COMPARISON OF PROPERTIES OF A PITCHED-BALL ROTATION MEASURED BY THREE DIFFERENT METHODS

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The purpose of this study was to compare the properties of a pitched-ball rotation, such as the spin rate and direction of the spin axis, which were measured by 2D images with a 3D registration method (2DR), the 3D direct linear transformation method (3DLT), and a Doppler radar measurement system (DRS). The pitched baseball was recorded by using two high-speed cameras (2,000 Hz) and DRS (48,000 Hz). For 2DR and 3DLT, some landmarks on the pitched ball were digitized to calculate the location in 2D and 3D space. For DRS, the 3D spin axis was calculated using equations developed by Nathan (2015). We found that the properties of the fastball were comparable among the three methods, but the properties of pitches that were not fastballs were not always comparable with the others.

KEY WORDS: baseball, pitching, direct linear transformation, 3D registration, Doppler radar measurement system

INTRODUCTION: The trajectory of a pitched/batted ball is determined by its initial properties, that is, the translational velocity, the spin rate, and the axis of rotation. According to Jinji et al. (2007), the location of the pitched fastball at the home plate deviated 0.37 m vertically and 0.2 m horizontally, due to the force derived from the ball rotation. However, it took long time for them to digitize the landmarks on the pitched ball to derive these numerical values. Recently, properties of a pitched/batted ball have been available in real time by using a Doppler radar measurement system (DRS). Major League Baseball officially announces the spin rate as well as the pitched ball velocity. Information on the properties of ball rotation is important for pitchers to improve their pitching performance, for batters to work out countermeasures for the pitched ball, and for team management to recruit new promising players. DRS is an apparatus that meets some of these demands. It provides information on the properties of ball movement in real time. However, there remains doubt as to the accuracy of DRS in some situations (Nathan, Kensrud, Smith & Lang, 2014). According to Nathan et al. (2014), data from DRS for batting were not accurate when the batted ball was a line drive. They mentioned that we should take care of the problem of inaccuracy when using DRS to measure the spin of a pitched ball. The purpose of this study was to compare the spin rate and direction of the spin axis of a pitched baseball by measuring with three different methods including DRS.

METHODS: Ethics approval was obtained from the institutional ethics committee of National Institute of Fitness & Sports in Kanoya. Three participants (two right handed and one left handed) who gave an informed consent threw a baseball on which some letters and marks (A, E, M, H, square, and triangle) were written (Fig. 1). The ball was thrown from the pitcher's rubber on an indoor mound to the home plate. Each participant threw fastball and curveball two to five pitches each. In addition, one participant threw 2 forkballs. The total number of pitches was 20. The mean velocity and standard deviation for the fastballs was 30.0 ± 1.3 m/s. The pitched baseball was recorded using two high-speed cameras (MEMRECAM HX-5, NAC Image Technology Inc., Tokyo) (2,000 Hz) and measured by the TrackMan system (TrackMan Baseball, TrackMan, Vedbaek, Denmark) (48,000 Hz). One of the high-speed cameras was located between the pitching mound and second base (back view), and the other high-speed camera was located at a spot perpendicular to the line from the pitcher's plate to the home plate and approximately 2.5 m away from the line and the pitcher's plate.

Each camera was focused on the ball just after the instant of ball release. The TrackMan system was deployed at 3 m behind the home plate and 3 m above the floor.

The corners of the letters or marks written on the pitched ball were digitized to calculate the 3D location using the 3D direct linear transformation method (3DLT). The calibration volume was 0.5 m cube and mean reconstruction error was below 1.0 mm. The center of the ball for 3DLT was calculated using the equation for a sphere with the nonlinear least square method based on four landmarks on the ball (Matsuo et al., 2016).

The method using 2D images with a 3D registration was also adopted (2DR). The method is similar to that employed in the previous study (Nagami et al., 2011), but the baseball used for analyzing the ball spin was rotated in mathematical world instead of using the custom-made apparatus. Reflective markers (6-mm diameter) were placed on the corners of the letters or marks and were recorded with an eight-camera motion capture system (Mac3D system, Motion Analysis Corp., Santa Rosa, CA, USA) after the pitching sessions were completed (Figure 1). The 3D locations of the corners of the letters or marks were calculated using the 3D DLT method. Then, the center of the ball was calculated using the same method as mentioned above. The orthogonal local coordinate system of the ball was set at the center of the ball. The ball size was scaled into the same pixel size as the back-view 2D images, and the ball coordinate system was rotated to minimize the difference of the location from the corresponding three landmarks of the back-view 2D image which were arbitrarily selected from the corners of the letters or marks, using the nonlinear least square method.

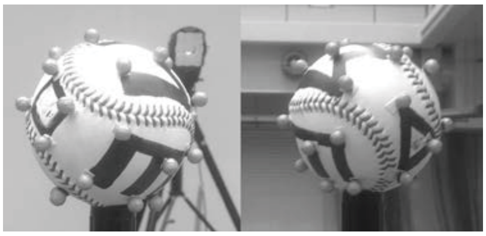

Figure 1: Ball used for 3D registration.

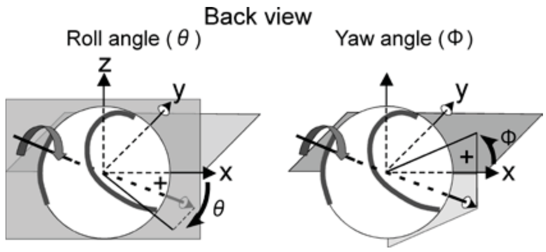

Figure 2: Angle definition.

The angular velocity of the ball and the axis of rotation were calculated based on the derivatives of the axes of the local coordinate system which set on the registered ball for 2DR or on the pitched ball for 3DLT.

Output from the TrackMan system did not include the 3D direction of the spin axis. Therefore, we used equations developed by Nathan (2015) and calculated the following angles.

The angle between the global x-axis and the projected vector of the spin axis onto the frontal plane was defined as a roll angle (θ in Figure 2). The angle between the global x-axis and the projected vector of the spin axis onto the transverse plane was defined as a yaw angle (ϕ in Figure 2).

RESULTS and DISCUSSION: The spin rates of the pitched ball were comparable with each other and the previous studies (Jinji, et al., 2007; Ngami, et al., 2011). The coefficient of correlation between all combinations among the three methods were greater than 0.92. Figure 3 shows a typical example of these relationships. The coefficient of correlation between 2DR and DRS was 0.971 ($r^2 = 0.944$, $p < 0.01$). Although a significant relationship was found between these two methods, approximately 500 rpm of the difference in the spin rate between these methods was found during one trial (the hash-marked circle in Figure 2).

From the viewpoint of practical use, this was too large to be ignored. After this outlier was removed, the coefficient correlation was 0.999 ($r^2 = 0.991$, $p < 0.01$), the slope of the regression line was 0.989, and the intercept was 0. This means that the spin rates measured by these methods almost completely coincided with each other. The outlier was a forkball.

The participant throwing this forkball threw another forkball during the pitching session. However, DRS could not access its rotation properties. The spin rate of the forkball measured by 2DR was 375 rpm. These results suggested that DRS has the same accuracy as 2DR and 3DLT for fastballs and curve balls, but not for pitch types with a low spin rate, such as the forkball.

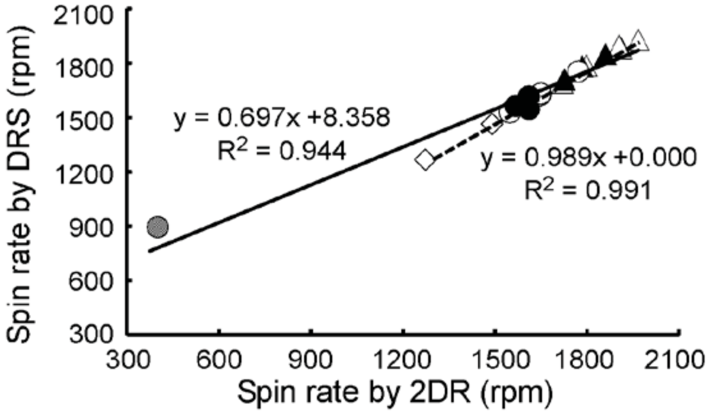

Figure 3: Relationship of spin rates measured by 2DR and DRS. Each plot indicates a pitch. Each shape (circle, triangle, or diamond) is a participant. Circles indicate a left-handed pitcher. Open marks are fastball, filled marks are curve balls, and hash-marked circle indicate a forkball.

For the roll angle, the coefficients of correlation between all combinations among the three methods were greater than 0.960. The relationship of the roll angles between 2DR and DRS is shown in Figure 4A as a typical example. The coefficient of correlation was 0.973. This means that these methods highly agree with each other. However, we found a greater variation in the curve balls thrown by a pitcher (filled circles). The roll angles of the curve balls for the pitcher measured by DRS ranged from 125° to 216°. By contrast, those measured by 2DR ranged from 128° to 133°. The range of roll angle measured by DRS was much greater than that reported in the previous studies (Nagami, et al., 2015, 2016).

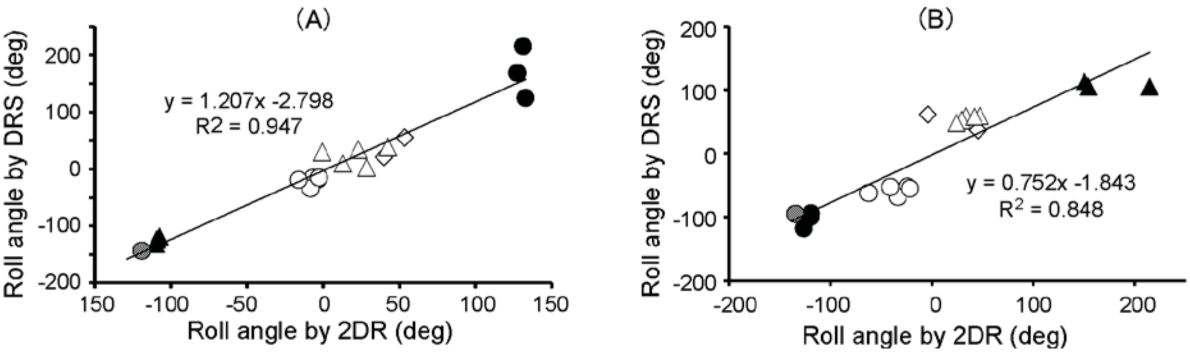

Figure 4: Relationship of roll angles (A) and yaw angles (B) between 2DR and DRS. Solid line indicates regression line. Each plot is a pitch. Each shape (circle, triangle, or diamond) is a participant. Circles indicate a left-handed pitcher. Open marks are fastball, filled marks are curve balls, and hash-marked circle indicate a forkball.

The range of the roll angles of curveballs for another pitcher measured by 3DLT was greater (−130° to −50°) than the others (−110° to −107° for 2DR and −119° to −131° for 3DLT).

For the yaw angle, the coefficients of correlation between all combinations of the three methods were greater than 0.9, similar to the roll angle (Figure 4B). However, the variation in the yaw angle of the curve ball pitched by a pitcher and measured by 2DR was greater than that measured by DRS. The ranges were 150° to 214° for 2DR and 106° to 113° for DRS. A similar trend was found in the relationship between 3DLT and DRS. The range measured by 3DLT (34° to 123°) was greater than that of the other two methods.

There is no gold standard for measuring the spin properties of a pitched baseball. Thus, we cannot decide which method is the most accurate. However, both the spin rates and directions of the spin axis of the fastballs measured by the three different methods were comparable with each other and the previous studies (Jinji, et al., 2007; Nagami, et al., 2011, 2016). Therefore, it is reasonable to say that any method employed in this study is suitable for measuring the spin properties of fastballs. On the other hand, the spin properties for some pitch types (except for the fastball) were not always comparable during practical use. In this study, the yaw angle of the curveball thrown by a right-handed pitcher had greater variability in 2DR and 3DLT. Weak points of DRS included the following: pitch types with lower spin rates, and the roll angle of the curve ball thrown by a left-handed pitcher in this study.

Inaccuracies may result from the relationship between the direction of the spin axis and the camera position, and errors in the digitizing procedure. We must pay attention to the fact that spin parameters measured by the methods employed in this study sometimes includes inaccurate values, especially in the case of pitch types except for fastballs.

CONCLUSION:
We compared the spin rate and direction of the spin axis of a pitched baseball. Measurements were conducted using 2DR, 3DLT, and DRS. Most of these properties were comparable with each other, but not in all cases. Therefore, when we measure or use the spin properties, we should pay attention to the characteristics of the method employed, especially when measuring pitches that are not fastballs.

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