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LAPORAN PROJEK SARJANA MUDA

DESIGN AND DEVELOPMENT OF HIGH ACCURACY SHUTTLECOCK LAUNCHING SYSTEM

Shitian Ling

Bachelor of Mechatronics Engineering with Honours

June 2014

“ I hereby declare that I have read through this report entitle “Design and Development of High Accuracy Shuttlecock Launching System” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronics Engineering with Honours.”

Signature : ....

Supervisor’s Name : ....

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DESIGN AND DEVELOPMENT OF HIGH ACCURACY SHUTTLECOCK LAUNCHING SYSTEM

SHITIAN LING

A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Mechatronics Engineering with Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

I declare that this report entitle "Design and Development of High Accuracy Shuttlecock Launching System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

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ABSTRACT

In many sports such as tennis and table tennis, there are training machines available for exercises or training purpose. The benefits in using these machines with high functionality and comparatively low cost have contributed to their extreme skills improvement. The machines setting duplicated accurately for every shots. Thus training on particular areas of the player's game is relatively simple and more focused. Badminton players can acquire same advantages as mentioned with a shuttlecock feeder machine. There are machines rarely available in the market. One of the options for consumers is the Knight Trainer, which consists of two rotating wheels to transmit the shuttlecock. However, the cost is extremely expensive to invest in with a minimum of RM15, 000. The overall look of Knight Trainer has all the desired qualities but it does possess numerous deficiencies. From the reviews by several badminton players, the machine is unpractical, less accurate and retains high initial and operating costs. This research aims to improve the accuracy of Shuttlecock Launching System (SLS) by studying the shuttlecock trajectory. Besides, the aim to design and develop a low cost solution in manufacturing so that the SLS is allowed for a retail price comparable to machines in other sports. Research had been conducted on the trajectory of shuttlecock to predict the angles and velocities needed to launch different types of shot. From the study, a desired motor specification can be obtained by computing the torque and speed required. The results obtained with two approaches are compared by analyzing the trajectory models occurred from the simulations. The accuracy of feeder mechanism are founded (12 ± 15.8) mm and (15.4 ± 13) mm with standard deviation of 5.716 mm and 5.824 mm respectively. For the launching mechanism, results showed an error percentage as low as 4.70% at an angle setting of $22.5°$ for the shuttlecock trajectory. For overall system of SLS, the accuracy for angle settings of $22.5°$, $45°$ and $67.5°$ achieved 20%, 0% and 60% respectively.

ABSTRAK

Dalam banyak sukan seperti tenis dan *ping pong*, terdapat mesin latihan yang disediakan untuk tujuan latihan. Manfaat dalam menggunakan mesin ini dengan fungsi yang tinggi dan kos yang agak rendah telah menyumbang kepada peningkatan kemahiran yang melampau mereka. Penubuhan mesin diulang tepat untuk setiap pukulan. Oleh itu, latihan dalam bidang-bidang tertentu permainan pemain adalah agak mudah dan lebih fokus. Pemain badminton boleh memperoleh kelebihan yang sama seperti yang dinyatakan dengan mesin feeder *shuttlecock*. Salah satu pilihan untuk pengguna adalah *Knight Trainer*, yang terdiri daripada dua roda berputar untuk menghantar bola itu. Walau bagaimanapun, kos sangat mahal untuk melabur dalam sekurang-kurangnya RM15,000. Kelihatan keseluruhan *Knight Trainer* mempunyai semua ciri yang dikehendaki tetapi ia mempunyai banyak kekurangan. Dari ulasan mengikut beberapa pemain badminton, mesin tersebut kurang praktikal, kurang tepat dan mengekalkan kos permulaan dan operasi yang tinggi. Penyelidikan ini bertujuan untuk meningkatkan ketepatan *Shuttlecock Launching System (SLS)* dengan mengkaji trajektori *shuttlecock* itu. Selain itu, matlamat untuk mereka bentuk dan membangunkan satu penyelesaian kos rendah dalam pembuatan supaya *SLS* dibenarkan untuk harga runcit setanding dengan mesin dalam sukan lain. Penyelidikan telah dijalankan pada trajektori *shuttlecock* untuk meramalkan sudut dan halaju yang diperlukan untuk melancarkan pelbagai jenis pukulan. Dari kajian ini, spesifikasi motor yang dikehendaki boleh diperolehi dengan mengira *torque* dan kelajuan yang diperlukan. Keputusan yang diperolehi dengan dua pendekatan berbanding dengan menganalisis model trajektori berlaku dari simulasi. Ketepatan mekanisme feeder adalah diasaskan (12 $\pm$ 15.8) mm dan (15.4 $\pm$ 13) mm dengan sisihan piawai masing-masing 5.716 mm dan 5.824 mm. Untuk mekanisme pelancaran tersebut, keputusan menunjukkan peratusan kesilapan serendah 4.70% pada tetapan sudut sebanyak 22.5° untuk trajektori *shuttlecock* itu. Untuk sistem keseluruhan *SLS,* ketepatan untuk tetapan sudut sebanyak 22.5°, 45°, dan 67.5° mencapai 20%, 0%, dan 60% masing-masing.

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FIGURE	TITLE	PAGE

LIST OF SYMBOLS

x	-	Horizontal displacement
y	-	Vertical displacement
t	-	Time taken
v	-	Velocity
a_c	-	Constant acceleration
g	-	Gravity acceleration
F	-	Force
F_i	-	Resistive force
F_a	-	Buoyant force
α, k	-	Constant
m	-	Mass
θ	-	Angle
d	-	Distance travel
V	-	Volume
ρ	-	Density
η	-	Dynamic viscosity
R	-	Radius

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CHAPTER 1

INTRODUCTION

1.1 Motivation

These days, badminton is one of the famous racquet sports in the world and has been comprised in Olympic Games organizations, which are the leading international sporting event with more than 200 nations participating. Footwork is about movement skills. While it's obvious that racket skills are important, good movement skills are often underestimated by players. Good footwork supports players to reach the shuttlecock early and it is desirable in all state of affairs.

There are various types of training for the experts in the badminton circles. One of the popular ways of training is the “Multi-shuttle” training session. This training works with a lot of shuttlecocks which the coach will throw towards the player to achieve the strokes. The training phase can be distributed into two types:

a) Technical
   - Carry out different shot techniques such as smash, clear, drop and defensive shots, net play, backhands and drive shot.
   - Practice various movements on court which includes running to net, to side, backwards and jumping.

b) Physical
   - For the stamina, aerobic and anaerobic endurance
   - For the durability, explosive strength and concentration strength
   - For the speed consistency, stability and speed of reaction and action

Multi shuttlecock drills suit the technical training very well because it allows coach to allocate the direction, speed and angle of the flight of shuttlecocks. For drop, clear, smash and backhand strokes, shuttlecock travels at a high trajectory to the back line of the court. Player has to reach the shuttlecock and perform an overhead stroke as shown in Figure 1.1.

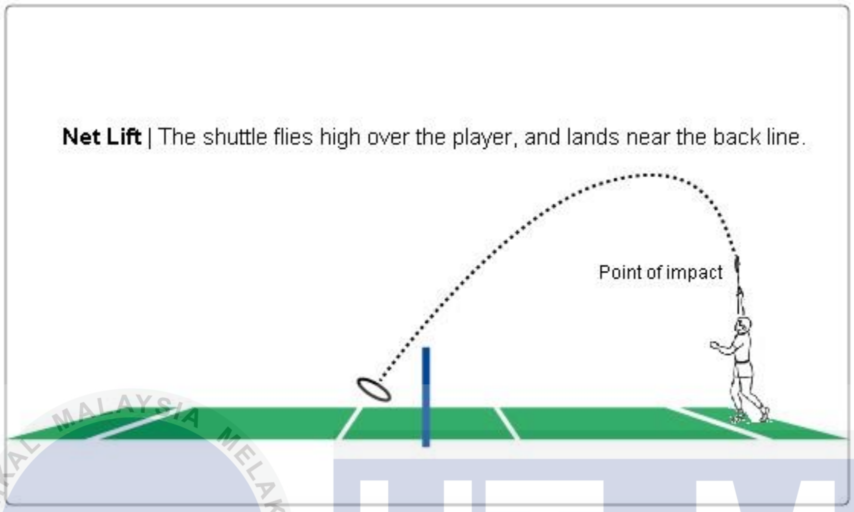


Figure 1.1 Net lift

For net play and drive shot, these shots are done in the fore court which is nearest to the net area. Net play is targeted shot that propel the shuttlecock across the net at an angle perpendicular to the floor. This will make the player runs toward the net to perform net play as well as drive shot. The trajectory of the shuttlecock is the lowest as shown in Figure 1.2.

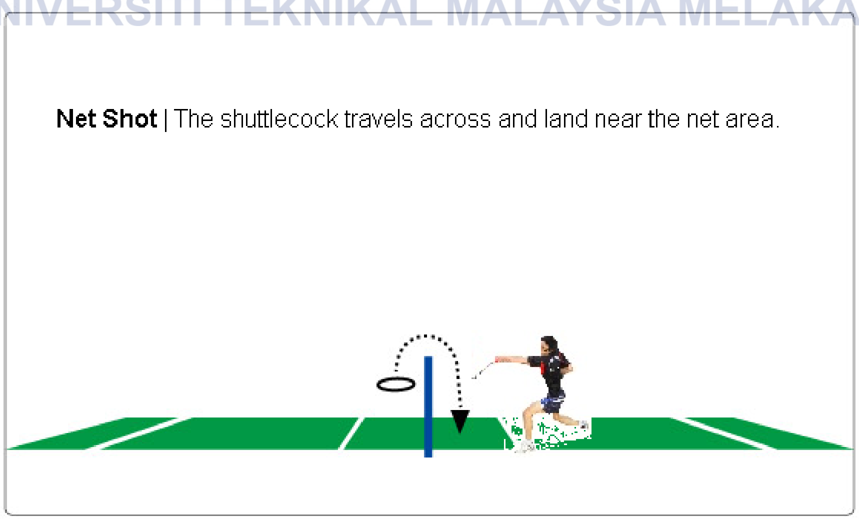


Figure 1.2 Net shot

Regarding defensive shot, it is performed after a smash shot. During smash shot, shuttlecock travels with a high speed and power downward to the player which is usually done from the back line of the court. The angle of shuttlecock's trajectory is relatively low with high steepness as shown in Figure 1.3. Therefore, it is difficult for player to carry out a defensive shot.

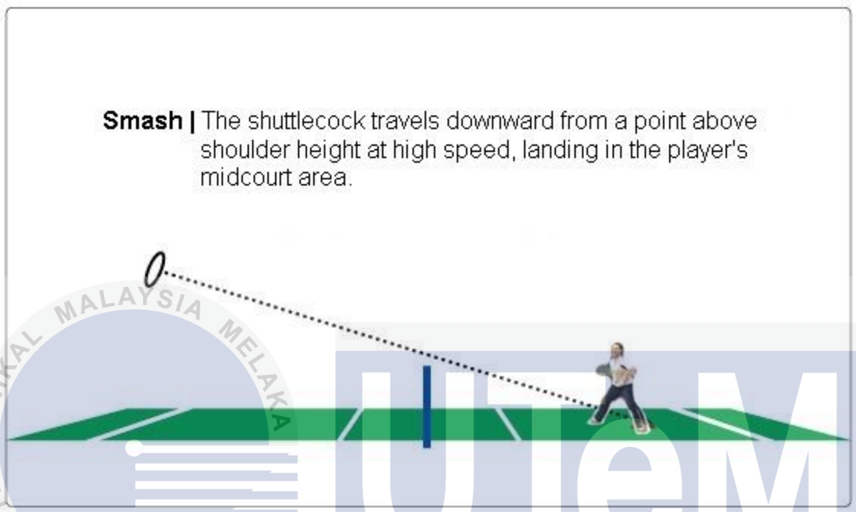


Figure 1.3 Smash shot

As a badminton coach to conduct a technical training, he/she has to perform shuttlecock serve to the player with different speeds, directions, as well as angles. A set of this training usually requires 100 shuttlecocks serve at a time. During training period, coach has to repeat the serve and collect the shuttles. This will consume lots of energy for a coach to deal with several players at a time. With this Shuttlecock Launching System (SLS), coaches can simply concentrate on coaching whilst improve badminton skills of the players. Furthermore, players can improve their performance which focuses on their agility in the competition.

1.2 Problem Statement

The research is initiated by evaluating the problem statement so that the objective can be achieved among the scope and limitation of the research.

The problem faced in badminton field there is no machine which is comprehensive to replace coaches or practice partner during training. The ability to practice independently has been limited. However, the available products on the market are expensive which cost at least RM9000 and make the product has not be in great demand to the public. This is because the machines contain two high speed motors which are costly. Besides, the other problem is the existing products mostly consist of two rotating wheels as the shuttlecock launcher. From the research it was examined that this type of actuation system can destroy the cork when it is dragged into the launching mechanism[2]. Also, the accuracy of launching the shuttlecock to a target is affected by the rotating wheels. This is led by different speeds of the rotating wheels which are difficult to be synchronized[3]. For the feeder mechanism, the problem faced during the operation is the irregular position of shuttlecocks in the storage as shown in Figure 1.4. This may lead to the inaccurate shot when the shuttlecock is supplied to the launching mechanism. Other than that, another challenge is the time-optimal control between the feeder and launching mechanism which is shown in Figure 1.5. The racket has to move to an exact position where the intersection between racket and shuttlecock occurs.

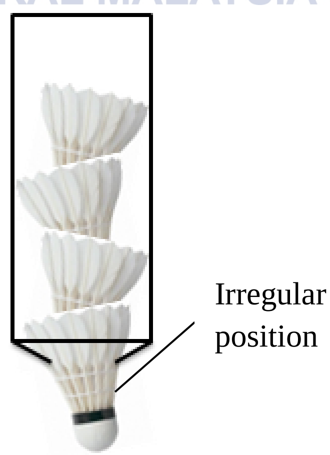


Figure 1.4 Illustration of feeder storage with irregular shuttlecocks' position

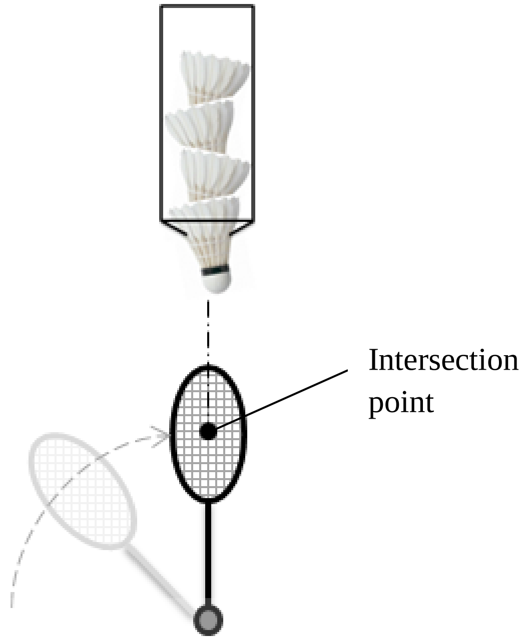


Figure 1.5 Overview of hit operation

1.3 Project Objectives

- To design and develop a Shuttlecock Launching System (SLS) with lateral swing.
- To analyze the accuracy and improve performance of the machine by simulating the existed trajectory of shuttlecock.

1.4 Scope of the project

This research focuses on:

- The design of electric and electronic parts of SLS.
- The development of shuttlecock launching prototype in which the desired position of shot is adjustable.
- Analysis on the accuracy of the shots and verify with the existed trajectory equation.

1.5 Outline of the Dissertation

The remainder of the report is organized as follows. First, the theory of SLS is introduced in Chapter 2, which also involves SLS problem, performance indices, comparison among available solutions and summary of literature review. Next, research methodology is developed in Chapter 3. The experimentally obtained results and analysis are then presented in Chapter 4 and discussed in details. Finally, conclusion and future works are drawn in Chapter 5 and the references are stated after that.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory of Shuttlecock Launching System (SLS)

2.1.1 Motion of a Projectile

The current study is to understand the aerodynamics of shuttlecock. Shuttlecock travels in curvilinear motion which moves along a curved path. Thus, vector analysis is used to formulate the position, velocity and acceleration of the shuttlecock. Consider a shuttlecock launched at a point (x_0, y_0), with an initial velocity of v_0, having components $(v_0)_x$ and $(v_0)_y$ as shown in Figure 2.1. The weight causes the projectile to have a constant downward acceleration, $a_c = g = 9.81\ m/s^2$.

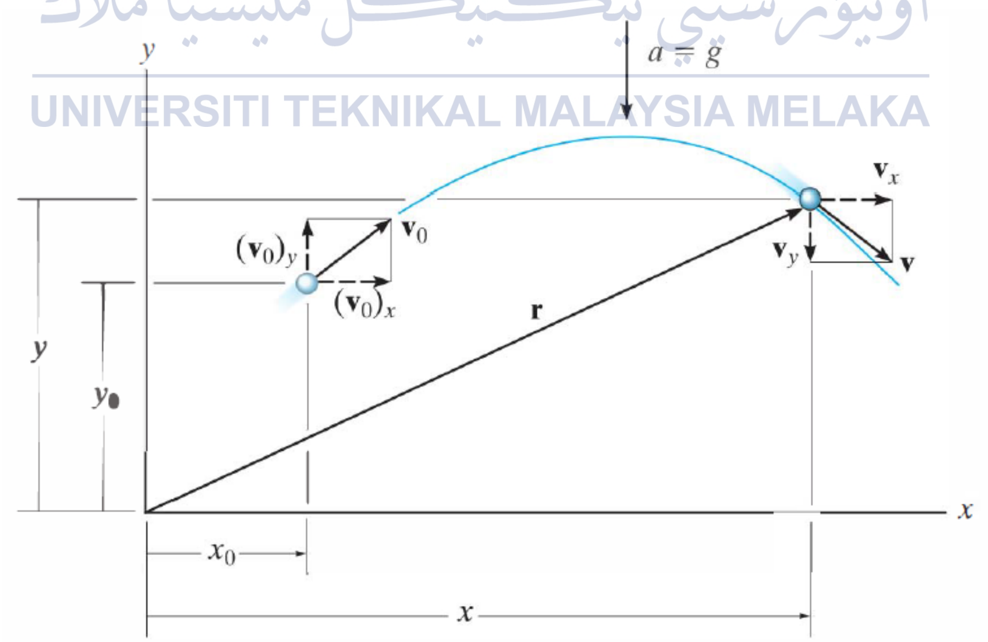


Figure 2.1 Trajectory of shuttlecock[4]

Horizontal Motion

The velocity in the horizontal direction always remain constant, and $a_x = 0$. Hence,

$$x = x_0 + (v_0)_x t \tag{2.1}$$

Vertical Motion

Since the acceleration is directed upward, then $a_y = -g$. Then,

$$v_y = (v_0)_y - gt \tag{2.2}$$

$$y = y_0 + (v_0)_y t - \frac{1}{2} g t^2 \tag{2.3}$$

$$v_y^2 = (v_0)_y^2 - 2g(y - y_0) \tag{2.4}$$

To analyze the motion of shuttlecock in the air, the air resistive force is taken into account. There are two models of equation: a linear model (air resistive force is assumed linear in the velocity of shuttlecock) and a quadratic model (air resistive force is assumed quadratic in the velocity of shuttlecock). Since the air resistive force is assumed linear in this research, linear model of air resistance is chosen to describe the motion of shuttlecock. It does not require complicated calculation in collecting data. Theoretically, the resistive force is written as $F_i = -(\alpha_i + kv_i)$, Assume that $\alpha_x = \alpha_y = \alpha$[5].

For horizontal direction,

$$m\frac{dv_x}{dt} = -\alpha - kv_x \tag{2.5}$$

For vertical direction,

$$m\frac{dv_y}{dt} = -mg + F_a - \alpha - kv_y \tag{2.6}$$

where F_a is the buoyant force. By integrating both equations 2.5 and 2.6, the velocities for the vertical and horizontal direction will be,

$$v_x = \frac{dx}{dt} = v_0 cos\theta e^{-\frac{kt}{m}} - \frac{\alpha}{k}(1 - e^{-\frac{kt}{m}}) \tag{2.7}$$

$$v_y = \frac{dy}{dt} = v_0 sin\theta e^{-\frac{kt}{m}} + \frac{mg + F_a - \alpha}{k}(1 - e^{-\frac{kt}{m}}) \tag{2.8}$$

Equation 2.7 and 2.8 is then integrated to give the position of shuttlecock,

$$x = x_0 + v_0 cos\theta \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right) - \frac{\alpha}{k}\left(t - \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right) \tag{2.9}$$

$$y = y_0 + v_0 sin\theta \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right) + \frac{-mg + F_a - \alpha}{k}\left(t - \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right) \tag{2.10}$$

2.1.2 Principle of Linear Impulse and Momentum

From Newton's second law, the principle of impulse and momentum is obtained by integrating the equation of motion with respect to time. Using kinematics, the equation of motion can be written as

$$\Sigma \boldsymbol{F} = m\boldsymbol{a} = m\frac{d\boldsymbol{v}}{dt} \tag{2.11}$$

where **a** and **v** are measured from an inertial frame of reference. Between the limits $\boldsymbol{v} = \boldsymbol{v_1}$ at $t = t_1$ and $\boldsymbol{v} = \boldsymbol{v_2}$ at $t = t_2$, we have

$$\Sigma \int_{t_1}^{t_2} \boldsymbol{F}\, dt = m \int_{v_1}^{v_2} d\,\boldsymbol{v} \tag{2.12}$$

$$m\boldsymbol{v_1} + \boldsymbol{\Sigma} \int_{\boldsymbol{t_1}}^{\boldsymbol{t_2}} \boldsymbol{F}\, dt = m\boldsymbol{v_2} \tag{2.13}$$

Equation 2.13 can be illustrated graphically on the impulse and momentum diagrams as shown in Figure 2.2.

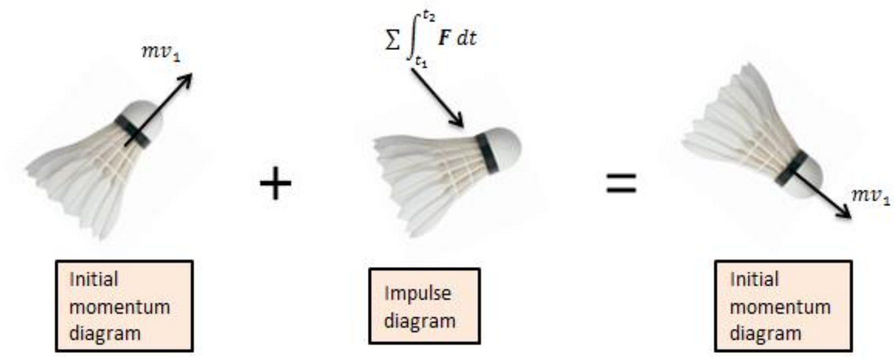


Figure 2.2 Impulse and momentum on shuttlecock

The principle of linear impulse and momentum stated above can use to obtain the shuttlecock's final velocity, $\boldsymbol{v}_2$ and the force acting on it when the initial velocity of shuttlecock is known with a specified time period[4]. The calculated force acting on shuttlecock is needed to analyze the torque of motor required during launching. While final velocity, $\boldsymbol{v}_2$ is determined for further analysis on the trajectory and the required speed to reach a specified target.

$$\tau = F \times d \tag{2.14}$$

where τ is the torque required, F is the force acting on the shuttlecock and d is the distance travelled to a specific target.

2.1.3 Block Diagram of SLS

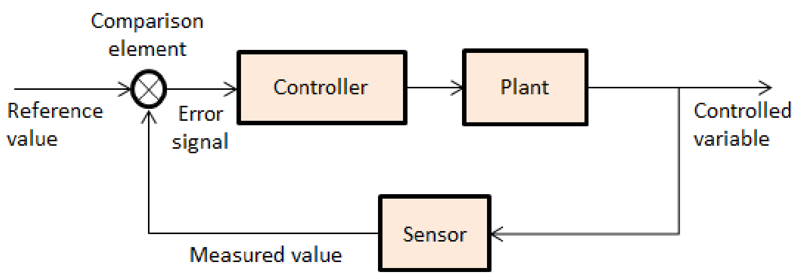


Figure 2.3 Closed-loop Control System

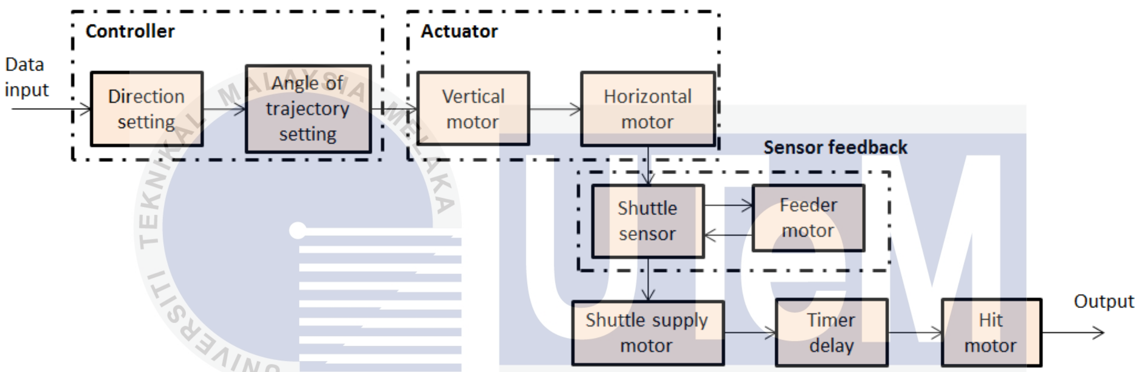


Figure 2.4 Shuttlecock Launching System

Figure 2.3 shows the general form of closed-loop system and Figure 2.4 shows the Shuttlecock Launching System (SLS). It consists of the following elements:

1. *Direction setting*

   This element receives the input signal from the user and decides the next action. User can set the desired direction of machine to launch the shuttlecock towards a specified position.

2. *Angle trajectory setting*

   User enters the desired trajectory angle of the machine to launch the shuttlecock towards a specified position. This element will get the input command and send to the actuator.

3. *Vertical motor*

   The motor is set up for the shuttlecock launcher to move in up and down motions. The motion is done by following the input angle from the user.

4. *Horizontal motor*

   The motor is installed for the machine to move in left and right motions. The motion is regarding to the desired direction from the user.

5. *Shuttle sensor*

   This sensor will sense the presence of shuttlecock in the storage. If there is no shuttlecock detected, the signal will send to the feeder motor for the next action. When the shuttlecock is detected, the shuttle supply motor will be activated.

6. *Feeder motor*

   This is located at the shuttlecock storage. The motor will rotate the storage if the shuttlecock is finished and sensed by the shuttle sensor.

7. *Shuttle supply motor*

   This motor will be turned on if the shuttle sensor detects the shuttlecock. Shuttlecock is then supplied to the launcher for the projection.

8. *Timer delay*

   A delay of time will be set regarding the shuttle supply motor and hit motor. When the shuttle supply motor is activated, there is a time interval for the shuttlecock to drop till certain position. Then the hit motor will be turned on.

9. *Hit motor*

   The motor will activate after the shuttle supply motor is opened. This motor is assigned to hit the shuttlecock to a desired position. A racket is attached to the motor.

2.2 Review of Existing Shuttlecock Launcher System

Nowadays, there are various types of shuttlecock launching machines listing in the market. However, each of the products has their weaknesses and deficiencies. Apollo Trainer, Knight Trainer and SIBOASI Badminton Shooter are the machines currently available. The major problems faced by these machines design are the cost and accuracy. The cost of Knight Trainer has been stated on the forum which is about $3500 (RM11, 000) while the other machines cost about the same value. This amount is comparatively expensive as it’s easier to find a practice partner or hire a coach which is much cheaper than purchase a machine. Regarding accuracy, there are experiments being conducted from other researchers. Results found that the target of shuttlecock launched by the machine is not precise[3]. This problem could affect a player’s prediction on the shuttlecock during the competition.

2.3 Performance Indices

Table 2.1 Comparison of three badminton trainers available in market

Product / Feature	Apollo Trainer[6]	Knight Trainer[7]	SIBOASI[8]
			
Cost (RM)	17,000	15,000	9000
Weight (kg)	-	45	80

Height (m)	1.9	2	2.3
Max Speed (km/h)	130	100	150
Power Supply (V)	120	110	110
Frequency (s/ball)	1.2	0.4-16	2-10
Ball capacity	250	50	90
Remote control	√	√	√
Randomizer	√	√	√
Portability	X	√	X

From Table 2.1, first we can see the costs of all three products available in the market where the cheapest product is the SIBOASI badminton trainer, which costs about RM9, 000. However, it is still consider expensive to the individual as compare to train with a partner. The weights of the products are different where the lightest weight goes to the Knight Trainer, which is about 45 kg. There is no much information regarding the weight of Apollo Trainer, but it can be concluded from the figures that it will be heavier than the Knight Trainer. The maximum height that the product can operate is 2.3 m by SIBOASI. This is useful due to the variety of shots it can perform.

Besides that, the maximum speed of each shot is also important for training purpose. The maximum speed of shots is 150 km/h which goes to SIBOASI again. Nevertheless, Knight Trainer provides the greatest frequency of shots among the other two. It can run with a frequency of 0.4 to 16 seconds/ball, which means that it can operate as fast as 0.4s/ball and has a wider range of frequencies that is adjustable. For the capacity to store shuttlecocks, Apollo Trainer has the greatest number of 250 pieces. Other than that, all three of the products contain remote control and randomizer. But, the greatest portability goes to the Knight Trainer. The structure of the machine can be disassembled and easy to carry.

From the analysis, it is clear that SIBOASI contains more features which are better than the other products. Therefore, the shuttlecock launcher prototype of this project will be designed by following the features that SIBOASI has.

Table 2.2 Comparison among available solutions

Criterion \ Product	Apollo Trainer[9]	Knight Trainer[10]	SIBOASI[8]
Accuracy	- Two 120W DC Brush Motors. - Actual speed is 20% less than displayed value.	- Two 120W DC Brush Motors. - Capable of operating at 95% accuracy.	- Two 120W DC Brush Motors. - Accuracy is not considered.
Cost	- High speed brushless DC motor. - Computer control system - Spur gear DC motor - Servo motor	- High speed DC motor. - Remote control - DC electric motor	- High speed DC motor. - Remote control - Spur gear DC motor - Stepper motor - DC servo motor
Degree of freedom	- 3 DOF	- 2 DOF	- 3 DOF

Table 2.2 shows the comparison among available solutions from three different shuttlecock launchers in the market. There are three important criterions being considered which consist of the accuracy, cost and the degree of freedom.

From the aspect of accuracy, Knight Trainer provides a better feature in which the accuracy of shots can reach up to 95% during operation. This is due to less degree of freedom in the system. Without comprising the automatic ball storage changer and vertical as well as horizontal motion control, Knight Trainer design focused only on the feeder and launching mechanism which aided to the accuracy of the overall system.

As shown in Table 2.1, the cost of SIBOASI is lower than the other two machines. However, it contains more degree of freedom in the system than the Knight Trainer. The added spur gear DC motor in SIBOASI is used to change the ball storage automatically. Additional stepper motor is used to control the vertical motion which does not included in the other two machines. Even though SIBOASI retains low in the cost, diversification of its functions do affects the accuracy which they did not take into consideration.

From the comparison, we can see that it is better to reduce the functionalities of the machine in order to meet the objectives of this project. It is better in term of accuracy and cost of operation which are beneficial to be developed.

2.4 Design and Development of SLS

The study of Shuttlecock Launching System (SLS) gives significant impact to the badminton field especially in training session. It is considerable for a coach to choose SLS as it offers numerous advantages. The system has the ability to improve playing standard of the players. Coaches can benefit from this system with its wide availability as the speed, trajectory and direction are adjustable. This can save a lot of energy for coaches to focus wholly on coaching. Besides, high accuracy of the system setting for each ball on specific areas during training makes the training more focused. SIBOASI have successfully developed an automatically shuttlecock shooter which is economic and convenient to operate[11]. Recently, there are several groups who have published papers regarding automated badminton machine. i.e. Smith, C.[2], Jalil, N.B.A.[3], and Ivan Laszlo, H.F.[10].

From the research in journal [1], new shuttlecocks were chosen for the study of the aerodynamic properties which the dimensions of the shuttlecocks are shown in Table 2.3. From these dimensions, the average length of shuttle, length of cock, the mass and width of the shuttlecock are taken to design the shuttlecock launching machine in this research.

Table 2.3 Physical parameters of shuttlecocks

ID	Type	Length of shuttle (mm)	Length of cock (mm)	Width of skirt end (mm)	Mass (g)
S-1	Synthetic	84	25	65	5.2
S-2	Synthetic	82	25	63	4.9
S-3	Synthetic	83	25	66	6.2
S-4	Synthetic	78	25	68	5.3
S-5	Synthetic	80	25	65	5.2
F-1	Feather	85	25	66	5.0
F-2	Feather	86	25	65	4.9
F-3	Feather	85	25	66	5.1
F-4	Feather	85	25	65	5.2
F-5	Feather	85	25	65	4.9

In a research article by [12], the feeding mechanism was designed only one Pololu 131:1 geared motor to grip the shuttle down from the stack to the launcher by transforming the rotational energy into linear motion. Figure 2.6 shows the prototype of the machine designed. 80RPM of motor speed was proved that the motor was enough to provide a maximum of one shuttle every 0.75 seconds. Besides, the mechanism would pull the shuttle by the ridge above the cork where no gripping force acting on the cork which would get damaged as the designs in [7], [6] and [8]. The launching mechanism was designed by using two conventional rotating wheels method, which was driven by one motor powering two gears and a teethed belt drive. Yet the design should ensure that only the cork would drive through the wheels but not the feathers.

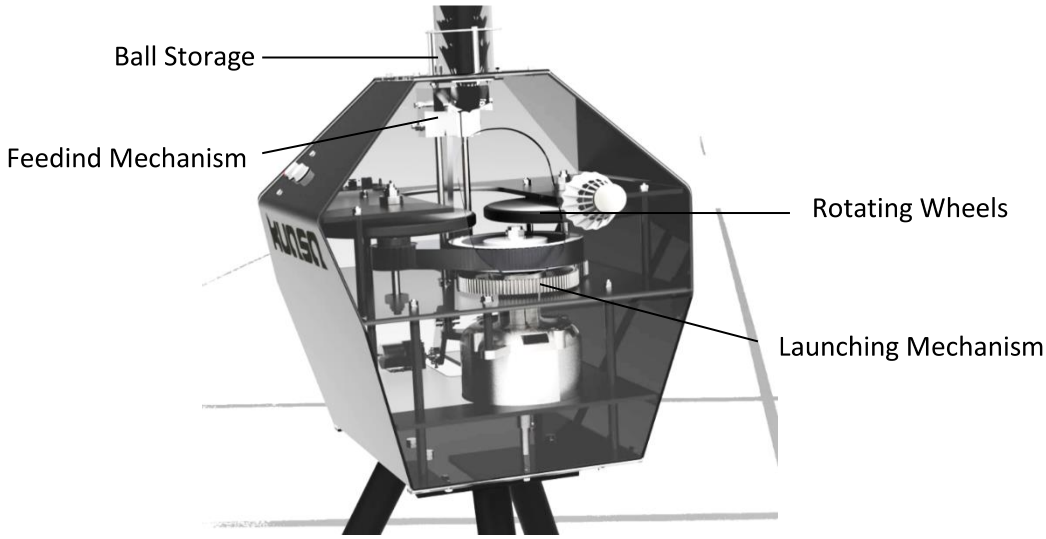


Figure 2.6 Kuasa Automated Badminton Trainer[12]

From the study of paper [13], the author proposed a fully automated ball serving badminton machine for training purpose. The machine consists of lifting mechanism with ball storage mechanism stand, which accurately supplies the ball to the launcher. The whole system is controlled by the commands input. The ball storage mechanism is designed in rotational motion and connected with a ball gripper to allocate the ball to a standby position. Ball launcher mentioned above is actuated by the motor in which a racket is directly mounted on it. By using the controller, the racket imitates the serve motion of human hand to complete the propel action. With the use of racket as launching mechanism, the angle of trajectory is satisfied as $\pm 60°$. However, the overall design seems bulky as shown in Figure 2.7.

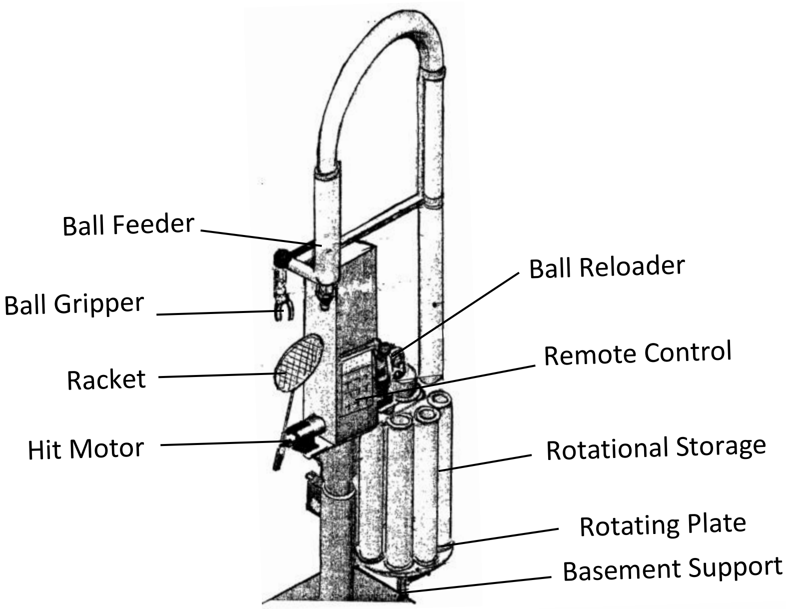


Figure 2.7 Fully automated ball serving badminton machine[13]

In paper [14], another design of badminton machine is initiated by a group of researchers, named Portable Badminton Training Robot as shown in Figure 2.8. The function is similar to the design in [13], only that the robot is composed with a briefcase box. The mechanism is attached to the basement. The robot body can be folded and transformed into a box shape to enhance the mobility. It provides adjustable frame to pack into the box. The robot consists of a ball storage shielded with wires to prevent balls drop out. A gripper mechanism is included in the design to carry the ball to the propeller. The launcher is developed using gear mechanism with a racket mounted on the actuator. This robot is patterned in small size, ease of portability, low cost, and suitable for training as well as entertainment.

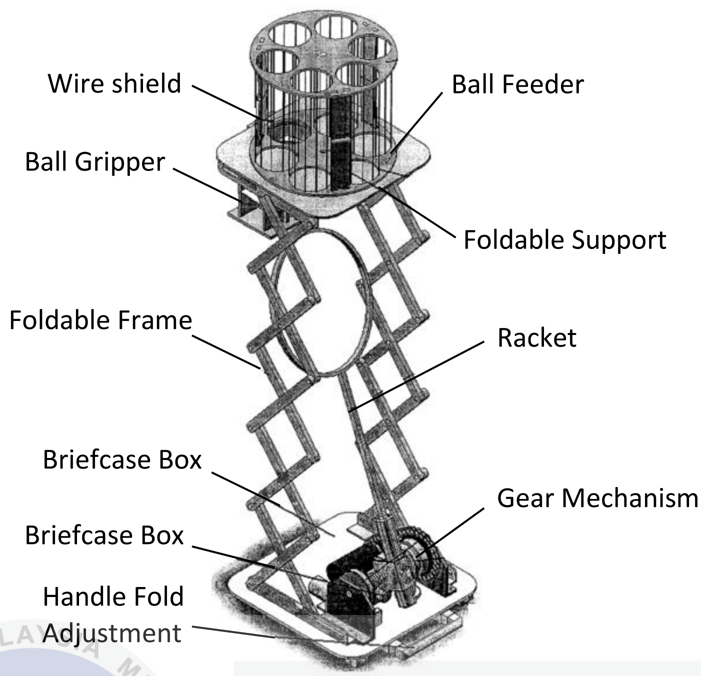


Figure 2.8 Portable badminton training robot[14]

2.5 Improve Performance of SLS

In an extensive study of model-free and model-based time-optimal control of a badminton robot, Liu, Depraetere, Pinte, Grondman, and Babuska [15] claimed that the time-optimal motion is considered a challenge for the serve operation of a badminton robot. The racket has to move from an initial posture to a prescribed hit position with a desired velocity as shown in Figure 2.9. Time-optimal control helps to reduce the actuator demand on the hit motion.

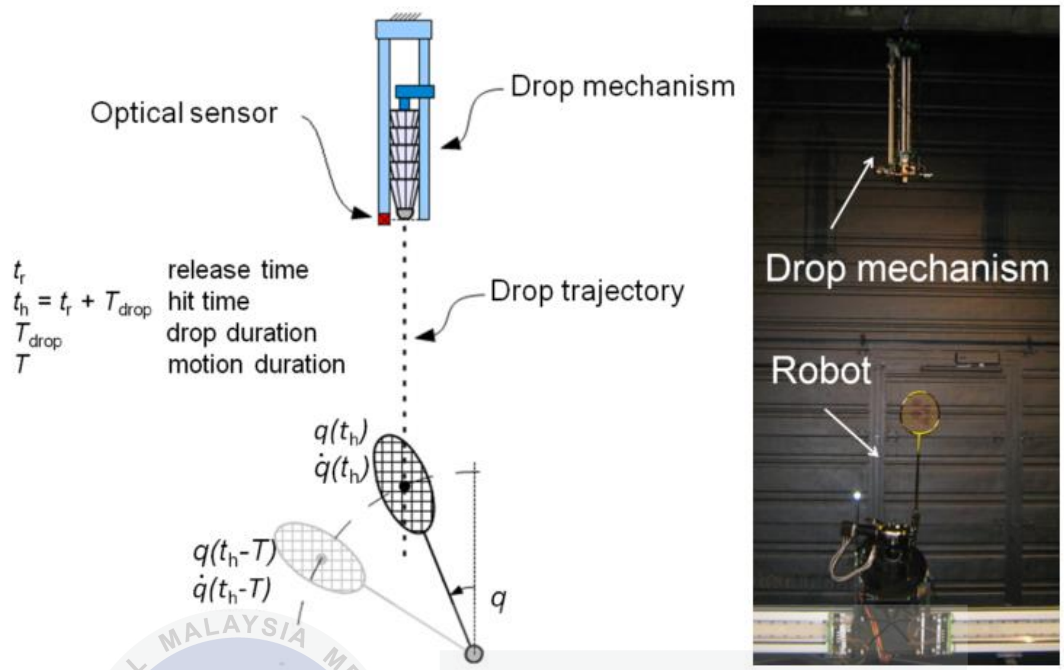


Figure 2.9 Schematic overview of the serve operation[15]

To carry out serve operation as shown in Figure 2.9, a shuttle starts to fall at $t = t_r$. By assuming the shuttles are always released at the same time with a period of time T_{drop}, the hit point is approximately the same. Thus, the hit time $t_h = t_r + T_{drop}$. To get a time-optimal motion, moving time of the racket should be at $t = t_h - T$, by reducing the motion's duration T. Besides, the racket motion has to begin at an angle $q(t_h - T)$ and angular velocity $\dot{q}(t_h - T)$ and has to reach to the intersection with shuttlecock at $q(T)$ and $\dot{q}(T)$. By considering these parameters, the specification of motors used can be determined without exceed any boundaries on the motor requirements.

From the study in [16], researchers noted that the speed and trajectory of a shuttlecock could affect by the angle and strength of stroke. The effects of air resistance force will also influence the accuracy of a stroke. The paper also proved that by measuring the terminal velocity, the motion equation of shuttlecock's trajectory can be determined using the derived equation of the trajectory,

$$y = \frac{{v'_t}^2}{g} \ln \left| \frac{\sin\left[\frac{v'_t}{v_{x_i}}\left(e^{\frac{gx}{{v'_t}^2}} - 1\right) + \tan^{-1}\left(\frac{v'_t}{v_{y_i}}\right)\right]}{\sin\left[\tan^{-1}\left(\frac{v'_t}{v_{y_i}}\right)\right]} \right| \tag{2.15}$$

However, the terminal velocity v'_t has to be measured before the shuttlecock's trajectory can be found[17]. This should be done by conducting a model-based experiment which is an unnecessary effort since there are several method to determine the shuttlecock's trajectory such as the method in [18].

A further consideration is the study of curved motion of a shuttlecock. Susanti, D.P.[18] found that the linear model of air resistance gives well explanation on the motion of shuttlecock and it does not require complex mathematical prove. By extracting the parameters (velocities and positions) of shuttlecock using the World In Motion software, the analysis is done and compared between two models of air resistance: linear model (air resistive force is assumed linear in the velocity of shuttlecock) and quadratic model (air resistive force is assumed quadratic in the velocity of shuttlecock). The following figures show the well fits for vertical position, horizontal position, vertical velocity, and horizontal velocity of the shuttlecock, both for linear and quadratic models.

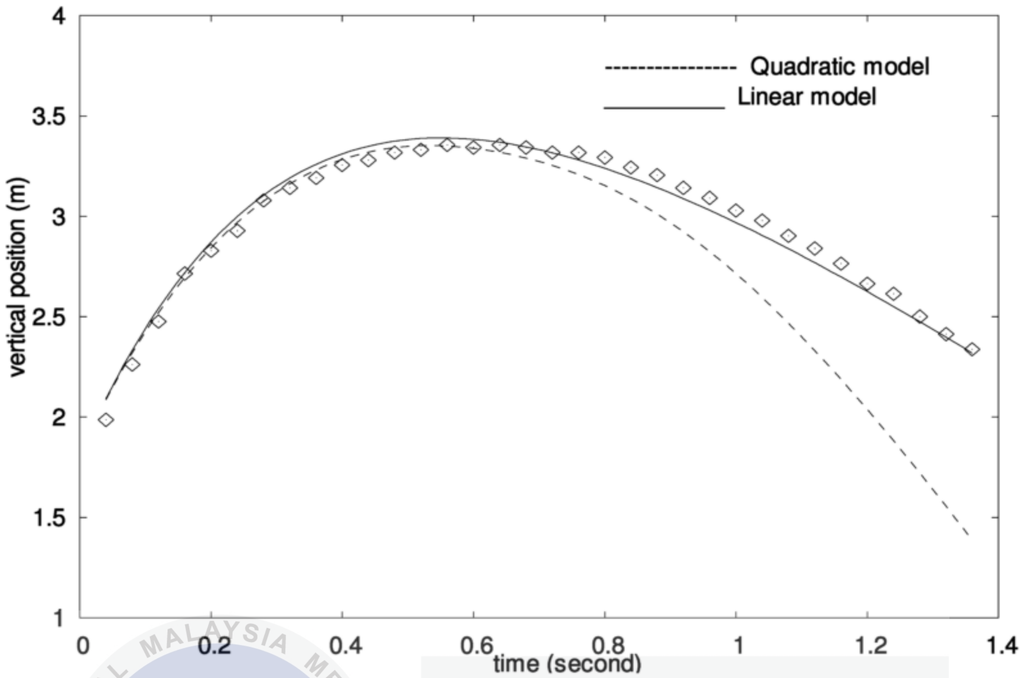


Figure 2.10 The vertical position y of the shuttlecock versus time

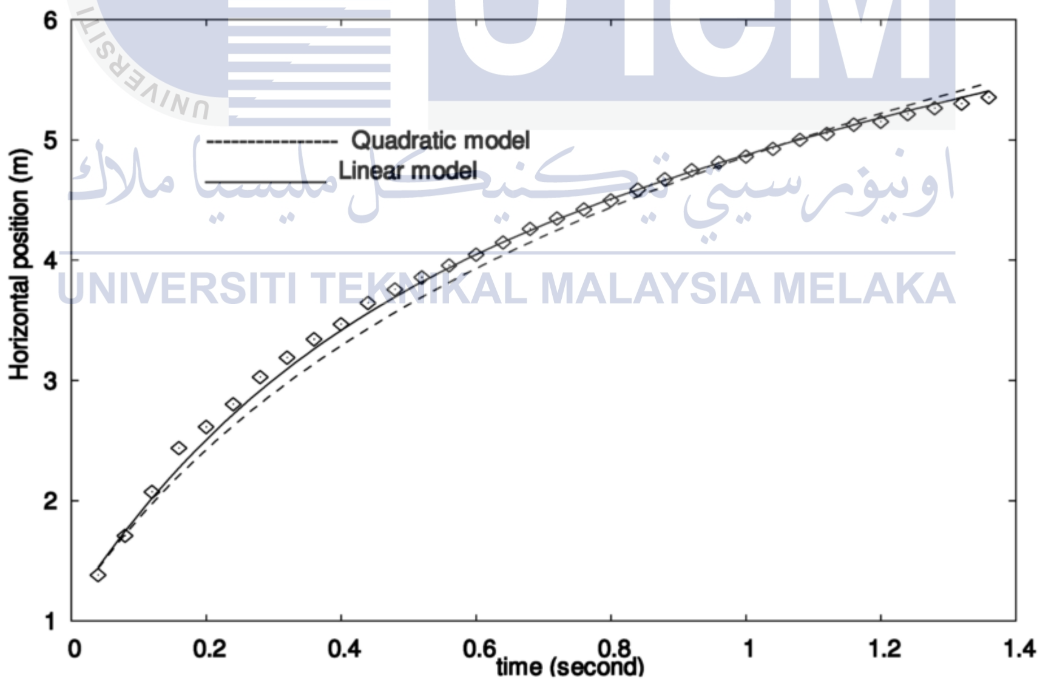


Figure 2.11 The horizontal position x of the shuttlecock versus time

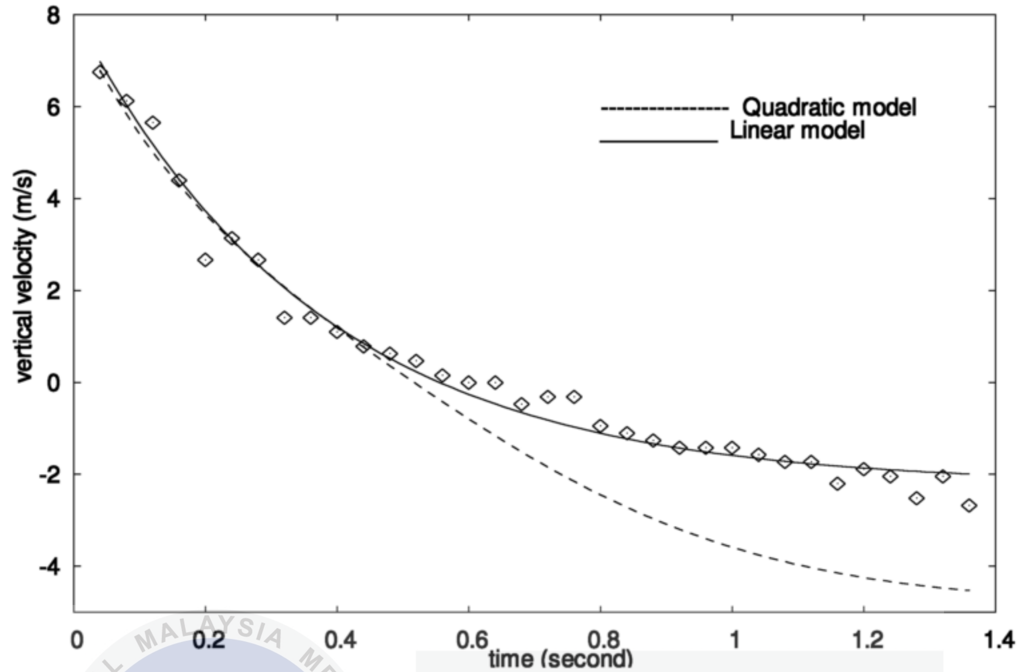


Figure 2.12 The vertical velocity v_y of the shuttlecock versus time

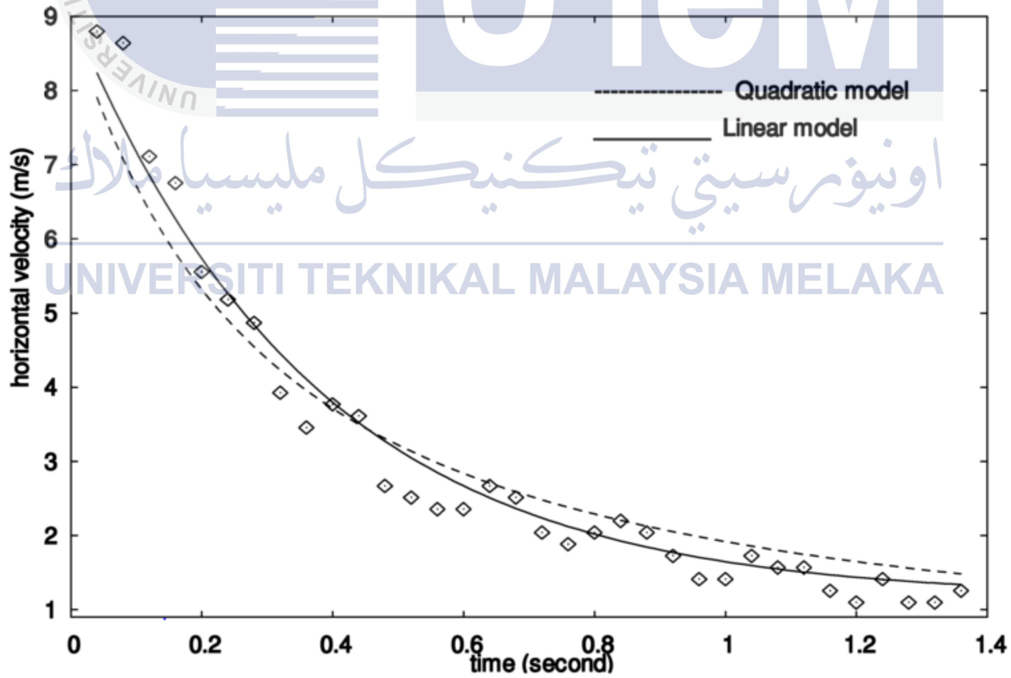


Figure 2.13 The horizontal velocity v_x of the shuttlecock versus time

From the experimental graphics, it is clear that the experimental data distribute to the linear model. Therefore, it may be advantageous to use the linear model of air resistance of shuttlecock for better description on the motion of shuttlecock.

2.6 Summary of Literature Review

As an early conclusion, the average length of shuttle, length of cock, the mass and width of the shuttlecock are taken from the research in [1] to design the shuttlecock launching machine in this research. Several types of shuttlecocks are considered in the research to ensure the designed shuttlecock machine suits the shuttlecocks used for operation. Besides, the design in [12] shows that the feeder mechanism would pull the shuttle by the ridge above the cork where no gripping force acting on the cork which would get damaged. However, the design should ensure that only the cork would drive through the wheels but not the feathers. In paper [13], the shuttlecock storage is designed in rotational motion and connected with the feeder mechanism to allocate the ball to a standby position. This design is beneficial to increase the shuttlecock capacity. With the use of racket as launching mechanism, it imitates the serve motion of human hand to complete the propel action. Therefore, the new design of shuttlecock launching machine proposed in this project is believed to improve the accuracy, the trajectory performance and the cost.

CHAPTER 3

METHODOLOGY

3.1 Description of Methodology

The methodologies utilized are simulation and experimentation in this research. The existed trajectory equation simulation will be conducted using MATLAB/SCILAB in computer. Experimental manipulation of SLS will be fabricated to test the trajectory angles and velocities. Arduino UNO Rev3 microcontroller will be used to command the SLS. Figure 3.1 shows the processes to accomplish this research. The literature review found that most of the previous experimental research about the trajectory equation was carried out to analyze the parameters of projectile motions using linear model and quadratic model. There has been limited research works on applying the trajectory equation to the motion of shuttlecock which will be conducted in this research. The parameters that will study are angle of trajectory, velocity and distance travelled of the shuttlecock. Next, the prototype of SLS will be designed and developed to obtain model-based experimental data. The data collected will then use to compare with the existed trajectory equation so as to improve the accuracy of shots. The program of SLS will be produced on Arduino Uno Rev3 microcontroller and simulated using Proteus software before applying on the prototype. After all the procedures are satisfied, the experimental data will then be finalized.

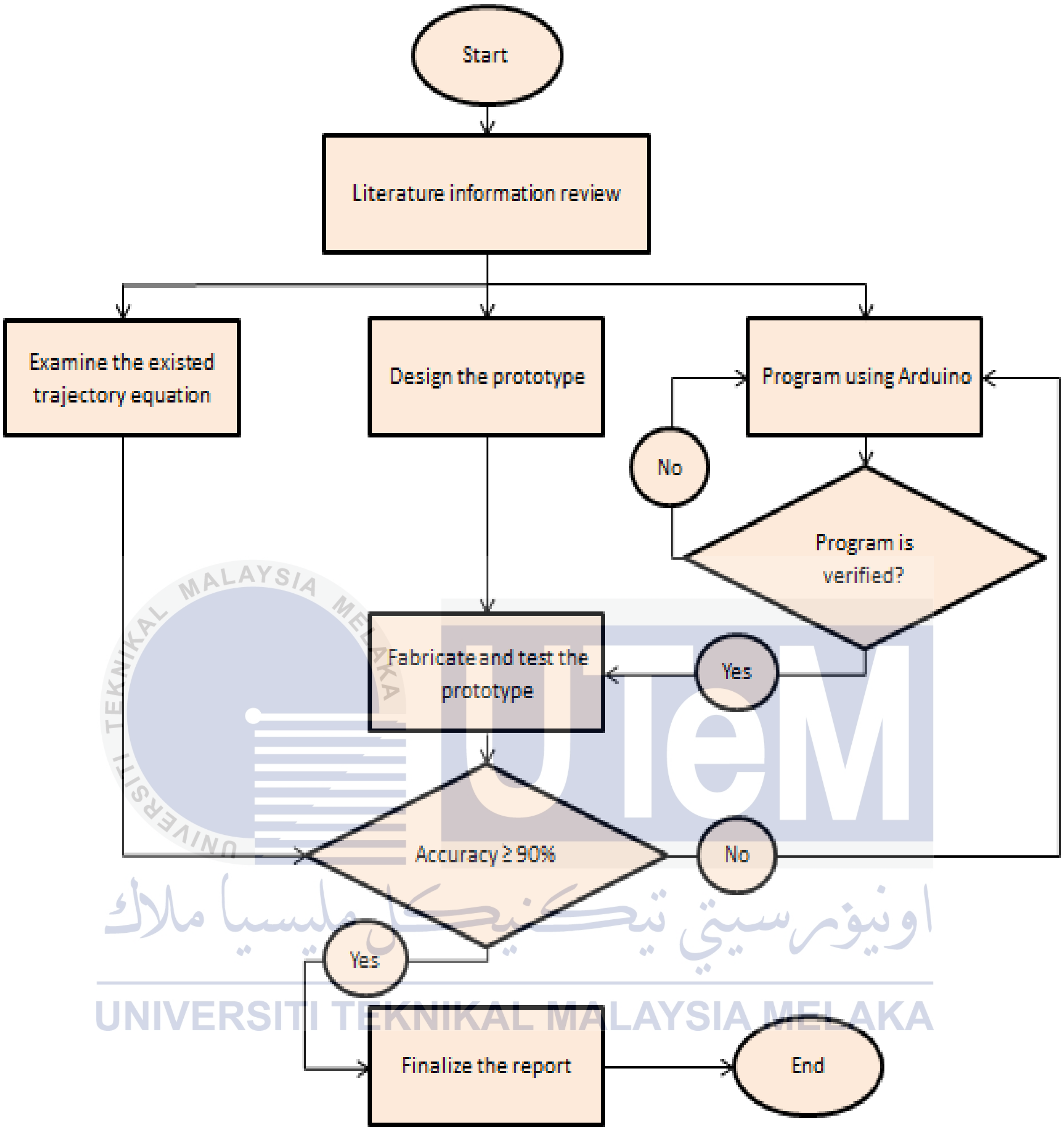


Figure 3.1 Flow chart of research methodology

3.2 Development of the Prototype for Experimentation

3.2.1 Equations for Calculating Feeder Rate

For the feeder mechanism, I want to make sure that the feeder can feed at least 2 shuttlecocks per second to meet the requirements for a professional training where there was researches showed that an elite player in the defensive position has 0.1s to react to the opponent's attack[21]. Figure 3.2 shows the diameter and number of teeth of gear design.

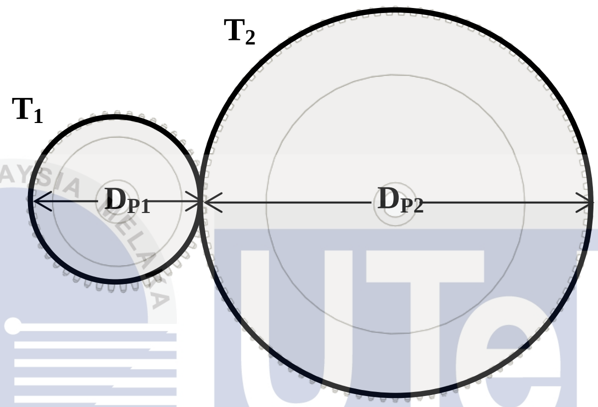


Figure 3.2 Diameter and number of teeth of gear design

The equations for estimating feeder rate for my desire are

$$T_2 = \frac{T_1}{D_{P1}} D_{P2} \quad (3.1)$$

$$\frac{D_{P1}}{D_{P2}} = \frac{RPM_2}{RPM_1} \quad (3.2)$$

where D_{P1} and D_{P2} are pitch circle diameters and T_1 and T_2 are number of teeth of the spur gears. RPM_1 and RPM_2 are the speed of gear 1 and 2 respectively.

Assume the values of $T_2 = 100$, $D_{P1} = 38mm$ and $D_{P2} = 80mm$. By solving equation 3.1, the value of $T_1 = 47.5$. The number of teeth for T_1 is reduced to 45 to find D_{P1} since the value of T_1 obtained from the calculation is not an integer. By recalculating equation 3.1, the value of D_{P1} was determined as $36mm$.

Next, the speed ratio of gears in equation 3.2 is used to determine the maximum speed of gear can reach in terms of pitch circle diameters. From the design, the motor used to drive the feeder has a maximum rated speed of 185rpm. With the values of $D_{P1} = 36mm$, $D_{P2} = 80mm$ and $RPM_1 = 185rpm$, the speed of second gear can reach up to 83.25rpm.

By using the equations 3.1 and 3.2, we can vary the gear system and motor design to obtain the rate of the feeder. For my project, I set the gear ratio to 9:20 and the number of teeth for smaller gear and bigger gear to 45 and 100 respectively. From that, I can get the feeder rate that I desired and meet the requirement.

3.2.2 Cam Design

The design of cam in the feeder mechanism is rather important to avoid any flaws during machine operation. Figure 3.3 shows the space constraint of cam design, in which the designed cam should fit within a space limit relative to the diameter of gears.

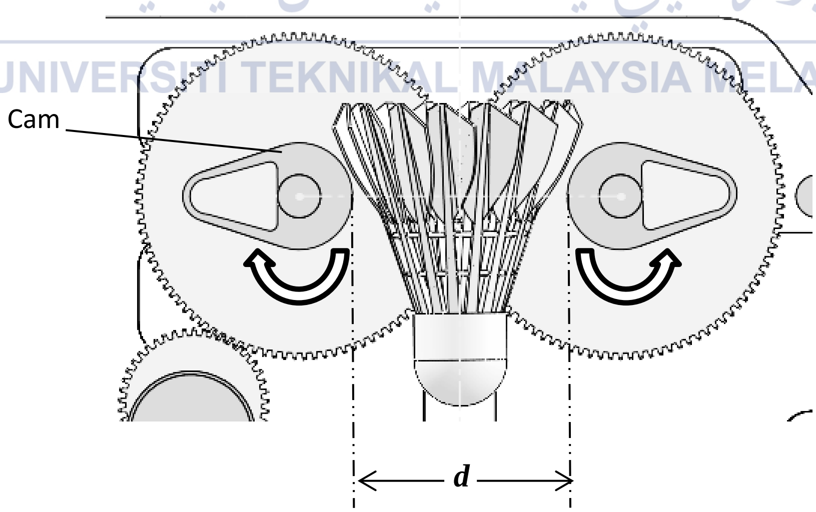


Figure 3.3 Space constraint of cam design

In my design, the feeder mechanism consists of two cams which will rotate 360° during the operation. The function of the cams is to pull the shuttlecock down from the storage. In standby mode, the cams will grip the cork of the shuttlecock and ready to pull downward. When the cams rotate about 180° from the standby position, the backend of the cams will block the shuttlecock to go smoothly. Therefore, distance between backend of the cams, *d* has been taken care to ensure the smoothness of the shuttlecock dropping motion. Since the diameter of the circle overlapping by the feather is about 70mm, thus distance *d* is designed to about 80mm apart.

3.2.3 Calculation for Motor Selection

3.2.3.1 Motor in feeder mechanism

To choose a suitable motor which uses to drive the gears in feeder mechanism, speed is the main factor that will affect the performance of the system. The feeder has to feed at least 2 shuttlecocks per seconds as mentioned in previous section. Thus 3 models of different DC geared motor are chosen for the options. By using the formula,

$$\frac{60\ seconds}{1\ second} = \frac{Number\ of\ revolutions\ per\ minute}{Number\ of\ revolutions\ per\ second}$$

Table 3.1 is then generated from the calculations.

Table 3.1 Specifications of DC geared motor[22] with calculated speed of each motors

Model Code	Rated		Speed (RPS)
	Speed (RPM)	Torque (mN.m)	
SPG30-20K	185	78.4	3.08
SPG30-30K	103	127.4	1.72
SPG50-20K	170	196	2.83

From Table 3.1, calculations showed that the SPG50-20K fulfills the required speed for feeder mechanism. However, the torque of this model is high. From the formula of $\tau = mgR$, the required torque to drive the gears is 58.86 mN.m. Since the motor used in feeder mechanism aim on the speed to have a wide range of variety, the SPG30-20K model is selected in this project.

3.2.3.2 Motor in launching mechanism

In launching mechanism, the speed and torque of the motor are both required to accomplish the goals of this project. As reviewed from product available in the market, the maximum velocity of the shuttlecock machine can operate up to 160 km/h, which has been proven that a speed of 2600 rpm is sufficient to launch the shuttlecock to the back boundary line of a badminton court[3]. Besides that, the required torque to drive a racket with a shuttlecock can be calculated by using the formula,

$$\tau = (m_r + m_s)\left(\frac{v}{t}\right)R \qquad (3.3)$$

where τ = the torque required, mass of racket m_r = 0.085 kg, mass of shuttlecock m_s = 0.0052 kg, v is the velocity of shuttlecock required , time taken $t = 1\ s$ and the length of the racket R = 0.3 m.

To determine the velocity of shuttlecock required, equations regarding the position of shuttlecock can be implemented[18]. For the shuttlecock to reach the back boundary line of badminton court, the distance travelled should be about 9 m as shown in Figure 3.4. Thus substituting x = 9 and y = 0 into equations 3.4 and 3.5 to get the desired velocity v_0.

$$x = x_0 + v_{0x} cos\theta \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right) - \frac{\alpha}{k}\left(t - \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right) \qquad (3.4)$$

$$y = y_0 + v_{0y} sin\theta \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right) + \frac{-mg + F_a - \alpha}{k}\left(t - \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right) \tag{3.5}$$

From the equations, the values of v_{0x} and v_{0y} are calculated as 12.12 ms^{-1} and 7.47 ms^{-1} respectively. The trigonometry function is then used to obtain the desired velocity v_0 as shown in Figure 3.5. The value of v_0 computed is 14.24 ms^{-1}. By integrating $v_0 = 14.24$ into equation 3.3, the torque required will be 0.39 N.m. Thus by considering the requirements, a 350W electric scooter motor is chosen in this project. The data sheet in [23] shows that at a torque of 0.4 N.m, the 350 W electric scooter motor can reach up to 3200 rpm with 96 A current, which had met the requirement to launch the shuttlecock to a distance of 9 m.

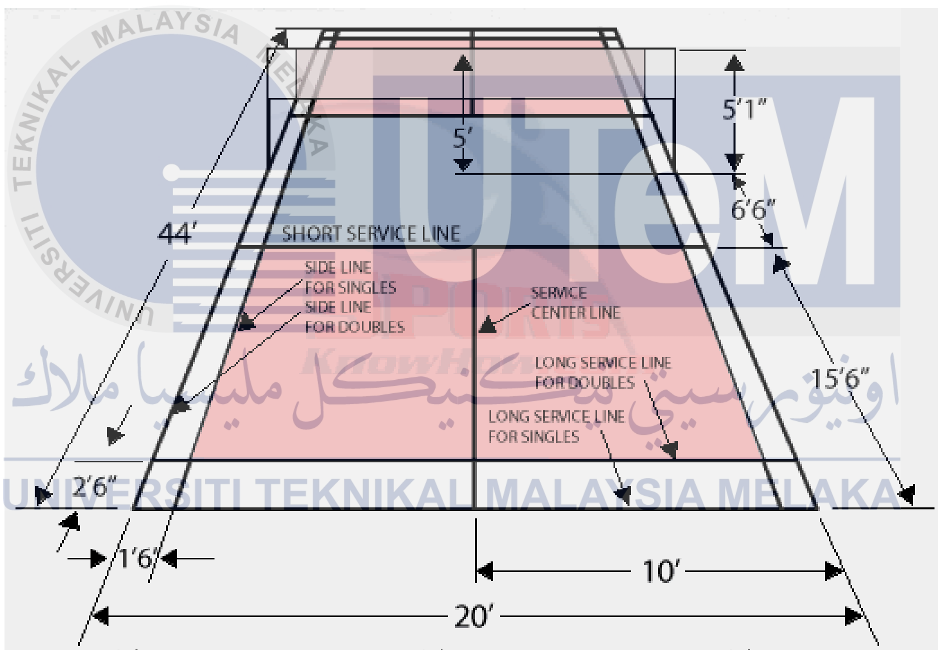


Figure 3.4 Diagram of badminton court dimensions[24]

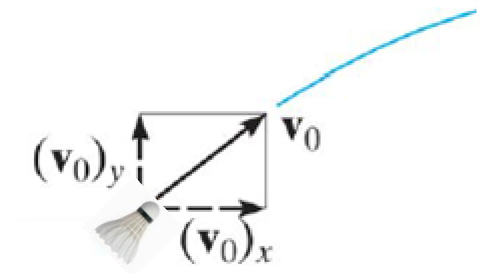


Figure 3.5 Diagram of trigonometry function to obtain the desired velocity v_0

3.2.4 Testing for Ideal Height for SLS Prototype

Before the SLS prototype being developed, the height of machine has to be considered. Due to the structure of shuttlecock, the aerodynamic force exerts on it will affect the performance of shuttlecock free fall, which will then reduce the accuracy of shots. Intersection between shuttlecock and racket will lead to the deviation of shuttlecocks, which will cause the racket to hit the feather of shuttlecock. Therefore, suitable distance between the shuttlecock release point and the point where shuttlecock and racket contact should be determined.

The experiment will be set up as shown in Figure 3.6. Different heights of shuttlecock release point from 500 mm to 900 mm will be tested. The results from each height will record by using the slow motion video at a speed of 1/8 at a frame size of 800 $\times$ 450 pixels to get the motion patterns of shuttlecock.

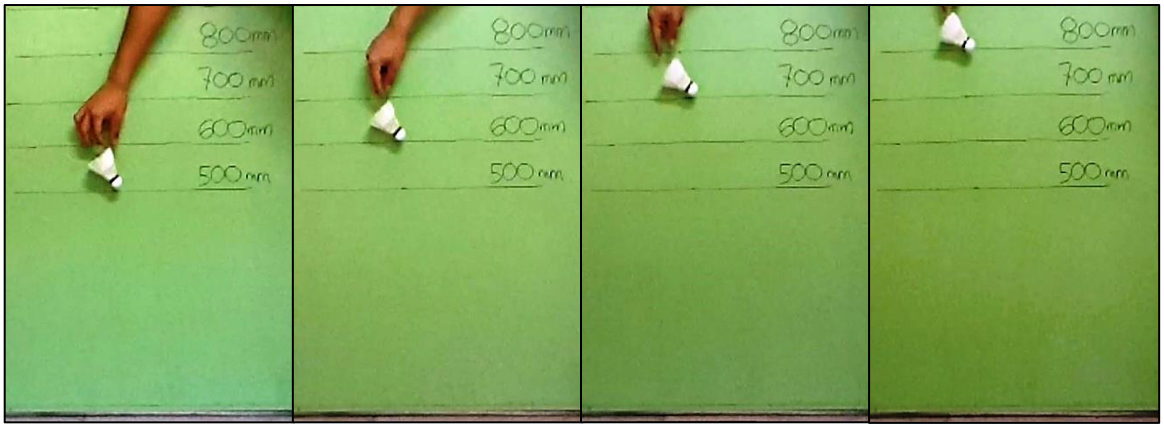


Figure 3.6 Setup for testing ideal height of SLS prototype

3.2.5 Design of Electric and Electronic Parts of SLS

First of all, an electronic prototyping platform is required to interact with the mechanisms. Arduino Uno Rev3 is chosen as a microcontroller to program the prototype because it is open-source and easy to do programming and communicate with it. Since the designed SLS will not need 10 outputs, Arduino Uno Rev3 provides 14 digital I/O pins which are sufficient to use. Then, a DC motor driver will be needed to drive the motor used in feeder mechanism. 10A DC Motor Driver is chosen due to low affordable price and bi-directional control for 1 DC motor.

To power the electric scooter motor which used in the launching mechanism, a 24V with 100A ADC power adapter is required. However, it is expensive. Therefore a 12V with 30A ADC power adapter is chosen as shown in Figure 3.7. Since the voltage supply is not sufficient to drive scooter motor to the desired speed, a power booster with 12VDC to 24VDC output is chosen in this project as shown in Figure 3.8.

Figure 3.7 12V with 30A ADC power adapter

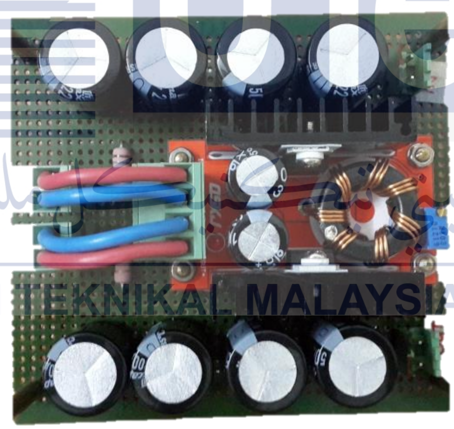


Figure 3.8 Power booster 12VDC-24VDC output

Next, a circuit is designed to interact with Arduino to control the system as shown in Figure 3.9. The voltage input from power adapter is being regulated to a 12V and 5V power output. 12V output with yellow LED indicator is required to power up the DC geared motor in feeder mechanism while 5V output with red LED indicator is used to supply power to the Arduino. Besides that, the circuit is also designed to control the scooter motor. Two signal ports with white and yellow wires are developed to activate the scooter motor with run and stop functions accordingly. Since the scooter motor requires high power to be operated, two contactors are used to handle the power and directly control the motor as shown in Figure 3.10. Furthermore, Figure 3.11 shows a potentiometer which is added to the circuit to adjust the voltage supply to the scooter motor so as to alter the speed.

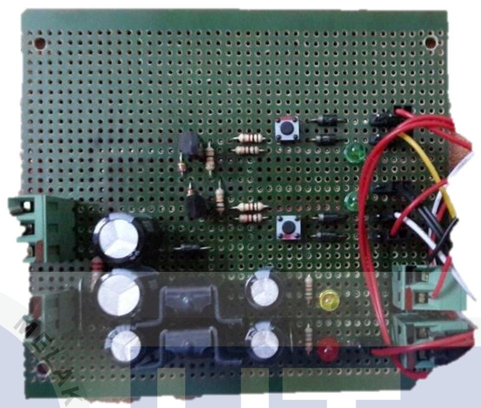


Figure 3.9 Circuit design to interact with Arduino

Figure 3.10 Contactors

Figure 3.11 Potentiometer with overload protection

3.2.6 Examine Existed Trajectory Equation

To get a well description of shuttlecock trajectory, the linear model of air resistive force is considered in the existed trajectory equation, which is written as $F_i = -(\alpha_i + kv_i)$, where α_i and k are constant. α is assumed the same throughout the calculation to reduce the number of parameters. By using the equations in [18],

For horizontal direction, the equation will be

$$m\frac{dv_x}{dt} = -\alpha - kv_x \tag{3.3}$$

For vertical direction, the equation will be

$$m\frac{dv_y}{dt} = -mg + F_a - \alpha - kv_y \tag{3.4}$$

where the buoyant force $F_a = V\rho_{air}g$, density of air $\rho_{air} = 1.293kg/m^3$, gravitational acceleration $g = 9.81m/s^2$ and the volume of shuttlecock $V \cong 9.18 \times 10^{-5}m^3$. The constants $\alpha_i = (m - m^*)g$, m is the mass of shuttlecock, m^*g is the buoyant force, and

$k = 6\pi\eta R$ with the dynamic viscosity of air, $\eta = 1.983 \times 10^{-5}$ Pa.s and R is radius of shuttlecock's cross sectional area[1, 19].

By integrating equations 3.3 and 3.4, the velocities with initial condition $v_0 = (v_0 \cos\theta, v_0 \sin\theta)$ will be,

$$v_x = \frac{dx}{dt} = v_0 cos\theta e^{-\frac{kt}{m}} - \frac{\alpha}{k}(1 - e^{-\frac{kt}{m}}) \tag{3.5}$$

$$v_y = \frac{dy}{dt} = v_0 sin\theta e^{-\frac{kt}{m}} + \frac{mg + F_a - \alpha}{k}(1 - e^{-\frac{kt}{m}}) \tag{3.6}$$

Integrate again the equations 3.5 and 3.6 with initial position (x_0, y_0) to yield the position of the shuttlecock,

$$x = x_0 + v_0 cos\theta \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right) - \frac{\alpha}{k}\left(t - \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right) \tag{3.7}$$

$$y = y_0 + v_0 sin\theta \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right) + \frac{-mg + F_a - \alpha}{k}\left(t - \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right) \tag{3.8}$$

Rearrange the equations 3.7 and 3.8,

$$\alpha = \frac{k\left(y_0 - y + v_0 sin\theta \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right)}{\left(t - \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right)} + F_a - mg \tag{3.9}$$

$$v_0 = \frac{x - x_0 + \frac{\alpha}{k}\left(t - \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)\right)}{cos\theta \frac{m}{k}\left(1 - e^{-\frac{kt}{m}}\right)} \tag{3.10}$$

The equations 3.9 and 3.10 which related to the position of shuttlecock are then simulated in MATLAB/SCILAB to predict the shuttlecock trajectory motion by using the parameters shown in Table 3.1 and 3.2. The parameters in Table 3.2 are calculated based on [1]. SLS designed is said to be satisfied if its shuttlecock trajectory of different shots meet the equations stated above and produce a set of trajectory models similar to the patterns shown in

Figure 3.12. Since the launching conditions mentioned in [19] did not state the value for mid court shot, there are only serve and net shot being considered in the simulation.

Table 3.1 Launching conditions for four common badminton shots[19]

Type of shots	**Serve**	**Net shot**	**Smash**	**High clear**
Velocity ($\boldsymbol{m/s}$)	10.2	7.7	47	47
Launch angle (°)	26	75	10	36
Initial height ($\boldsymbol{m}$)	1	0.15	3	3

Table 3.2 Specifications of shuttlecock used based on [1]

Type	**Mass, *m* (g)**	**Radius, R (mm)**	**Volume, *V* ($\boldsymbol{m^3}$)**
Feather	5.2	32.5	9.18×10^{-5}

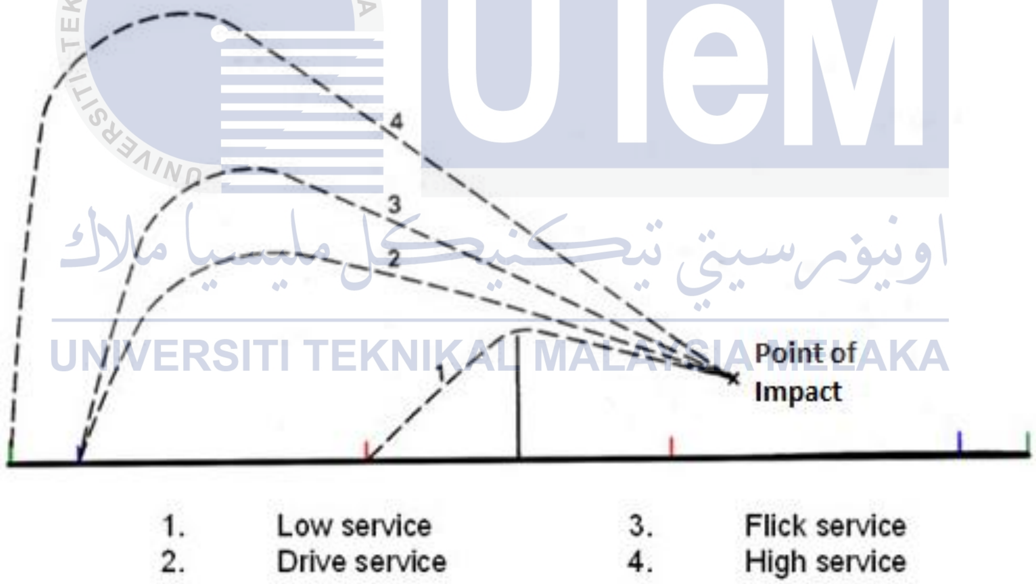


Figure 3.12 The trajectories of the basic strokes in badminton[20]

3.3 Experiment 1: Feeder Repeatability Test

Research Question

How does the application of gear system with designed cams in the feeder mechanism can improve the accuracy of shuttlecock launcher?

Hypothesis

I hypothesized that with the use of gear system and designed cams which mount on the gears in the feeder mechanism will improve the accuracy of shuttlecock launcher above 90%.

Objective

To improve the accuracy of feeder mechanism by feeding the shuttlecocks within intersection area on the racket.

Apparatus

1. Shuttlecock feeder mechanism
2. Arduino Uno Rev3 microcontroller
3. Shuttlecock
4. Paper
5. Tracker 4.84 software - Video Analysis and Modelling Tool
6. Computer
7. Cellophane tape
8. Marker pen (blue and black colors)

Procedure

1. Program the settings using Arduino software in the computer.
2. Set up the desired values to control motor in the feeder mechanism.
3. Connect the motor to Arduino Uno Rev3 microcontroller.
4. Set up the experimental rig as shown in Figure 3.13.
5. Set up the target area beneath the feeder mechanism with a distance of 80 cm apart and place a plain paper on that target.

6. Color the cork on the head of shuttlecocks and load 10 shuttlecocks into the storage.
7. Start the machine and label the color marked by the shuttlecock immediate after the shuttlecock drops on the paper. The following bouncing marks on the paper or outside the paper are ignored.
8. Stop the machine and reload 10 shuttlecocks into the storage.
9. Repeat step 7 until a total of 50 shuttlecocks is done.
10. Repeat step 6 to 9 with different types of shuttlecocks.
11. Scan the color-marked papers to the computer to be processed.
12. Use Tracker 4.84 software to detect the coordinate of the marks.
13. Calculate the accuracy of the shots by finding the range, mean and standard deviation from the coordinates.

Figure 3.13 Setup for experiment 1

3.4 Experiment 2: Verify Reliability of Lateral Swing Design

Research Question

How does the lateral swing design can launch the shuttlecocks by following the existed trajectory equation?

Hypothesis

I hypothesized that the design of lateral swing which imitates human hand will launch the shuttlecocks by following the path created as in the existed trajectory equation with accuracy more than 90%.

Objective

To determine the trajectory of shuttlecock launched by lateral swing of shuttlecock launcher design.

Apparatus

1. Shuttlecock launcher prototype
2. Arduino Uno Rev3 microcontroller
3. Shuttlecock
4. Badminton court
5. Video recorder
6. Tracker 4.84 software - Video Analysis and Modelling Tool
7. Computer

Procedure

1. Program the settings using Arduino software in the computer.
2. Set up the desired values to control specific motors in each part of SLS based on the result obtained in the simulation on existed trajectory equation.
3. Connect the motors to Arduino Uno Rev3 microcontroller board respectively.
4. Set up the experimental rig as shown in Figure 3.14.
5. Set up the video recorder and start recording.

6. Set up the shuttlecock launcher to an angle of 45° and load 10 shuttlecocks into the storage.
7. Start the machine and record the trajectory of shuttlecocks.
8. Repeat step 2 and 4 with different angles 22.5°, 45° and 67.5°.
9. Use Tracker 4.84 to track the trajectory of shuttlecocks travelled at different angles.
10. Plot the graph of the trajectory by using Tracker 4.84 software and compare with theoretical curve from MATLAB simulation as shown in Figure 3.15.
11. Adjust the settings in shuttlecock launcher to improve the trajectory of shots.

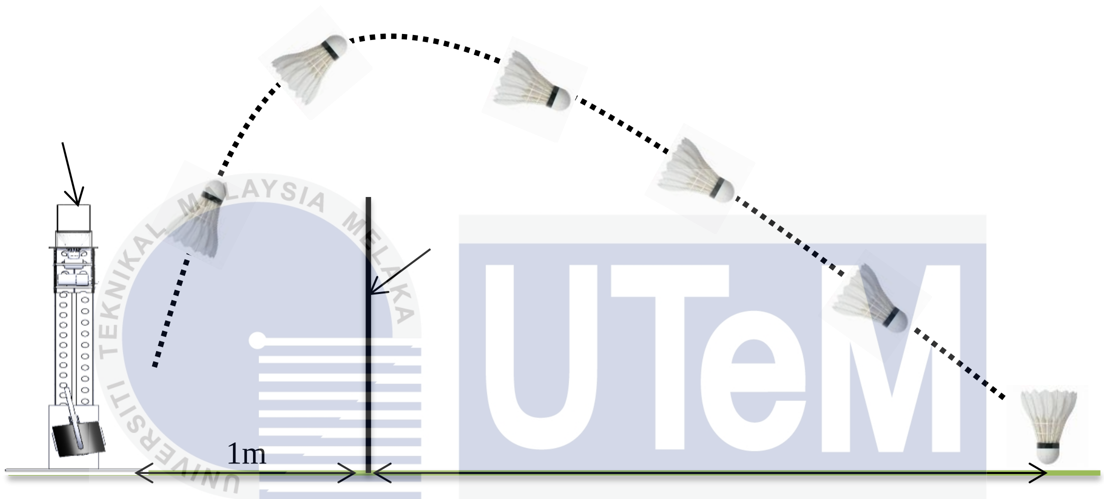


Figure 3.14 Setup for experiment 2

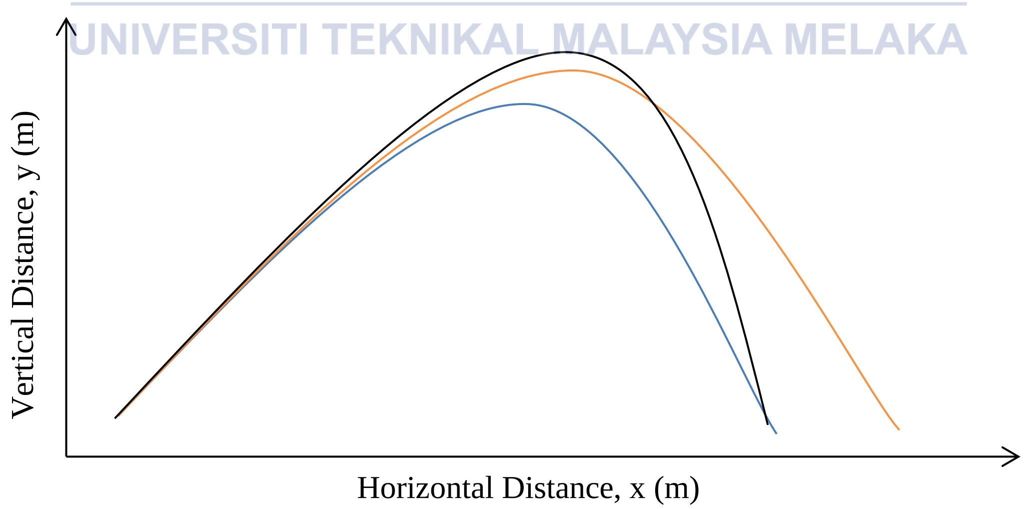


Figure 3.15 Illustrated graph of trajectory plotted by Tracker 4.84

Design of Experiment 2

In my design of this experiment, position of shuttlecocks in the feeder mechanism may vary during standby mode as shown in Figure 3.16. This is due to different size of the shuttlecocks used and their body structure. At standby position, shuttlecock may incline and affect the cams to hold and release the shuttlecock. This may lead to inconsistency of launching process when shuttlecocks intersect with the racket at different points. To improve the reliability of result, I will use identical brand and new shuttlecocks to conduct this experiment. However, the size of shuttlecocks may slightly differ even they are from the same brand.

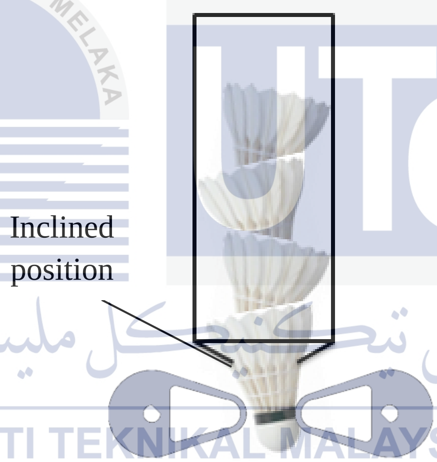


Figure 3.16 Illustration of shuttlecocks' inclined position

Reliability of Data in Experiment 2

The measurement of data may be influenced by systematic and environmental errors. When the launching mechanism is executed, systematic error may occur due to zero setting in which the motor does not return to its initial position for the second launch. This problem will cause the shuttlecock to intersect with racket at different points. Thus may lead to different trajectory of shuttlecocks happened in the experiment. Since the motor used in launching mechanism is with high speed and torque as calculated previously, overshoot will occur during operation and is difficult to be compensated. Therefore, the motor will be designed to rotate continuously.

First of all, the shuttlecock drop duration will be determined. The acceleration of shuttlecock drop is assumed to be 9.806 ms^{-2}, which is equal to the gravitational acceleration of earth. The drop duration of shuttlecock can be calculated by using the equation,

$$a = \frac{v}{T_{drop}} = \frac{d}{{T_{drop}}^2} \tag{3.11}$$

where acceleration of gravity a = 9.806 ms^{-2}, distance travelled d = 0.8 m and T_{drop} is the drop duration of shuttlecock. From the equation, the shuttlecock drop duration calculated is about 0.3 s. It means that the shuttlecock will take 0.3 s to reach the intersection with the racket to be launched.

Next, moving time of the racket is required to ensure that both racket and shuttlecock will reach the intersection point. Due to high cost of the power adapter with 24V 100A which is required to operate the scooter motor, power supply with 12V 30A is chosen to run the machine. Thus the speed of scooter motor can reach up to 1000 rpm as referred to [23]. By using the formula,

$$\frac{60\ seconds}{t_{spr}} = \frac{Number\ of\ revolutions\ per\ minute}{Number\ of\ revolutions\ per\ second}$$

where the moving time of racket per revolution t_{spr} is then calculated as 0.06 s. Therefore, the scooter motor will take 5 revolutions per second to operate 1 shot.

Other than that, there may have environmental error occurred during the experiment. The wind may resist the shuttlecocks to maintain smooth trajectories. However, it is assumed that the ventilation of the badminton court is sealed. Therefore, there is no airflow which will affect the result of the experiment.

3.5 Experiment 3: Accuracy Test

Research Question

How does the lateral swing design can improve the accuracy of the shuttlecock launcher?

Hypothesis

I hypothesized that the design of lateral swing will improve the shuttlecock launcher with accuracy more than 90%.

Objective

To improve the accuracy of shuttlecock launcher when lands the shuttlecock within the ideal area.

Apparatus

1. Shuttlecock launcher
2. Shuttlecock
3. Badminton court
4. Camera
5. Paper
6. Cellophane tape
7. Marker pen (red and black colors)
8. MATLAB software

Procedure

1. Set up the experimental rig as shown in Figure 3.17.
2. Set up the shuttlecock launcher to an angle of 45°.

3. Set up the target on the ideal area of the badminton court and place a plain paper on that target.
4. Color the cork on the head of shuttlecocks as shown in Figure 3.18 and load 10 shuttlecocks into the storage.
5. Start the machine until 10 shots are done.
6. During each shot, label the color marked by the shuttlecock immediate after the shuttlecock drops on the paper as shown in Figure 3.19. The following bouncing marks on the paper or outside the paper are ignored.
7. Stop the machine and replace a new paper on new target area.
8. Repeat step 2 to 6 with different angles 22.5°, 0° and -22.5°.
9. Scan the color-marked papers to the computer to be processed.
10. Use MATLAB software to detect the coordinate of the marks.
11. Calculate the accuracy of the shots by finding the mean and standard deviation from the coordinates.

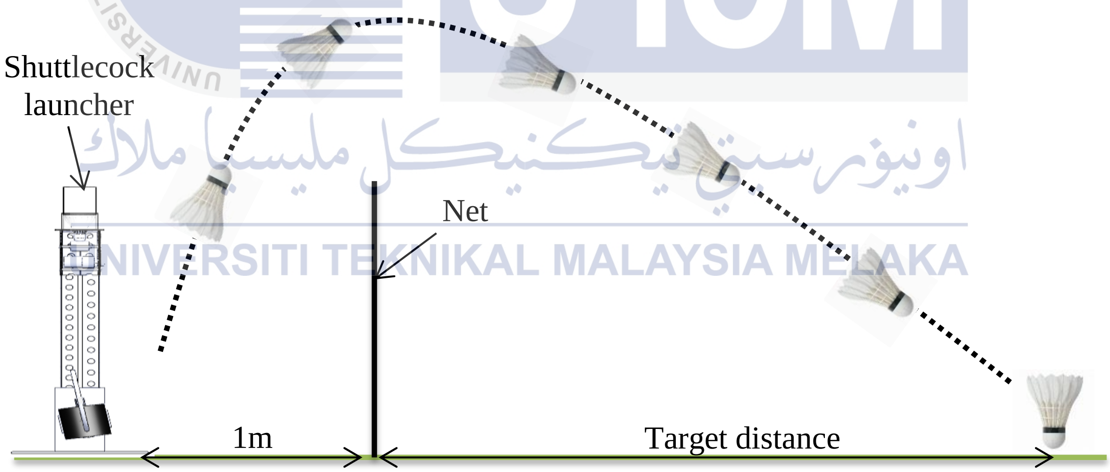


Figure 3.17 Setup for experiment 3

Figure 3.18 Colored cork of a shuttlecock

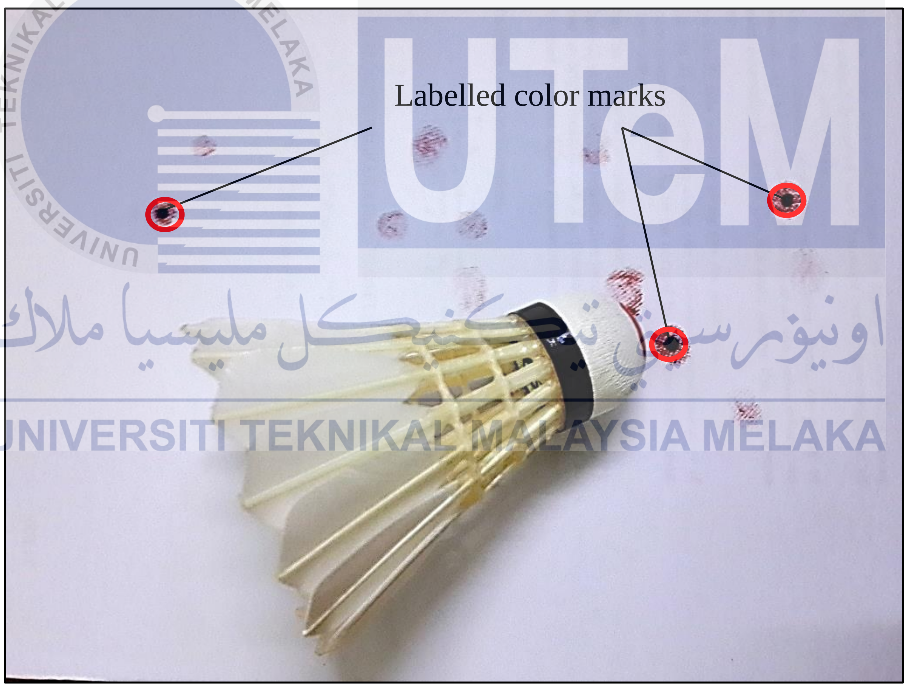


Figure 3.19 Color marked by the shuttlecocks

Design of Experiment 3

In this experiment, the shuttlecocks will bounce several times when landing on the target area. Thus the first position of shuttlecock dropped on the surface has to be labelled immediately by using a marker pen, while the marks which located outside the target area are ignored. This situation has to be taken care to validate the data collected for the analysis of data after the experiment.

Reliability of Data in Experiment 3

The measurement made during the experiment will rely on the marks labelled by human and the environment. Some data may be unreliable due to human error where the first position of shuttlecock landed on the paper may not clear. To improve the reliability of data collected, I will take the center of each marks labelled after the experiment as shown in Figure 3.20. Besides that, there may have environmental error occurred during the experiment. Again, it is assumed that the ventilation of the badminton court is sealed and therefore no airflow which will affect the result of the experiment.

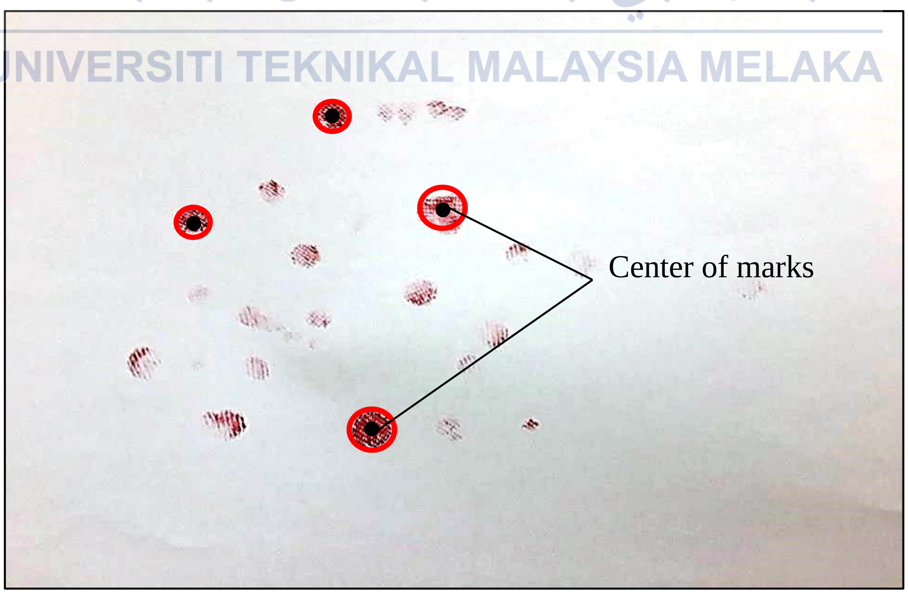


Figure 3.20 Illustration of center of marks

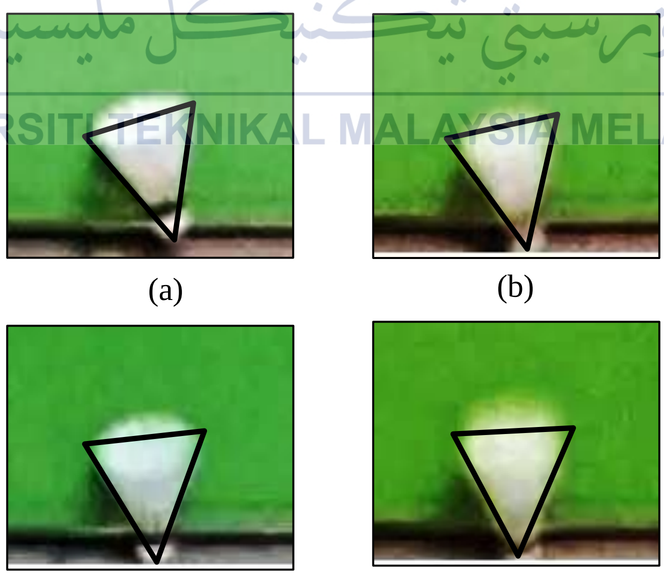
CHAPTER 4

RESULT AND DISCUSSION

4.1 Results Obtained

4.1.1 Testing for Ideal Height

From the experiment conducted in this section, the results are obtained from the video recorded. Different angle deviations of shuttlecock are shown in Figure 4.1 as the height changed. On observation of each pattern, it was apparent that the angle deviated slightly as shuttlecock dropped at different heights. For the height of 500 mm, angle of shuttlecock showed the most deviation. While for 800 mm, angle of shuttlecock has deviated a little.



(a) (b) (c) (d)

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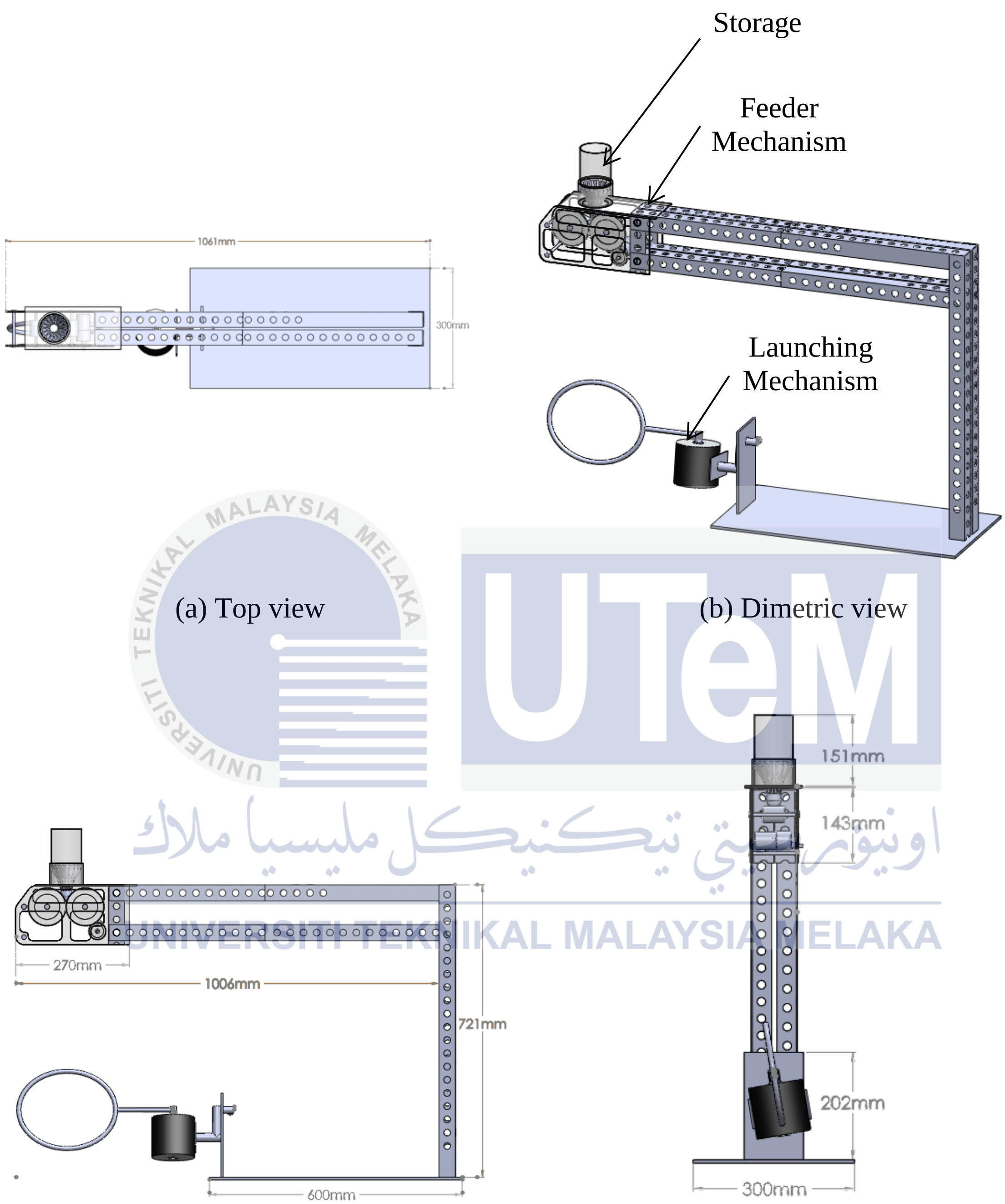
Figure 4.1 Motion patterns of shuttlecock at different heights (a) 500mm, (b) 600mm, (c) 700mm and (d) 800m

4.1.2 Prototype of Shuttlecock Launcher Design



(c) Front view (d) Side view

Figure 4.2 Prototype of SLS machine (in mm)

4.1.3 Shuttlecock Trajectory Test

A mathematical model will describe the motions of shuttlecock trajectory. The existed trajectory equation is simulated using MATLAB and the results which shown in Figure 4.3 fit the actual dynamic of the shuttlecock and patterns claimed in [20]. The angle and velocity of each shot are set up as shown in Table 4.1. However, the results are not ideal when the parameters suggested in [19] are used in the simulation as shown in Figure 4.4.

Table 4.1 Variables of trajectory equation

Type of shots (Color)	Mass (g)	Initial height (m)	Angle $(^{\circ})$	Velocity (m/s)
Net lift (Blue)	5.2	1	67.5	10.2
Mid court shot (Red)	5.2	1	45.0	10.2
Net shot (Yellow)	5.2	1	22.5	10.2

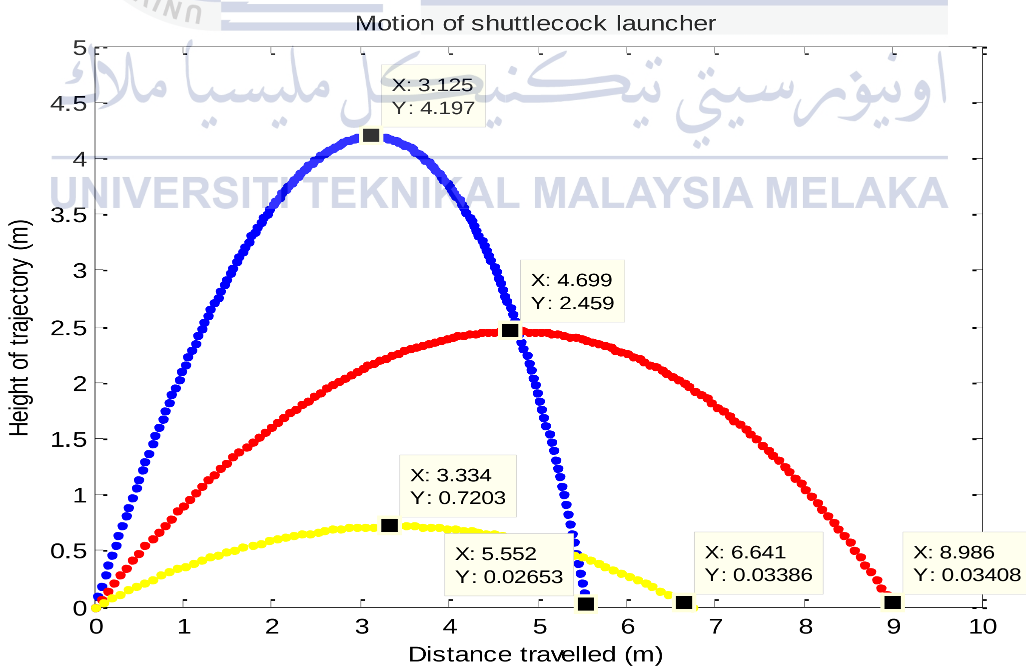


Figure 4.3 Preliminary results from MATLAB simulation

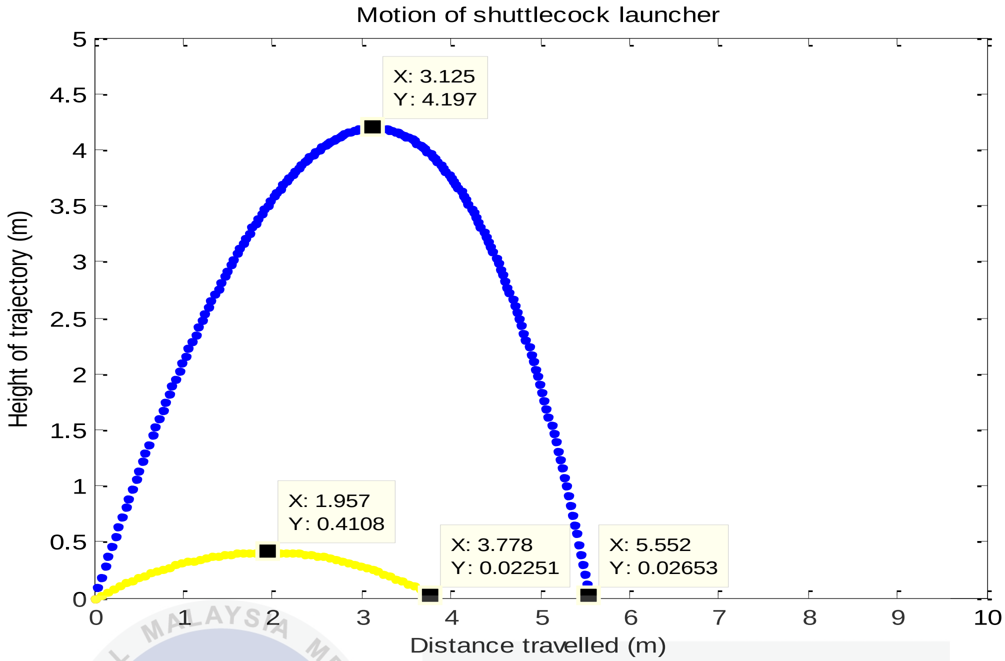


Figure 4.4 Results obtained by using the parameters in [19]

4.1.4 Result of Experiment 1: Feeder Repeatability Test

From the experiment, the results obtained in Figure 4.5 shows the data points collected by using both new and used shuttlecocks. There are 50 repetitions being done to get the result. The red circle shown in Figure 4.5 indicates the reference data point. During the experiment, some of the data overlapped on the same position are ignored. From the result, we can observe that most of the data points collected are concentrated in two groups.

Result shown in Figure 4.5 is then analyzed by using Tracker 4.84 software. The coordinates of 50 data points are identified and listed in Appendix C.

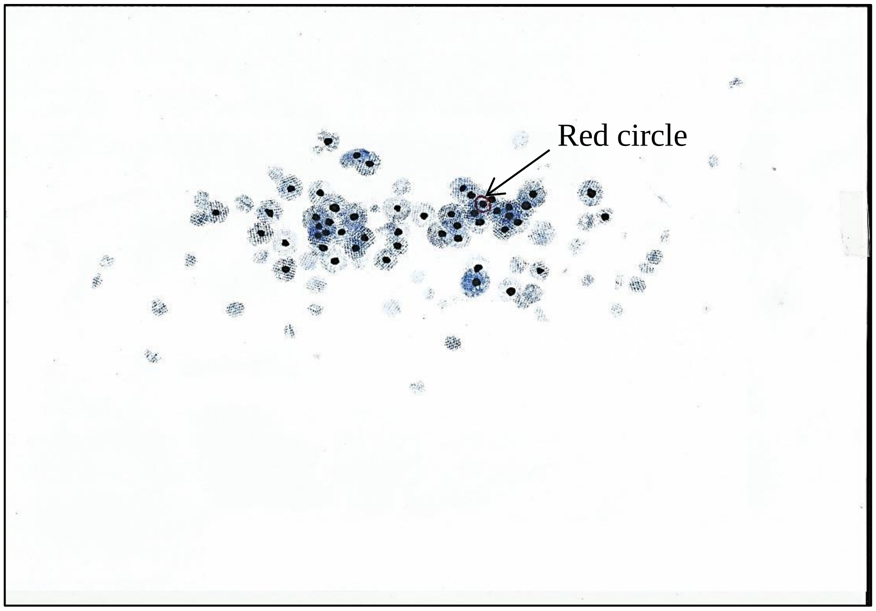


Figure 4.5 Data points collected by using both new and used shuttlecocks

Next, the experiment is repeated by using only new shuttlecocks and the result is shown in Figure 4.6. The coordinates of 50 data points are identified by Tracker 4.84 software and listed in Appendix D.

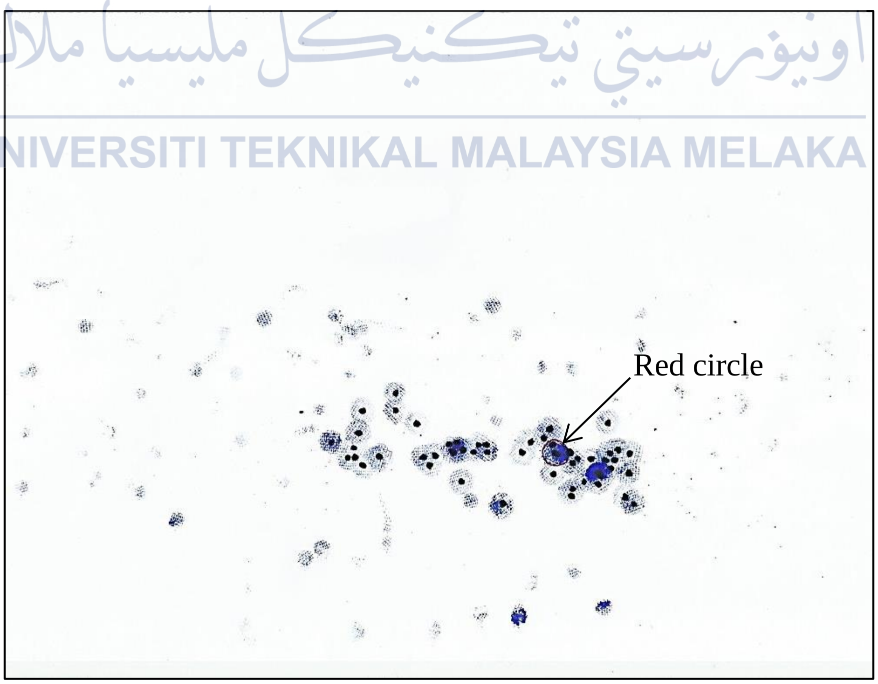


Figure 4.6 Data points collected by using new shuttlecocks

4.1.5 Result of Experiment 2: Verify the Reliability of Lateral Swing Design

Figure 4.7, 4.8 and 4.9 show the plots of data point which are associated with the video frame recorded from the experiment. The graphs are plot by using manual tracking tool due to vague videos recorded which are unable to be tracked by using automated tracking tool in the Tracker 4.84 Video Analysis software. Besides that, one of the best trajectories among 10 trials for all angle setting of 22.5°, 45° and 67.5° is chosen to be analyzed.

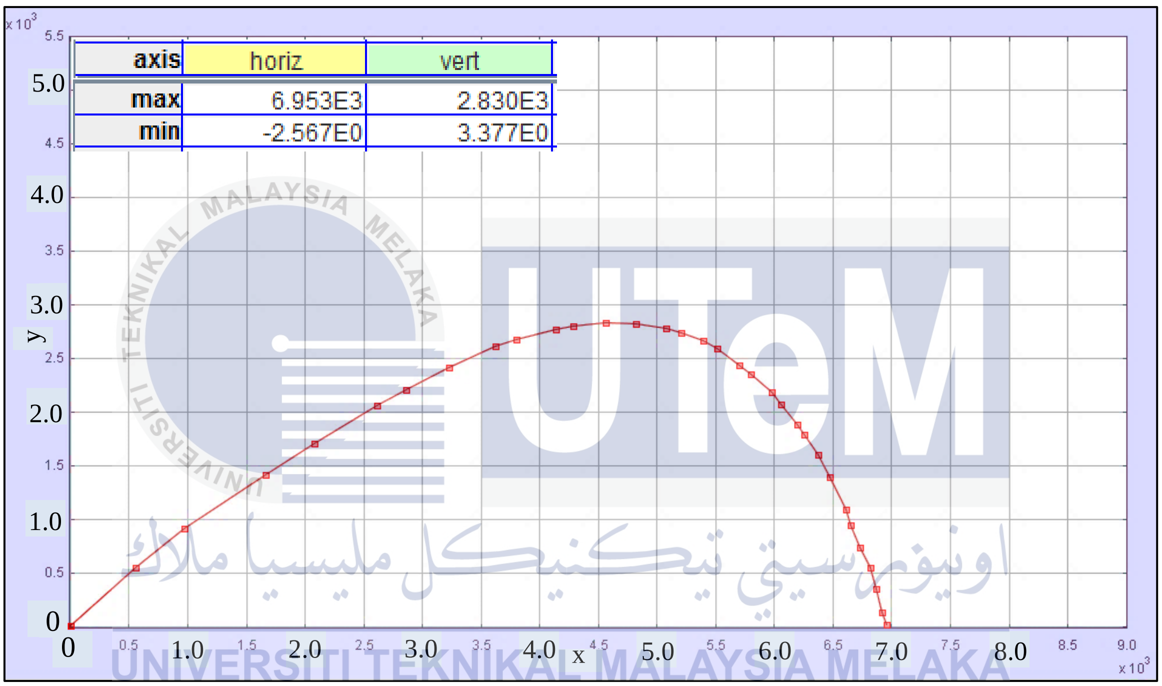


Figure 4.7 Plot of data point with angle setting of 22.5° in mm

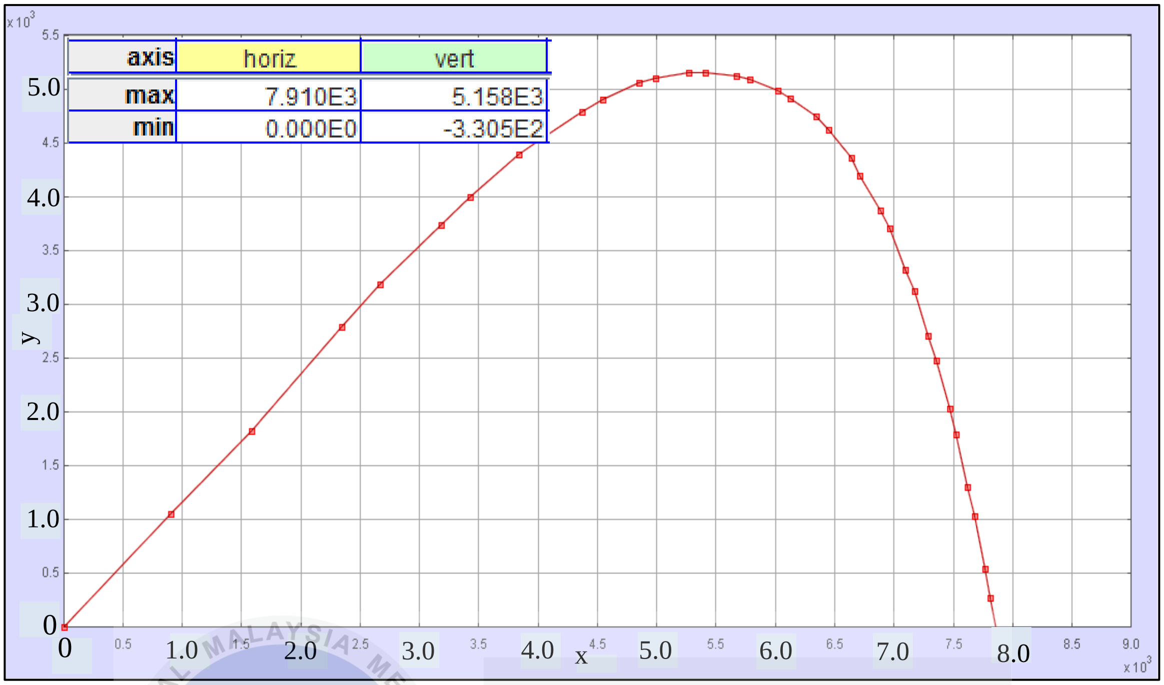


Figure 4.8 Plot of data point with angle setting of 45° in mm

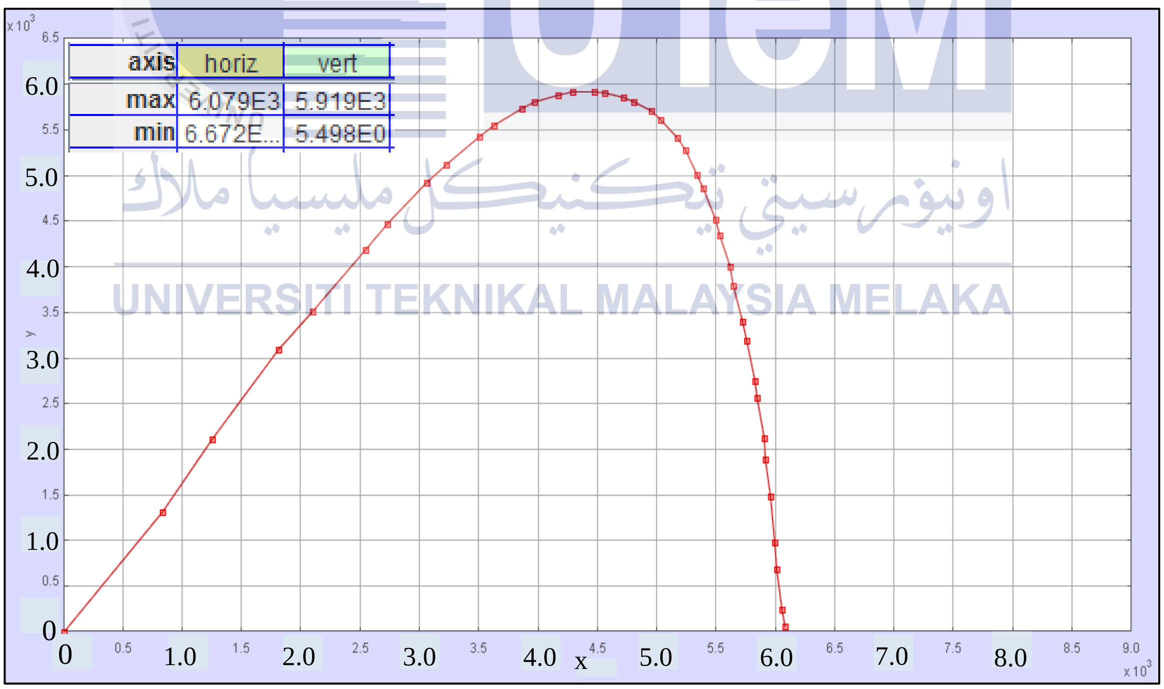


Figure 4.9 Plot of data point with angle setting of 67.5° in mm

For the angle setting of 22.5°, the results show that the maximum height and distance travel of shuttlecock can reach are about 2.830 m and 6.953 m respectively. For the angle setting of 45°, the maximum height and distance travel of shuttlecock are 5.185 m and 7.910 m respectively. While for angle setting of 67.5°, the height of the flight achieves 5.919 m and the distance travelled by the shuttlecock decreases to 6.079 m.

It can be observed that when the launching angle is adjusted, the height and distance travelled by the shuttlecock will be affected accordingly. When the launching angle is set within 0° to 45°, the two parameters are increased proportionally as shown in Figure 4.7 and 4.8. However in Figure 4.9, as the angle setting of 67.5° is executed, the height of flight increases but distance travelled by the shuttlecock reduces.

4.1.6 Result of Experiment 3: Accuracy Test

In this experiment, it went as expected with no unusual results that would have introduced the inaccuracy. The results obtained in Figure 4.10 and 4.11 show the data points collected by using random types of shuttlecocks with the angle settings of 22.5° and 67.5° respectively. From 10 shots of angle setting of 67.5°, the result shows in Figure 4.11 achieved 6 shots out of 10 on the target. For angle setting of 22.5°, there are only 2 out of 10 shots achieved on the target. However, there are no shots reached the target at angle setting of 45°. The red circles in both Figure 4.10 and 4.11 show the locations of shuttlecocks marked.

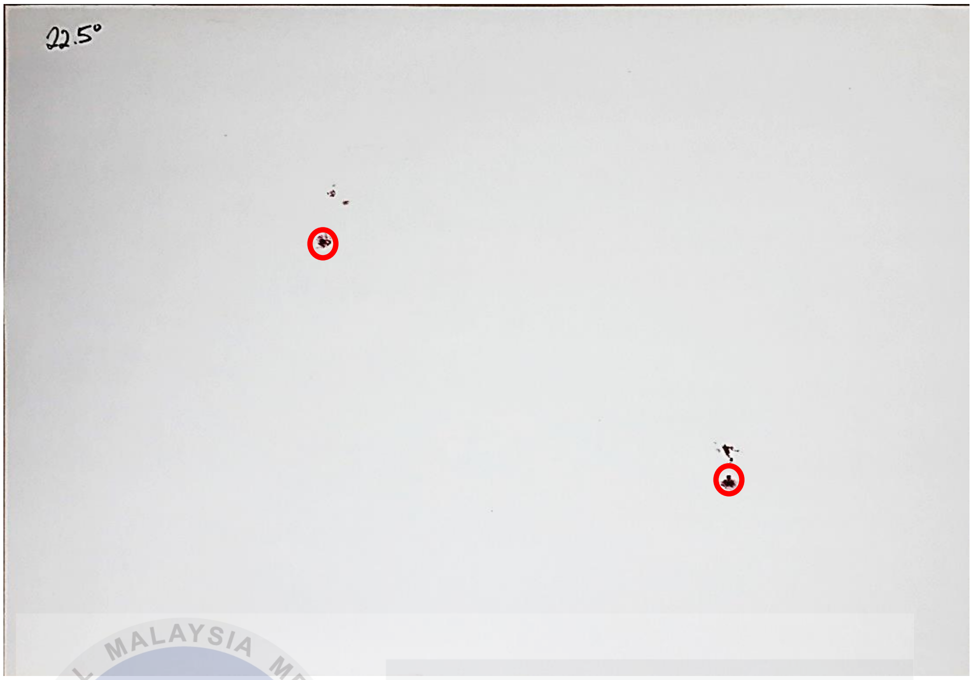


Figure 4.10 Data points collected with an angle setting of 22.5°

Figure 4.11 Data points collected with an angle setting of 67.5°

4.2 Discussion

4.2.1 Testing for Ideal Height

Figure 4.12 shows the angle deviations of shuttlecock at different heights. The dashed line in the figures illustrates the angle deviations of shuttlecock. It can be observed that as the height of feeder mechanism from the target area increases, the angle deviation of shuttlecock will decrease. The relationship can be described as:

$$height \propto \frac{1}{angle\ deviation}$$

From the result obtained in the experiment, the height of 800 mm will allow the least angle deviation of shuttlecock. Thus it is chosen as a height of the prototype machine to be developed.

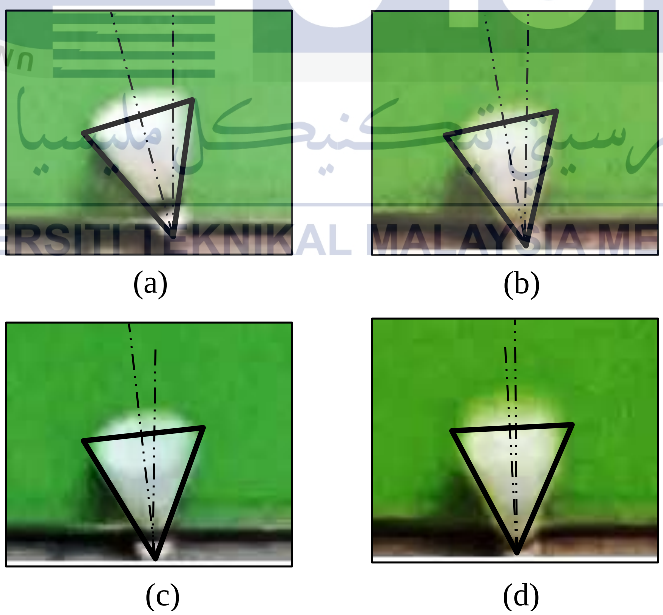


Figure 4.12 Angle deviations of shuttlecock at different heights (a) 500mm, (b) 600mm, (c) 700mm and (d) 800mm

4.2.2 Prototype of Shuttlecock Launcher Design

In the feeder mechanism, the shuttlecock storage is developed to store a maximum 10 shuttlecocks at a time. This is due to inefficient of the shuttlecock holder design as shown in Figure 4.13. The holder where shuttlecock located during standby mode is developed with a ratio of 12:13 to the diameter of a shuttlecock. This causes the holder unable to withstand the weight which is more than 10 shuttlecocks. Besides that, it is recommended to use new or moderate used shuttlecock because the holder is designed by following the dimension of a standard shuttlecock. Therefore, shuttlecock which is badly damaged are not applicable in this prototype.

Figure 4.13 Shuttlecock holder in feeder mechanism

4.2.3 Shuttlecock Trajectory Test

From the results obtained in Figure 4.14, it shows that the results are not ideal when the parameters suggested in [19] are considered in the simulation by using the trajectory equation. The velocity of 47 m/s is considered too high for net lift which the distance travelled has exceeded 200 m. However the velocities suggested for net shot and mid court shot are acceptable. Therefore, the velocity of shuttlecock is then fixed and the angle differences are taken into consideration. Three different angles of 22.5°, 45° and 67.5° are selected to conduct the experiment. The distance travelled for net shot and mid court shot are then achieved 3.778 m and 5.552 m respectively. For the variables which are set up based on player's experience, the results shown in Figure 4.14 have given appropriate values. The distance travelled for net shot, mid court shot and net lift are 5.552 m, 6.641 m and 8.986 m respectively. By comparing the data analyzed from the results obtained, the angle settings and velocities that are suitable for the three types of shot could be determined. The specification of motor used to launch the shuttlecock can also be defined without exceed any boundaries on the motor requirements.

The link between height of the trajectory at y-axis and the distance travelled at x-axis are interrelated to one another. As the velocity of the shuttlecock increases, the height of trajectory will increase and thus the shuttlecock travels further as shown in Figure 4.14. From the data obtained, it is clear that the velocity of the shuttlecock is increasingly proportional to the height of trajectory as well as the distance travelled by the shuttlecock. The relationship can be described as:

$$Velocity \propto (Height\ of\ trajectory)(Distance\ travelled)$$

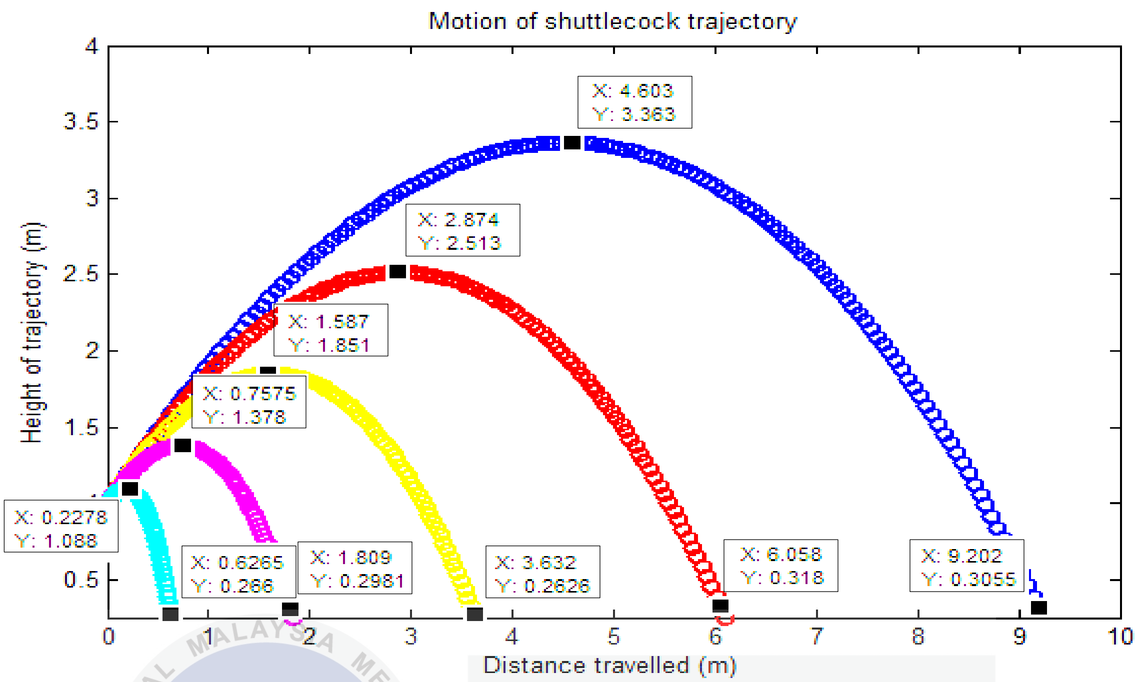


Figure 4.14 Trajectory of shuttlecock with 5 different velocities

4.2.4 Experiment 1: Feeder Repeatability Test

From the results shown in Chapter 3 regarding the feeder repeatability test, the hypothesis that shuttlecock launcher would increase in accuracy when the gear system and designed cams are used was supported by the data. From the analysis, the range, mean and standard deviation of the data points for x and y components are determined as shown in Table 4.2. Table 4.3 shows the analysis of range, mean and standard deviation of the data points for x and y components.

Table 4.2 The analysis for range, mean and standard deviation (new and used shuttlecocks)

Statistic	Axis (mm)	
	x	y
Range	19.3 ±55.8	12 ±15.8
Mean	-10.982	0.377
Standard Deviation	24.107	5.716

Table 4.3 The analysis for range, mean and standard deviation (new shuttlecocks)

Statistic	Axis (mm)	
	x	y
Range	19.5 ±51.3	15.4 ±13
Mean	-11.215	-0.31
Standard Deviation	22.577	5.824

In the analysis of both experiments using new shuttlecock or both new and used shuttlecocks, x component showed a wider range and greater standard deviation as compared to the y component. However, the result is still acceptable because data in Table 4.2 and 4.3 show that the shuttlecocks landing position are within racket area. In this experiment, y components are more important than the x components. The direction of shots is depended on the intersection between racket and shuttlecocks as shown in Figure 4.15. Shuttlecocks which landed behind the reference line of racket will be directed to the left, while those landed in front will be directed to the right as shown in Figure 4.16. Thus the lower the range and standard deviation of y component, the better the performance of the shot.

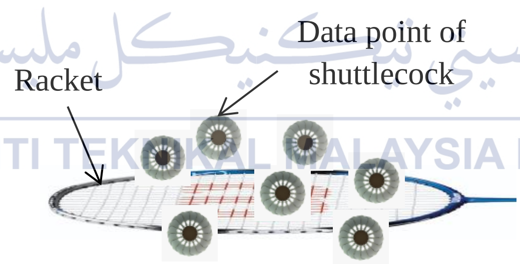


Figure 4.15 Intersection between racket and data points

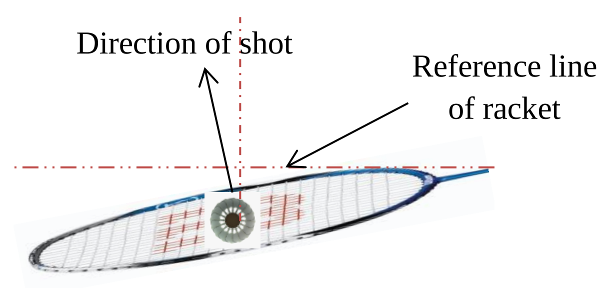


Figure 4.16 Shuttlecock directs to the left when dropped behind reference line

4.2.5 Experiment 2: Verify the Reliability of Lateral Swing Design

Table 4.4 shows the comparison of height and distance travel by shuttlecock from the existed trajectory simulation and experimental results. As the angle setting increases from 22.5° to 45°, the height and distance travel by the shuttlecock increase in both the simulation and experimental results. However, these parameters are decreased when the angle changed from 45° to 67.5°. Besides that, it is obvious that there are a wide range of different results for all three angle settings from either simulation and experimental.

Table 4.4 Comparison of height and distance travel from simulation and experimental results

Result	Angle Setting (°)	Height (m)	Distance Travel (m)
Simulation	22.5	0.920	6.641
	45.0	2.459	8.986
	67.5	4.197	5.552
Experimental	22.5	1.380	6.953
	45.0	3.158	7.910
	67.5	5.919	6.079

Therefore, it can be concluded that the design of lateral swing prototype will launch the shuttlecocks by following the path created as in the existed trajectory equation. However, based on the calculations shown in Table 4.5, the trajectories of shuttlecock produced from the experiment do not follow exactly as the existed trajectory equation. From the calculations, data shows that the distance travel by shuttlecock for all the three angle settings are more accurate as compare to the height of flight. The less percentage of error in Table 4.5 indicates a higher accuracy. Angle setting of 22.5° has the highest accuracy with an error percentage of 4.70 % of the distance travel. But, it exists 50 % of height error which is considered low in accuracy.

Table 4.5 Calculation of accuracy in error for the shuttlecock trajectories from the experiment

Angle Setting ($^{\circ}$)	Accuracy (Error)	
	Height (%)	Distance Travel (%)
22.5	50.00	4.70
45.0	28.43	11.97
67.5	41.03	9.49

4.2.6 Experiment 3: Accuracy Test

Table 4.6 obtained from the experiment of accuracy test shows the number of shots achieved out of 10 shots on the target by different angle settings. The angle setting of 67.5° obtained the most number of successful shots among the others, while angle setting of 22.5° shows the least number of successful shots.

From the observation of experiment, it can be deduced that the flight motion of shuttlecock is depended on the structure of that shuttlecock. The motion of shuttlecock will first follow the starting launching angle which is set initially, but when it reaches a certain level of height, the flight motion will then depend on the body structure of the shuttlecock. At an angle setting of 22.5°, shuttlecock will obey a motion pattern during landing as shown in Figure 4.17. The black illustration indicates the path of shuttlecock's motion. Due to different body structure, the aerodynamic acts on the shuttlecocks will influence the flight patterns, which will lead to the inaccuracy of shots. The accuracy for angle setting of 22.5° achieved 20% only.

However at an angle setting of 67.5°**,** the shuttlecock will follow the motion pattern which is shown in Figure 4.18 during landing. The motion of shuttlecock during landing is in vertical direction. Since the shuttlecock is pulled by gravitational force during free fall, the landing position will not be affected by the structure of shuttlecock. Thus a more accurate shot can be achieved as compare to the other two angles, where the accuracy can reach up to 60%.

Table 4.6 Number of shots achieved by different angle settings

Angle Setting (°)	**Number of shots (pcs)**	**Accuracy (%)**
22.5	2	20
45.0	0	0
67.5	6	60

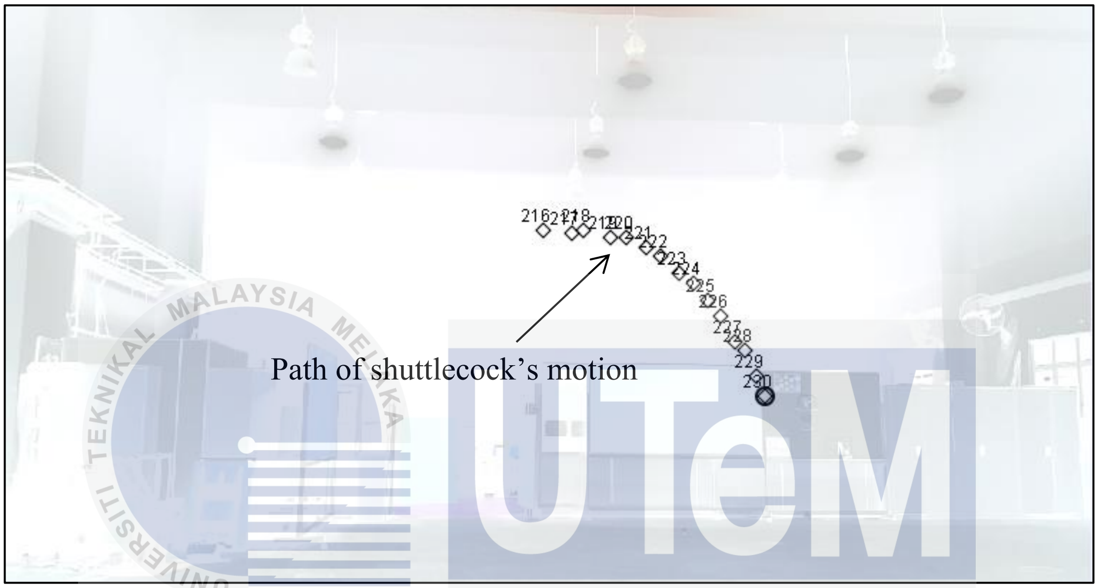


Figure 4.17 Motion pattern of shuttlecock at angle of 22.5° during landing

Figure 4.18 Motion pattern of shuttlecock at angle of 67.5° during landing

In this experiment, there are only 10 shots being done due to overheating of the power booster. This is caused by the continuous energy storage in the capacitors. Even though there are heat sinks mounted on the transmitters to dissipate heat, it is still consider unsafe to run the machine without stopping. If the power booster is damaged, it may as well damage the other circuits and components.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

A new Shuttlecock Launching System (SLS) is developed for badminton training purpose. The objective to analyze the performance of the shuttlecock launching system by simulating the existed trajectory equation was achieved. Based on the simulation in MATLAB, it is clear that by considering the linear model of air resistance in trajectory equation, it gave well description on the shuttlecock motion. By giving the appropriate velocities and angle settings for the three types of shot, the distance travelled by the shuttlecock is said to be reliable. Additionally, it is found that the velocity of shuttlecock is increasingly proportional to the height of trajectory as well as the distance travelled by the shuttlecock. However, the distance travelled by shuttlecock will be inversely proportional to the launching angle when the setting exceeds 45°.

Through simulation and testing, the motors chosen were believed appropriate for SLS function and methods to improve the performance of SLS were also found. The development of the shuttlecock launching prototype is done. Then, the experiments have been conducted by operating the prototype to analyze the performance of shots. For feeder repeatability test, the accuracy of shuttlecocks in feeder mechanism are (12 ± 15.8) mm and (15.4 ± 13) mm with standard deviation of 5.716 mm and 5.824 mm respectively. From experiment 2, it can be concluded that the lateral swing design of the machine has the ability to provide high accuracy in the distance travelled by the shuttlecock. The data shows an error percentage as low as 4.70% at an angle setting of 22.5°. However, the highest error percentage of the height of flight reaches 50% at the same angle. For experiment 3, the accuracy for angle settings of 22.5°, 45° and 67.5° achieved 20%, 0% and 60% respectively.

Further research on specific parts of the SLS can be increased to reduce the need of fabrication. The efficiency of the shots can be improved through employing the advanced technology available in the future. Advanced systems such as wireless information transfer and fully autonomous platform can be implemented to the SLS.

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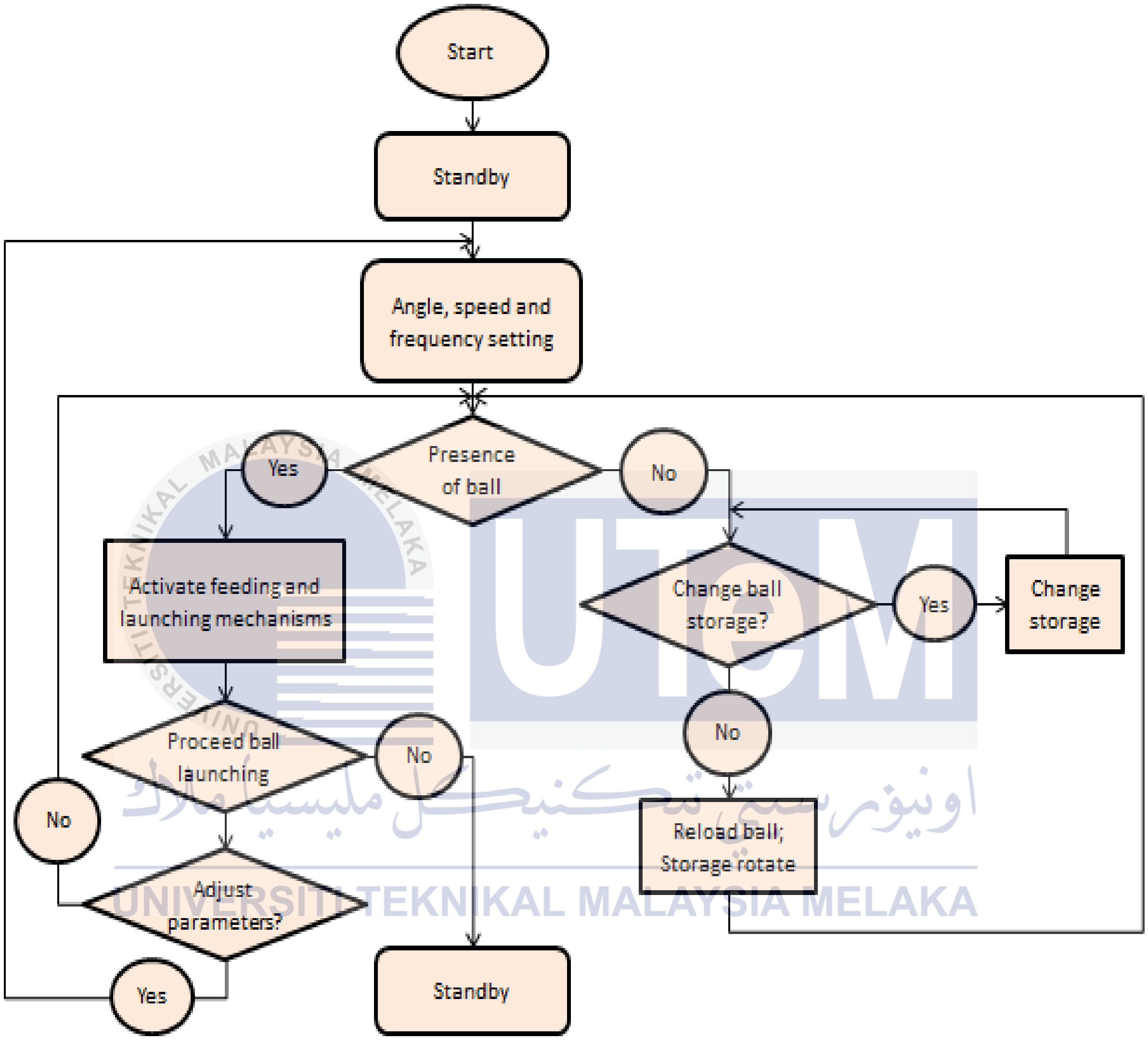
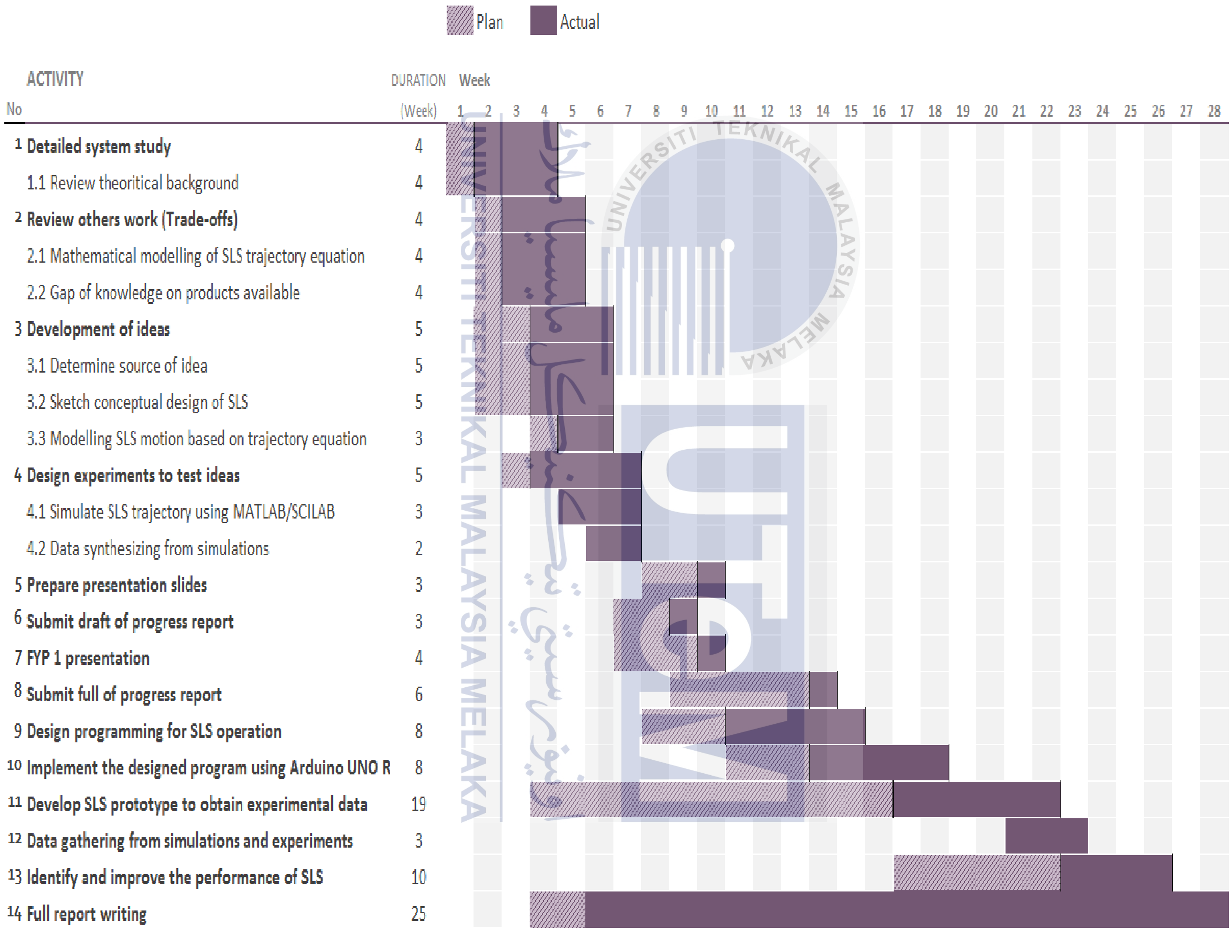
APPENDIX A

How the Shuttlecock Launching System works



APPENDIX B

Gantt Chart of Research Activities with Milestones



APPENDIX C

Table of data points collected from Experiment 1 (new and used shuttlecocks)

No.	Coordinate (mm)	
	x	y
1 (reference)	0	0
2	19.3	12.8
3	17.2	10.9
4	17.8	4.9
5	18.3	0.0
6	15.3	-1.2
7	14.5	1.4
8	13.6	3.6
9	13.2	0.0
10	12.7	-0.8
11	12.2	1.5
12	10.8	5.2
13	10.4	7.8
14	8.8	1.3
15	6.9	7.1
16	5.6	1.1
17	4.3	2.3
18	3.6	-0.4
19	4.1	8.7
20	3.7	10.5
21	-1.6	-6.6
22	-0.8	-2.3
23	-0.7	5.2
24	-2.9	-4.1
25	-6.1	-3.1
26	-8.3	-0.4
27	-13.2	12.7
28	-17.4	-2.4
29	17.1	-0.4
30	19.3	-2.3
31	-20.4	-0.6
32	-23.0	-1.2
33	-24.6	-2.9
34	-25.7	-0.6
35	-26.4	-2.5
36	-23.4	6.9
37	-29.9	0.5
38	-31.4	2.8
39	-32.7	0.9

40	-34.4	-7.8
41	-39.8	-15.8
42	-39.8	-11.2
43	-43.8	0.5
44	-48.0	-11.2
45	-48.9	-5.4
46	-50.0	-1.8
47	-49.6	0.8
48	-51.4	0.9
49	-47.8	0.3
50	-55.8	-3.0
Max	**19.3**	**12.8**
Min	**-55.8**	**-15.8**
Mean	**-10.982**	**0.377**
Standard Deviation	**24.107**	**5.716**

APPENDIX D

Table of data points collected from Experiment 1 (new shuttlecocks)

No.	Coordinate (mm)	
	x	y
1 (reference)	0	0
2	19.5	-13.0
3	17.4	-11.3
4	18.3	-5.1
5	18.4	-0.1
6	13.1	7.7
7	15.6	0.8
8	13.8	0.0
9	14.7	-0.2
10	13.9	-3.7
11	12.4	-1.8
12	11.0	-5.3
13	8.9	-1.6
14	10.6	-7.9
15	7.2	-7.4
16	5.7	-1.4
17	3.7	0.2
18	4.4	-2.5
19	4.4	-9.1
20	4.1	-10.9
21	0.8	-0.2
22	-0.5	2.1
23	-1.4	6.1
24	0.3	-5.2
25	-2.7	3.8
26	-6.0	2.7
27	-8.1	0.2
28	-12.9	-12.8
29	-17.0	2.1
30	-16.7	0.1
31	-18.9	2.1
32	-20.1	0.2
33	-22.8	0.9
34	-24.3	2.7
35	-26.1	2.3
36	-25.2	0.4
37	-23.2	7.1
38	-29.5	-0.7
39	-30.9	-3.0

40	-32.5	-0.9
41	-34.2	7.5
42	-39.4	15.4
43	-39.4	11.0
44	-43.5	0.9
45	-47.5	10.9
46	-48.8	5.0
47	-49.8	1.4
48	-51.3	-1.0
49	-49.4	-1.0
50	-47.5	-3.0
Max	**19.5**	**15.4**
Min	**-51.3**	**-13.0**
Mean	**-11.215**	**-0.31**
Standard Deviation	**22.577**	**5.824**

APPENDIX E

Arduino Source Code of SLS

```
int encA = 3;
int encB = 4;
int encPos = 0;
int encALast = LOW;
int n = LOW;
int pwm1 = 5;
int pwm2 = 6;
int dir2 = 7;

void setup()
{
 pinMode(encA, INPUT);
 digitalWrite(encA,HIGH);
 pinMode(encB, INPUT);
 digitalWrite(encB,HIGH);
 pinMode(dir2,OUTPUT);
 Serial.begin(9600);
}

void loop()
{
 n = digitalRead(encA);
 if((encALast == LOW) && (n == HIGH))
 {
  if(digitalRead(encB) == LOW)
  {
   encPos--;
  }
  else
  {
   encPos++;
  }
  Serial.print(encPos);
  Serial.print(",");
 }
 for(int i=0; i<10; i++)
 {
  enc_control(135);
  scooter_motor(255);
  delay(50);
 }
 power_off(5000);
```

```
  encALast = n;
}

void enc_control(int limit) //with feeder motor overshoot compensation
{
  if(encPos > -limit)
   {
     motor(100,true);
   }
  else if(encPos <= -limit)
   {
     motor(0,false);
   }
}

void motor(int pwm, boolean reverse)
{
   analogWrite(pwm2,pwm);
   if(reverse)
   {
     digitalWrite(dir2,LOW);
   }
   else
   {
     digitalWrite(dir2,HIGH);
   }
}

void scooter_motor(int spwm)
{
  digitalWrite(pwm1,spwm);
  delay(50);
}

void power_off(int data)
{
  motor(0,true);
  scooter_motor(0);
  delay(data);
}
```