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# Evaluation of an Anthropometric Fast Bowling Machine

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**Abstract**

The use of bowling machines to train batsmen, whether it be indoors or outdoors, has increased significantly. In the absence of bowlers, batsmen can bat for hours without any bowlers getting tired. The designs of these machines are often derivatives of ball projection machines used for other sports, such as tennis. Reviewed literature highlights the deficit in visual information in the form of an arm and hand when using these machines. Hence, a cricket bowling machine was developed with an arm and hand. The usability, functionality, repeatability, and accuracy of the cricket bowling machine with an arm and hand were tested, which had been previously designed and built by Loutan Jr. (2016) at the University of Trinidad and Tobago. A trajectory model was developed for an indoor environment and experimentally validated with data collected from extensive testing of the bowling machine using Pitch Vision hardware and software. A design procedure had to be formulated to determine what tests had to be done and the method of collecting data. The testing, data collection, and validation of the model were done with the cricket bowling machine in its current state, with minor changes to the hand. The release angle at which the ball leaves the hand was found to have a significant impact on the length (distance along the pitch the ball bounces) of the delivery. Finally, the bowling machine was able to bowl various lengths and varying speeds consistently. The variation in speed placed the machine in the category of medium-fast, that is, speeds between 120 km/h (75 mph) and 130 km/h (81 mph).

*Keywords:* Arm and Hand; Testing Procedure; Collecting data; Repeatability and Validation.

## 1. Introduction

With the advent of the twenty-over format, the spectatorship of cricket has increased. This increase is fueled by the formation of individual country leagues that showcase teams comprised of players of various nationalities. The countries with the top 5 leagues are India, Australia, Pakistan, the Caribbean, and England, with the Indian Premier League having the highest brand value in 2018 at 4.5 billion USD [1-3]. Cricket has 3 major aspects: batting, bowling, and fielding, with bowling being the most difficult task in the game. Pace bowling generates the most injuries [4-8], with hamstrings being the most commonly reported and lumbar stress fractures being the most severe [7]. In reviewing data from South African national teams, it was identified that players younger than 24 years old were the most susceptible to bowling injuries [6].

Bartlett (2003) [5] correlated poor bowling technique (which is more predominant with younger bowlers) to greater rotational stress on the lumbar spine, causing disc bulging and degeneration. In a 9-year (2010-2018) study conducted, empirical proof was generated to highlight the importance of injury prevention and treatments to a team's success [9]. While it may be intuitive to assume that increased injuries decrease success, the authors found that this was only

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statistically true for division 1 teams in England and Wales and not for division 2 teams. The authors postulated that this phenomenon reflected the varying competitive standards between both divisions. It is evident that strategies are required to mitigate injuries sustained by players. One such strategy is an exercise-based injury prevention program [10].

The program also identified the need for managing bowling loads during training sessions and game time. This proposal of bowling load management is consistent with the findings [8] where 106 out of 276 match time-loss hamstring injuries occurred during training and warm-up sessions. Keeping track of bowling loads can be difficult in training as not all bowling deliveries constitute a pace delivery. Using a low-cost Inertial Measurement Unit (IMU) attached to bowlers and Machine Learning (ML) algorithms [11], they were able to accurately identify fast bowling events during training sessions. With managing bowling loads as the main rationale for the authors' research, the use of IMUs with ML can also be used to identify poor bowling techniques. Managing a bowler's bowling load, however, can affect batsmen training. Bowlers repetitively bowl deliveries that are particularly difficult for batsmen, thus allowing the batsmen to become attuned to the bowling action. To facilitate bowling load management without affecting batting drills, cricket bowling machines are employed by clubs and academies. Cricket bowling machines also provide solo training in the absence of a bowler.

Cricket bowling machines were originally repurposed ball pitching machines from other sports such as tennis. While bowling machines specific to cricket have since been developed, the mechanisms of ball delivery remain the same, counter rotating wheels, pneumatic cannons, and catapult mechanisms. The counter rotating wheel type bowling machines can be further categorised into the single, 2, 3 and 4 wheel types. Some common brands of the wheel type machines are Flicx, Bola, Winters, JUGS, Leverage, Merlyn, Slider, Paceman, Deuce and Heater. The Kanon Bowling Machine, manufactured by Howard Manufacturing in South Africa, is the only commercially available pneumatic cricket bowling machine.

To rationalize the development of a cricket bowling machine with an arm and hand, the mechanics of how a batsman generates a shot needed to be understood. An average fast bowler's delivery takes 600 ms to reach the batsman [12] while the batsman takes 200 ms to react and up to 700 ms to execute his body movement to play a shot [13]. Müller et al. (2006) conducted experiments where batsmen were asked to identify the delivery type from viewing videos of a fast bowler's run up, recorded from the batsman's end [13]. Varying body segments were occluded from the videos and the percentage accuracy in predicting the delivery type was recorded. It was concluded by the authors that the information regarding the ball's trajectory is gathered prior to the release of the ball, from the arm and hand. This conclusion agreed with a similar experiment previously done [14], where no statistical difference in predictions were obtained between run up and run up with early ball flight. While existing traditional machines can deliver balls at consistent length (distance along the pitch at which the ball bounces) and speed, they offer the batsman no pre-release data. The batsman thus becomes dependent on early ball flight data as suggested by experiments conducted [12]. The fovea's gaze angles of batsmen of varying skill levels were observed when facing a traditional bowling machine. The authors determined that the batsman gathers information about the flight of the ball during the first 100–150 ms of ball flight, at the time of bounce and 200 ms after bounce. The effects of this attunement to early ball flight data were determined experimentally [15, 16]. Differences in batsmen setup (batsman's body position before the ball is bowled) and trigger movement (the initial step the batsman does before striking the ball) when facing a human bowler and a traditional bowling machine were observed. To mitigate this, bowling machine operators signal the batsman before the ball is fed through the machine. This led to the development of a bowling machine with an arm and hand pneumatically actuated [17].

Capable of bowling speeds between 70 to 85 mph at vary delivery lengths, this proof of concept was deemed a success as batsmen were able to predict the delivery parameters more accurately as compared to a traditional bowling machine. A spring actuated arm type machine was developed at the University of Adelaide capable of bowling speeds up to 75 mph [18]. This machine however had limited control over the delivery speed and length, as well as a limited arm motion to provide a substantial visual cue. A cricket ball was delivered by a machine via a fully rotating arm at varying delivery lengths but no control of the speed [19]. The overall dimensions of the machine and arm are however not anthropometric. The batsman can thus become attuned to visual cues that are not as per a human bowler. The ProBatter Video Pitching Machine [20] developed by ProBatter Sports LLC, was establish in 1999 as a baseball pitching machine. In 2010 the machine was adapted for cricket bowling and in 2018 ProBatter developed the PX2 Cricket Simulator [20].

The system comprises of a conventional bowling machine hidden behind an 8' by 10' screen with a hole for passage of the ball. A video of an entire bowler's delivery from run up to ball release, recorded from the batsman's perspective, is projected on the screen. The TrueMan Bowling Simulator [21] developed by Bola also utilizes video projection and a conventional bowling machine. While pre-release information is provided to the batsman, the release point of the ball is identical for every delivery thus providing the batsman with a constrained variable that would otherwise be unconstrained when facing a human bowler. A bowling machine to simulate a human delivery must therefore be anthropometrically dimensioned, if it is to adequately address the lack of pre-release information afforded by current bowling machines and systems. This study focuses on evaluating the efficacy of an anthropometrically dimensioned fast bowling machine with an arm and hand, design and built by Loutan Jr. (2016) [22].

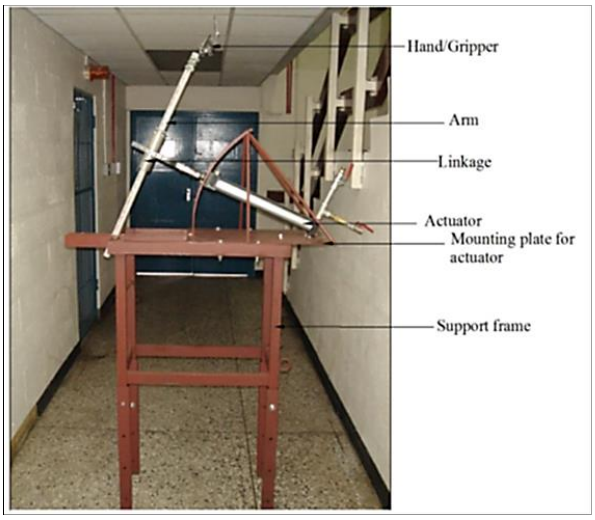


**Figure 1. Working bowling arm prototype [17]**

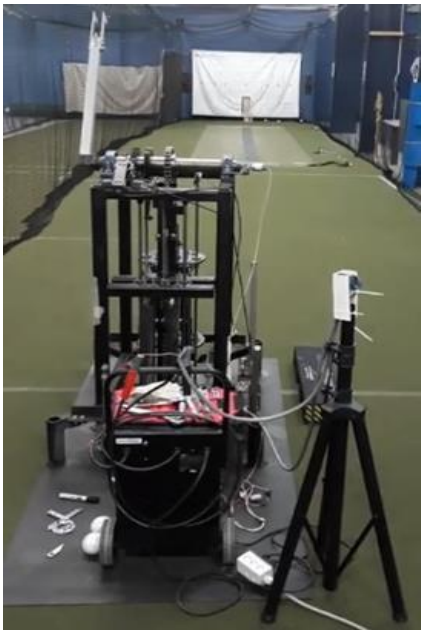

**Figure 2. An Anthropometric Fast Bowling Machine [22]**

## 2. Machine Design

Dieter (2000) [23] generalises the engineering design process to 8 stages starting with problem definition and ending with detailed design. This methodology is appropriate for the design of individual components or a system comprising of components of a similar type. Complexed systems however require methodologies specific to the type of system being designed. One such methodology is proposed by Puig et al. (2008) [24] for an anthropometrically dimensioned mechatronic device. Reviewed anthropometric data drives the mechatronic system design, followed by a re-evaluation of system dynamic models using experimentally obtained data this design process was thus adopted for the design of the cricket fast bowling machine with the problem being defined as a lack of pre-release data associated with existing bowling machines.

The design functions of the proposed machine were to be:

- Deliver a cricket ball at fast bowling speeds (88+ mph).
- Deliver a cricket ball via an arm with hand.
- Be anthropometrically dimensioned.

The operational steps of the machine were developed, and a functional flow chart was obtained. From this flowchart, the major components identified were:

- Actuation system
- Arm

- Hand
- Mechanical transmission system
- Braking system
- Measurement system
- Retract system
- Control system
- Frame

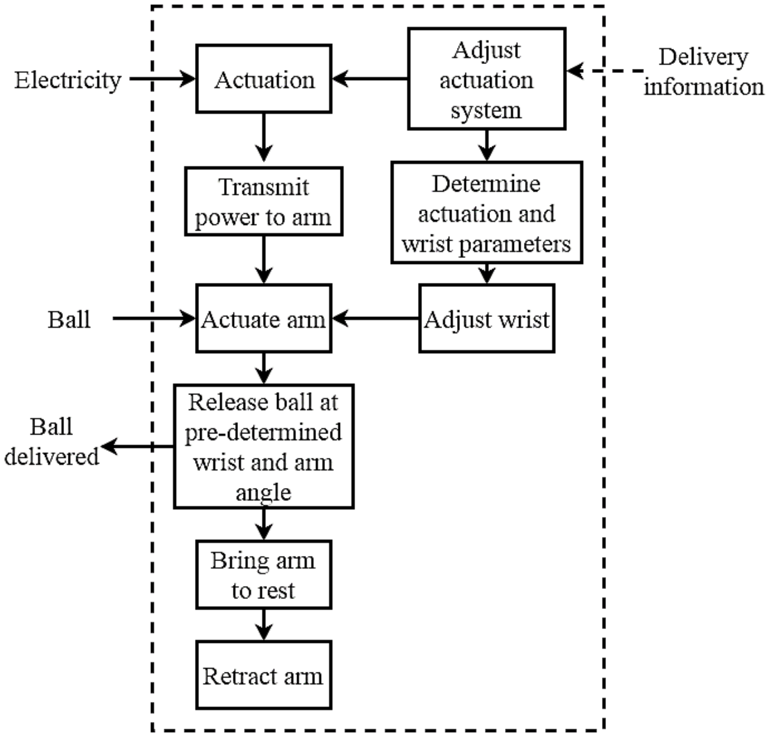


**Figure 3. Functional flow chart**

To establish the general dimensions of the machine, the biomechanics of a fast bowler's delivery was reviewed. During the delivery stride, the ball, just before release, acquires a height of 110 +/- 5% of the bowler's standing height [25]. The average height of 26 top ranking fast bowlers was determined to be 1.85 +/-0.085 m, which gave a corresponding ball release height of 2.035 m. Utilizing the anthropometric data of [26], this corresponded to arm, hand and shoulder dimensions of 0.614, 0.2 and 0.479 m respectively. These arm and hand lengths were comparable to the data obtained by Glazier et al. (2000) [27] of 0.661 and 0.199 m. The release position of the arm was proposed to be vertical to maximize the delivery length [28]. The evolution of the machine's final dimensions is given in Figure 2.

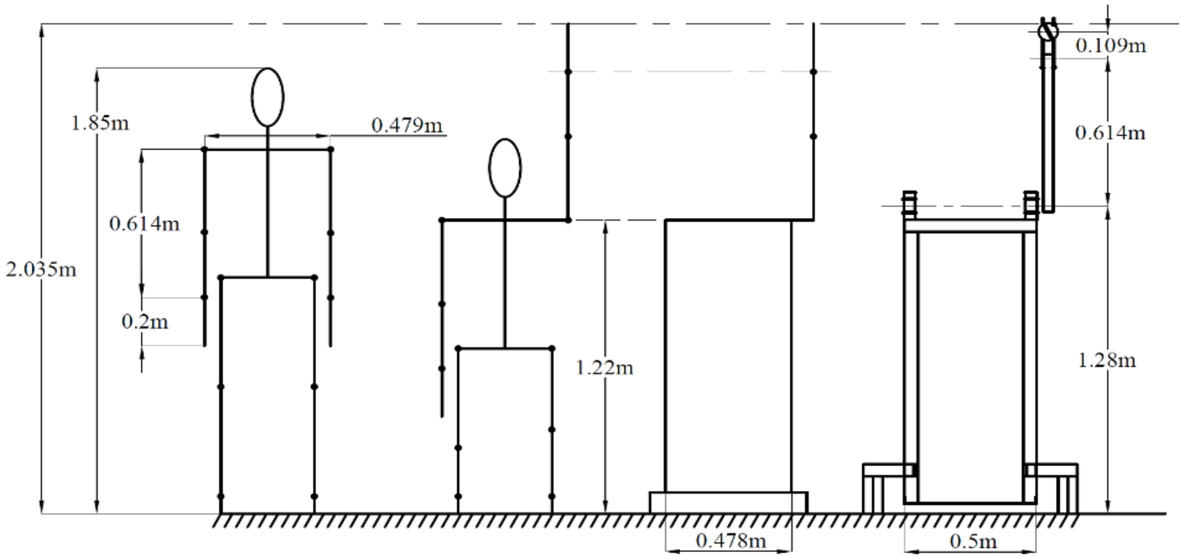


**Figure 4. The proposed overall machine dimensions: The arm, hand and shoulder lengths for a standing height of 1.85 m; During ball release, the stride length increases, and the shoulder is lowered**

### 2.1. Actuation and Braking System

The actuation system influenced the design of the braking, control, transmission, and retraction systems. In addition to being geometrically constrained to the anthropometric dimensions of the machine, other criteria; manufacturability, operational safety, power transmission, accuracy of mathematical model, power requirements and braking control, needed to be considered. The Analytic Hierarchy Process (AHP) was the decision-making tool employed. Having the highest rank, a linear spring assembly coupled to a shaft via a chain drive was selected as the actuation system. This chain drive extended to a pulley assembly coupled to another linear spring assembly to act as the braking system. The actuation springs are extended to a predetermined distance depending on the desired ball speed by a motor and power screw assembly. A bowling cycle is initiated by the release of this stored potential energy. As the braking springs are engage, the ball is released, and the kinetic energy of the arm is stored in the braking springs. The tension in the braking springs is utilized to retract the arm to its initial position. The delivery speed can be controlled by manipulating the extension of the actuation springs.

### 2.2. Hand Design

For fast and medium pace deliveries, the index and middle fingers are placed on either side of the seam, with the thumb on the underneath gently supporting the ball. An anthropometric survey of the hand conducted [29], was used to determine appropriate hand and finger lengths for a corresponding average fast bowler height of 185 cm. This height, which was in the 90$^{th}$ percentile of personnel surveyed, corresponded to a hand length of 20.7 cm [26, 27]. Corresponding thumb, index and middle finger lengths obtained were 7.6, 8.2 and 9.1 cm. The hand was fabricated out of aluminium with the ability of the wrist angle being adjusted. The thumb was spring loaded to keep the ball in the hand before initiating a bowling cycle. The delivery length can be controlled by manipulating the wrist angle.

### 2.3. Testing Methodology

Preliminary tests were done to validate the machine's mathematical models which were used to derive design parameters for component design. These tests did not evaluate the machine's efficacy as a training tool and as such the details of which are not presented in this paper. Evaluation testing of the machine was conducted in 2 phases.

The first phase of testing utilising the Pitch Vision Software was done with variation of the wrist angle at -5$^0$, 0$^0$, 5$^0$, -10$^0$, 2.5$^0$, -13$^0$, and -12.5$^0$. The speed of the deliveries remained constant at 80 mph, which corresponded to a spring extension or plate separation of 780 mm. The Pitch Vision software gave an accurate pitch map (position the ball bounces on the pitch) and length of each delivery for each wrist angle setting [30].

In the second phase of testing, batsmen at four (4) different levels, such as minor league, division league, national and international level batted against the bowling machine. Each batsman faced one (1) over (six (6) deliveries) delivered by the machine and then were asked to complete a survey.

## 3. Trajectory Model

For this project, we considered projectile motion of the ball leaving the hand. Then using projectile motion equations [31], a model equation was derived to predict the path of the cricket ball and to calculate the distance the ball will hit the pitch.

The conditions given for completing the model is as follows:

- Constant launch velocity, $V = 80$ mph (35.7 m/s).
- Forearm linkage, $l_1$ was held at an angle ($\Phi$) to the horizontal.
- Assumption that the ball was launched at 90$^0$ normal to the hand, $l_2$.

From the equations of motion [31], the Cartesian position of the ball is given as.

$$y = V_y t + \frac{1}{2} g t^2 \tag{1}$$

$$x = V_x t \tag{2}$$

Where; $V_x$ and $V_y$ are the velocity of the projected ball in the $x$ and $y$ directions, and $g$ is gravitational acceleration. From Figure 5, $V_x$ and $V_y$ are given as:

$$V_y = V \sin \propto \tag{3}$$

$$V_x = V \cos \propto \tag{4}$$

Considering the Figure 5,

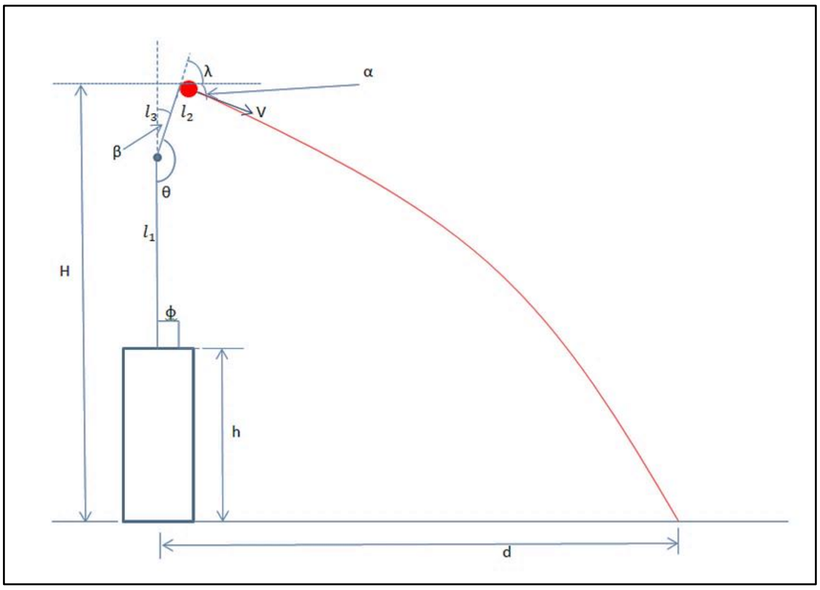


**Figure 5. The projected path with the wrist β to the vertical [32]**

Where $\propto$ is the angle between the $y$ or horizontal axis and the velocity $(V)$.

The release height of ball is given as:

$$H = l_1 + l_3 + h \tag{5}$$

At which the ball is projected. The velocity $(V)$ is projected $90^o$ from the hand.

Using trigonometry, it was determined that $\propto = \beta$, where $\beta$ is the wrist angle from the vertical.

For varying angle of the arm and wrist,

$$l_3 = l_2 \cos\beta \tag{6}$$

Combining the equations above and using projectile motion theory. The projected distance of the ball can be calculated using the model as follows:

$$\mathrm{d} = \mathrm{V}\cos\propto \left[\frac{-\mathrm{V}\sin\propto + \sqrt{(\mathrm{V}\sin\propto)^2 - 4\left(\frac{\mathrm{g}}{2}\right)(-\mathrm{H})}}{\mathrm{g}}\right] \tag{7}$$

Bartlett et al. (1996) [28] determined that a human bowler releases the ball at a forearm angle between $0–15^0$ to the vertical. Via video recording at 240 frames per second, it was determined that the machine's arm released the ball at a vertical angle of 7.97. This corresponded to $\Phi$= 82.03 and thus was used in predicting the delivery length in Table 1.

**Table 1. Calculation of delivery lengths at varying wrist angles with V =35.8 m/s (80 mph), Φ = 82.03$^0$, $l_1$= 0.614 m and $l_2$=0.2 m, h = 1.221 m [32]**

| Wrist Angle, β (degrees) | Distance from Bowler, d (m) | Distance from Striker, D (m) | Delivery Type |
|---|---|---|---|
| -5 | 17.123 | 2.997 | Full |
| -2 | 13.019 | 7.100 | Good |
| 0 | 11.028 | 9.012 | Short |
| 2 | 9.604 | 10.516 | Short |
| 2.5 | 9.137 | 10.983 | Short |
| 3 | 8.821 | 11.299 | Short |
| 5 | 7.722 | 12.398 | Short |
| 7 | 6.829 | 13.291 | Short |
| 9 | 6.096 | 14.024 | Short |
| 10 | 5.777 | 14.343 | Short |

## 4. Results and Discussion

In phase 1 testing, 6 overs were bowled at a constant spring extension of 780 mm (80 mph), with the wrist angle being manipulated for each over. Three (3) overs were then bowled at a constant wrist angle of $0^0$ but with the spring extension varied for each over. The Pitch Vision system obtained the length of each delivery from the striker's end (D) and generated a pitch map colour coded by over number. The $7^{th}$ over has been eliminated from Table 2 due to its results being compromised.

**Table 2. Table of results for 9 overs bowled.**

| Delivery Number | Length of Delivery (Meters, m) | Type of Delivery |
|---|---|---|
| | ***$1^{st}$ Over - Wrist angle at $0^0$ (White dots on pitch map)*** | |
| 1 | 9.8 m | Short |
| 2 | 9.5 m | Short |
| 3 | 9.1 m | Short |
| 4 | 8.6 m | Short |
| 5 | 8.8 m | Short |
| 6 | 9.5 m | Short |
| | ***$2^{nd}$ Over - Wrist angle at $-5^0$ (Green dots on pitch map)*** | |
| 1 | 9.7 m | Short |
| 2 | 9.9 m | Short |
| 3 | 10.0 m | Short |
| 4 | 9.8 m | Short |
| 5 | 10.0 m | Short |
| 6 | 10.0 m | Short |
| | ***$3^{rd}$ Over - Wrist angle at $5^0$ (Orange dots on pitch map)*** | |
| 1 | 10.6 m | Short |
| 2 | 10.3 m | Short |
| 3 | 10.5 m | Short |
| 4 | 10.3 m | Short |
| 5 | 10.6 m | Short |
| 6 | 10.7 m | Short |
| | ***$4^{th}$ Over - Wrist angle at $-10^0$ (Red dots on pitch map)*** | |
| 1 | 3.7 m | Full |
| 2 | 4.5 m | Good |
| 3 | 6.0 m | Good |
| 4 | 5.7 m | Good |
| 5 | 4.1 m | Good |
| 6 | 3.7 m | Full |
| | ***$5^{th}$ Over - Wrist angle at $2.5^0$ (Light Blue dots on pitch map)*** | |
| 1 | 9.8 m | Short |
| 2 | 10.1 m | Short |
| 3 | 10.0 m | Short |
| 4 | 10.0 m | Short |
| 5 | 10.3 m | Short |
| 6 | 9.4 m | Short |
| | ***$6^{th}$ Over - Wrist angle at $-12.5^0$ (Yellow dots on pitch map)*** | |
| 1 | 2.6 m | Full |
| 2 | 3.5 m | Full |
| 3 | 3.3 m | Full |
| 4 | 4.0 m | Full |
| 5 | 3.5 m | Full |
| 6 | 3.6 m | Full |

| | | |
|---|---|---|
| ***8th Over – Wrist angle at 00 and plate separation of 600 mm (Blue dots on pitch map)*** | | |
| 1 | 7.3 m | Just short |
| 2 | 6.9 m | Good |
| 3 | 6.9 m | Good |
| 4 | 6.4 m | Good |
| 5 | 7.0 m | Good |
| 6 | 6.8 m | Good |
| ***9th Over – Wrist angle at 00 and plate separation of 550 mm (Black dots on pitch map)*** | | |
| 1 | 3.5 m | Full |
| 2 | 3.9 m | Full |
| 3 | 3.9 m | Full |
| 4 | 4.2 m | Good |
| 5 | 4.2 m | Good |
| 6 | 4.0 m | Full |
| ***10th Over – Wrist angle at 00 and plate separation of 700 mm (White dots on pitch map)*** | | |
| 1 | 7.9 m | Short |
| 2 | 7.9 m | Short |
| 3 | 8.4 m | Short |
| 4 | 7.8 m | Short |
| 5 | 8.0 m | Short |
| 6 | 7.9 m | Short |

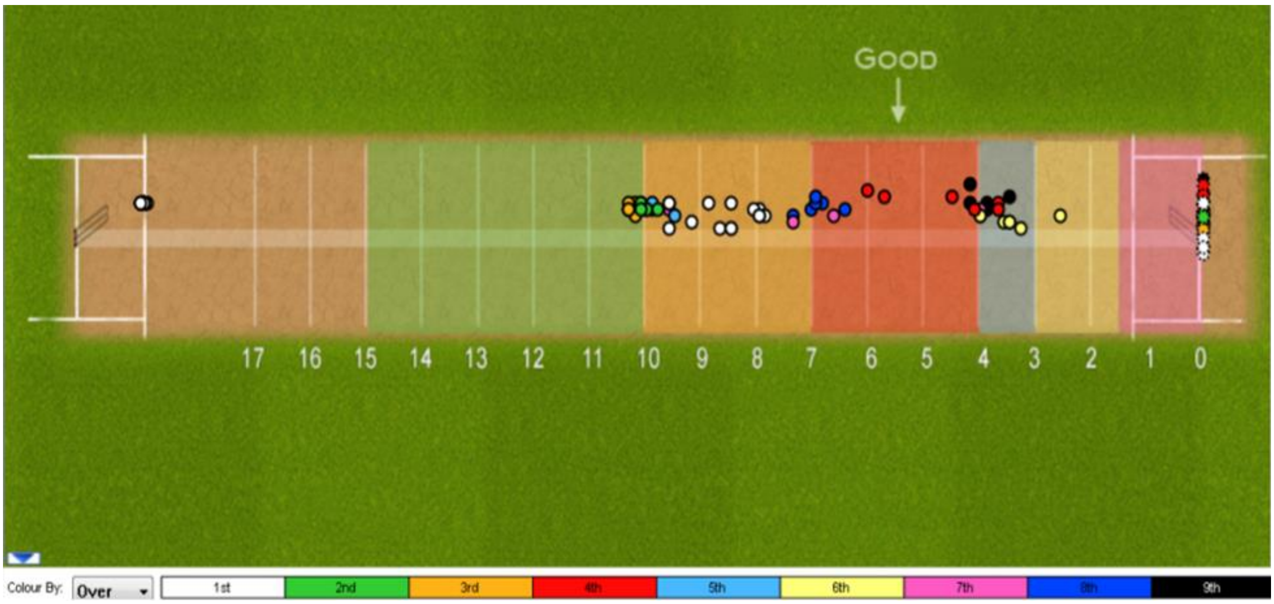


**Figure 6. Pitch map of data collected for from Table 2.**

Phase Two (2) testing involved batsmen coming up against the machine at the Novel Sports facility [33]. The data below was taken at a wrist angle at $0^0$, with the forearm linkage ($l_1$) at $82^0$ to horizontal ($\Phi$) and the assumption remains that the ball launches at $90^0$ normal the hand. These settings coupled with varying the plate separation between 600 mm and 800 mm will give the different types of lengths and variation on speed. The table below shows the data collected from testing with batsmen.

**Table 3. Showing data used in test with batsman.**

| **Wrist angle at $0^0$** | | |
|---|---|---|
| **Plate Separation (mm)** | **Length of Delivery (m)** | **Type of Delivery** |
| 600 mm to 700 mm | 2 m to 4 m | Full |
| 701 mm to 750 mm | 4 m to 8 m | Good |
| 751 mm to 800 mm | 8 m to 12 m | Short |

The plate separation on the bowling machine corresponds to the speed of the deliveries. The range of the plate separation shown in Table 3 gives a speed range of 50 mph to 83 mph which places the bowling machine in the medium fast category.

A survey was done to get the coach's and the players perspective of the machine. A total of ten (10) batsmen were asked to bat against the machine and complete a survey. Each batsman faced six (6) deliveries at varying length and speed. Then five (5) coaches were asked for their views and comments about the bowling machine with the arm and hand. The table below shows the results of the survey.

**Table 4. Results of the survey conducted [32]**

| | **Feasibility** | | **Training Aid** | | **Compared with other Machines** | | |
|---|---|---|---|---|---|---|---|
| | Feasible | Not | Yes | No | Better | Not Better | Do not know |
| Coach | 5 | 0 | 5 | 0 | 5 | 0 | 0 |
| | **Feasibility** | | **Batsman Set-Up** | | **Compared with other Machines** | | |
| | Feasible | Not | Normal | Different | Better | Not Better | Do not know |
| Batsman | 10 | 0 | 10 | 0 | 9 | 0 | 1 |
| Others | 2 | 0 | | | 2 | 0 | 0 |

Some of the comments made by the batsmen who faced the machine are; "it's very realistic, since you can follow the ball from the hand", "much better than the traditional machine", "I am really impressed with the machine and its performance", "the ability to follow the arm was clear and clean", "good swift movement which mimic a bowling action", "like how it quick".

The design process assisted in making several changes and recommendations for the bowling machine. Some of the changes made were the redesign of the hand for testing. These changes included replacing the 3D printed fingers with 2 single fingers were fabricated out of aluminium and bolted directly to the arm with bigger bolts and spacers for strength and stability and a spring-loaded thumb made of aluminium 1" flat and wrapped with duct tape to provide better gripping of the ball before delivery. A rubber band was used in place of an extension spring for the thumb as the band's non-linear elastic nature provided a more desirable ball release than a linear spring.

Another addition was the limiter for the upper plate which prevented the plate from running out of the threaded bar and made the reloading process faster and more efficient. To decrease the reload time further, markings were placed on a metal angle iron running alongside the plates to indicate specific distances between the plates such as 600, 650, 700, 750, 780, and 800 mm.

A new hand design was done as a recommendation for upgrade and future work on the machine. This new hand design will allow for thumb movement and axial wrist rotation. The thumb will be actuated by a solenoid and spring loaded for return. A servo motor will be connected to the wrist from inside the arm to axially rotate the wrist. The 1st and 2nd fingers will be fixed to grip the ball. The 3rd and 4th finger will also be fixed in a closed position. The thumb will be hinged, and spring loaded to hold or grip the ball in position. Aluminium or a lightweight composite material will be used to build the hand.

The procedure to set the wrist angle was a bit difficult and inaccurate since the bolts had to be loosen, the fingers set at the required angle using a protractor and then held in place while the bolts were tightened. Hence, the wrist angle would not be precise and from calculations done, if the angle is off by 0.5 of a degree it will give a difference in length of 0.5 meters which will account for the variation in lengths.

These changes before and during testing gave rise to successful testing and data collection. It can be concluded that the machine is proficient in achieving the design function.

### 4.1. Comparison of Data

The experimental values were obtained from the Pitch Vision software [30] during testing, while the calculated values were derived from the model equation (Equation 7). The average experimental value was calculated since six (6) values were taken for each wrist angle setting. Table 5 shows the comparison of the data for three (3) wrist angles.

**Table 5. The table showing a comparison of experimental data and calculated data.**

| Wrist angle, β (deg) | Plate Separation (mm) | Average Experimental value. (m) | Calculated Value, D (m) |
|---|---|---|---|
| 0 | 780 | 9.217 | 9.012 |
| 2.5 | 780 | 9.933 | 10.983 |
| **5** | **780** | **10.500** | **12.395** |

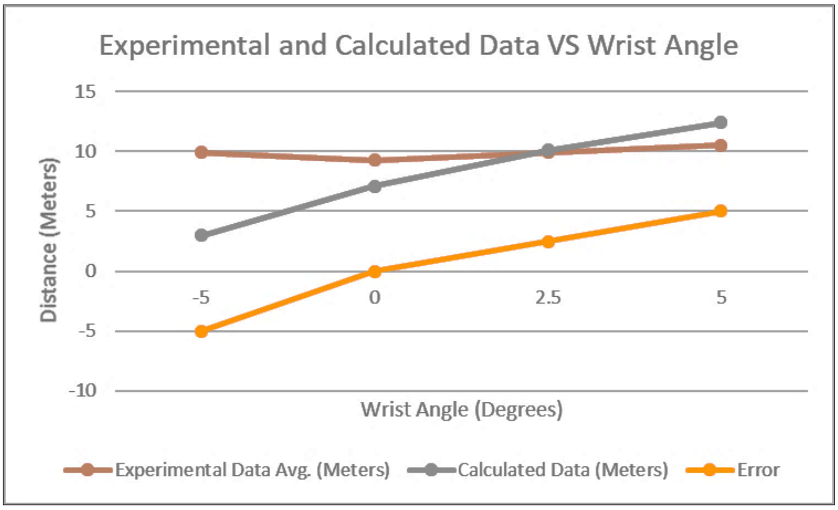


**Figure 7. The graph showing a comparison of experimental data and calculated data against Wrist Angle.**

The results showed at $0^0$ wrist angle the error was at 2.2% between the experimental and calculated value. At the larger angles, the error increased to 9.7% for a $2.5^0$ wrist angle and 14.6% for a wrist angle of $5^0$. As the wrist angle increases from the $0^0$ in both directions, the error increases. This was due to the inaccurate adjustment of the wrist angle. The wrist had no specific setting for the various angles.

A study was done in 2010 to determine how often fast and fast medium bowlers were bowling balls in the channel outside the off stump [34]. The results indicated that 73% of balls bowled were in the channel outside off-stump, and nearly a quarter of balls are bowled short of a good length. The data used to produce those results included all Twenty20 internationals from June to November 2009, and the 2009 Twenty20 Champions League. The data included approximately 4800 balls bowled by fast and medium-fast bowlers. Looking at the data collected from Pitch Vision, after testing the bowling machine, showed that of the 78 balls bowled 92.3 % of the balls were outside the off-stump channel. This indicates that the bowling machine is statistically more accurate and repeatable when compared to actual bowlers.

## 5. Conclusions

The testing procedure was developed to perform specific tests on the bowling machine using Pitch Vision to evaluate the machine's accuracy and repeatability. Looking at the experimental data in the results above, the machine is very accurate and reliable, as presented in Table 2. For instance, the 2nd and 3rd overs showed a variation in length of 0.4 meters, the 8th over had a variation in length of 0.5 meters, and the 10th over had a variation of 0.6 meters. The grouping of the deliveries in each over is in and around the one (1) meter mark.

The testing with the batsmen proved that the machine is functional and valid since it allowed the batsmen to set up or perform their trigger movements as they would in a match and not have to change to suit the traditional bowling machine. The batsmen were able to follow the ball from the hand of the machine all the way to the bat, rather than being unsighted for a fraction of time when the ball passes through the traditional bowling machine before being shot out to the batsmen. The bowling machine would be able to bowl different types of deliveries with various combinations of wrist angle and plate separation (which correspond to speed). This variation in length and speed could also be achieved by maintaining a fixed wrist angle and varying the plate separation as presented in Table 2.

In conclusion, the evaluation done on the bowling machine with the arm and hand, developed by Loutan Jr. at the University of Trinidad and Tobago, with and without a batsman, proves that the machine is usable, functional, repeatable, and accurate. Hence, it would be a great piece of equipment to assist coaches in their quest to produce the best cricketers. This also proves that the machine can be used for training (working on specific skills or techniques) and game situations (making it as unpredictable as in a real match).

## 6. Declarations

### 6.1. Author Contributions

Conceptualization, P.P. and K.L.Jr.; methodology, K.L.Jr.; software, Ronnie Bickramdass.; validation, P.P., K.L.Jr. and R.B.; formal analysis, R.B.; investigation, R.B.; resources, K.L.Jr.; data curation, R.B. and K.L.Jr.; writing—original draft preparation, R.B.; writing—review and editing, P.P., K.L.Jr. and R.B.; visualization, R.B.; supervision, P.P.; project administration, R.B.; funding acquisition, K.L.Jr. and R.B. All authors have read and agreed to the published version of the manuscript.

### 6.2. Data Availability Statement

The data presented in this study are available in article.

### 6.3. Funding and Acknowledgements

The students and other team members used their personal finances to build and test the bowling machine with some assistance from The University of Trinidad and Tobago. However, university laboratory facilities and materials were used to build and test the bowling machine with the permission of the institution.

### 6.4. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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