate note. In this test, a violinist is playing in the order to increase the reliability of the test. At this point, the reference note is fourth-octave C-note. The sound quality rating system then numerically expresses the aspirate frequency\( f_{\text{peak}} \) and magnitude\( M_{\text{peak}} \). This objective index regarding numerical value is based on a generally used frequency scale, as shown Table 1. According to Table 1, the frequency of the fourth-octave C-note is 261.6 Hz.

![Fingerboard](image)

**Fig. 2.** Three cases of classification of fingering force

<table>
<thead>
<tr>
<th>Octave</th>
<th>Scale</th>
<th>C</th>
<th>C#</th>
<th>D</th>
<th>Eb</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.7</td>
<td>34.7</td>
<td>36.7</td>
<td>38.9</td>
<td>41.2</td>
<td>43.7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>65.4</td>
<td>69.3</td>
<td>73.4</td>
<td>77.8</td>
<td>82.4</td>
<td>87.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>130.8</td>
<td>138.6</td>
<td>146.8</td>
<td>155.6</td>
<td>164.8</td>
<td>174.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>261.6</td>
<td>277.2</td>
<td>293.7</td>
<td>311.1</td>
<td>329.6</td>
<td>349.2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>523.3</td>
<td>554.4</td>
<td>587.3</td>
<td>622.3</td>
<td>659.3</td>
<td>698.5</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Frequencies of the musical scale (unit: Hz)

**Table 2.** Average values of \( f_{\text{peak}} \) and range of \( M_{\text{peak}} \): (human violinist)

<table>
<thead>
<tr>
<th>Case</th>
<th>Average value of ( f_{\text{peak}} ) (Hz)</th>
<th>Average range of ( M_{\text{peak}} ) (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>261.7</td>
<td>48.6 ~ 85.2</td>
</tr>
<tr>
<td>Case 2</td>
<td>773.9</td>
<td>39.6 ~ 74.0</td>
</tr>
<tr>
<td>Case 3</td>
<td>807.2</td>
<td>36.6 ~ 70.0</td>
</tr>
</tbody>
</table>

**Fig. 3.** Result of sound quality analysis: human violinist. (a) plot of \( f_{\text{peak}} \) (b) plot of \( M_{\text{peak}} \)
The testing results of the three classified cases of fingering force on the fourth-octave C-note performance are shown in Fig. 3 and Table 2. In cases 1-3, case 1, with an average value of $f_{\text{peak}}$ (261.7 Hz), is the closest to the quality rating result of 261.6 Hz. Thus, it can be seen that the experimental result of force in case 1 is appropriate for accurate sound generation.

3.2. Sound quality analysis: robot finger

In order to find out whether the developed robot finger produces the same performance sound as when a human violinist presses the violin strings, a sound quality-rating test is implemented. Experimental condition is the fourth-octave C note as the reference note. And violin string is pressed according to the same testing condition as case 1 of Fig. 2. Then, in the same process as the human violinist test, the sound quality evaluation uses the sound quality rating system. And the test is implemented upon constructing a jig for robot finger on the violin, as shown in Fig. 4. And Fig. 5 shows the results of the sound quality rating of the robot finger and the human violinist. At this point, Fig. 5(a) indicates the aspirate frequency ($f_{\text{peak}}$), and unlike when the human violinist perform the violin, the results show that the aspirate frequency of when the robot finger performs changed at every moment. It is not possible to state that an accurate sound was performed.

![Fig. 4. Jig for robot finger](image)

![Fig. 5. Result of sound quality analysis: robot finger. (a) plot of $f_{\text{peak}}$; (b) plot of $M_{\text{peak}}$](image)

4. Mechanical impedance modeling of human finger

The sound quality rating result of robot finger, there is disadvantage about aspirate frequency changing at every moment. It is caused by difference in structure of a robot finger and a human finger. Violin is played by producing vibration from the friction of the bowstrings. Since the proposed robot finger is made of metal, the vibration caused by the friction of the string and the bow with the robot finger causes resonance, which results in the generation of inaccurate sound (Fig. 5(a)). In the case of the human violinist, the bone of the hand is surrounded by outer skin, which reduces the vibration caused by the friction of the string and bow to generate accurate sound. In other words, the skin is role of damper about vibration caused by the friction of the bow and strings. As shown in Fig. 6(a), the outcome of a human finger pressing the strings of a violin is explained with the mass-spring-damper system model.

![Fig. 6. Mass-spring-damper system model of human finger. (a) modeling of human finger; (b) free-body diagram of human finger](image)
The free-body diagram (FBD) of the mass-spring-damper system can be expressed in Fig. 6(b), where $F_f(t)$ is the human finger force and $X_f(t)$ is the displacement of $F_f(t)$. $M$, $K_s$, and $D_s$, which are finger mass, stiffness, and damper of finger, respectively. The dynamic equation of this system is as follows:

$$F_f(t) = M\ddot{X}_f(t) + D_s\dot{X}_f(t) + K_sX_f(t)$$

Eq. (1) is represented by the transfer function, as shown eq. (2). Thus, when human violinist plays the violin, the dynamic characteristics the human finger possesses prevent it from having the same adverse effects caused by resonance, unlike the robot finger. To reflect these dynamic characteristics, poly-urethane foam is attached to the surface of the robot finger. And it is implemented to sound quality analysis same as section 3.2. The results are shown as Fig. 7.

$$G_f(s) = \frac{X_f(s)}{F_f(s)} = \frac{1}{Ms^2 + Ds + K}$$

In Fig. 7(a), the aspirate frequency graph is consistent with performance sound of robot finger and human violinist. This result shows that the performance sound of robot finger was very accurate. However, the magnitude of performance sound of robot finger is still comparatively smaller than one of the human violinist (Fig. 7(b)). Therefore, we should be compensated about this.

### Table 3. Average values of $f_{peak}$ and range of $M_{peak}$: (improved robot finger and human violinist)

<table>
<thead>
<tr>
<th>Case</th>
<th>Average value of $f_{peak}$ (Hz)</th>
<th>Average range of $M_{peak}$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved robot finger</td>
<td>262.6</td>
<td>51.4 ~ 83.2</td>
</tr>
<tr>
<td>Human violinist</td>
<td>261.7</td>
<td>48.6 ~ 85.2</td>
</tr>
</tbody>
</table>

5. Conclusions

This paper introduces a study to improve the performance of robot finger for violin fingering. Authors developed the violin-playing robot, this robot only controlled for violin bowing. Also, authors have designed robot hand anthropomorphic type for the violin fingering. The results of generating the fourth-octave C-note by a human violinist and the robot finger were compared by adopting the sound quality rating system developed previously by the authors. Since the bone of the human hand is surrounded by skin, the vibration due to the friction between the bow and string was reduced, which does not cause any resonance and results in accurate playing of the note. In other word, the skin is role of damper about vibration caused by the friction of the bow and strings. To reflect these dynamic characteristics,
poly-urethane foam was attached to the surface of the robot finger. Then, upon completing the sound quality analysis, we found that the robot finger was able to produce a performance sound very similar to that of a human violinist.

In the future, an organized system should be designed so that the vibrato technique is possible for the violin-playing robot, and force control of robot finger should be implemented by progressing the calibration three-axis load cell.

Acknowledgements

This research was supported by Technology Innovation Program of the Knowledge economy (No. 10041834, 10045351) funded by the Ministry of Knowledge Economy (MKE, Korea), the National Research Foundation of Korea Grant funded by the Korean Government(No. 2012R1A1A2043822, 2014S1A5B6035098) and the MSIP(Ministry of Science, ICT and Future Planning), Korea, under the Global IT Talent support program (H09051510020001002) supervised by the IITP(Institute for Information and Communication Technology Promotion).

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