Ball Touching Net Detection Using Piezoelectric Element in Table Tennis

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Abstract

The study aims to develop a small and low-power sensor for judging whether a table tennis ball touches the top of a table tennis net or not in service during a table tennis match. A flexible piezoelectric element was attached to the center of a table tennis net. When the ball touches the net, the net deforms, and the piezoelectric element fixed on it also deforms, and the larger the deformation, the higher the voltage generated. In addition, the trajectory of the ball was captured by two high-speed cameras to calculate the spin rate, the speed of the ball, and the length overlapping part of the ball and the net for the evaluation of the factors affecting the output voltage of the piezoelectric element when the ball touches the net. The results showed that the values of the correlation coefficient of the number of revolutions, the speed of the ball, the length of overlapping part of the ball and the net are 0.48, 0.60, and 0.59, respectively. For each factor, 30 trials were used to minimize the error. As the result of the evaluation, the speed of the ball and the length of overlapping part are more strongly affect the output peak voltage of the piezoelectric element attached to the net when the ball touches the net in service. Analyze which factors affect the voltage generated by the piezoelectric element when the ball touches the net and use the data to design touch detection sensors that are difficult to detect with the human eye.

Keywords

Table tennis, piezoelectric element, ball touching net detection, low power sensor

1. Introduction

In recent years, table tennis has become one of the most popular sports in the world with a fan base of approximately 850 million people [1]. The International Table Tennis Federation (ITTF) achieved a full house of 226 National Association in 2017 [2]. This means that table tennis is played in many parts of the world. In addition, ITTF has started the new series of international competition which is called WTT (World Table Tennis) Series in 2021. WTT aims to engage fans and players with digital transformation [3]. Using multimedia technology, interactive data collection techniques, and intelligent analytics in sports have been developed to analyze game tactics [4][5][6]. Furthermore, systems that assist referees using high-frame rate camera have also developed and used in a wide variety of sports such as ice hockey [7], tennis, football, and baseball [8]. For example, Hawk-Eye's tracking system determines whether the tennis ball crosses the line of the tennis court or not when player serves using between 8 and 12 cameras. In table tennis, if the ball touches the net assembly in service, the result is not scored. However, sometimes to judge whether the ball touches the net or not is difficult for umpires [9]. T. LEAGUE was launched for domestic table tennis league in Japan in 2018 and decided to adopt instant replay system with high-frame rate cameras. On the other hand, it is difficult to adopt the system in amateur tournaments due to space constraints and the high-power consumption of cameras and video

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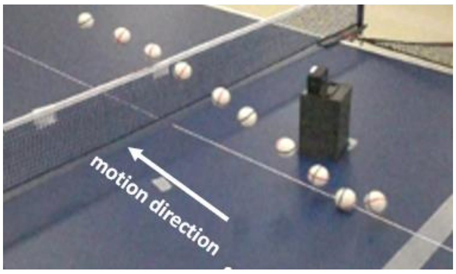
analysis systems because a lot of matches were played at the same time. To address this issue, the method for judging whether the ball touches the top of the net or not using a flexible piezoelectric element was proposed and the evaluation of the factors affecting the output voltage of the piezoelectric element when the ball touches the net in this study.

This paper consists of chapters 1 to 5. As an overview of the structure of this paper: Chapter 1 gives the purpose and a brief overview of this study. Chapter 2 describes the proposed method of judging whether the table tennis ball touches the table tennis net. Chapter 3 describes experimental method for the evaluation of the factors affecting the output voltage of the piezoelectric element, Chapter 4 shows the experimental result, and Chapter 5 summarizes this paper and discuss future tasks based on the experimental results.

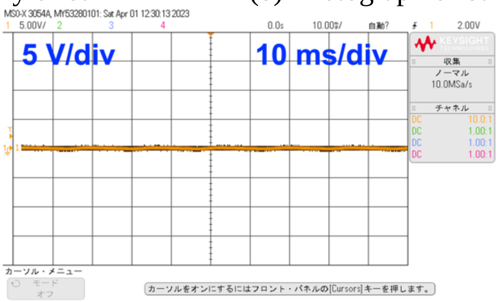
2. Proposed method of judging whether ball touches net

By attaching a piezoelectric element to the center of a table tennis net, whether a table tennis ball touches the net or not is detected by the power generated by the piezoelectric element. Figure 1 shows an example of when the ball passes over the net without touching the net. In this case, the measured output voltage of the piezoelectric element keeps the noise level while the ball is passing over the net. However, when the ball touches the net, the measured output voltage become much higher than the noise level (Fig.2).



(a) Trajectory of ball

(b) Photograph of ball passing over net

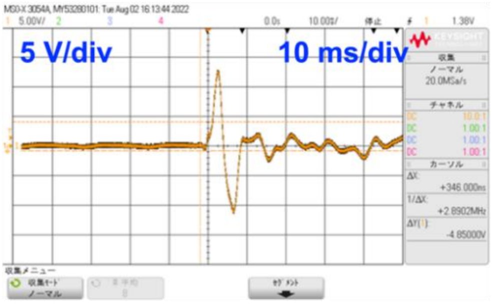


(c) Measured output waveform of piezoelectric element

Figure 1: Example of when ball passes over net

(a) Trajectory of ball

(b) Photograph of ball touching net



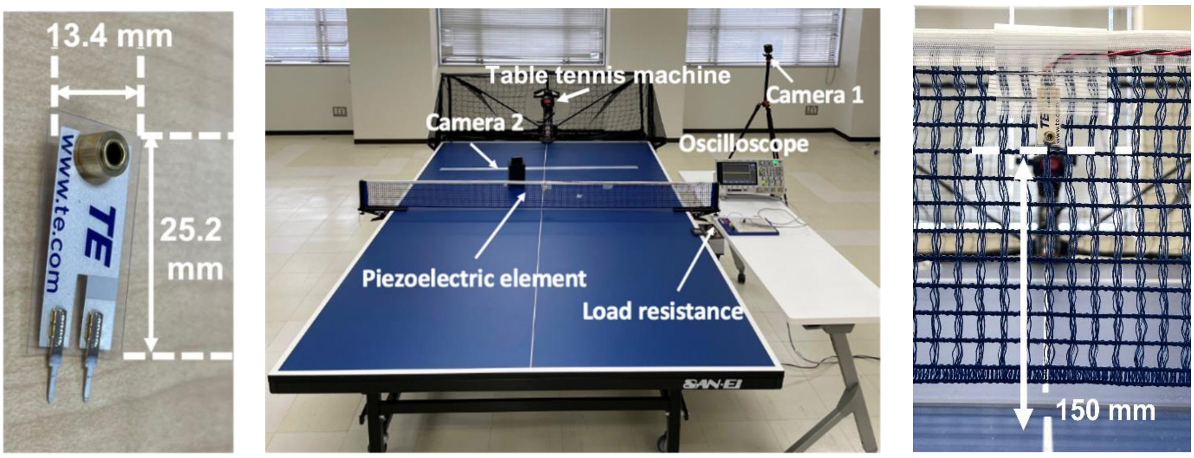
(c) Measured output waveform of piezoelectric element

Figure 2: Example of when ball touches net

3. Experimental method

3.1 Overview

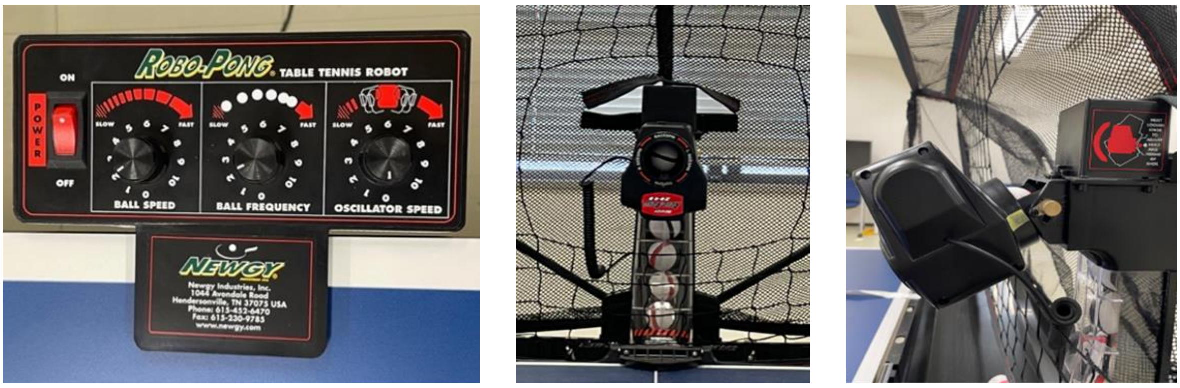
Figure 3 shows a photograph of the experimental setup for the evaluation of the factors affecting the output voltage of the piezoelectric element when the ball touches the net. In this experiment, a flexible piezoelectric element was attached to the center of a table tennis net, and it is connected to a load resistance of 2.7 MΩ. The setting of the piezoelectric element is shown in Figure 3(c). The side with the metal, called the lower end, is parallel to the surface of the table tennis table, and the upper end is secured to the edge of the net with tape. The distance of the lower end from the surface of the table is 150 millimeters. The output voltage of the piezoelectric element was measured with an oscilloscope. Two high speed cameras (DSC-RX0) with a frame rate of 960 fps were installed to capture the ball trajectory. One was installed next to the table (camera1) and observed the trajectory of the ball to calculate the spin rate and the speed of the ball. The other was installed on the table in front of the net (camera2) to capture the ball when it touches the net to calculate the length of overlapping part of the ball and the net. A table tennis machine was also used to launch table tennis balls.



(a) Piezoelectric element (b) Experimental setup (c)Set of piezoelectric element

Figure 3: Photograph of experimental setup for the evaluation of the factors affecting the output voltage of the piezoelectric element.

Figure 4(a) shows the control box of the table tennis machine. It has three adjusting knobs to change the ball speed, the ball frequency, and the oscillator speed of the machine head. Figure 4(b) shows the front view of the machine head with backspin. By rotating the machine head, the spin direction of the ball can be changed. The launching angle of the ball can be changed by adjusting the head angle (Fig.4(c)). By changing the ball speed and the angle of the machine head, various of the ball touching the net can be simulated.



(a) control box (b) front view of machine head (c) side view of machine head

Figure 4: photograph of parts of table tennis machine

3.2 Method of calculating spin rate and speed of ball

To make it easier to observe how the ball rotates and how many times it rotates, we put black and red lines on the surface of the ball as markers (Fig.5). We find a way to calculate the spin rate and the speed of a table tennis ball using a recorded video with camera1. Figure 6 shows the trajectory of the ball from touching the table to touching the net.

The number of revolutions of the ball can be calculated how many times the ball has rotated after hitting the table and before hitting the net from the recorded video. The time can be calculated from the number of frames and the playback speed of the recorded video. In this experiment, the playback speed was set at 60 fps. It means the playback speed of the video is slowed down by 16 times of real speed. The spin rate of the ball, RPM_{ball}, can be calculated according to equation (1).

$$RPM_{ball} = \left(the\ number\ of\ ball\ revolutions / \frac{the\ number\ of\ frames}{60\ fps \times 60\ min} \right) \times 16 \tag{1}$$

The trajectory of the ball from touching the table to touching the net is approximately a straight line, we set the distance measured on the screen as *D*. To calculate the actual distance, the ration of the ball size on the screen to the actual ball size was used. The speed of the ball can be obtained as shown in the following equation (2).

$$V_{ball} = \left(\frac{actual\ ball\ size}{screen\ ball\ size} \times D \right) / \left(\frac{the\ number\ of\ frame}{60 fps} \right) \times 16 \tag{2}$$

Figure 5: Photograph of table tennis ball with black and red lines as marker

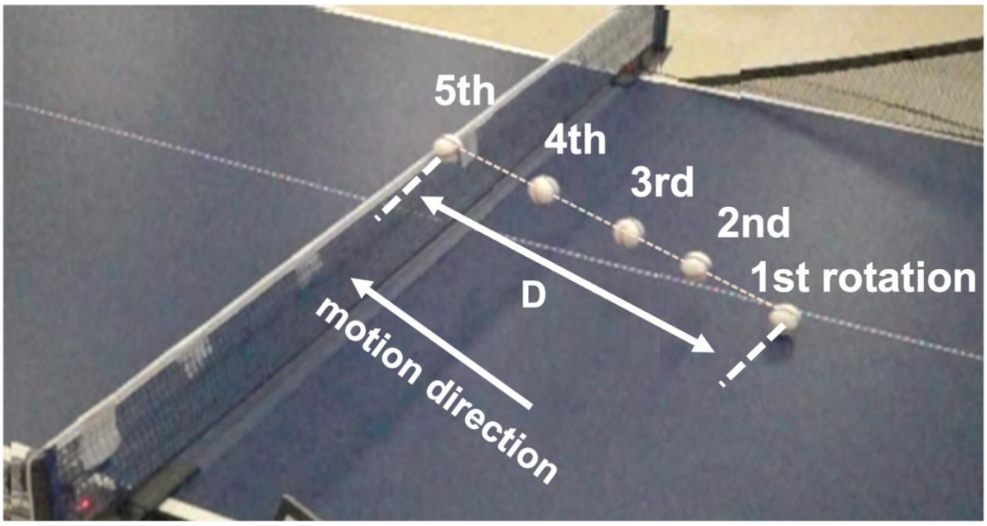


Figure 6: Trajectory of the ball

3.3 Method of calculating length of overlapping part of ball and net

The high-speed camera (camera2) took a frontal video of the ball hitting the net. To calculate the length of overlapping part of the ball and the net, a frame just before the ball touches the net was selected from the video. We proposed an algorithm based on MATLAB to calculate the length of overlapping part of the ball and the net using the frame.

Figure 7 shows parameters for calculating the length of overlapping part of the ball and the net. Figure 8 shows the follow chart of the algorithm. First, the coordinates of the center *O* and radius *r* of a circle can be found from the three points that are randomly selected on the circumference of the table tennis ball. Furthermore, the circle equation can be obtained. Second, the equation of the straight line can be set up with two points that are randomly selected on the top of the table tennis net. Next, the coordinates of the intersection points *A* (x_1, y_1) and *B* (x_2, y_2) are calculated by solving the simultaneous equations. Then, using the coordinates of these two points, the distance *d* between the two points is obtained. *M* is the midpoint of *d*, the triangle *OMA* is a right-angled triangle, so the length of the side of the triangle *s* can be calculated by the Pythagorean theorem. Finally, the length of overlapping part of the ball and the net *l* can be calculated by subtracting the length of the side of the triangle *s* from the radius *r*.

Since this calculation is performed on an image clipped from a moving image taken with a camera, the value of length *l* will change if the size of the image taken changes depending on the position of the camera. The actual length *l* is given by equation (3).

$$\frac{Actual\ ball\ diameter}{Ball\ diameter\ on\ image} \times Length\ l\ on\ image \tag{3}$$

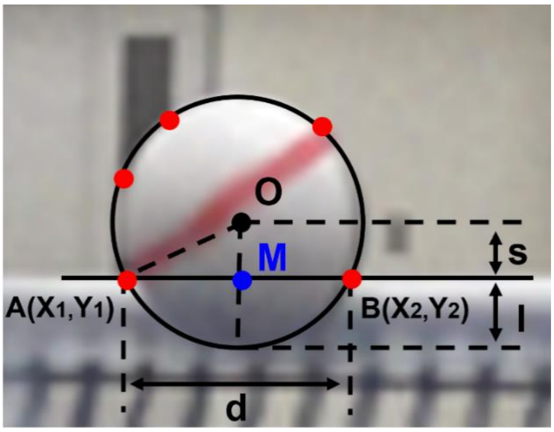


Figure 7: Parameters for calculating length a

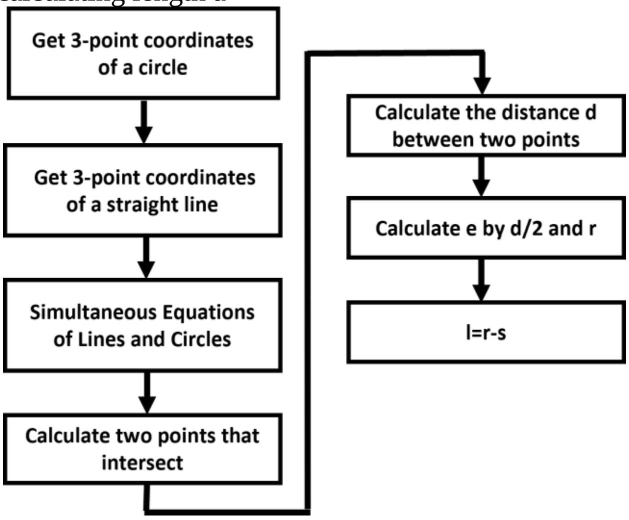


Figure 8: Flowchart for calculating length *l*

4. Experimental result

First, since the spin rate and the speed of the ball that launched by the table tennis machine we used cannot be set independently, we evaluated the relationship between these parameters (Fig. 9). The calculated value of the correlation coefficient was 0.45.

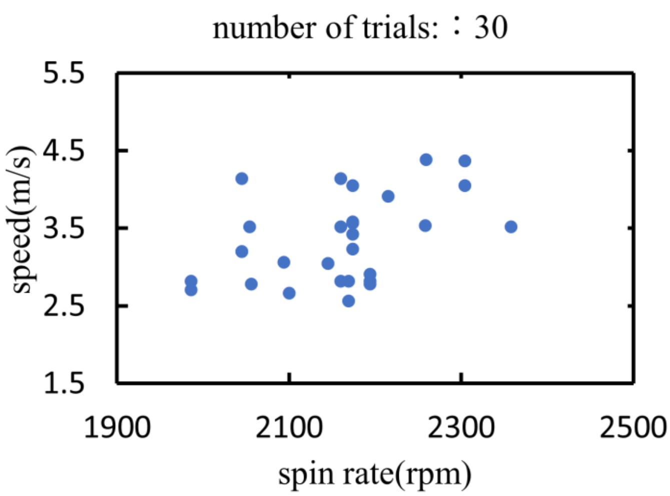


Figure 9: The relationship between ball speed and spin rate

In this evaluation, we define the peak value at the first fluctuation of the waveforms of the output voltage that were measured using an oscilloscope as peak voltage. From Figure 10 to Figure 12 show the relationship between the peak voltage and the spin rate, the speed of the ball, the length of overlapping part of the ball and the net, respectively. Table 1 shows the correlation coefficient between the output peak voltage of the piezoelectric element and the factors. The values of the correlation coefficient of the number of revolutions, the speed of the ball, the length of overlapping part of the ball and the net are 0.48, 0.60, and 0.59, respectively. The result showed that the speed of the ball and the length of overlapping part of the ball and the net are more strongly affect the output peak voltage of the piezoelectric element attached to the net when the ball touches the net in service. It is worth mentioning that in the above experiment, we detected the voltage when the ball touched the net in every 30 times of the trials. Therefore, it can be proved that this experiment has a high possibility of being practical.

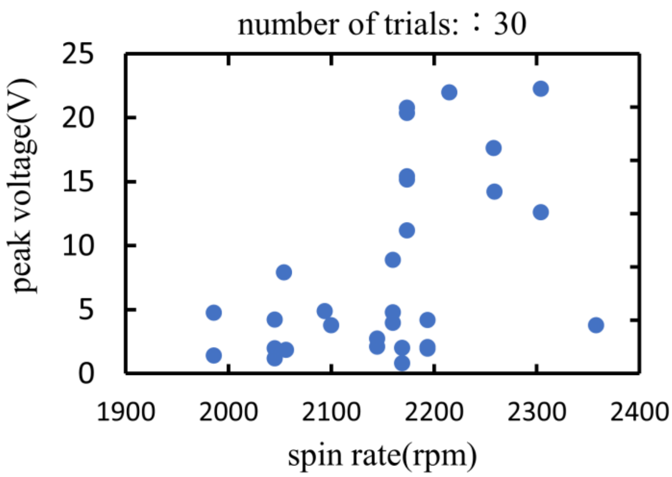


Figure 10: The relationship between peak voltage and spin rate

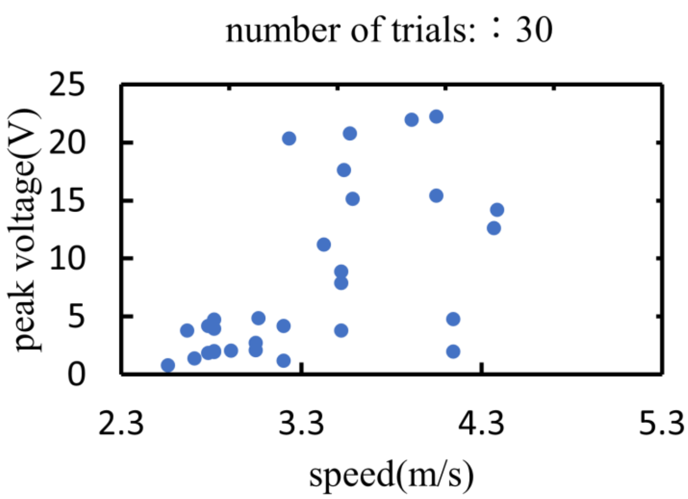


Figure 11: The relationship between peak voltage and ball speed

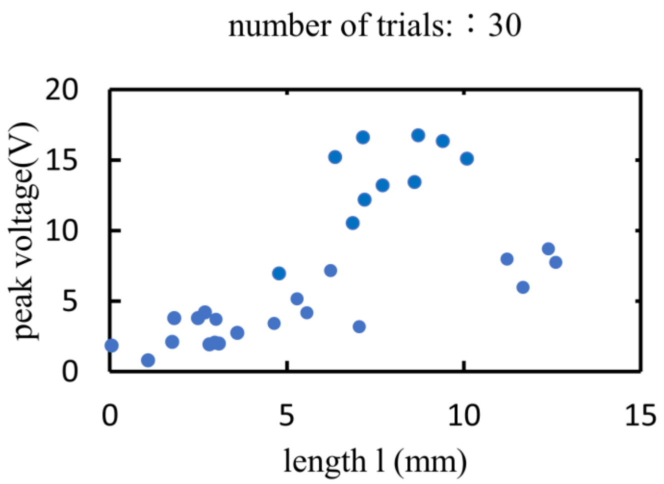


Figure 12: The relationship between peak voltage and length *l*

Table 1
Correlation coefficient between the output peak voltage of the piezoelectric element and the factors

The factors	Correlation coefficient
The number of revolutions	0.48
The speed of ball	0.60
The length of overlapping part	0.59

5. Conclusion

This work proposed the judging method of whether a table tennis ball touches the top of a table tennis net or not by attaching a piezoelectric element to the center of the net. In this experiment, the factors affecting the output voltage of the piezoelectric element when the ball touches the net were evaluated. The result showed that the values of the correlation coefficient of the number of revolutions, the speed of the ball, the length of overlapping part of the ball and the net are 0.48, 0.60, and 0.59, respectively. The speed of the ball and the length of overlapping part of the ball and the net are more strongly affect the output peak voltage of the piezoelectric element when the ball touches the net. Adding the situation of left and right spin on the ball to confirm if there is an effect on the output voltage will be for future work. In addition, the three conditions of the ball described above were used to obtain the minimum peak voltage generated by the sensor after a ball touches net. In the future, it is expected to design circuits that can detect its minimum peak voltage for whether the ball touches net. This will replace conventional camera detection. This is because power consumption can be reduced and there is no need to consider limitations in terms of camera placement, memory required for the camera, etc. Expected to be used in amateur table tennis tournaments.

6. Reference

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