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Non-contact measurement of bow force and friction force in bowed string instruments using a camera

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Abstract

Visualizing the mechanical parameters given by the player to the instrument may help to improve the performance technique. Thus, the methods to measure parameters that have less influence on musical performance are required. In this research, we proposed a non-contact measurement method of bow force and friction force using an ordinary camera (not high speed). By using an ordinary camera instead of a high-speed camera, we can obtain the average position of the strings from the blurred image. The process consists of the following 3 steps: (1) Taking the video of illuminated strings with a camera. (2) The position of the strings is calculated from the center of gravity illuminated part. (3) String displacement from a neutral position is converted into bow force and friction force using the relation between position and force in a string. In addition, this method is possible to visualize the bow force and friction force with the proposed method by a verification experiment.

Keywords: bowed string instruments, image processing

1 INTRODUCTION

When playing an instrument, the player gives the instrument mechanical several parameters such as bow speed and bow force. By measuring these parameters and providing feedback in real-time, it is expected that they can be used to support the improvement of performance techniques. Actually, methods using 3D motion capture [1] and methods using armband sensors [2] have been tried as measurement methods for bowed string instruments. Also, a measurement method of bow motion and bow force has been proposed using strain gauges, accelerometers, and resistance wires.[3],[4] However, these methods can not be measured casually because the equipment is large-scale and multiple devices need to be installed. Therefore, we proposed a measurement method of bow motion and bow force using an ordinary camera (not high speed).[5],[6] In this method, it is expected that it is possible to measure bow force, friction force, bow velocity, and bow position simultaneously by performing image processing from the captured image. In addition, it is very easy to measure because it is equipped with one camera. In this paper, among the four parameters, the method of measuring the bow force and friction force was verified.

2 METHOD

2.1 Theory

The definitions of bow force and friction force in this paper are shown in Figure 1. Of the forces applied to the string at the point of contact between the bow and the string, the force parallel to the traveling direction of the bow is the friction force, the bow pressure is perpendicular to that.

The string vibration of the bowed string instruments is represented by the combination of the vibration by Helmholtz movement and the static displacement by the bow force and the friction force. Therefore, it is considered that the displacement due to the bow force and the friction force can be obtained by removing the vibration due to the Helmholtz movement.

For a string of length L that is tensioned at points A and B with a tension T, such as Figure 2, let us consider the bowing motion at point P. It is assumed that the straddling motion is performed parallel to the x-axis, and the point P moves in the x-axis direction u_x and y-axis direction u_y. Assuming that the string has a small amplitude, the bow force F_x and friction force F_y are approximately expressed as Eq 1, 2.

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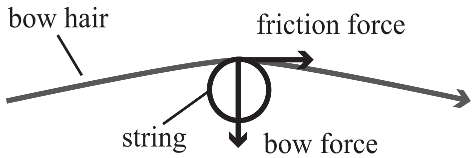


Figure 1. Bow force and bow friction

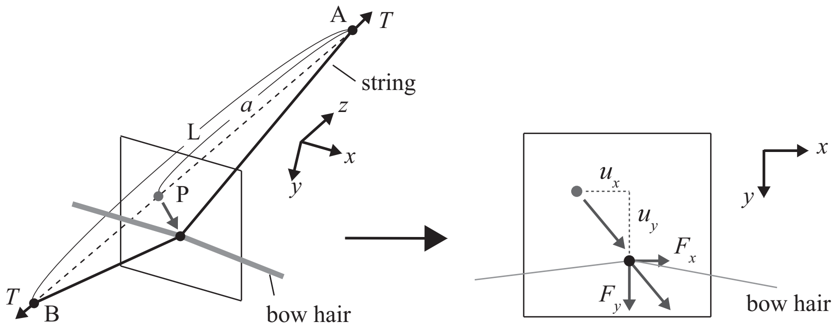


Figure 2. Strings in bow action

$$F_x \approx \frac{T\mathrm{L}}{aL - a^2} u_x \tag{1}$$

$$F_y \approx \frac{T\mathrm{L}}{aL - a^2} u_y \tag{2}$$

Therefore, by obtaining the relationship between displacement and force in advance, it is possible to convert the acquired displacement into bow force and friction force.

2.2 Measurement method

Figure 3 show a flowchart of the proposed method. Arrange the camera at an angle to the strings, and taking the video of illuminated strings by light. Calculate the displacement corresponding to the bow force and friction force by image processing of the video. After that, convert the displacement into bow force and friction force using the relationship between displacement and force.

In this paper, we propose two image processing methods as shown in the Figure 3.

Method (A) is the method for which brightness on the picture isn't used. First, the acquired video is noise reduction and binarization. Next, we obtain the displacement of the string corresponding to the bow force and friction force by calculating the center of gravity of the image. This method is suitable for removing the vibration where mid-range and the average coincide in one cycle.

Method (B) use the brightness of the image. First, the acquired video is noise reduction and binarization. Second, an outline is extracted from the image of the light spot on the image, and a mask is created based on it. Next, we obtain the displacement of the string corresponding to the bow force and friction force by calculating the center of gravity of the image by performing mask processing on the original image. This method is suitable for removing the vibration in which the mid-range and the mean do not match in one cycle.

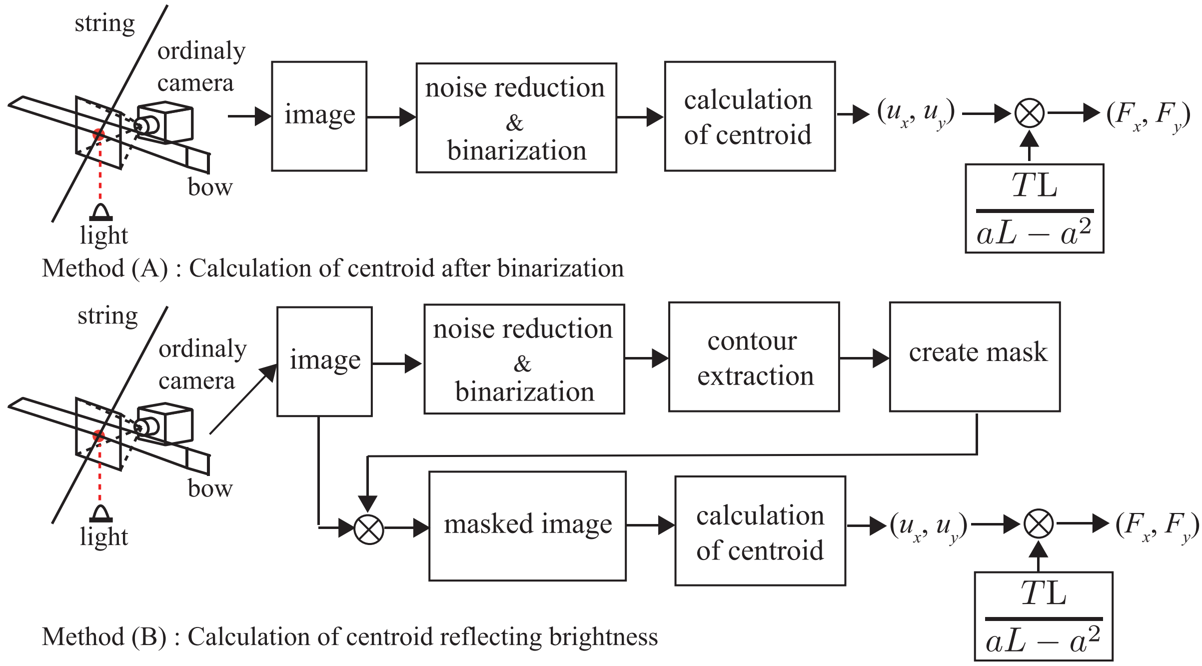


Figure 3. Flow chart of the proposed method

3 SIMULATION

3.1 Experimental method

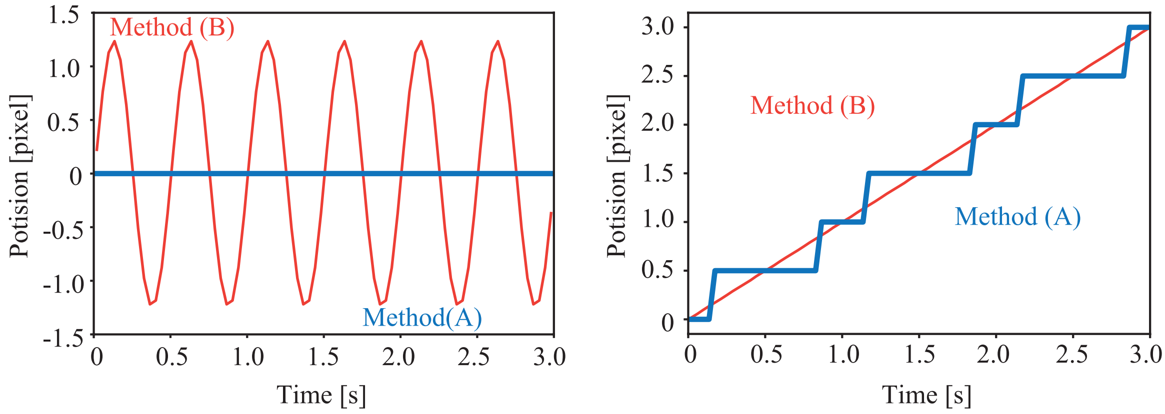
A simulation was performed to compare Method (A) and Method (B) in image processing. On the image at 500 [pixels] wide by 300[pixels] in height, a pseudo-weighted string was created along the x-axis. Assuming that the string is moving at a sine wave or at a constant velocity, images were generated at 1/4160 intervals. By combining 160 sheets of the image, a blurred image taken at 26 fps was generated. Method (A) and Method (B) were compared using these pictures.

3.2 Result

Figure 4 (a) shows the displacement of the center of gravity when the string is moved to the x-axis with a sine wave with an amplitude of 50 [pixel] and a frequency of 80 [Hz]. The center of gravity of the initial image is taken as the origin. Method (A), the origin was shown without blurring. Because the sine wave is equal in average to the mid-range in one cycle and the cycle of the sine wave is sufficiently faster than the frame rate. On the other hand, Method (B) showed a sine wave with a frequency of about 2 [Hz]. because aliasing has occurred by reflecting the brightness. However, the amplitude of the sine wave is suppressed.

Figure 4 (b) shows the displacement of the center of gravity when the string is moved one pixel per second. Method (A)shows a change like stairs. Because the center of gravity is taken from the binarized image, so displacements less than 1 [pixel] can not be reproduced. On the other hand, Method (B) shows a straight line proportional to time. Because the displacement less than 1 [pixel] can be analyzed by taking the center of gravity in consideration of the luminance.

From the above, Method(A) is excellent for eliminating vibration components whose mean value is equal to the mid-range in one cycle. However, it is not suitable for measuring displacement smaller than one pixel. Method(B) can be smoothed even though some vibration components remain, It has been confirmed that it can cope with even smaller displacements.



(a) Sine wave

(b) Proportional to time

Figure 4. Displacement by simulation

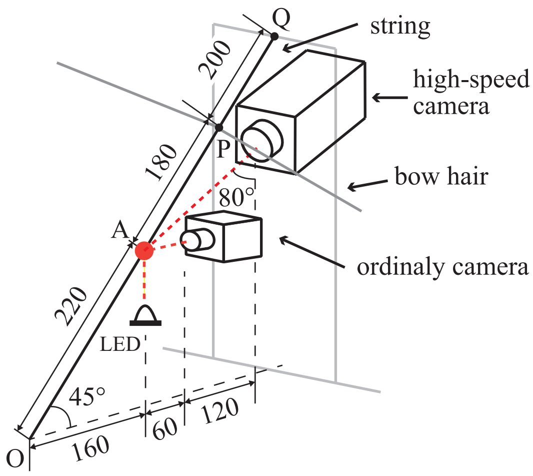


Figure 5. Experimental configuration

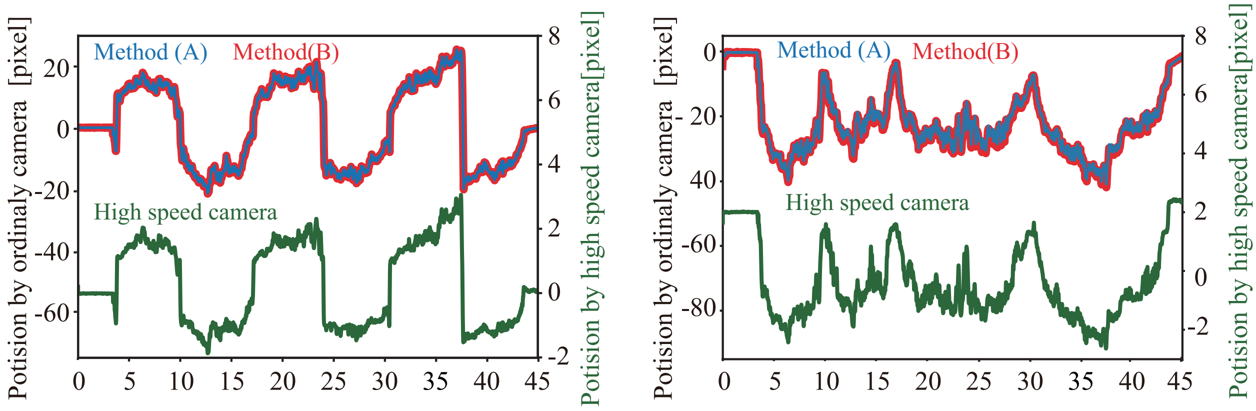
4 VERIFICATION EXPERIMENT

4.1 Experimental method

A verification experiment was performed to compare Method (A) and Method (B). Also, as a reference for displacement measurement, simultaneous measurement with a high speed camera (1200fps)was performed. Figure 5 show an experimental device. A string (cello A string, Alloy-steel) of 600 [mm] in length was stretched from point O to point Q in the y-z plane, It was placed so that the angle between the string and the stage was 45 degrees. The LED was given a current of 1.2 [A] and irradiated to point A on the string. The light-receiving surface of an ordinary camera was placed so that the light-receiving surface and the stage were vertical. Then, taking the video of illuminated strings. .Rubbing movement was performed three times at point P.

4.2 Result

Figure 6 shows string vibration measured with a high-speed camera, multiplied by moving average, and those using Method (A) and Method (B). Figure 6 (a) is the displacement corresponding to the friction force, Figure



(a) Displacement corresponding to friction force

(b) Displacement corresponding to bow force

Figure 6. Displacement measured by ordinary camera and high speed camera

6 (b) is the displacement corresponding to the bow force. The displacement measured by the high-speed camera and the displacement measured by the proposed method has similar responses. Thus, it is considered possible to measure the displacement corresponding to the bow force and friction force by the proposed method. Also, no significant difference was found in the displacement measured at Method (A) and Method (B). From this, even the proposed method that does not use the brightness of the image may be sufficiently useful for the measurement of the bow force and the friction force.

5 DISCUSSION

In this research, it was found that it is possible to measure the displacement corresponding to the bow force and friction force in the rubbed instrument using an ordinary camera (not high speed). We proposed two methods, one using brightness and the other not using brightness, and as a result of the comparison, it was shown that A without using brightness may be sufficiently useful. This is considered to be the vibration that we want to remove because the Helmholtz motion is equal to the mid-range and average in one cycle. ff Vibrations that differ from the mid-range may occur, such as when the bow is released from the string. In such cases, the analysis method using brightness may be able to measure more accurately. Therefore, it is considered necessary to use two analysis methods according to the purpose of measurement.

Also, Method (A) can process to RealTime, but Method (B) is done by post-processing.

In this paper, we measured the displacement corresponding to the bow force and friction force, but it is possible to convert the displacement into a force. Therefore, when converting to power, it is necessary to examine whether there is any harm.

As a future development, we will convert displacements into forces and check if we can measure them. In addition, we examine the measurement method of bow velocity and bow position, and confirm whether simultaneous measurement using a camera is possible.

6 CONCLUSION

In this paper, we propose a measurement method using an ordinary camera(not high speed) as a measurement method of bow force and friction force in bowed string instruments. It is expected that measuring these parameters will help to improve the performance technique. In this method, the light emitted to the strings is acquired as a movie, and the displacement of the strings corresponding to the bow pressure and the frictional force is calculated by image processings. The bow forces and the friction force are measured by converting this displacement into a force. We proposed two methods, one using brightness and the other not using brightness. As a result of comparison by experiment, it is possible to measure the displacement corresponding to the bow force and the friction force using the camera, and the method without using the brightness is sufficiently useful.

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