*proceedings*

Proceedings

# Development of New Baseball Pitching Machine with Four-Roller Throwing Mechanism †

**Shinobu Sakai * and Jin-Xing Shi**

Department of Production Systems Engineering and Sciences, Komatsu University, Nu 1-3 Shicyo-machi, Komatsu 923-8511, Japan; jinxing.shi@komatsu-u.ac.jp

* Correspondence: shinobu.sakai@komatsu-u.ac.jp; Tel.: +81-761-48-3147

† Presented at the 13th conference of the International Sports Engineering Association, Online, 22–26 June 2020.

Published: 15 June 2020

**Abstract:** At present, there are only a few developed pitching machines that can throw a ball with gyro spin. In this study, we aimed to develop a new baseball pitching machine using four rollers, where the rotational speed of each of the four rollers and the crossing angle of the opposite gyro rollers can be controlled optionally to generate an objective gyro spin more efficiently. We also elucidate the throwing mechanism of the developed baseball pitching machine and confirm its performance by finite element analysis. The newly developed pitching machine can throw a baseball with a wide range of speeds from 22.2 m/s (80 km/h) to 44.4 m/s (160 km/h) with all pitch types (fastball, curveball, gyroball, etc.), and the spin axis can be controlled in any designated direction. Moreover, this machine is capable of throwing a baseball with higher accuracy compared to commercially available pitching machines.

**Keywords:** sports engineering; baseball; pitching machine; throwing mechanism; gyroball; motion control; finite element analysis

## 1. Introduction

Ball games, such as baseball, tennis, and table tennis, have attracted plenty of players all over the world. Accordingly, ball pitching machines have been developed and widely utilized in the exercise of ball players [1]. The most important purpose of a baseball pitching machine is to reproduce the throws of a pitcher, which is quite helpful for the improvement of batting technique.

The existing baseball pitching machines are classified into three pitch types according to the throwing mechanism, which are the "arm", "roller (wheel)", and "air" types [2,3]. All of the maximum ball speeds of these pitching machines are over 150 km/h, so the ball speed performance of the existing pitching machines is sufficient. However, for the arm type, breaking balls are limited to fastball and curveball. On the other hand, though various breaking balls such as curveballs, sliders, and forkballs can be thrown by adjusting the rotation number of each roller in the roller type and by adjusting the position of the spin pad in the air type, it is still difficult to throw gyroball using all of the mentioned three types.

In one of our previous works, we developed a three-roller baseball pitching machine, which showed high throwing performance like a top-ranking professional baseball pitcher by independently controlling rotation speed, elevation, and declination angle of each roller [3]. This machine can also throw various breaking balls with high speed (over 150 km/h), and the position error on the home base is about 150 mm (approximately twice the diameter of a baseball).

At present, there are only a few pitching machines that can throw a baseball with a gyro spin, like a pitched football or a fired rifle bullet, where the axis of the ball spins in the same direction that the ball travels. In general, the breaking ball with a gyro spin is called a gyroball [4,5]. Though a few of the existing pitching machines (including the three-roller type mentioned above) are able to throw a simple gyroball due to their simple throwing mechanisms, they can only change the direction of the spin axis of a pitching baseball within a plane perpendicular to its pitching direction, and they cannot throw complicated breaking balls (e.g., gyroballs and cutballs) the spin axes of which are not in the perpendicular plane [6–8].

According to the above, we aimed to devise a new throwing mechanism of the roller type pitching machine that can throw a more complicated gyroball like a top-ranking professional baseball pitcher. In this study, we designed and manufactured this four-roller baseball pitching machine, and the throwing mechanism of the machine is elucidated in this paper. We also tested the throwing performance of the new baseball pitching machine, which shows higher performance than the existing pitching machines.

## 2. Throwing Mechanism of Four-Roller Baseball Pitching Machine

As shown in Figure 1, the basic posture of the four-roller baseball pitching machine is that of a cross-shaped arrangement with four rollers perpendicular to the top, bottom, left, and right faces. To throw a gyroball, the left and right gyro rollers 3 and 4 are rotated around the $z$-axis, and the two rollers intersect with an intersection angle $\gamma$. This roller orientation is called the "gyro posture" in the present work. In the coordinate system ($x$, $y$, $z$), the center (center of gravity) of the ball to be pitched is the original point O, and the basis vectors of ($x$, $y$, $z$) are $\boldsymbol{e}_1$, $\boldsymbol{e}_2$, $\boldsymbol{e}_3$, respectively. Note that the insertion and pitching direction of the ball is along the $x$ direction, and the influence of the gravity of the ball is ignored.

We set the radial vectors of upper, lower, left, and right rollers as $\boldsymbol{R}_1$, $\boldsymbol{R}_2$, $\boldsymbol{R}_3$, and $\boldsymbol{R}_4$, respectively.

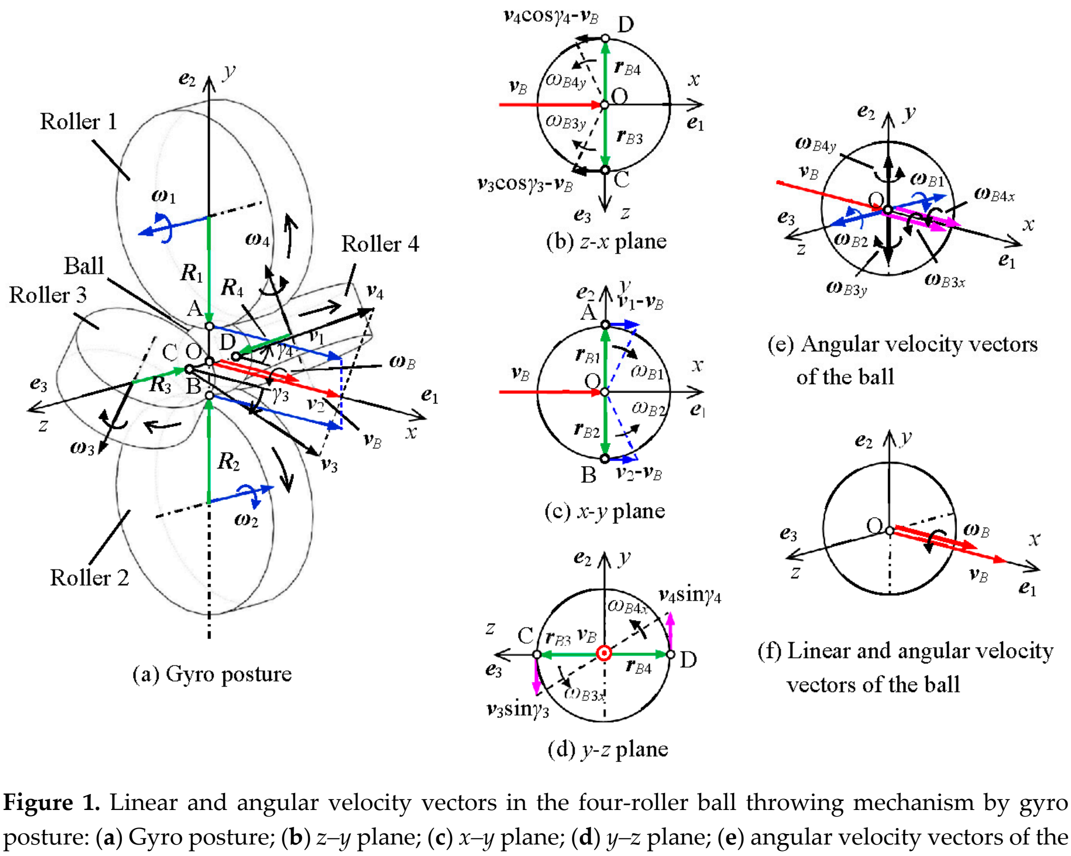


**Figure 1.** Linear and angular velocity vectors in the four-roller ball throwing mechanism by gyro posture: (**a**) Gyro posture; (**b**) $z$–$y$ plane; (**c**) $x$–$y$ plane; (**d**) $y$–$z$ plane; (**e**) angular velocity vectors of the ball; (**f**) linear and angular velocity vectors of the ball. When the linear velocity vectors are $v_1 = v_2 = v_3 = v_4$, and the linear velocity vector $v_B$ and angular velocity vector $\boldsymbol{\omega}_B$ of the ball are in the same direction, a gyroball can be thrown.

When all of the rollers are rotated in the pitching direction of the ball, angular velocity vectors $\boldsymbol{\omega}_1$, $\boldsymbol{\omega}_2$, $\boldsymbol{\omega}_3$, and $\boldsymbol{\omega}_4$ are generated on each roller. In the four-roller baseball pitching machine, the linear velocity vectors ($v_1$, $v_2$, $v_3$, and $v_4$) of rollers are transferred to the ball, so that it can generate designated ball speeds and specified breaking balls. Here, the velocity vector $v_B$ of the ball is represented by the value ($v_{Rx}$, $v_{Ry}$, $v_{Rz}$), which can be obtained by dividing the summation of components of the four linear velocity vectors by the number of components $m$, as shown in Equation (1).

$$\boldsymbol{v}_B = \begin{Bmatrix} v_{Rx} \\ v_{Ry} \\ v_{Rz} \end{Bmatrix} = \begin{Bmatrix} v_{Bx} \\ v_{By} \\ v_{Bz} \end{Bmatrix} = \begin{Bmatrix} \dfrac{v_1 + v_2 + v_3 \cos\gamma_3 + v_4 \cos\gamma_4}{4} \\ \dfrac{-v_3 \sin\gamma_3 + v_4 \sin\gamma_4}{2} \\ 0 \end{Bmatrix} \tag{1}$$

We calculated the angular velocity vector $\boldsymbol{\omega}_B$ of the ball with the gyro posture. Figure 1b–d shows the velocity vectors (or the velocity difference of each component) of the ball at the contact points (A, B, C, and D) between the four rollers and the ball. When the angular velocity vectors ($\boldsymbol{\omega}_{B1}$, $\boldsymbol{\omega}_{B2}$, $\boldsymbol{\omega}_{B3}$, and $\boldsymbol{\omega}_{B4}$) are considered, the angular velocity vector $\boldsymbol{\omega}_B$ of the ball can be obtained from Equation (2), where the subscripts $x$ and $y$ shown in the final results indicate the components with respect to the $x$-axis and $y$-axis.

$$\boldsymbol{\omega}_B = \frac{\boldsymbol{\omega}_{B1} + \boldsymbol{\omega}_{B2} + \boldsymbol{\omega}_{B3} + \boldsymbol{\omega}_{B4}}{m} = \begin{Bmatrix} \omega_{Bx} \\ \omega_{By} \\ \omega_{Bz} \end{Bmatrix} = \frac{1}{2} \begin{Bmatrix} \omega_{B3x} + \omega_{B4x} \\ -\omega_{B3y} + \omega_{B4y} \\ -\omega_{B1} + \omega_{B2} \end{Bmatrix} \tag{2}$$

As shown in Equation (2), $\omega_B$ has three components in the $x$, $y$, and $z$ axes, so the four-roller baseball pitching machine with the gyro posture can throw breaking balls with the spin axis in any direction in three dimensions, which is far superior to the existing pitching machines, the spin axes of which are limited to only the perpendicular $y$–$z$ plane. Hence, we elucidate the throwing mechanism of the four-roller pitching machine and claim that the four-roller baseball pitching machine can throw all pitch types (fastball, curveball, slider, etc.) including gyroball. The throwing performance of this throwing mechanism was confirmed by finite element analysis.

## 3. Prototyped Four-Roller Baseball Pitching Machine

The four-roller baseball pitching machine based on the above throwing mechanism was designed and prototyped as shown in Figure 2. Each roller is directly connected to a motor, and the inverter device performs precise control of the rotation speed. The elevation and azimuth of the ball launch outlet can be adjusted. The pitching test was conducted using the four-roller baseball pitching machine. Figure 3 shows the setup of the pitching test. Using the prototyped pitching machine, ten baseballs were thrown at a target distance of 14 m using three typical pitch types (i.e., fastball, curveball, and gyroball).

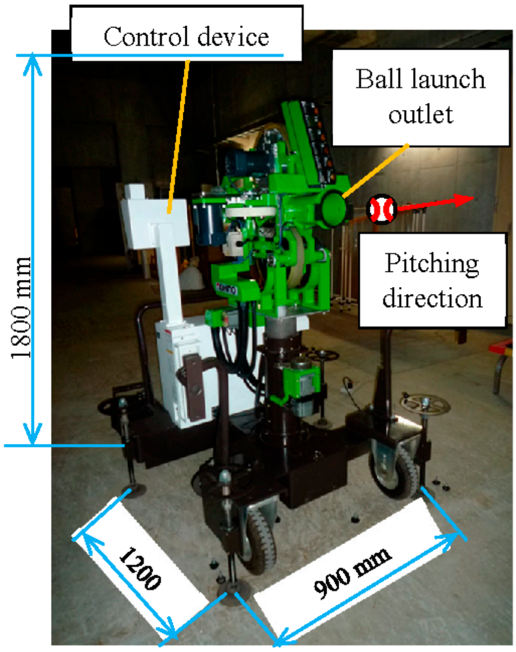


**Figure 2.** Prototyped four-roller baseball pitching machine.

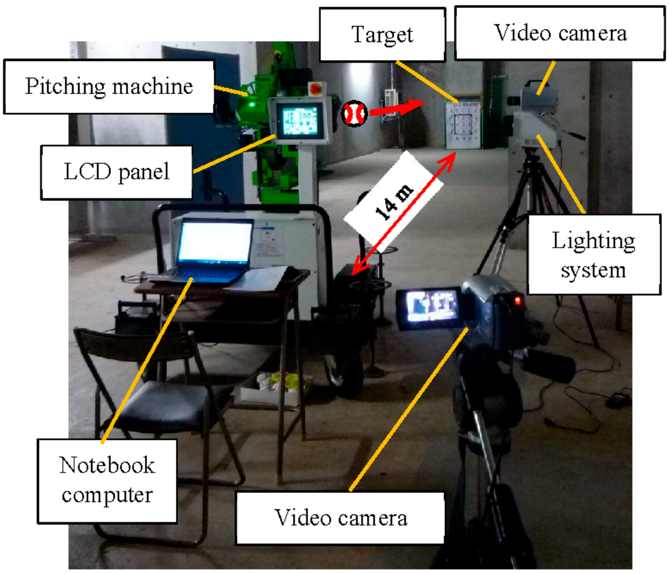


**Figure 3.** Setup of pitching test using the four-roller baseball pitching machine.

## 4. Results and Discussion

Figure 4 shows the experimental results of ball speeds in the three pitch types observed by a high-speed video camera (filmed at 4000 Hz). The numerical values in the figure indicate the average values, and the error bars express the standard deviations.

The ball speed $V$ in the fastball reached 160 km/h, so the ball speed performance in this machine is sufficient. In addition, all the deviations of ball speeds in the three pitch types had a very small variation (≤1.5 km/h), which means the ball speed generated by the machine is stable.

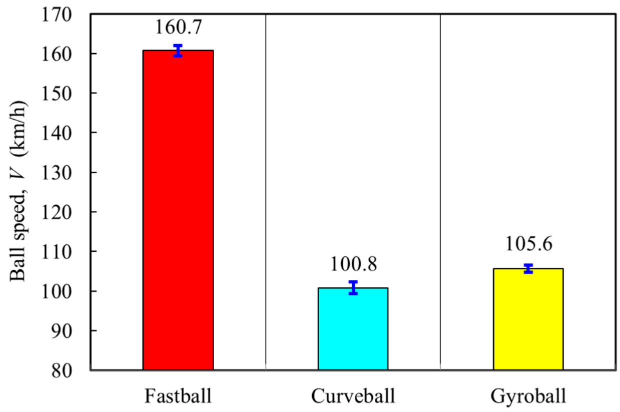


**Figure 4.** Ball speed $V$ in three pitch types (fastball, curveball, and gyroball) using the prototyped four-roller baseball pitching machine.

Figure 5 shows the stroboscopic image of a baseball thrown as a fastball at each 1.5 ms/frame. The ball speed $V$ reached 161 km/h. It was captured when the rotation of the ball was a back spin, where the ball spin rate $S$ was 3700 rpm, and the spinning axis of $\boldsymbol{\omega}_B$ was in the direction of the $z$-axis. In the case of the gyroball, as shown in Figure 6, the stroboscopic image of the baseball was captured at each 3.0 ms/frame. The ball speed $V$ reached 105 km/h. We can see that the rotation of the ball was a gyro spin, where the gyro spin rate $S$ was 800 rpm, and the spinning axis of $\boldsymbol{\omega}_B$ was almost in the flight direction of $\boldsymbol{v}_B$, which is nearly the same as the $x$-axis. From the results of pitching tests, we confirmed that the direction of spinning axis ($\boldsymbol{\omega}_B$) of the thrown baseball can be controlled in any designated direction, and all of the pitch types can be thrown.


**Figure 5.** Stroboscopic image of a baseball thrown as a fastball. The ball speed $V$ is 161 km/h and the rotation of the ball is a back spin. The ball spin rate $S$ is 3700 rpm, and the spinning axis of $\boldsymbol{\omega}_B$ is in the direction of the $z$-axis.

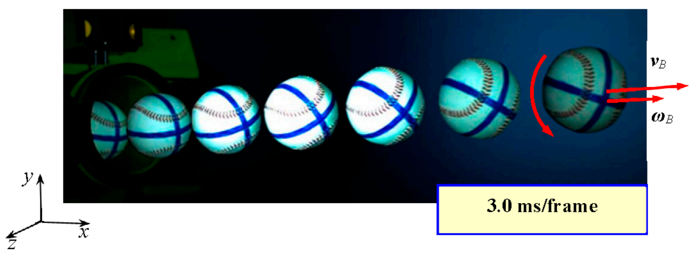


**Figure 6.** Stroboscopic image of a baseball thrown as a gyroball. The ball speed $V$ is 105 km/h and the rotation of the ball is a gyro spin. The gyro spin rate $S$ is 800 rpm, and the spinning axis of $\boldsymbol{\omega}_B$ is nearly the same as the flight direction of $\boldsymbol{v}_B$, which is in the direction of the $x$-axis.

The ball positions in the target of the ten balls in each of the three pitch types are shown in Figure 7. The experimental results of the gyroball shows a slight variation, whereas the baseballs thrown as fastballs and curveballs were almost pitched at the desired position in the target. Hence, the four-roller baseball pitching machine also performs stably in terms of the ball position in the target.

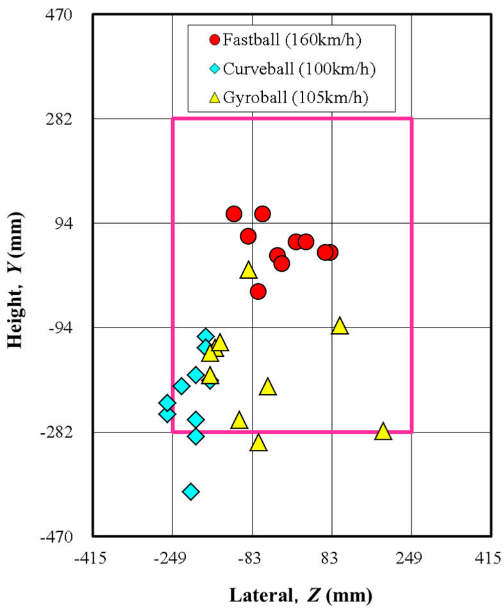


**Figure 7.** The ball positions in the target, where ten balls were thrown using each of the three pitch types.

In order to quantitatively evaluate these position errors, the standard deviations of the position error in each of the three pitch types were calculated and are shown in Figure 8. The results show that in the cases of the fastball and curveball, the errors in the *Y* and *Z* directions were within 77 mm, which is only approximately the diameter of one baseball (72 mm). The maximum position error in the case of the gyroball is 116 mm, which is equivalent to 1.5 times the diameter of a baseball. All of the position errors are smaller than those of the three-roller baseball pitching machine developed by us previously.

Considering that the throwing accuracy of the commercial pitching machines on the market is about 150 mm [3], the developed four-roller baseball pitching machine has the highest level of throwing accuracy compared to the existing pitching machines.

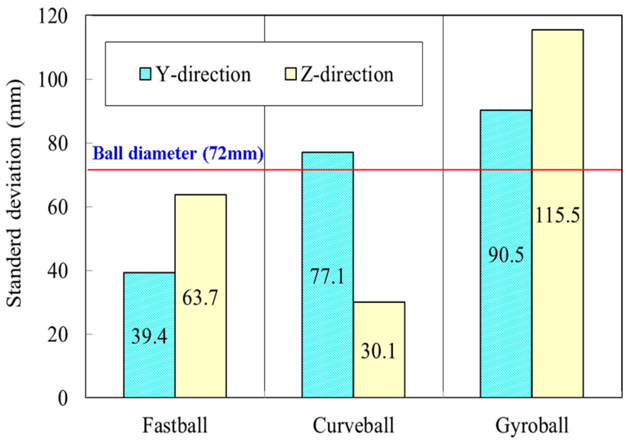


**Figure 8.** The standard deviations of the position error in each of the three pitch types. The errors of the fastball and curveball are approximately the diameter of one baseball, and the error of gyroball is less than 1.5 times the diameter of a baseball.

## 5. Conclusions

In this study, we designed and prototyped a new four-roller type machine, and its throwing mechanism is elucidated in this paper. To confirm its superior performance to the existing pitching machines, we conducted the tests using three typical pitch types. According to the results, compared to the existing pitching machines, the new developed baseball pitching machine had the highest throwing performance in terms of the ball speeds, the pitch types, and the pitching accuracy.

**Acknowledgments:** This work is supported by JSPS KAKENHI Grant Number JP18K10884. The authors would like to thank the support from JSPS.

## References

1. Adair, R.K. *The Physics of Baseball*; Harper Perennial: New York, NY, USA, 1994.
2. Mish, S.P.; Hubbard, M. Design of a Full Degree-of-freedom Baseball Pitching Machine. *J. Sports Eng.* **2001**, *4*, 123–133, doi:10.1046/j.1460-2687.2001.00076.x.
3. Sakai, S.; Oda, J.; Yonemura, S.; Kawata, K.; Horikawa, S.; Yamamoto, H. Research on the Development of Baseball Pitching Machine Controlling Pitch Type Ball Using Neural Network. *J. Syst. Des. Dyn.* **2007**, *1*, 682–690, doi:10.1299/jsdd.1.682.
4. Himeno, R.; Miyazaki, T. Aerodynamics of Baseball. In Proceedings of the 34 International Conference of Biomechanics in Sport, Tsukuba, Japan, 18–22 July 2016; pp. 14–17.
5. Nathan, A.M.; Baldwin, D.G. An Analysis of the Gyroball. *Baseb. Res. J.* **2007**, *36*, 77–80.
6. Nagami, T.; Higuchi, T.; Kanosue, K. How Baseball Spin Influences the Performance of a Pitcher. *J. Phys. Fit. Sports Med.* **2013**, *2*, 63–68, doi:10.7600/jpfsm.2.63.
7. Alaways, L.W.; Hubbard, M. Experimental determination of baseball spin and lift. *J. Sports Sci.* **2001**, *19*, 349–358, doi:10.1080/02640410152006126.
8. Jinji, T.; Sakurai, S. Direction of spin axis and spin rate of the pitched baseball. *Sports Biomech.* **2006**, *5*, 197–214, doi:10.1080/14763140608522874.