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Developing an Intelligent Table Tennis Ball Machine with Biomimetic Simulation for Technical Training

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Abstract

This research aims to develop a homemade innovative table tennis ball machine with biomimetic simulation for skills training, where the ball machine can throw balls imitating human strike courses. The machine can help table tennis coaches to provide table tennis players with more efficient training and instructions. It also makes the sport more entertaining. In the study, the researcher explained the concept of the machine. The machine with two counter-rotating wheels is designed for ball trajectory generation. These two wheels change the absolute rotating speeds that can adjust the struck forces and the rotating speed of the ball. The researcher(s). Change this throughout the entiremeasures, the outcoming speed, the ejected distance, and the rotating speed of the ball by changing the absolute rotating speed of the two wheels. The data of the absolute rotating speed of both wheels were collected for calibration; based on the collected data, the outcoming speed and the ejected distance of the ball were further converted to the struck forces of the ball. The balls thrown out by the intelligent ball machine were based on the received calibration curves with the aid of the computation. Experiments used technical photosensitive devices to detect the injection speed of the ball. The design of this machine is expected to improve the development of table tennis skill training and table tennis sports.

Keywords: table tennis; ball machine; human strike; training

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1. Background/ Introduction

Table tennis is originated around the early 1880s in England, where it was played as after-dinner leisure among the upper class. Since 1988, the table tennis competition has been included in the official Olympic games. It not only becomes a fun game for physical exercise but also a notable skill competition in the world (Guan, 2011). Table tennis is popularized since there are less demand for space requirement, more minor sports injuries for players, and relatively simple sports equipment. For sure, both physical exercise and competition expect the same skillful technique to yield pleasure and expect to win the game.

To gain skillful techniques requires massive training, which provides high density, high strength, and many drills to promote the expert technique for athletes. It can be not easy to do repeated practices when playing with a partner (Gong, 2015). However, multi-ball training of table tennis is one of the most applied strategies, which often receives effective feedback and reduces the training time (Ming, 2005., Hou, 2008). Multi-ball training gives the coach and trainer an extremely high labor load which is high strength-consuming without the aid of a ball machine. During the multi-ball training, a professional coach must take the service and give the player instruction simultaneously. Therefore, developing an intelligent table tennis ball machine with human strike simulation for technical training is significant to reduce the teaching load of the coach and could be possible to replace the coach in the near future (Mulling, 2010., Zhang, 2012). The table tennis ball machine is very useful to assist in training because it can continuously provide balls with different landing spots, spins, strengths, and effective ball route control to improve the shot's accuracy. The ball machine can reduce workload for coaches and trainers, relieve muscle fatigue, and improve the quality and quantity of training (Wu, 1999). Also, it can work high-intensity without rest, maintain consistency and stability, reduce the randomness and subjectivity of the ball supply, and offer a significant effect in table tennis skill training (Wang, 2007). The ball machine has known effects on developing basic stroke, improving footwork, correcting stroke, and enhancing motivation. It is a widely recognized and encouraged method in table tennis skill training (Wang, 2011). Ball machines are suitable for different ages and skill levels because the player's techniques can control the tempo, spin, and drop spot. The device can adjust the difficulty of training to meet the needs of players. For beginners, it is easier to maintain the fundamental skills; the machine is helpful in training posture and correcting strokes. For experienced players who require professional coaching, the machine can imitate the opponent’s skills and tactics. For amateur players who need to better their skills, the machine can create different practices and drills like professional coaches and trainers. The players find a sport more entertaining when they play with a partner with equivalent skills (Li, 2012).

The development of the table tennis ball machine can be traced back to (Billingsley, 1984) and is still in progress until now (Knight, 1986., Miyazaki, 2006., Muelling, 2013., Sun, 2011., and Matsushima, 2005). (Anderson, 1988) combined a high-speed video system and a six degree of freedom robot arm PUMA 260 with a 0.45m long stick mounted on it which is capable of playing against humans and machines. However, only a few groups attempted to track the ball spin since the ball spin can reach 150 rotations per second (Glover, 2014). Because of indirect measurements of the spin, the estimation of spin is extremely noisy. (Anderson, 1988., Glover, 2014) presents an approach to track the spin of the table tennis ball from direct measurements of the ball's orientation with a high-speed camera. An intelligent table tennis ball machine with human strike simulation can provide multi-ball training and various training by adding smart control and fun.

The concept of the table tennis ball machine is not new, which is already applied universally. However, (Zhang, 2008) conventional table tennis ball machines can only provide few balls of balls, which cannot satisfy all human play situations but also reduce pleasure. It is proposed that in the process of skill training, the ball machine is used to replace the coach as an auxiliary tool for delivering the ball. For most players and students, the ball machine is interesting, and it can also promote the active learning of players and students. A desire for coaches and teachers can also enrich the diversity of training and teaching (Zhang, 2009). It is found that the use of a ball machine in training eliminates the human subjective and randomness when delivering the ball. For beginners, when the action has not been finalized, it can also improve players' and students' participation and training motivation (Xu, 2015).

In summary, a homemade intelligent table tennis ball machine with multiple balls serving for technical training following a series of precise measurements implemented in this study. It should be able to complement the lack of workforce and increase the efforts of a trainer. Moreover, this is very important that an intelligent table tennis ball machine must create more pleasure for players. This is also the purpose of the study which is to develop an intelligent table tennis ball machine, a human play simulator, to replace the coach and become a real player.

2. Basic theory/ Purpose

The study from Ramanantsoa and Durey (1994), the motion of table tennis exhibits a very regular and modular structure. To simplify the striking movement, the researcher(s) consider a rigid body motion by neglecting the deformation of the ball. Translation and rotation are two main motions considered in this ball movement. Hence, it requires independent control of the straight-line speed and the tangential speed of the ball. Two counter-rotating rollers are used for generating the ball trajectories. The ball straight-line speed is determined by the absolute wheel rotational speed under the no-slip boundary condition between the ball and the wheel and can be defined as follows:

$$v = \frac{2\pi r}{T} = \omega r, \qquad \textbf{(1)}$$

where v is the ball straight-line speed, r is the radius of the wheel, T is the period of one rotation, and ω is the absolute wheel angular speed. The ball spin speed is based on the rotational speed difference of two counter-rotating wheels. In terms of ball games, topspin is defined as spin about an axis perpendicular to the traveling direction, where the top surface of the ball is moving forward with the spin and backspin has the opposite effect. From the Bernoulli theorem (Ramanantsoa, 2004), the rotational ball will yield the static pressure (p_s) difference by neglecting the influence of position as follows:

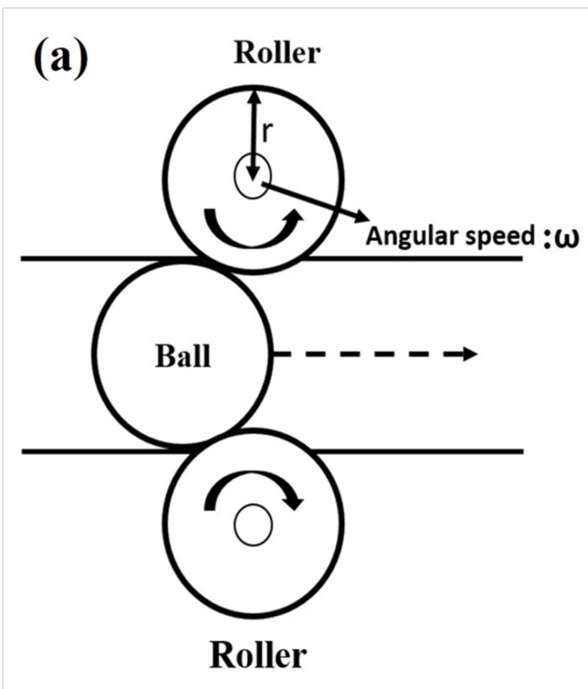
$$p_s + \frac{1}{2}\rho v^2 = constant, \quad (2)$$

where ρ is the density of the air and v is the flow velocity. In other words, the ball topspin yielded by the upper wheel faster condition receives the larger static pressure on the upper side of the ball, which causes the ball to spin and yields the adding effect with the gravity known as the Magnus effect. On the contrary, the ball backspin produced by the lower wheel faster condition receives the larger static pressure on the more down side of the ball, which causes the ball to run upward and yields the reduced effect with the gravity. Figure 1(a) shows the schematics of the table tennis ball machine with two counter-rotating rollers.

3. Methods/ Experimental details

This work aims to develop a homemade intelligent table tennis ball serving machine which can imitate all courses of a ball from a human strike

Figure 1 (a). *Schematic of the table tennis ball machine with two counter rotating rollers*



following a series of precise measurements. The main structure of this table tennis ball machine is made of a ball reservoir with ball serving apparatus and two counter-rotating wheels. In the process, the balls are served by a ball reservoir and driven by the two counter-rotating wheels. Figure 1(b) shows the photo of this homemade table tennis ball machine. To imitate all courses of a ball from human play, we determine the relationship between the outcoming ball speed and the wheel rotational speed under the condition no slip between the ball and the wheel.

Figure 1 (b). *Photo of the homemade table tennis ball machine*

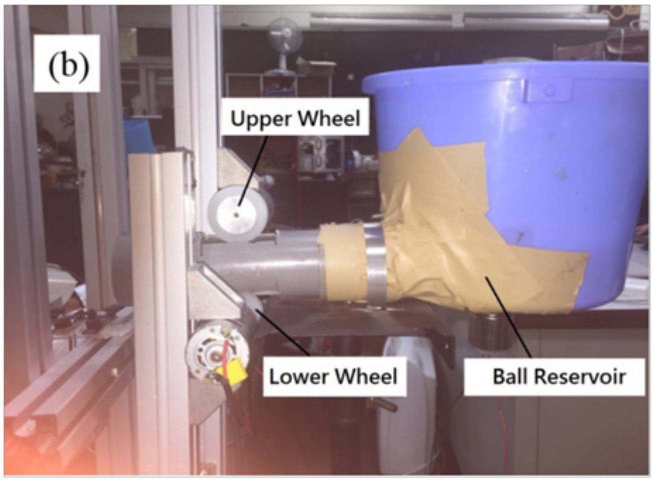
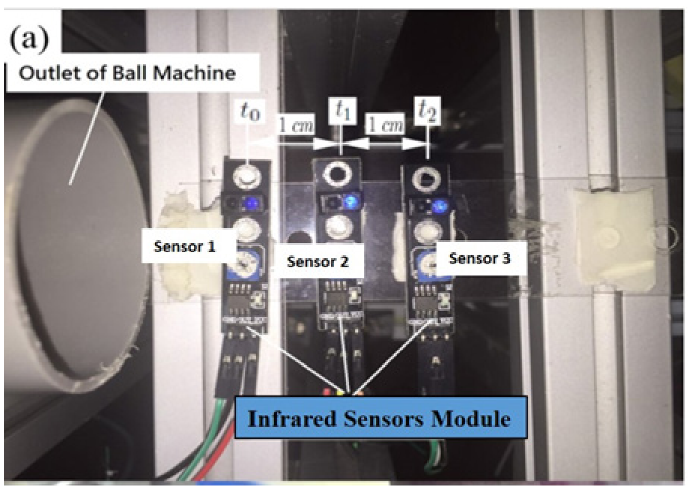


Figure 2(a) shows the photo of the experimental setup for measuring the outcoming ball speed, where there are three infrared sensors aligned with an interval of 1 cm between each other to record the arrival time of t_0, t_1, and t_2 of the injecting ball. The applied infrared sensor is TCRT5000 with a response time of 0.1 ms.

Figure 2 (a). *Photo of the experimental setup for measuring the out-coming ball speed*



The speeds (v_1,v_2) and the acceleration (a) of the outcoming ball can be therefore determined in terms of the following equations:

$$v_1 = \frac{1}{t_1 - t_0}(cm/s) \quad \textbf{(3)}$$

$$v_2 = \frac{1}{t_2 - t_1}(cm/s) \quad \textbf{(4)}$$

$$a = \frac{v_2 - v_1}{t_2 - t_0}(cm/s) \quad \textbf{(5)}$$

According to the Newton's 2nd *law, F=ma*, the resulting force of the ball can be estimated and the mass of the table tennis ball (m) is around 2.75 g. Figure 2(b) exhibits the ball speed measuring process of sensor control diagram, where the Arduino controlling card reads the signals of sensors from 1 to 3 and calculates the speed of the ball at the same time.

Figure 2 (b). *The ball speed measuring process of sensor control diagram*

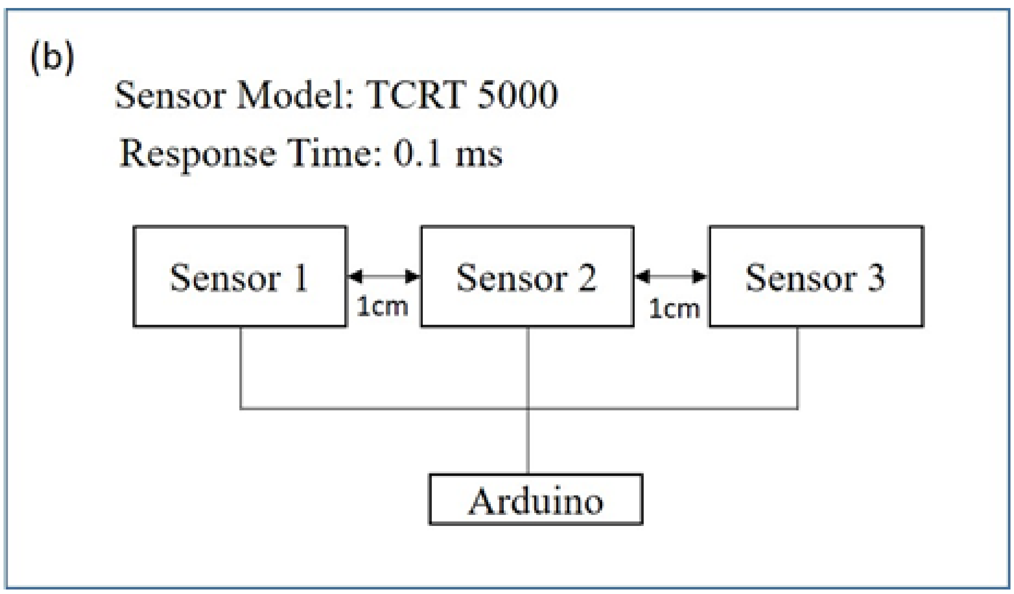
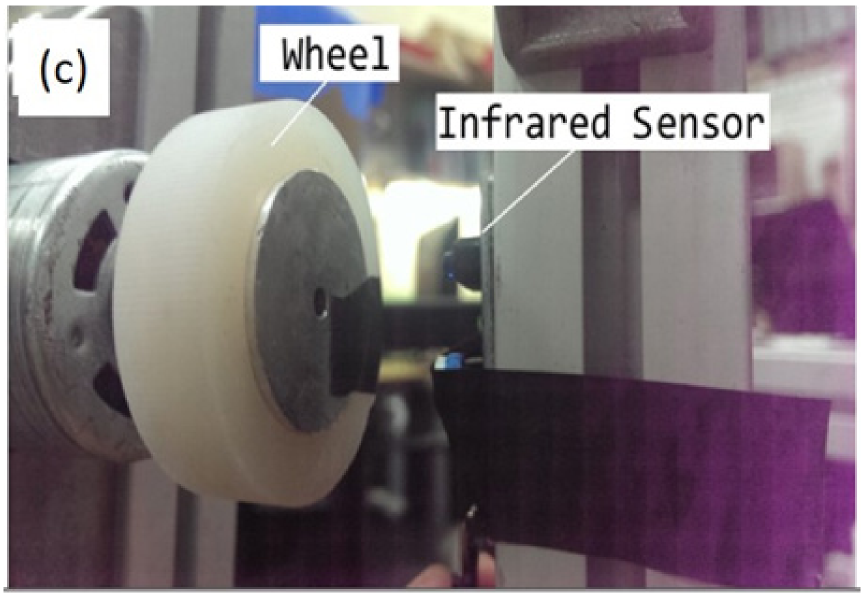


Figure 2(c) shows the photo of the experimental setup for measuring the wheel rotational speed, where the applied infrared sensor is also a TCRT5000. The wheel speed is calculated by the Arduino controlling card using the captured two signals a circle by the infrared sensor of TCRT5000. Figure 2(c) clearly indicates that a reflection point on the wheel side is made to reflect the infrared light. Calibration for the wheel rotational speed measurement in this work used the stroboscope and received an error of calibration of 4%.

Figure 2 (c). *Photo of the experimental setup for measuring the wheel rotational speed*



4. Results and Discussion

This work is focused on developing the intelligent table tennis ball machine that can simulate all courses of a ball from human play by using two counter-rotating rollers with a series of precise measurements. Imitating the ball played by a human should consider the straight-line and the tangential speeds of the ball. A topspin ball tends to fly off the paddle up into the air. The spin of the ball is created by setting the rotational speed difference of the two rollers. The spin and speed of the ball depending on the rotational speed difference between the two rollers. Under the no-slip condition between the ball and the wheel, the spin speed of the ball is equal to the rotational speed difference between the two rollers (Wu et al., 1988, Zhao et al.,2014).

Moreover, the straight-line speed of the ball is determined by the absolute rotational speed of the wheel. The faster and absolute rotational speed of the wheel can be, the faster the straight-line speed of the ball is. Figures 3(a)-(d) show the relationships of the ball straight-line speed relative to the wheel rotational speed with the ball spin speeds of 0, 1000, 2000, and 3000 rpm, respectively, where the ball spin and speed are determined by the difference between the rotational speeds of the upper and the lower wheels in the no-slip condition. Figures 3(a)-(d) indicate the good linearity between the ball straight-line and the wheel rotational speeds. Equations (6)-(12) are the fitting curves with the measuring errors of Figures 3(a)-(d), respectively.

$$y = 0.00267x - 4, \quad \text{error} < 3\% \tag{6}$$

$$y = 0.00197x + 0.59111, \quad \text{error} < 3.8\% \tag{7}$$

$$y = 0.97956x + 0.36926, \quad \text{error} < 3.7\% \tag{8}$$

$$y = 0.00184x + 2.25455, \quad \text{error} < 2.2\% \tag{9}$$

$$y = 0.00198x - 2.23879, \quad \text{error} < 2.4\% \tag{10}$$

$$y = 0.00197x + 2.52791, \quad \text{error} < 2.1\% \tag{11}$$

$$y = 0.00155x + 0.78264, \quad \text{error} < 2\% \tag{12}$$

Figures 3(a)-(d) exhibit two different curves of the faster-upper wheel and the faster-lower wheel conditions. The ball's straight-line speed is faster with a faster-upper wheel condition due to the Bernoulli theorem and the gravity. That is, the faster-upper wheel condition yields the ball spin, and the upper side static pressure on the ball is, therefore, more significant than the lower side in terms of the Bernoulli theorem. The ball, thus, runs downward and yields the added effect with gravity. On the contrary, the faster-lower wheel condition produces the ball backspin, and the lower side static pressure on the ball is larger than the upper side. The ball runs upward and yields a reduced effect with gravity. In summary, the developed ball machine will take the service with human strike simulation in terms of apparent equations of the fitting curves. Moreover, the designed ball machine can provide balls with the same property for multi-ball training and various training by adding the intelligent control soon (Rahmani, 2016., Baldwin, 1977., Gygi, 2016., Russel, 2017., &Vayur, 2015).

Figure 3 (a). *Relationship of the ball straight-line speed relative to the rotational speed with the ball spin speed of 0 rpm*

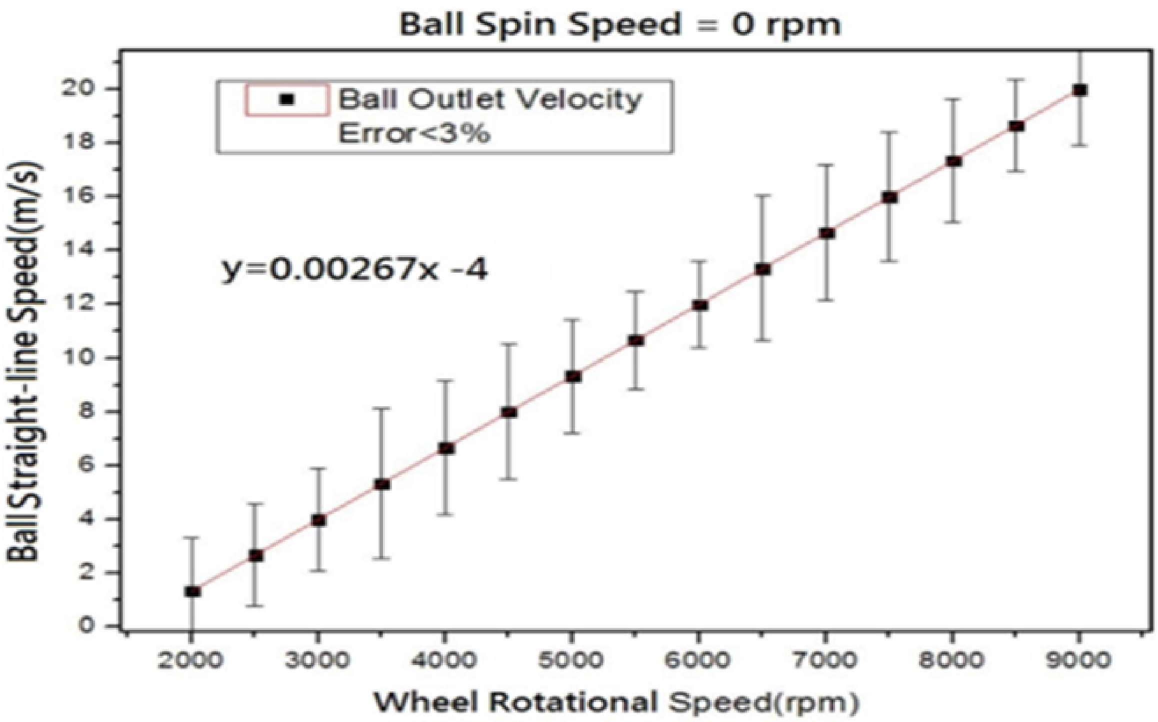


Figure 3 (b). *Relationship of the ball straight-line speed relative to the rotational speed with the ball spin speed of 1000 rpm*

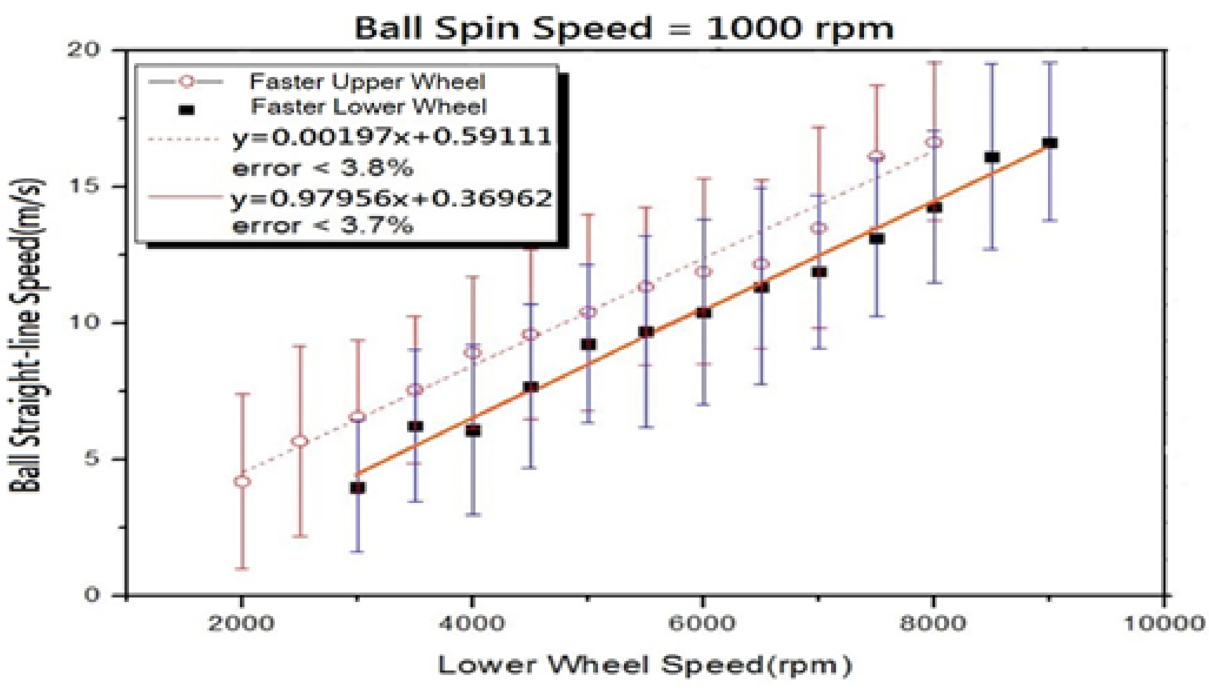


Figure 3 (c). *Relationship of the ball straight-line speed relative to the rotational speed with the ball spin speed of 2000 rpm*

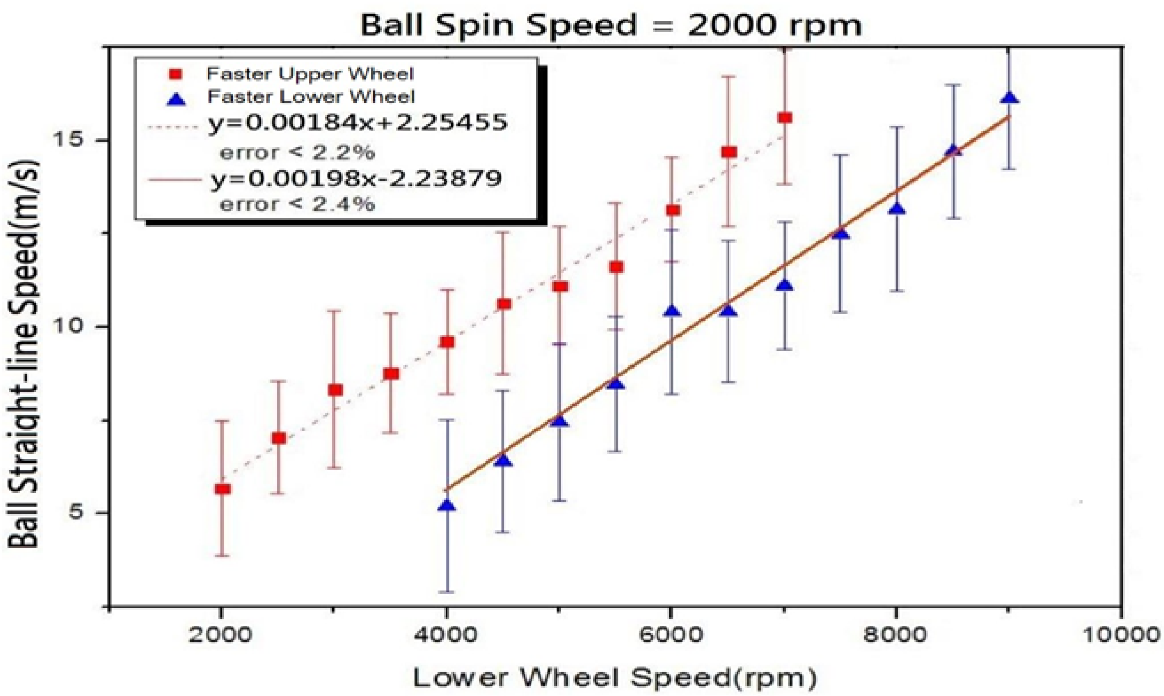
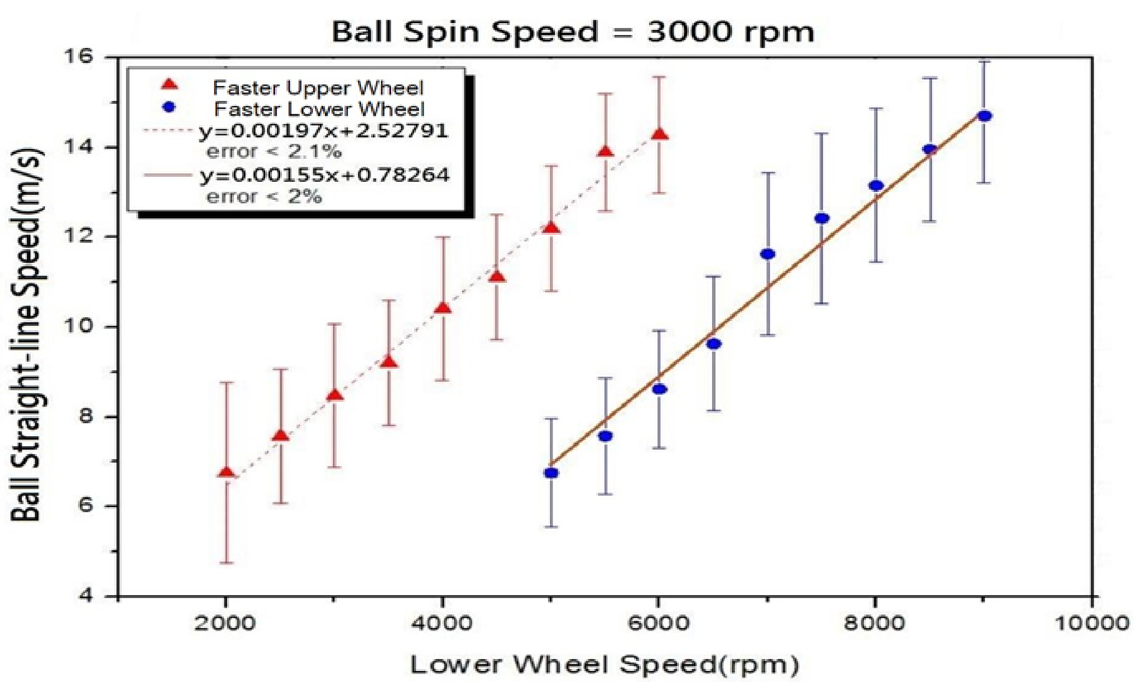


Figure 3 (d). *Relationship of the ball straight-line speed relative to the rotational speed with the ball spin speed of 3000 rpm*



6. Conclusions

A prototype of the intelligent table tennis ball machine with human strike simulation for technical training including the required relationships of the ball's straight-line speed relative to the wheel rotational speed with the ball spin speeds of 0, 1000, 2000, and 3000 rpm following a series of precise measurements are successfully implemented. The results show good linearity between the ball's straight-line speed and the wheel rotational speed. This prototype ball machine will take the service with human strike simulation in terms of equations of the fitting curves. This homemade table tennis ball machine with a ball trajectory generator is low-cost, easy-controlling, and with multiple trajectories. It can be a good substitute for a real human partner. With our innovative design of table tennis ball machine with ball trajectory sensor devices, we believe that it can be a complete intelligent table tennis ball machine providing efficient real-time training and assisting coaches and trainers in table tennis skill training.

In future research, we will add more functions to our intelligent table tennis ball machine by integrating automatic detection sensors, artificial intelligence, and control devices that can automatically detect the direction and speed of the ball. During the training process, several intelligent table tennis ball machines with automatic detection functions will be set up on the opposite side of the player. These intelligent table tennis ball machines can instantly detect the speed, height, and drop point of the ball. With the aid of artificial intelligence, the control device will trig and send related information to one of the intelligent table tennis ball machines that is close to the drop point of the ball. This intelligent table tennis ball machine sending a ball to the opposing side of the table based on the information from AI, These intelligent table tennis ball machines provide the player with auxiliary equipment for technical training that will be more close to playing a match with real people.

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