Cricket Catching Drills

Application of a Redundantly Actuated 2-DOF 3-UPS Parallel Platform to Increase the Efficacy of Providing Catching Practice Drills in Cricket

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Abstract: 'Catches win matches' is probably the oldest adage in Cricket. A fielder may only be required to take one catch in an entire game, but his success in taking that catch may have a considerable effect on the outcome of the match. Application of technology to sports equipment has a great impact on performance and has a potential to revolutionize the entire sporting culture.

This paper presents an application of a redundantly actuated 2-DOF 3-UPS Parallel Chain Platform to boost the efficacy of providing catching practice drills by maintaining a degree of realism. The basic idea is to swerve a ball shot from a Ball Shooting Machine onto the platform, in random or desired directions by changing the orientation of the platform instantaneously as the ball hits it. We have formulated a method to calculate the velocity and angle of launch of the ball, required to provide practice drills for high catches and simulated the same.

1 INTRODUCTION

Catching in Cricket requires a range of skills, some of which include intense concentration, ability to take quick reactions, anticipate the trajectory of the ball and excellent athleticism. Mastering these skills require intense practice of catching drills. To increase the effectiveness of providing catching drills, we thought of introducing a 2 Degree Of Freedom (DOF) (Roll and Pitch) platform to direct a ball shot from a Ball Shooting Machine towards the fielder. This could pose an immediate question, Why use a 2-DOF Platform separately along with the Ball Shooting Machine, as using a 2-DOF Ball Shooting Machine solely might serve the purpose? This can be answered if one looks at the Late-cut shot (Figure 1) played by Eoin Morgan (Morgan, 2014). If one observes carefully, the wicket-keeper initially followed the ball by anticipating its trajectory, but did not keep an eye on the blade of the bat, and the brilliant late-cut shot left him helpless. This is the reason why a wicket-keeper or any fielder should always keep an eye on the ball as it leaves the bowler as well as the blade of the batsman's bat because they have a very small reaction time. Using a 2-DOF Platform for practicing catches creates an analogous situation as mentioned above. One of the keys to improving performance is being able to create a training exercise that holds a degree of realism, to accurately simulate what a player would do in their performance environment. Here, the Ball Shooting Machine acts as the bowler and the Platform as the batsman's bat, thus, maintaining a degree of realism.

Figure 1: The Late-cut shot by Eoin Morgan (Morgan, 2014).

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The paper has been organized as follows: Section 2 discusses the equipment/methods being used for catching drills in Cricket. Section 3 provides a justification for the use of a redundantly actuated platform for our application and also describes the details of the geometry of the platform and its Inverse Kinematical Analysis. Section 4 discusses in great detail our formulated method to calculate the velocity and angle of launch of the ball from the platform required for providing High catches. Articulating these details is one of our main contributions. Section 5 discusses the nitty-gritty of the required velocity and angle of launch of ball shot from the Ball Shooting Machine. Section 6 discusses about the control input to the platform required to orient it for providing the desired catches. The simulation results are presented in Section 7 and conclusions and the scope for the future work are discussed in Section 8.

2 CURRENT METHODS

We can broadly differentiate between the catches taken in Cricket as in-field catches and out-field catches examples of which are Slip catches and High Catches respectively.

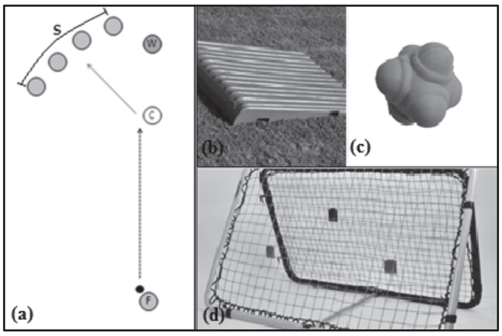

Figure 2: (a) Catching Practice (Hinchliffe, 2010), (b) Katchet, (c) Reflex Ball and (d) Crazy Catch.

A traditional way of practicing slip catches is by shooting a ball on a pitch roller. The ball hits the curved surface of the roller and gets swerved towards the fielder. Another realistic way to practice slip catching requires a well-practiced coach to make it worthwhile. As shown in Figure 2(a), the feeder (F) throws the ball such that it reaches the coach (C) at chest height, wide to the off side and the coach deflects the ball with a bat into the slip cordon (S) for practicing catches (Hinchliffe, 2010). A practice for high catches can similarly be provided by an experienced coach.

A Katchet, Reflex Ball and the Crazy Catch, shown in Figure 2(b-d), are some presently used devices that are used for practicing catches. These methods deflect the ball in unpredictable directions giving the fielder a good catching practice. But with these devices, it is very difficult to send the ball in desired directions, at desired angle or with desired velocity to practice specific type of catches. Sending the ball in desired manner is required to practice specifically on players' weak spots.

These existing methods are heavily dependent on coach and do not provide any controlled training for practicing catches. The work presented here proposes the use of robotics technology to provide a controlled and robust catching practice environment by using a 2-DOF Platform to provide a variety of catches in desired locations.

3 DESIGN, GEOMETRY AND INVERSE KINEMATIC ANALYSIS OF THE PLATFORM

3.1 Design

There are two choices for the architecture of the 2-DOF platform, a Serial Chain or a Parallel Chain (Mecademic, 2013). Parallel chain platforms have high payload capacity, are stiffer, faster, and more accurate than serial ones, and is suitable for our application. In our work, we have assumed that the Ball Shooting Machine has a rotary degree of freedom and is able to shoot the ball accurately on the centre the platform. Hence, there is no requirement for translational degrees of freedom for the platform and the two rotational degrees of freedom i.e. roll and pitch are sufficient to direct the ball in desired directions.

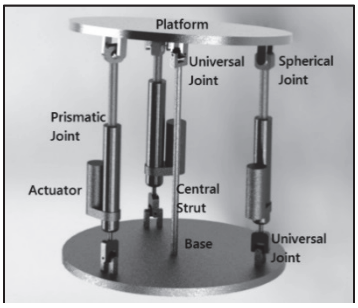

Figure 3: A CAD model of the Redundantly Actuated 2-DOF 3-UPS Parallel Platform.

An obvious choice is, therefore, a 2-DOF Parallel Mechanism. Redundant actuation and novel redundant kinematics are discussed by Andreas Muller (Müller 2008). Redundant actuation of the platform increases the payload and acceleration, and can yield an optimal load distribution among the actuators. It also promises to improve platform stiffness, dexterity and reliability. This led us to use and explore the 2-DOF redundantly actuated 3-UPS (Universal Joint – Prismatic Joint – Spherical Joint) parallel mechanism (Figure 3) to manipulate the ball for catching practice.

The design consists of a platform, a fixed base, three identical limbs, and a central strut connected to the platform with a universal joint, as in Figure 3. The central strut is used to connect the platform to the base. Each limb consists of a prismatic joint and is attached to the platform with a spherical joint and to the base with a universal joint. Due to the fact that three actuators are used for operating this 2 DOF platform, the mechanism is redundantly actuated.

3.2 Inverse Kinematics of the Platform

The Inverse Kinematical Analysis of a 2-DOF Redundantly actuated 3-UPS Platform has been done by Saglia et al., (2008).

As shown in Figure 4, two Cartesian coordinate systems $O_{x,y,z}$ as the fixed frame attached to the base and $P_{u,v,w}$ moving reference frame attached to the platform, are chosen, with (x, y, z) and (u, v, w) as the unit vectors of the reference frames O and P, respectively.

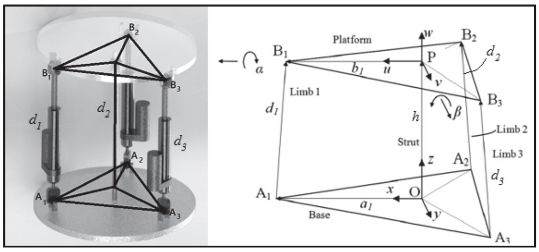

Figure 4: Geometry of the Parallel Mechanism and frame assignment.

Defining two rotation angles α and β as roll and pitch about axes u and v, we can describe the orientation of the moving platform with respect to the base frame.

Referring to Figure 4, a loop-closure equation for each limb i in vector form can be written as

$$\overline{A_i B_i} = d_i = p + b_i - a_i = p + R_P^O b_i^p - a_i \quad (1)$$

where d_i is the i^{th} limb vector, p is the position vector of moving frame origin in base frame, a_i, b_i, and b_i^p are the position vectors of the joint A_i expressed in the base reference frame, the position of the B_i joint expressed in the platform fixed orientation reference frame, and the position of the B_i joints expressed in the moving reference frame, respectively. R_P^O is the rotation matrix representing the orientation of moving frame in base frame. The vector of actuated joint positions for three limbs is defined as

$$t = [d_1 \ d_2 \ d_3]^T \quad (2)$$

However, we are more interested in finding out the unit vector $\hat{n}$ normal to the platform after it undergoes the rotation R_P^O. The vector $\hat{n}$ is given by

$$\hat{n} = [sin\beta cos\alpha \quad -sin\alpha \quad cos\beta cos\alpha]^T \quad (3)$$

Let $\hat{n} = [n_x \quad n_y \quad n_z]^T$ then,

$$\beta = atan2(n_x, n_z) \quad (4)$$

$$\alpha = atan2\left(-n_y, (n_x^2 + n_z^2)^{1/2}\right) \quad (5)$$

4 ALGORITHM TO CALCULATE THE VELOCITY AND ANGLE OF LAUNCH FOR THE BALL

4.1 Terminology and Symbols

Following terminology and symbols are used in the following development:

4.1.1 Ellipse of Points of Maximum Heights (Ê)

As shown in Figure 5, the curve joining the points of maximum height in the parabolas of ideal projectile motion can be shown to be an ellipse (Fernández-Chapou et al., 2004). We use this for formulating our method and denote this ellipse by the symbol Ê.

The equation of ellipse Ê is given by

$$\frac{x^2}{a^2} + \frac{(y-b)^2}{b^2} = 1 \quad (6)$$

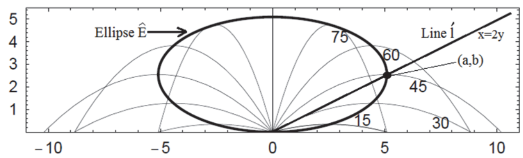

Figure 5: Ellipse of points of maximum heights (Fernández-Chapou et al., 2004).

where, $a = \frac{v_0^2}{2g}$, $b = \frac{v_0^2}{4g}$, with v_0 as the magnitude of initial velocity of projectile and g is the acceleration due to gravity.

4.1.2 Locus of the Rightmost Points of the Ellipse Ê (Line Ĺ)

The rightmost point of the ellipse Ê is (a, b) and as $a = 2b$, we get the locus of the rightmost points of the family of ellipses Ê as $x = 2y$ which turns out to be a line. We denote this line by the symbol Ĺ.

4.1.3 Angle of Launch ($\boldsymbol{\theta_k}$)

The angle of launch for any point k lying on the ellipse Ê can be found by the following equations:

$$\theta_k = \frac{1}{2}\sin^{-1}\left(\frac{2gx}{v_0^2}\right) \quad when\ y < b \tag{7}$$

$$\theta_k = \frac{\pi}{2} - \frac{1}{2}\sin^{-1}\left(\frac{2gx}{v_0^2}\right) \quad when\ y \geq b \tag{8}$$

where, x and y are coordinates of the point.

4.2 Computation of the Ball Velocity and Angle of Launch for High Catches

Every fielder has a maximum area of reach on the field where he can get to and make a catch possible. We define this area as a circle of radius R. A catch has been defined as a high catch if the point of maximum height of the ball's trajectory is greater than or equal to a user defined value H and falls in the area of maximum reach i.e. a circle of radius R. Figure 6 shows an example of a High catch.

Our aim is to find an appropriate velocity and angle of launch for the ball so that it lands in the area of maximum reach of the fielder.

As shown in Figure 7, let the line OB formed by the plane of the ball's trajectory and the ground make an angle of Φ with the line OA joining the centre of the platform and the position of the player. The value of Φ is restricted by the circle of maximum reach in the range $-\sin^{-1}\left(\frac{R}{D}\right)$ and $\sin^{-1}\left(\frac{R}{D}\right)$ where, D is the distance of the fielder from the platform. The distances d and r are given by the following equations:

$$d = \frac{\cot\Phi\, D}{\sqrt{1 + \cot\Phi^2}} \tag{9}$$

$$r = \sqrt{R^2 - \frac{D^2}{1 + \cot\Phi^2}} \tag{10}$$

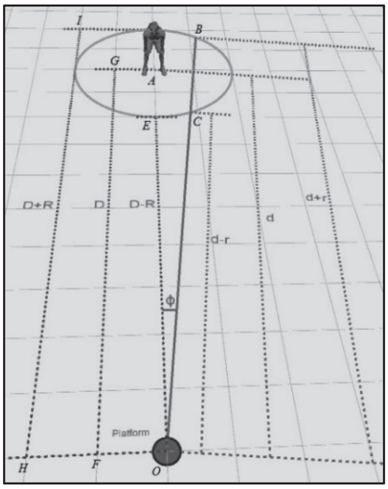

Figure 7: The projected ball must fall anywhere on the segment BC.

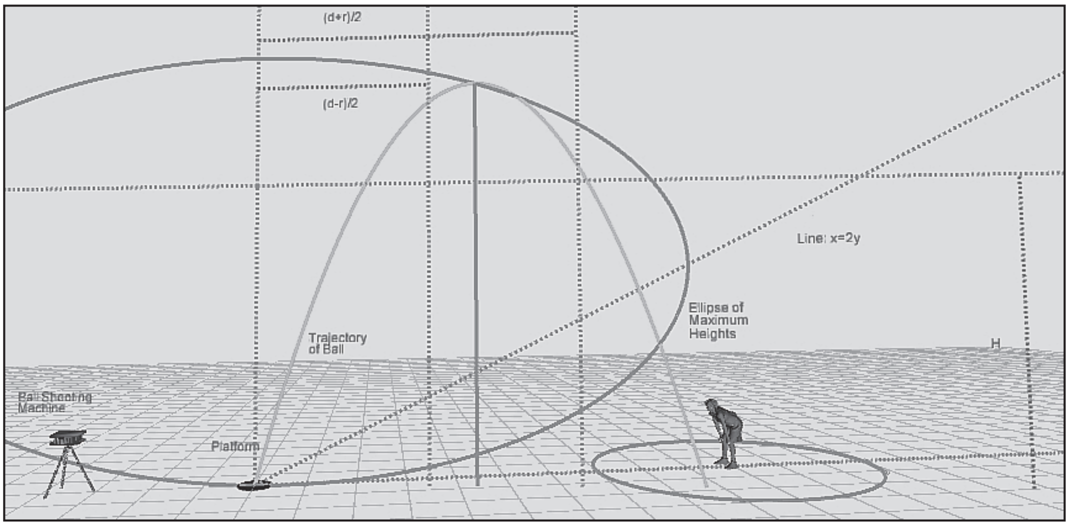

Figure 6: A High Catch Geometry.

The solution is developed by restricting the horizontal range of the ball between $d-r$ and $d+r$ (i.e. segment BC) such that the maximum height attained by the ball is greater than or equal to H. A projectile attains maximum height when it has covered half of its horizontal range. Therefore, the x coordinate of the point of maximum height for the projected ball must lie between the values $p=(d-r)/2$ and $q=(d+r)/2$. Figure 8 shows an ellipse Ê drawn for a certain velocity. The segment AB of the ellipse Ê shown in this figure, thus contains the suitable points of maximum height of the trajectory of projected ball.

Three situations are possible for the catch as shown in Figure 9. Case I has both the points p and q on the left hand side of the line Í, Case II has the line Í lying between the points p and q and Case III has the points p and q on the right hand side of line Í. Each case will have an Ellipse Ê corresponding to the minimum velocity v_{min} that satisfies the condition for the range of the ball to lie between $d-r$ and $d+r$ and attain maximum height greater than or equal to H. For Case I, this ellipse should pass through the point (p,H) as shown in Figure 10(a). Substituting this point in the ellipse equation (6) gives us the expression for v_{min} as:

$$v_{min}=\sqrt{\frac{4g(p^2+4H^2)}{8H}} \tag{11}$$

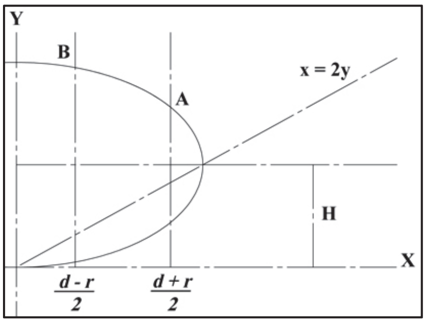

Figure 8: The segment AB of the ellipse contains the suitable points of maximum heights.

The ellipse Ê corresponding to the minimum velocity for Case II also passes through the point (p,H) and the velocity is again given by the equation (11). For Case III, this ellipse passes through the point $\left(p,\frac{p}{2}\right)$ sitting on the line Í as shown in Figure 10(b). Substituting this point in equation (6) gives the following expression for v_{min}

$$v_{min}=\sqrt{2gp} \tag{12}$$

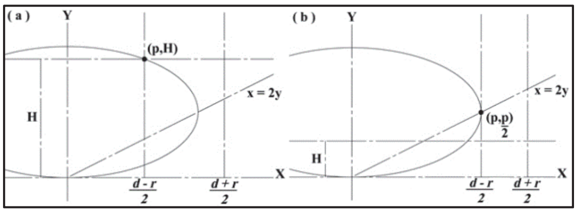

Figure 10: Ellipse corresponding to the velocity v_{min} (a) passing through *(p,H)* for Case I and (b) passing through $\left(p,\frac{p}{2}\right)$for Case III.

The maximum velocity v_{max} of the ball is restricted by the Ball Shooting Machine. We choose a random velocity v_o between v_{min} and v_{max} , draw the ellipse Ê corresponding to this chosen velocity, find suitable segments of this ellipse (as was done in Figure 8) and hence calculate the range of values for the angle of launch which satisfy the conditions required.

Depending on the distances *d, r, H* and the chosen velocity v_o, two subcases for Case I, three subcases for Case II and five subcases for Case III arise which are shown in Figure 11. The segments on each of the ellipse constrained by the region $x \geq \frac{(d-r)}{2}, x \leq \frac{(d+r)}{2}$ and $y \geq H$, contain the suitable points of maximum height. A range of values for the angle of launch is calculated for each case and a random angle θ is selected from this range.

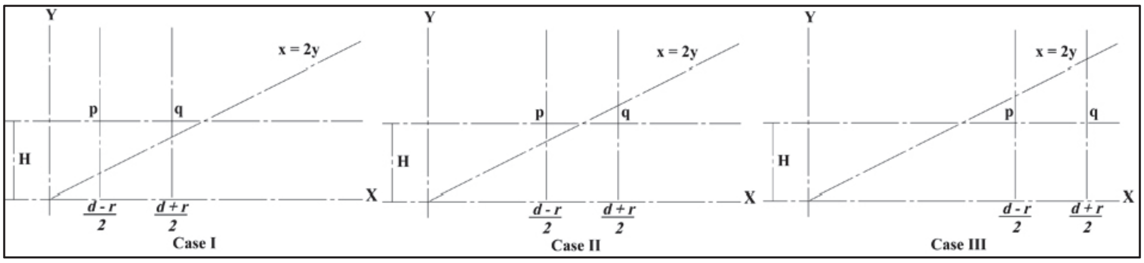

Figure 9: Three Cases for a High Catch.

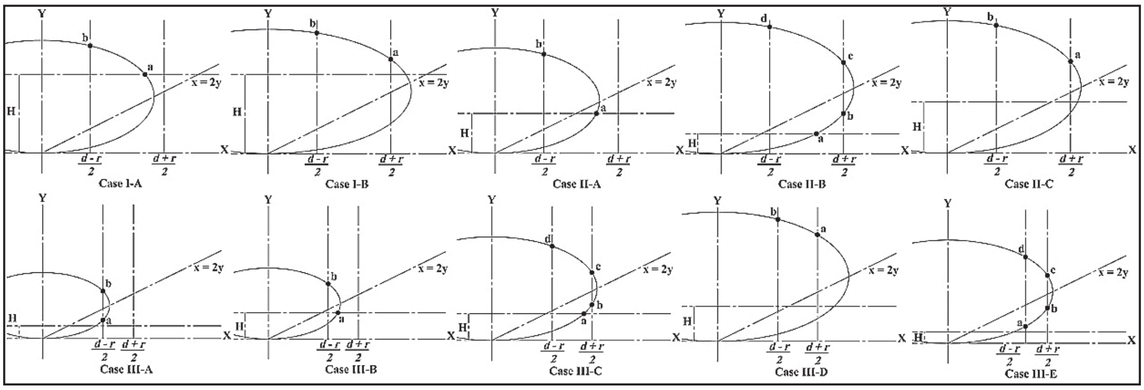

Figure 11: Subcases for Case I, Case II and Case III of High Catches.

For example, for Case III-C in Figure 11,

$$\theta_1 = random(\theta_a, \theta_b) \tag{13}$$

$$\theta_2 = random(\theta_c, \theta_d) \tag{14}$$

$$\theta = random(\theta_1, \theta_2) \tag{15}$$

where, the function $random(s,t)$ returns a random value between the values s and t.

5 VELOCITY AND ANGLE OF LAUNCH OF THE BALL SHOT FROM BALL SHOOTING MACHINE

As shown in Figure 12, let the Ball Shooting Machine be placed at a distance A from the platform and the ball be shot from a height of B from the ground. If v_o is the required velocity of launch as the ball leaves the platform after hitting it, then the velocity of launch v_b from the Ball Shooting Machine is given by the expression

$$v_b = \sqrt{({v_o}^2 - 2gB)} \tag{16}$$

The angle of launch θ_s can be found from the expression

$$\theta_s = \tan^{-1}\left(\frac{-A + \sqrt{A^2 - 2(\frac{gA^2}{v_b^2})(\frac{gA^2}{2v_b^2} - B)}}{(\frac{gA^2}{v_b^2})}\right) \tag{17}$$

6 ORIENTATION OF PLATFORM

The orientation of the platform to swerve the ball shot from the ball shooting machine is computed as follows. If $\overline{v_{in}}$ be the velocity vector of the ball just before striking the platform and $\overline{v_{out}}$ the velocity vector just after striking the platform, then the unit vector normal to the platforrm $\hat{n}$ is given by

$$\hat{n} = norm(\overline{v_{out}} - \overline{v_{in}}) \tag{18}$$

where, *norm* provides a normalized vector. Equations (2)-(5) along with equation (18) can be used to calculate vector of actuated joint positions of three limbs supporting the platform.

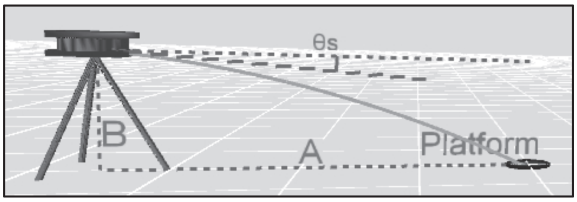

Figure 12: Trajectory of the ball shot from the Ball Shooting Machine onto the platform.

7 SIMULATION AND RESULTS

The simulation of the proposed system was done in an Open-Source Software, *Processing* (Processing.org, 2001). The simulation results for High Catches launched at various speeds and launch angles are shown in the Figures 13-15. For all the simulations, the maximum velocity of launch for the ball that can be provided is constrained by the Ball Shooting machine and is taken as 30 m/s. Figure 13 shows an example of the Case I-B for a High Catch. In this example, the parameters *D, R, Φ* and *H* have the values 10 m, 3 m, 0.2 rad and 6 m respectively. The minimum velocity of launch for this case can be found using the equation 11. This provides a range from 11.36 m/s to 30 m/s for choosing the velocity of launch for the ball. In this example, the velocity of launch was chosen as 13.00 m/s. This chosen velocity in turn provides a range from 1.184 rad to 1.344 rad for the angle of launch. In this example, the angle of launch was chosen as 1.30 rad. Figures 14 and 15 are the examples of Case II-C and Case III-D respectively. The velocity and the angle of launch for the ball are calculated using similar steps as used for the example in Figure 13.

These simulation results prove the idea that the proposed 2-DOF 3-UPS Parallel Platform can be very effectively used for catching practice drills in Cricket and can be used to train the players for their weak points. The platform is being fabricated to perform field trials.

8 CONCLUSIONS AND FURTHER WORK

Employing a 2-DOF platform creates catching drills maintaining a degree of realism. Our formulated method of simulating catches can be used to devise one's own set of catching drills.

This work focused on the formulation of a methodology to provide training for High Catches. With the success for High Catches training, the work is continuing with the formulation of models for other types of catches like Slip Catches and Flighted Catches and their verification by simulation.

This work does not consider the effect of air drag, wind velocity and other effects which deviate a projectile from its actual parabolic trajectory. In realistic situation, the ball shot from the Ball Shooting Machine may not hit the center of the platform due to these unconsidered effects. This problem will require the use of a 5-DOF (3 translational and 2 rotational) platform.

It is difficult to predict the trajectory of the ball considering changing environmental conditions leading to the varying air drag, wind velocity and other effects. This can be tackled by making use of Visual Servoing to control the 5-DOF platform in real-time, which in-fact is also a long term goal of this work.

Regrettably, our platform is incapable of simulating aspects, related to body position/movement of the batsman and we also aim to tackle this endeavour in our future work.

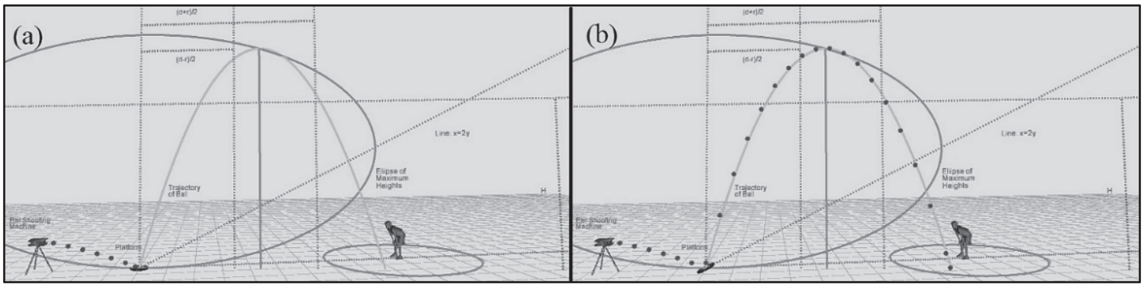

Figure 13: Screenshots of Simulation of a High Catch with Launch velocity of 13.00 m/s, angle of launch θ = 1.30 rad, H = 6 m, D = 10 m, R = 3 m and Φ = 0.2 rad. (a) Trajectory of the ball as shot from the Ball Shooting Machine towards the platform. (b) Swerved trajectory of the ball after actuation of the platform.

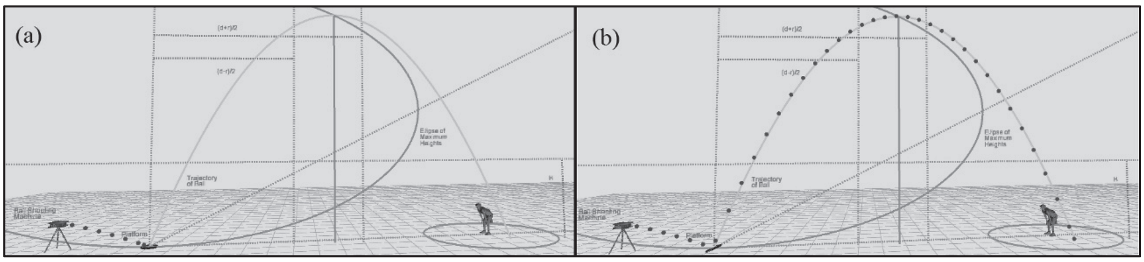

Figure 14: Screenshots of Simulation of a High Catch with Launch velocity of 15.00 m/s, angle of launch θ= 1.19 rad, H = 3.5 m, D = 15 m, R = 3 m and Φ = 0.079 rad. (a) Trajectory of the ball as shot from the Ball Shooting Machine towards the platform. (b) Swerved trajectory of the ball after actuation of the platform.

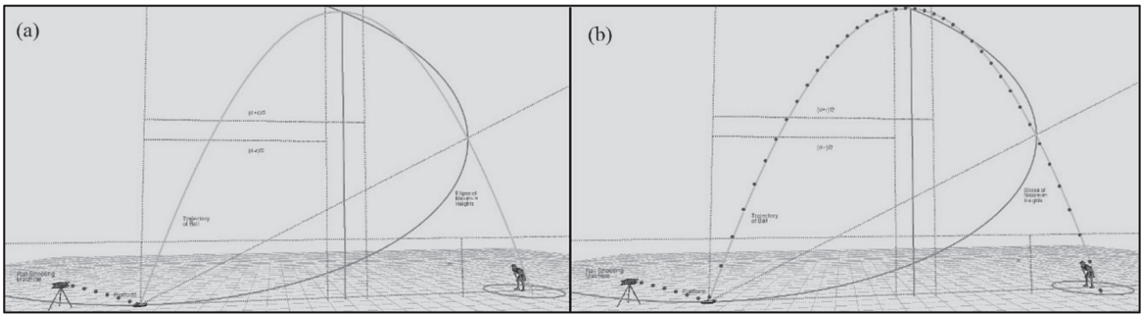

Figure 15: Screenshots of Simulation of a High Catch with Launch velocity of 18.00 m/s, angle of launch θ= 1.25 rad, H = 3 m, D = 20 m, R = 2 m and Φ = 0.059 rad. (a) Trajectory of the ball as shot from the Ball Shooting Machine towards the platform. (b) Swerved trajectory of the ball after actuation of the platform.

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