Badminton Robot Trainer – Lonely Champion Winner

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***Abstract* – Badminton is a sport that is difficult to play or be trained without a partner. Although there are shuttlecocks launchers available in the market to solve this problem, they are expensive and only have limited ball firing positions. In this technical report, an automation-based badminton robot trainer is introduced. This project is built within a reasonable budget and provides the ball feeding and firing mechanism for different directions and trajectories with high accuracy. In short, the automation-based badminton robot trainer is successfully built and project provides positive impacts on social, and economic.**

Index Terms – badminton robot trainer, ball feeding, ball firing.

I. Introduction

A. Background

Malaysia has entered a global advancement in sports. There are many reasons that people choose to play sports. Not only is good for your health, but it promotes teamwork and sportsmanship. These are both transferable skills which can be taken into different aspects of life, such as in the workplace and when studying. The discipline learnt when playing a sport is also a great life-skill to have. Sports is also a great way to socialize and make friends, that will most than likely have similar interests. This can be very helpful when trying to make friends, such as when starting university, as you will be able to meet people that already have a common interest to you. Furthermore, it can help individuals to learn to focus and to manage their time efficiently. This again is another transferable skill that is very valuable in places such as the workplace and when completing studies.

Over the last century, technology has affected sports for both officials and athletes, changing the way sports are prepared for, played, and reviewed by officials. Technology is utilized by almost everyone involved in a modern sporting event. Games can be prepared for by using technology that tracks the athlete's diet and workouts, giving them precise information, they need to appropriately prepare for a game. Practicing monitored, and safe training habits allows athletes to increase their efficiency in the game and potentially prolongs their careers. For example, during the game, players can be tracked by chips embedded into jerseys and mounted on helmets. Sensors in Jerseys and on helmets are utilized by team staff to monitor the athlete's performance.

One of the advancements in sports as done in badminton using the badminton robot trainer. This research involved the prototyping of a shuttlecock robot that enables a badminton player to practice independently. First, a three-dimensional model of the badminton robot was designed using SolidWorks. Subsequently, the dynamics of the mechanism were evaluated. Next, the hardware was designed using. Finally, the trajectory of the badminton shuttlecock was determined using a series of experimental tests.

B. Literature Review

Badminton is a common indoor sport in Southeast Asia. Generally, it requires two or four opposing players to hit a shuttlecock in opposite directions at varying speeds. However, at least two players are needed for training, which in some cases has been difficult. In such cases, players need a device that allows them to train independently. While there are no such resources for badminton players to practice badminton, this issue can be solved using an automatic machine designed to support badminton training. This device would be beneficial for talented players who cannot afford professional coaching or imported machinery. In addition, it provides an opportunity to practice and master the crucial skills required for the game. A machine would launch shuttlecocks at varying speeds and directions, providing the player with a practice session that mimics a real badminton game with an expert or experienced partner. Furthermore, because of its simple design, the machine could be manufactured locally, and the cost would be considerably reduced. Therefore, it could be used to train several players at a given location.

Several studies have been conducted to prove the capability of robots or machines in badminton training. Sun et al. proposed a new mobile badminton training robot with a pneumatic batting mechanism. Stoev et al. presented a mechatronics design approach and related technologies for a badminton-playing robot. Yamakawa et al. developed a fully automatic badminton-playing robot that served as a substitute for a human badminton player. Sakai et al. developed a shuttlecock-launching machine using two turn rollers for badminton exercises. Their research used a shuttlecock tracking algorithm for the badminton robot. Yousif et al. developed a new shuttle shooter machine with an impact mechanism for badminton training purposes. Sakai and Shirayama proposed a badminton launching machine using a revolving launch arm with a new launcher mechanism that can discharge at high speeds to reduce damage to the shuttlecock feathers. New insertion equipment and motion control systems were proposed by Sakai et al., and a training machine for badminton that project shuttlecocks at high speeds were developed. Two types of shuttlecocks made of different materials (feathers and plastic) were used for a new badminton robot by Tan et al.

According to PHILIP OSAMENDE OMOREGIE University of Education, Winneba GHANA technology increasingly is playing a leading role in the development of sports and enhancing performance in all faces. Thus, applications of technology allow for more effective training, stimulations, management, and tracking of athletes, accuracy of results, enhanced spectator viewing, developing performance, and preventing injuries, amongst many more functions (Busch, 1998). Technology in sports is a technical means by which athletes attempt to improve their training and competitive surroundings in order to enhance their overall athletic performance. It is thought of as a technical means or instrument utilized to pursue chosen ends. Hence, the paper investigates the impact of technology on sports performance.

Moreover, based on Jun Xie 1, Guohua Chen and Shuang Liu, School of Physical Education, East China University of Technology, Nanchang, China, explored the role of the intelligent badminton training robot(IBTR) to prevent badminton player injuries based on the machine learning algorithm. An IBTR is designed from the perspectives of hardware and software systems, and the movements of the athletes are recognized and analyzed with the hidden Markovmodel (HMM) under machine learning. After the design was completed, it was simulated with the computer to analyze its performance. The results show that after the HMM is optimized, the recognition accuracy or data pre-processing algorithm, based on the sliding window segmentation at the moment of hitting reaches 96.03%, and the recognition rate of the improved HMM to the robot can be 94.5%, showing a good recognition effect on the training set samples. In addition, the accuracy rate is basically stable when the total size of the training data is 120 sets, after the accuracy of the robotics analyzed through different data set sizes. Therefore, it was found that the designed IBTR has a high recognition rate and stable accuracy, which can provide experimental references for injury prevention in athlete training.

There are many approaches to increasing the accuracy and effectiveness of badminton machines. This project is primarily done to benefit three parties which are the player, the coach and the court owner.

C. *Problem Statement*

In the current global era, problems arise when a player is self-training. When a player is conducting self-training, the person needs someone else to feed them the ball. If the person doesn't have anyone to play with, most probably the player would quit badminton. Next, is the competition among players these days. Humans have become very competitive in badminton every year because they want to excel and be the best. Coaches cannot offer high-intensity or high-accuracy training all the time because they are humans too and they are prone to make mistakes and also get tired in between sets. This couldn't maximize the players full potential.

D. *Proposed Solution*

Our proposed solution is a badminton trainer robot. The robot can constantly shoot the shuttlecock with high intensity at random or specific places inside the badminton court for the player to counter. The robot can also shoot different types of shots which are high ball(lobby), netball(netting), and also drop ball (dropshot). Players have the option to choose the intensity of their game. The robot can also give shuttlecock at five different angles in the badminton court. Although the robot is capable of giving shuttlecock at all the angle in the badminton court, since we are focusing on beginner players only five angles were chosen. The robot is also capable of giving repetitive balls at the same angle if they player wanted to train only one specific angle.

E. *Objectives*

Based on the problem statement stated previously, below are the four objectives to be achieved in this project:

1. To design an automation-based badminton robot trainer for training purposes for beginner badminton players.
2. To design a badminton robot trainer which can feed the ball in multiple directions and positions.
3. To design a badminton robot trainer with high accuracy in ball feeding.
4. To design an economical and high-quality badminton robot trainer for badminton players.

II. METHODOLOGY

A. *Project Specification*

The badminton robot trainer is designed to provide the shuttlecock feeding function to the end user with different positions and angles for beginner-level training purposes. The system consists of two main parts which are the feeding mechanism and the firing mechanism. Besides, the badminton robot trainer is equipped with two modes of firing mechanisms which are the fixed pattern and randomized-position firing modes. There are a total of six different types of shots that will be provided by the badminton robot trainer which are the front left shot, front center shot, front right shot, high rear left shot, rear center shot (high ball), and high rear right shot respectively. For the fixed pattern firing mode, the badminton robot trainer will shoot out the shuttlecocks according to the sequence which has been set. Meanwhile, the robot trainer will shoot the shuttlecock to a randomized position without any sequence during the randomized mode.

In this project, the Arduino UNO board was chosen as the main microprocessor to interface with all components used. Moreover, the robot trainer is portable and user-friendly. The end user can simply change the desired firing mode by changing the position of the 3-pin toggle switch. The loading cylinder of the badminton robot trainer can hold up to 24 shuttlecocks.

B. *System Block Diagram*

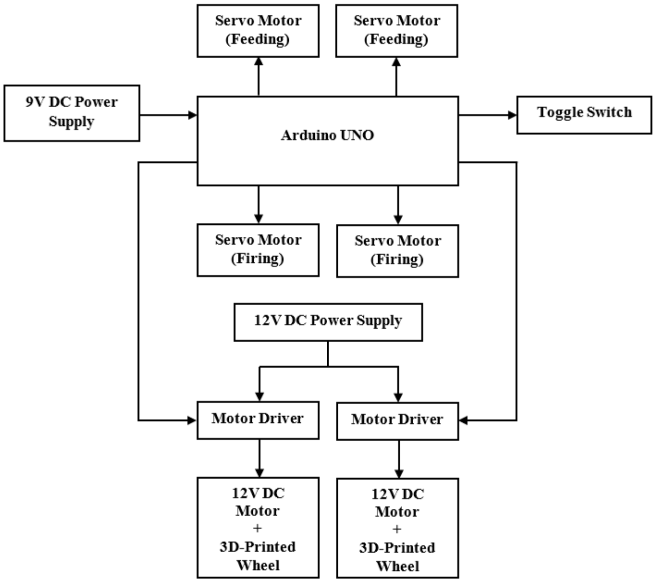

Fig. 1 Block diagram of the badminton robot trainer.

The whole system of the badminton robot trainer is controlled by using the Arduino UNO microcontroller. There are two different power supplies used in this project which are the 9V DC power supply (Arduino Power Adapter) and the 12V DC power supply (Dell PC power supply) respectively. The 12V DC power supply is used to power up the 12V DC motors which are controlled by the motor drivers, while the 9V DC power supply is used to power up the Arduino UNO board and the servo motors for the feeding as well as firing mechanisms.

The Arduino UNO microcontroller is programmed in order to make sure that the feeding and firing mechanisms of the badminton robot trainer are functioning properly. For the shuttlecock feeding mechanism, two servo motors are used to feed in the shuttlecocks from the loading cylinder to the slider by adjusting the angle of rotation of the feeding servo motors. On the other hand, the firing mechanism of this badminton robot trainer consists of two 12V DC motors and two servo motors. The DC motors are attached to 3D-printed wheels which are designed using SolidWorks software based on the desired dimension. In order to shoot the shuttlecocks to different positions, the rotational speed of each 12V DC motor with approximately 12000rpm is controlled by using the 'Cytron' motor drivers through the pulse width modulation (PWM) technique which can be controlled by the Arduino UNO microcontroller. Apart from that, the angle of inclination of the firing platform which is made of acrylic material where both 12V DC motors attached to it can be controlled by adjusting the rotational angles of the two servo motors attached to both sides of the firing platform. Thus, the badminton robot trainer will be able to provide shots with different trajectories. Moreover, the 3-pin toggle switch allows the end user to select the desired firing mode which is either fixed-pattern mode or randomized-position mode.

Arduino IDE software is an open-source software for code writing and uploading which can be used on any Arduino board. Therefore, Arduino IDE is used to upload the source code to the Arduino UNO board in order to enable the microcontroller to perform the required tasks in this project. Furthermore, the 'if' and 'else if' statement is used to switch the mode of the firing mechanism based on the input voltage signal given by the 3-pin toggle switch.

C. *List of Hardware and Software Used*

TABLE I
HARDWARE AND SOFTWARE USED.

No.	Hardware
1	Servo Motor (MG996R) x4
2	12V 775 DC Motor x2
3	3-Pin Toggle Switch x1
4	Arduino UNO Board x1
5	3D-Printed Spinning Wheel x2
6	Cytron Driver Motor (MD10C) x2
7	Dell PC Power Supply x1
8	Slider x1
9	Loading Cylinder x1
No.	**Software**
1	Arduino IDE
2	SolidWorks

D. *Hardware Description*

i. *MG996R Servo Motor*

Fig. 2 MG996R Servo Motor.

The MG996R is a metal gear servo motor having a maximum stall torque of 11 kg/cm. The motor rotates from 0 to 180 degrees according to the duty cycle of the PWM wave delivered to its signal pin, just like other RC servos. The majority of hobby servo motors run between 4.8 and 6.5 volts; the greater the voltage, the more torque is possible, but they usually run at +5 volts [9].

The MG996R servo motor is essentially an improved version of the well-known MG995 servo motor. It has improved shock-proofing and a completely new PCB and IC control system, which gives it far greater accuracy than its predecessor. The Arduino microcontroller and the MG996R servo motor have excellent compatibility. This is due to the ease with which an Arduino may be set up and controlled using the Servo library. It is perfect for beginners who want to make things move without developing a motor controller with feedback & gearbox since they can use any servo code, hardware, or library to drive these servos, and it will fit in small spaces [10].

ii. 12V 775 DC Motor

Fig. 3 12V 775 DC Motor.

A direct current motor is an electrical device that converts electrical energy into mechanical energy. In a DC motor, the input electrical energy is direct current, which is converted into mechanical rotation. A conductor that is carrying current generates torque and starts to move when it is kept in a magnetic field. A mechanical force develops, in essence, when electric and magnetic fields interact. The operation of DC motors is based on this theory.

The 775 DC Motor is a base motor, which means it lacks a gearbox to slow it down. It can be used for a variety of heavy-duty applications. These 775 motors are reasonably priced, incredibly effective, and robust. Therefore, the 775 DC motor can be used to create drill machines, electric bikes, grinders, remote-controlled cars and boats, solar fans, water pumps, strong table saws, etc [11].

iii. 3-Pin Toggle Switch

Fig. 4 3-Pin Toggle Switch.

The 3-pin toggle switch is also known as the SPDT switch. An SPDT switch consists of three terminals and connects the source terminal and one of two output terminals. An SPDT switch has a "ON/ON" configuration, which means that one of the two possible circuits that the switch can regulate is always completed at the input terminal. The first circuit is completed if the switch is in the "ON-1" position, which connects the input terminal to the first output terminal. When the switch is turned to "ON-2," the connection between the second output terminal and the input terminal completes the second circuit. This switch is a single pole switch because only one finished circuit can be present at any given time because both circuit alternatives depend on the input terminal. Confoundingly, certain SPDT switches can be set up in a third configuration. When neither circuits one nor two are finished, the third switch can be turned "OFF." "ON/OFF/ON" is the designation for this SPDT switch setup [12].

iv. Arduino UNO Board

Fig. 5 Arduino UNO Board.

Arduino is an open-source physical computing platform built on a straightforward I/O board and a development environment that supports the Processing/Wiring programming language. The 8-bit ATmega328P microprocessor serves as the foundation for the Arduino UNO microcontroller board. It contains a 16 MHz ceramic resonator, 6 analog inputs, 14 digital input/output pins (of which 6 can be used as PWM outputs), a USB port, a power jack, an ICSP header, and a reset button. It comes with everything required to support the microcontroller; to use it, simply plug in an AC-to-DC adapter or battery, or connect it to a computer using a USB cable [13].

There are 14 digital pins on the Arduino UNO board that can be used to connect devices like servo motors, LEDs, buzzers, etc. In addition, this board has 6 analog pins. Due to the fact that most sensors have analog values, these analogue pins are typically utilized to connect sensors. The analog pins are therefore connected to the majority of the input components. IOREF, GND, 3.3V, 5V, and Vin are the power supply pins that are utilized to power components that are attached to the board. The Arduino board can be uploaded with a program using the USB port. With the aid of the Arduino IDE program and a USB cable, the program may be uploaded to the board. The Arduino UNO board can also be powered by an external power source using the power jack or a USB port [14].

v. 3D-Printed Spinning Wheel

Fig. 6 3D-Printed Spinning Wheel.

The spinning wheel that attaches to the DC motor is used to launch the shuttlecocks during the firing mechanism. Since the specific dimensions needed for our design are not readily available in the market, it was designed using SolidWorks software. The dimensions of the spinning wheel are as follows: outer diameter = 9.5cm; inner diameter (shaft diameter) = 5mm; height/thickness = 3cm. PETG material was used to 3D print the spinning wheels. This material was chosen because of its resistance to vibration. In addition, this material is stronger, more durable, and pressure resistant. In order for the shuttlecocks to be launched by the 3D-printed wheels without any damage.

vi. Cytron MD10C Driver Motor

Fig. 7 Cytron MD10C Motor Driver.

Cytron MD10C motor driver is a robust motor driver that provides bi-directional control for one brushed DC motor (single channel). It is capable of supporting motor voltages between 5V and 30VDC. This motor drive has a maximum continuous current capacity of 13A and a peak 10-second capacity of 30A. The Arduino microcontroller is compatible with this motor driver. The solid-state components offer quicker response times and do away with the mechanical relay's wear and tear. There is no need for a heat sink because it uses entirely NMOS H-Bridge for increased efficiency. Additionally, the pulse width modulation (PWM) frequency used to control the speed of the DC motor can reach 20kHz. Furthermore, it allows PWM operation using Sign-Magnitude and Locked-Antiphase. This motor driver can be powered up using a single power source without the need for the additional Vin from the microcontroller [15].

vii. Dell PC Power Supply

Fig. 8 Dell PC Power Supply.

The desktop computer power supply transforms the mains electricity's alternating current (AC) from a wall outlet into low-voltage direct current (DC) to power the motherboard, processor, and peripherals. For the computer to operate steadily, a number of direct-current voltages must be present, and they must be precisely regulated. A single voltage supplied by a PSU is referred to as a power supply rail or voltage rail. A PC power supply is used in this project because steady 12V DC power is required for the DC motors to operate smoothly and for speed control to be managed effectively.

viii. Slider

Fig. 9 Slider.

The slider on the badminton robot trainer is utilized to ensure that shuttlecocks fed from the feeding servos from the loading cylinder are moved directly to the firing platform for launching. To allow the shuttlecocks to directly strike the center of the two 3D-printed wheels that spin in opposite directions, the slider must be constructed properly. So that, the shuttlecock can be fired out to the desired positions precisely. To minimize friction and ensure flawless shuttlecock transportation, the slider is made of smooth surface laminating film.

ix. Loading Cylinder

Fig. 10 Loading Cylinder.

The loading cylinder is used to store and hold shuttlecocks. To avoid the shuttlecocks being stuck during the feeding mechanism, it is built of a smooth surface laminating film. It has a length of about 80 cm and can accommodate up to 24 shuttlecocks.

E. Software Description

i. Arduino IDE

Fig. 11 Logo of Arduino IDE software.

Fig. 12 Editor of Arduino IDE software for writing and compiling the code.

Arduino IDE is an open-source software that is mainly used for writing and compilation of code into the Arduino module. It is used to write programs and then upload them to the microcontroller board to perform the tasks as instructed. It is available for various kinds of operating systems, such as Windows, Linux, macOS, etc. Besides, it will run on the Java platform that is used to debug, edit, and compile the source code in the environment. The IDE environment is composed of two main parts which are the editor and the compiler. The software's editor provides the environment for text cutting and pasting, searching, and replacing text, automatic indenting, brace matching, and syntax highlighting. The languages supported by this software are C and C++ languages.

ii. SolidWorks

Fig. 13 Logo of SolidWorks software.

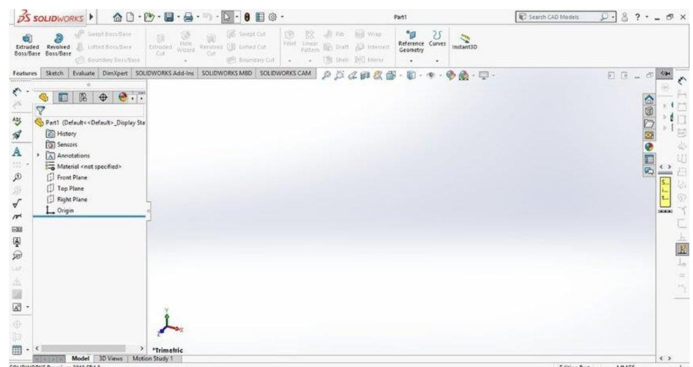

Fig. 14 Interface of SolidWorks software.

Dassault Systèmes produces SolidWorks, a solid modeling computer-aided design and computer-aided engineering tool. To create mechatronic systems from scratch, SolidWorks software is employed. Planning, visual ideation, modeling, determining the viability of a concept, prototyping, and project management are all early tasks carried out using the software. The design and construction of mechanical, electrical, and software components are subsequently done using this software. The software currently includes a number of applications that may be used for both 2D, and 3D design. Besides, SolidWorks offers a number of essential functions, including 3D solid modeling, direct component editing, large assembly design, sheet metal fabrications, the design of plastic and cast parts, and many more. The software can run on a variety of operating systems, including Windows, macOS, and others.

F. Hardware Operation

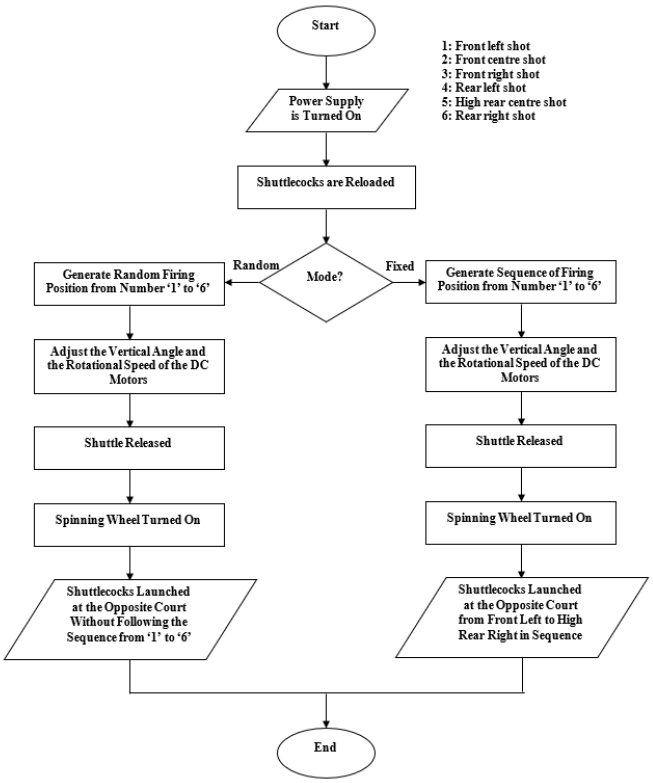

Fig. 15 Operational flowchart of the badminton robot trainer.

The smart automated-based badminton robot trainer is easy to use. First of all, the power supply is turned on. Then, the user needs to reload the shuttlecocks into the loading cylinder. After loading the shuttlecocks, the end user can choose the mode of training he/she wants which is either fixed pattern firing training or randomized position firing training. The end user can choose the desired mode of training by switching the position of the 3-pin toggle switch.

If the fixed pattern firing mechanism is chosen, the system will generate a sequence of firing positions ranging from number '1' to '6' where number '1' represents the front left shot, number '2' represents the front center shot, number '3' represents the front right shot, number '4' represents the rear left shot, number '5' represents the high rear center shot, and number '6' represents the rear right shot. Following that, the vertical angle of the firing platform will be adjusted based on the current number of the preset sequence. In the meantime, the 12V DC motors will adjust their respective rotational speed according to the current number in the sequence. Then, the shuttlecock is released from the loading cylinder to the firing platform through the slider with the help of the feeding mechanism. With that, the shuttlecock will be able to shoot out to feed the end user at the opposite court once the head of the shuttlecock hits the spinning wheels that rotate in opposite directions. In the fixed pattern mode, the shuttlecocks will launch at the opposite court in the following sequence as shown below:

(front left shot → front center shot → front right shot → rear left shot →high rear center shot → rear right shot → front left shot).

On the other hand, if the randomized position firing mechanism is chosen, the system will randomly generate a number between '1' and '6' where number '1' represents the front left shot, number '2' represents the front center shot, number '3' represents the front right shot, number '4' represents the rear left shot, number '5' represents the high rear center shot, and number '6' represents the rear right shot. Following that, the vertical angle of the firing platform will be adjusted based on the current-generated randomized number. In the meantime, the 12V DC motors will adjust their respective rotational speed according to the current number generated by the system. Then, the shuttlecock is released from the loading cylinder to the firing platform through the slider with the help of the feeding mechanism. With that, the shuttlecock will be able to shoot out to feed the end user at the opposite court once the head of the shuttlecock hits the spinning wheels that rotate in opposite directions. In the randomized mode, the badminton robot trainer will launch the shuttlecocks to the opposite court without following any sequence.

G. Software Operation

i. Arduino IDE

a. Fixed Pattern Firing Mode

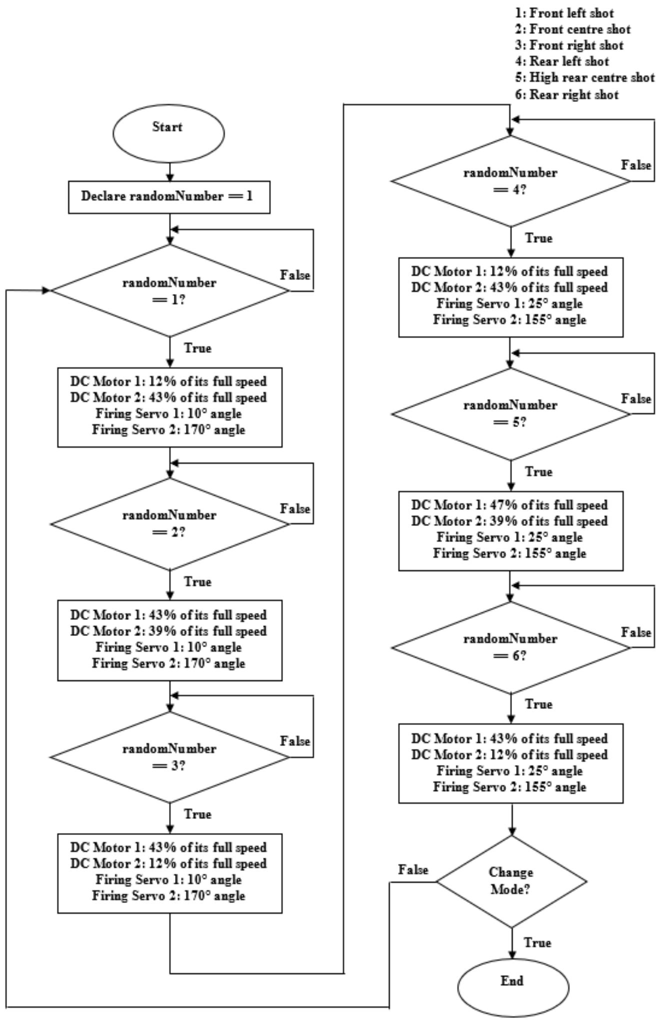

Fig. 16 Operational flowchart of the fixed pattern firing mode.

Since there are 6 types of shots will be provided by the badminton robot trainer, each type of shot will be represented by a specified number ranging from 1 to 6 where number ‘1’ represents the front left shot, number ‘2’ represents the front center shot, number ‘3’ represents the front right shot, number ‘4’ represents the rear left shot, number ‘5’ represents the high rear center shot, and number ‘6’ represents the rear right shot. In the fixed pattern firing mode, the badminton robot trainer will shoot the shuttlecock according to the preset sequence: 1 → 2 → 3 → 4 → 5 → 6 → 1. Therefore, the variable ‘randomNumber’ is declared to be 1 at the beginning of the code.

When the ‘randomNumber’ is equal to ‘1’, DC motor 1 will spin in the anticlockwise direction at 12% of its full speed, while DC motor 2 will spin in the clockwise direction at 43% of its full speed. At the same time, firing servo 1 will rotate to 10°, and firing servo 2 will rotate to 170° in order to make the inclination angle of the firing platform become 10°. Thus, a front left shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the ‘randomNumber’ is equal to ‘2’, DC motor 1 will spin in the anticlockwise direction at 43% of its full speed, while DC motor 2 will spin in the clockwise direction at 39% of its full speed. At the same time, firing servo 1 will rotate to 10°, and firing servo 2 will rotate to 170° in order to make the inclination angle of the firing platform become 10°. Thus, a front center shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the ‘randomNumber’ is equal to ‘3’, DC motor 1 will spin in the anticlockwise direction at 43% of its full speed, while DC motor 2 will spin in the clockwise direction at 12% of its full speed. At the same time, firing servo 1 will rotate to 10°, and firing servo 2 will rotate to 170° in order to make the inclination angle of the firing platform become 10°. Thus, a front right shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the ‘randomNumber’ is equal to ‘4’, DC motor 1 will spin in the anticlockwise direction at 12% of its full speed, while DC motor 2 will spin in the clockwise direction at 43% of its full speed. At the same time, firing servo 1 will rotate to 25°, and firing servo 2 will rotate to 155° in order to make the inclination angle of the firing platform become 25°. Thus, a rear left shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the ‘randomNumber’ is equal to ‘5’, DC motor 1 will spin in the anticlockwise direction at 47% of its full speed, while DC motor 2 will spin in the clockwise direction at 39% of its full speed. At the same time, firing servo 1 will rotate to 25°, and firing servo 2 will rotate to 155° in order to make the inclination angle of the firing platform become 25°. Thus, a high rear center shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the ‘randomNumber’ is equal to ‘6’, DC motor 1 will spin in the anticlockwise direction at 43% of its full speed, while DC motor 2 will spin in the clockwise direction at 12% of its full speed. At the same time, firing servo 1 will rotate to 25°, and firing servo 2 will rotate to 155° in order to make the inclination angle of the firing platform become 25°. Thus, a rear right shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

The badminton robot trainer will keep shooting out the shuttlecocks following the preset sequence from 1 to 6 unless there is a change in firing mode when the user changes the position of the 3-pin toggle switch which will trigger the randomized position firing mode.

b. Randomized Position Firing Mode

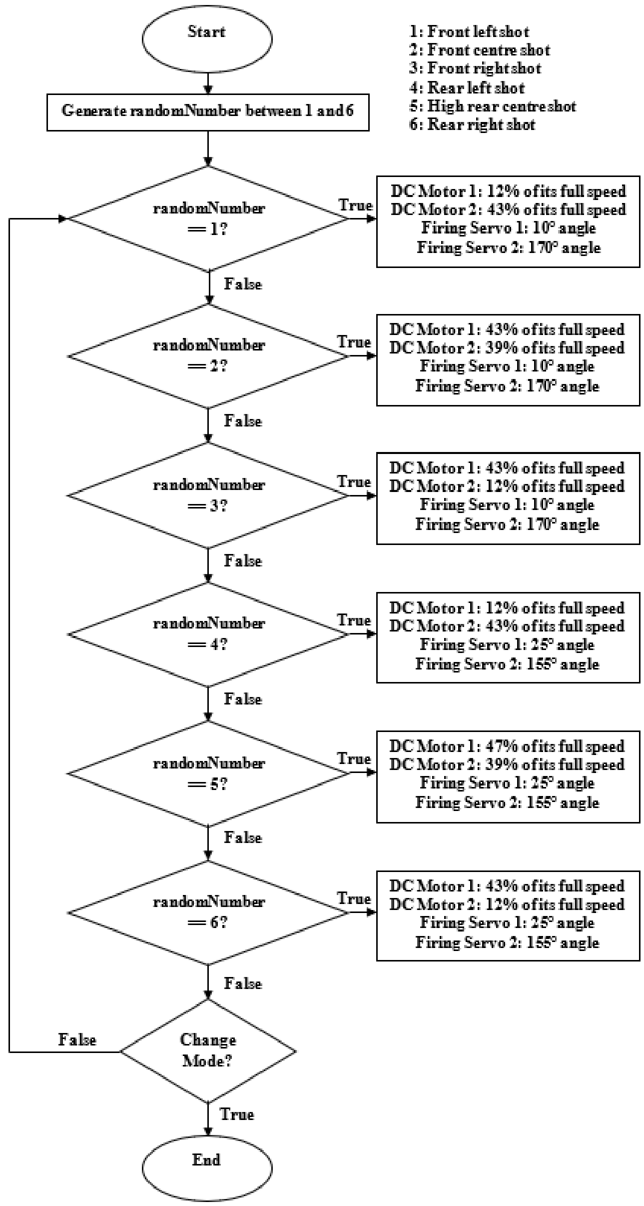

Fig. 17 Operational flowchart of the randomized position firing mode.

The same applies to the randomized position firing mode, each type of shot will be represented by a specified number ranging from 1 to 6 where number '1' represents the front left shot, number '2' represents the front center shot, number '3' represents the front right shot, number '4' represents the rear left shot, number '5' represents the high rear center shot, and number '6' represents the rear right shot. In the randomized mode, the variable 'randomNumber' does not start with the number '1' anymore. Instead, a random () function is used to generate a random number between '1' and '6' for the variable 'randomNumber'. Thus, the badminton robot trainer will be able to shoot out the shuttlecocks to randomized positions with different angles according to the 'randomNumber' generated by the random () function without following any sequence.

Once again, the same concept of controlling the type of shot provided by the robot trainer is applied here. When the 'randomNumber' is equal to '1', DC motor 1 will spin in the anticlockwise direction at 12% of its full speed, while DC motor 2 will spin in the clockwise direction at 43% of its full speed. At the same time, firing servo 1 will rotate to 10°, and firing servo 2 will rotate to 170° in order to make the inclination angle of the firing platform become 10°. Thus, a front left shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the 'randomNumber' is equal to '2', DC motor 1 will spin in the anticlockwise direction at 43% of its full speed, while DC motor 2 will spin in the clockwise direction at 39% of its full speed. At the same time, firing servo 1 will rotate to 10°, and firing servo 2 will rotate to 170° in order to make the inclination angle of the firing platform become 10°. Thus, a front center shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the 'randomNumber' is equal to '3', DC motor 1 will spin in the anticlockwise direction at 43% of its full speed, while DC motor 2 will spin in the clockwise direction at 12% of its full speed. At the same time, firing servo 1 will rotate to 10°, and firing servo 2 will rotate to 170° in order to make the inclination angle of the firing platform become 10°. Thus, a front right shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the 'randomNumber' is equal to '4', DC motor 1 will spin in the anticlockwise direction at 12% of its full speed, while DC motor 2 will spin in the clockwise direction at 43% of its full speed. At the same time, firing servo 1 will rotate to 25°, and firing servo 2 will rotate to 155° in order to make the inclination angle of the firing platform become 25°. Thus, a rear left shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the 'randomNumber' is equal to '5', DC motor 1 will spin in the anticlockwise direction at 47% of its full speed, while DC motor 2 will spin in the clockwise direction at 39% of its full speed. At the same time, firing servo 1 will rotate to 25°, and firing servo 2 will rotate to 155° in order to make the inclination angle of the firing platform become 25°. Thus, a high rear center shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

When the 'randomNumber' is equal to '6', DC motor 1 will spin in the anticlockwise direction at 43% of its full speed, while DC motor 2 will spin in the clockwise direction at 12% of its full speed. At the same time, firing servo 1 will rotate to 25°, and firing servo 2 will rotate to 155° in order to make the inclination angle of the firing platform become 25°. Thus, a rear right shot will be ready once the firing platform receives the shuttlecock from the feeding mechanism.

The badminton robot trainer will keep shooting out the shuttlecock randomly unless the user changes the mode of the firing mechanism.

c. Shuttlecocks Feeding Mechanism

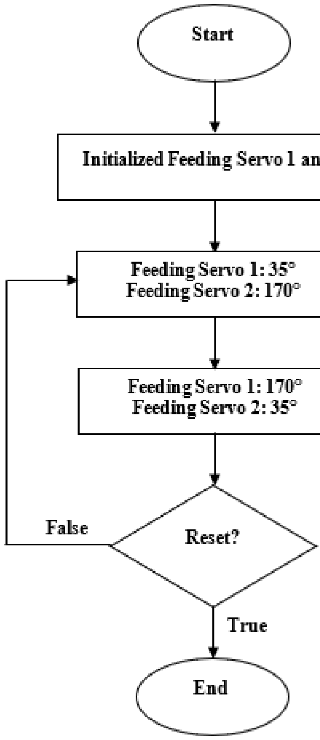

Fig. 18 Operational flowchart of the shuttlecock feeding mechanism.

For the feeding mechanism of the badminton robot trainer, the system will first initialize the feeding servos 1 and 2 by making feeding servo 1 rotate to an angle position of 35° and feeding servo 2 rotate to an angle position of 155° respectively. After initialization, feeding servo 1 which is attached to the left side of the opening end of the loading cylinder will keep turning its blades up and down from 35° to 170° and back to 35° repeatedly. In the meantime, feeding servo 2 which is attached to the right side of the opening end of the loading cylinder will keep turning its blades up and down from 170° to 35° and back to 170° repeatedly. Both feeding servos will keep repeating the same process unless the system is reset, or the power is turned off. With this, the robot will be able to feed in the shuttlecocks smoothly from the loading cylinder to the firing mechanism through the slider attached below it.

H. Prototype Design

The connection of the components used in this project including the Arduino UNO board, feeding servo motors, firing servo motors, 12V DC motors, motor drivers, and toggle switch are shown in the tables below:

TABLE III
CONNECTION OF FEEDING SERVO MOTOR 1 WITH ARDUINO UNO.

Feeding Servo Motor 1 (MG996R)	**Arduino UNO**
VCC	5V Power Pin
GND	GND
Signal Pin	Digital Pin 3

TABLE IV
CONNECTION OF FEEDING SERVO MOTOR 2 WITH ARDUINO UNO.

Feeding Servo Motor 2 (MG996R)	**Arduino UNO**
VCC	5V Power Pin
GND	GND
Signal Pin	Digital Pin 4

TABLE V
CONNECTION OF FIRING SERVO MOTOR 1 WITH ARDUINO UNO.

Firing Servo Motor 1 (MG996R)	**Arduino UNO**
VCC	5V Power Pin
GND	GND
Signal Pin	Digital Pin 7

TABLE VI
CONNECTION OF FIRING SERVO MOTOR 2 WITH ARDUINO UNO.

Firing Servo Motor 2 (MG996R)	**Arduino UNO**
VCC	5V Power Pin
GND	GND
Signal Pin	Digital Pin 8

TABLE VII
CONNECTION OF CYTRON MOTOR DRIVER 1 WITH ARDUINO UNO, 12V DC MOTOR 1, AND 12V DC POWER SUPPLY.

Cytron Motor Driver 1 (MD10C)	**Arduino UNO/ 12V 775 DC Motor 1/ 12V DC Power Supply**
DIR Pin	Digital Pin 6 of Arduino UNO
PWM	Digital Pin 5 of Arduino UNO
GND	Negative Terminal of the 12V DC Power Supply
Positive Power Pin	Positive Terminal of 12V DC Power Supply
Negative Power Pin	Negative Terminal of 12V DC Power Supply
Motor Pin A	Positive Terminal of 12V DC Motor 1
Motor Pin B	Negative Terminal of 12V DC Motor 1

TABLE VIII
CONNECTION OF CYTRON MOTOR DRIVER 2 WITH ARDUINO UNO, 12V DC MOTOR 2, AND 12V DC POWER SUPPLY.

Cytron Motor Driver 2 (MD10C)	**Arduino UNO/ 12V 775 DC Motor 2/ 12V DC Power Supply**
DIR Pin	Digital Pin 12
PWM	Digital Pin 11
GND	Negative Terminal of 12V DC Power Supply
Positive Power Pin	Positive Terminal of 12V DC Power Supply
Negative Power Pin	Negative Terminal of 12V DC Power Supply
Motor Pin A	Negative Terminal of 12V DC Motor 1
Motor Pin B	Positive Terminal of 12V DC Motor 1

TABLE IX
CONNECTION OF 3-PIN TOGGLE SWITCH WITH ARDUINO UNO.

3-Pin Toggle Switch	**Arduino UNO**
Terminal 1 (FixSwitch)	Digital Pin 9
Common Pin	GND
Terminal 2 (RandomSwitch)	Digital Pin 10

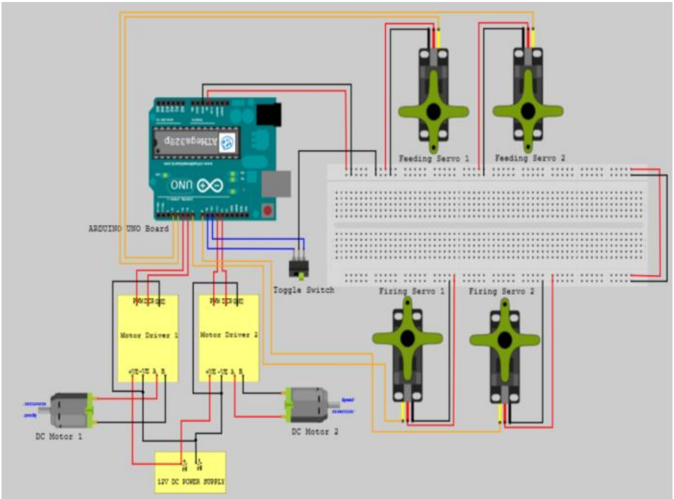

Fig. 19 Circuit design of the badminton robot trainer.

The casing of the badminton robot trainer is built using thick cardboard that is cut to a suitable size with a dimension of (length × width × height) which is (3800mm × 2900mm × 5800mm) to protect the hardware and circuits as well as to hold them in positions. The slider and loading cylinder of the badminton robot trainer is made of A4-size laminating films. The length of the loading cylinder is approximately 8000mm which can hold up to 24 shuttlecocks. The slider is also cut into a suitable shape in order to make sure that it can deliver the shuttlecock drops from the feeding mechanism to the firing platform smoothly. The reason why the laminating film is chosen as the primary material for building the loading cylinder and the slider is due to the smooth surface nature of the laminating film which can greatly reduce the friction between the shuttlecocks and the surface. Meanwhile, the firing platform is made of a 1mm-thick acrylic sheet with dimensions (length × width) which is (2600mm × 1600mm). The cut-out acrylic sheet is drilled with two circular holes with a diameter of 40mm each to fix and hold the 12V DC motors in place.

Besides, the pins of the toggle switch are soldered to prevent any loose connection. Moreover, the size of the prototype is minimized to reduce the manufacturing cost as well as the space occupied. Moreover, the 12V DC power supply, breadboard for connection purposes, and Arduino UNO board are placed at the base of the prototype, while both motor drivers are placed on either side of the wall of the prototype. Each component is stuck and glued firmly in a fixed position. Lastly, each 12V DC motor is attached to a 3D-printed spinning wheel. The dimension of the 3D-printed wheel is as follows:

- Outer Diameter = 950mm
- Thickness = 300mm
- Inner Diameter (Shaft Diameter) = 5mm

The 3D-printed wheel is wrapped with a 1mm-thick rubber sheet to provide greater friction and better grip during the firing mechanism.

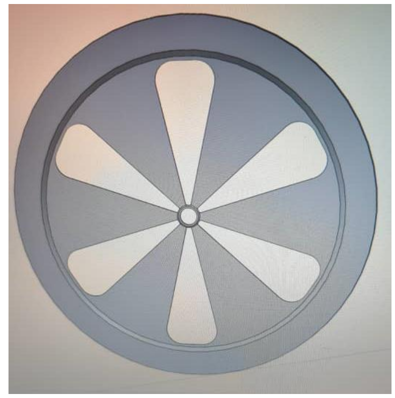
Fig. 20 Rim of the wheels designed on SolidWorks.

The wheels were 3D printed using PETG material. This material was used so that it could withstand vibration and also, it's a more reliable material that can last longer and can withstand pressure. Therefore, the constant use to launch shuttlecocks will not affect or damage the wheels.


Fig. 21 3D-printed rims of the wheels.

The prototype of the badminton robot trainer is shown below:


Fig.22 Prototype of Badminton Robot Trainer

III. VIABILTY

a. *Economical*

Our design is considered economical because the design cost of the components and materials used were taken into account due to our budget is limited. We have conducted related research to get the most cost-effective supplies to build our design using lower-cost materials with better performance. Therefore, consumers are encouraged to purchase the badminton robot trainer at an affordable and reasonable price. As the quantity demanded increases, the price of the product can be sold at a cheaper price.

a. Sustainability

According to the Global Sustainable Development Goals list by the United Nations, our focus in this project aims on SDG 3 Good health and well-being. This goal states to ensure healthy lives and promote well-being for all at all ages. Our project is designed to ensure everyone can play badminton even if they do not have partners. Our design tends to help in improvements in health, increasing life expectancy for all and reducing the most common and preventable causes of death.

b. Manufacturability

Our design is using flexible and scalable mechanisms. This can provide lower upfront investment for manufacturing. Besides, the materials and components used in this badminton robot trainer are low enough while maintaining high quality. Higher-priced materials are not always superior to lower-priced materials in terms of performance. As a result, our design has the readiness for replication and can be produced in large quantities.

IV. RESULTS & DISCUSSION

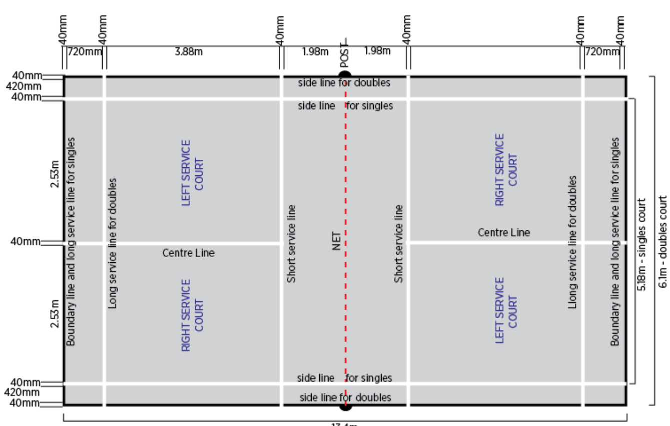

Fig. 23 Badminton Court Dimension.

To find the displacement x, from the robot position to each dedicated point, Pythagoras' Theorem is applied as shown below.

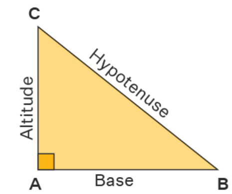

Fig. 24 Pythagoras' Theorem.

In this context, BC corresponds to the displacement, x while AB and AC are the horizontal components and vertical components of the displacement, looking at the court from the top view. Meanwhile, deflection angle, ∠ P which corresponds to ∠B in the figure above, can be found using the equation:

$$\angle B = \tan^{-1}\frac{AC}{AB} \quad ---(1)$$

Since time travel of the shuttlecock for both x-component and y-component are the same, Vx/Vy ratio can be found in such a way that,

$$V_x = \frac{AC}{t} \text{----------}(2)$$

$$V_y = \frac{AB}{t} \text{----------}(3)$$

Substituting (2) and (3) into (1),

$$\angle B = \tan^{-1}\frac{V_x}{V_y}$$

Rearranging,

$$\frac{V_x}{V_y} = \tan\angle B \text{----------}(4)$$

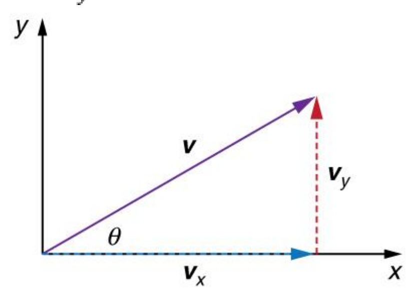

Fig. 25 Vector illustration of shuttlecock velocities.

Having the V_x/V_y ratio, resultant velocity, V_o , in term of V_x or V_y can be figured out by substituting equation (4) into the equation below.

$$V_o = \sqrt{V_x^2 + V_y^2} \text{----------}(5)$$

Implementing the aforementioned equations, the parameters are tabulated as shown below.

TABLE X

PARAMETERS OF ROBOT TO CALCULATE REQUIRED RESULTANT VELOCITIES.

Parameters	**Front sides**	**Back centre**	**Back sides**
Displacement, x (m)	4.70	7.84	8.24
Deflection angle, ∠P (º)	32.57	0	17.88
V_x/V_y ratio	0.6389	0	0.3227
Resultant velocity, V_o (ms^{-1})	$1.1867V_y$	V_y	$1.0508V_y$
Firing platform height, h (m)	1.30		
Gravitational force, g (ms^{-2})	9.81		

Commonly, the projectile motion of an object can be interpreted using the 4 equations below.

$$\boldsymbol{x = v_i t + \frac{1}{2} a t^2}$$

$$\boldsymbol{v_f = v_i + at}$$

$$\boldsymbol{v_f^2 = v_i^2 + 2ax}$$

$$\boldsymbol{x = \left(\frac{v_i + v_f}{2}\right) t}$$

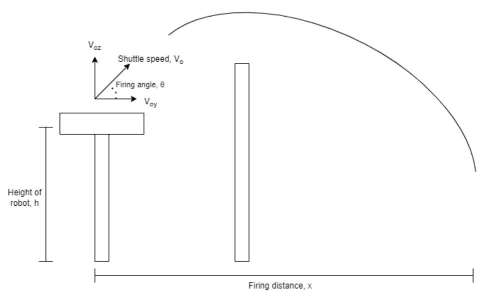

Fig. 26 Projectile motion of the shuttlecock.

Decomposing the parabolic motion of the shuttlecock with respect to each dedicated point into its perpendicular components and analysing them using the equations above, the required resultant velocity, V_o to reach the dedicated point is

$$V_o = \sqrt{\frac{gx^2}{\sqrt{h^2+x^2}\cos\left(2\theta - \tan^{-1}\frac{x}{h}\right) + h}} \text{ ----------(6)}$$

where θ = firing angle. The firing may affect the arc of the shuttlecocks, giving different types of shots to the user.

After calculating V_o based on different θ, the xy-component can then be calculated using equations (4) and (5). V_o, V_x, and V_y under varying θ conditions for front sides (FL, FR), back center, and back sides (RL, RR, HRL, HRR) are tabulated as shown below.

TABLE XI

V_o, V_x, and V_y under varying θ conditions for front sides with x = 4.70m, ∠P = 32.57º

Firing angle, θ (º)	**Resultant velocity, V_o (ms^{-1})**	**Velocity, V_y (ms^{-1})**	**Velocity, V_x (ms^{-1})**
10	7.24	6.10	3.90
20	6.38	5.38	3.44
30	6.00	5.06	3.23
40	5.93	5.00	3.19
50	6.16	5.19	3.32
60	6.78	5.71	3.65
70	8.07	6.80	4.35
80	11.34	9.55	6.10

TABLE XII

Vo, Vx, and Vy under varying θ conditions for back sides with x = 8.24m, ∠P = 17.88˚

Firing angle, θ (º)	**Resultant velocity, V_o (ms^{-1})**	**Velocity, V_y (ms^{-1})**	**Velocity, V_x (ms^{-1})**
10	11.17	10.63	3.43
20	9.37	8.91	2.88
30	8.56	8.15	2.63
40	8.31	7.91	2.55
50	8.51	8.10	2.61
60	9.25	8.80	2.84
70	10.91	10.38	3.35
80	15.16	14.43	4.66

TABLE XIII

Vo, Vx, and Vy under varying θ conditions for back centre with x = 7.84m, ∠P = 0˚

Firing angle, θ (º)	**Resultant velocity, V_o (ms^{-1})**	**Velocity, V_y (ms^{-1})**	**Velocity, V_x (ms^{-1})**
10	10.77	10.77	0
20	9.07	9.07	
30	8.31	8.31	
40	8.08	8.08	
50	8.28	8.28	
60	9.00	9.00	
70	10.62	10.62	
80	14.78	14.78	

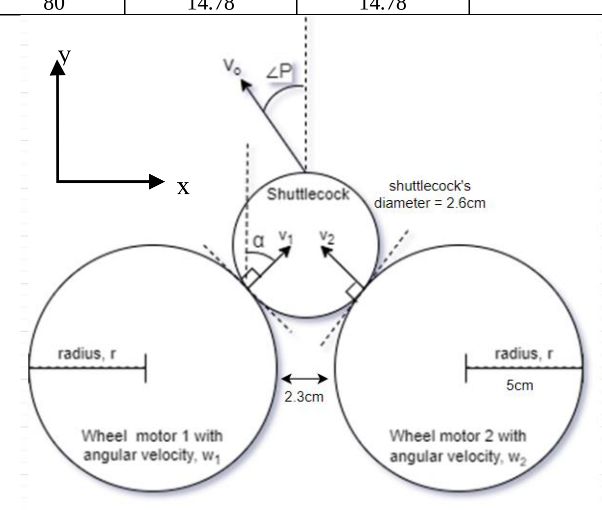

Fig. 27 Illustration of the body diagram of wheels and shuttlecock.

Having desired V_o, V_x, and V_y of shuttle speed worked out, parameters of DC motor are then to be determined to decipher the inputs to each DC motor in order to procure desired output, falling point of shuttlecock in this situation. In this project, DC motors of 100W, 12V rating are applied. Therefore, a power supply of 12V is needed. Nevertheless, the motor voltage is varied using 8-bit pulse width modulation (PWM). Wheels' radiuses are set at 5cm. Possessing wheel radius, shuttle radius, wheels' gap, pitch angle, α can then be calculated.

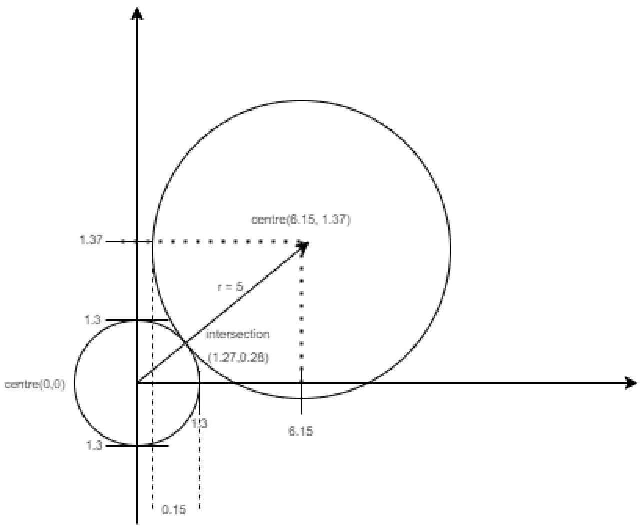

Fig. 28 Plane diagram of wheel and shuttlecock.

The x: y: r ratio of big circle's centre point from origin is 6.15: 1.37: 6.3 whereas the x: y: r ratio of small circle is x1: y1: 1.3. The ratios of the circles are the same, thus,

$$X1 = \frac{1.3}{6.3} \times 6.15 = 1.27$$

$$Y1 = \frac{1.3}{6.3} \times 1.37 = 0.28$$

Touching point of 2 circles falls at (1.27, 0.28). Given that:

$$y = m_{tangent} x + c \text{ ----------(7)}$$

$$m_{tangent} = \frac{-1}{m_{radius}} \text{ ----------(8)}$$

$$m_{radius} = \frac{y_1 - y_2}{x_1 - x_2} \text{ ----------(9)}$$

Finding gradient of the touching point's tangent using (8) and (9),

$$m_{tangent} = \frac{-1.27}{0.28} \text{ ----------(10)}$$

Substituting (10) into (7) along with the touching point coordinate to find y-intercept, c, the equation of the touching point's tangent line turns out to be,

$$y = \frac{-1.27}{0.28} x + 6.04 \text{ ---------(11)}$$

It is known that the line equations $L_i = a_i x + b_i y + c$ of vertical line across the touching point and tangent line is

$$L_1 = x - 1.27$$

$$L_2 = y + \frac{1.27}{0.28} x - 6.04$$

$$\tan \alpha = 90^o - \frac{a_2 b_1 - a_1 b_2}{a_1 a_2 + b_1 b_2} \text{ ----------(12)}$$

Placing the line equation values into (12), α = 77.57° is obtained. The parameters are tabulated as shown below.

TABLE XIV

PARAMETERS OF ROBOT TO CALCULATE VELOCITIES PROVIDED BY WHEELS TO SHUTTLECOCKS

Parameters	**Value**
Input voltage, V_s	12V
Wheel's radius, r	0.05m
Pitch angle, α	77.57°

Under varying PWM values with a step size of 0.0471V, the motor voltage, V_{in}, motor speed, n, motor's angular velocity, ω, and tip speed, $V_{1,2}$ are calculated and tabulated as shown below:

TABLE XIV

MOTOR VOLTAGE, VIN, MOTOR SPEED, N, MOTOR'S ANGULAR VELOCITY, Ω, AND TIP SPEED, V1,2 UNDER DIFFERENT PWM

PWM (0-255)	**Motor voltage, V_{in} (V)** $V_{in} = \frac{12 \times PWM}{255}$	**Motor's speed, n (rpm)** $\frac{12}{Vmotor} = \frac{12000}{motor\ rpm}$	**Motor's angular velocity, ω** ω = 2pi n/60	**Tip speed, $V_{1,2}$ (ms^{-1})** $V_{1,2}$ = rw
10	0.4706	471	49.30	2.47
20	0.9412	941	98.60	4.93
30	1.4118	1412	147.90	7.40
40	1.8824	1882	197.20	9.86
50	2.3529	2353	246.49	12.32
60	2.8235	2824	295.80	14.79
70	3.2941	3294	345.10	17.25
80	3.7647	3765	394.40	19.72
90	4.2353	4235	443.70	22.18
100	4.7059	4706	493.00	24.65
110	5.1765	5177	542.30	27.12
120	5.6471	5647	591.60	29.58
130	6.1176	6118	640.89	32.04

Different combinations of motors' PWM are formed to calculate the resultant velocities and their respective xy-components provided by the wheels to shuttlecocks to meet the required velocity by the shuttlecocks to reach the desired dedicated point. Relationship between the xy-components of resultant velocities and the tip speed is as shown below:

$$V_x = V_1 \sin \alpha - V_2 \sin \alpha$$

$$V_y = V_1 \cos \alpha + V_2 \cos \alpha$$

The values are then tabulated as shown below:

TABLE XV

Vx, Vy, Vo, ∠P under different combinations of motors' PWM

Motor 1's PWM	**Motor 2's PWM**	**Velocity, V_x (ms^{-1})**	**Velocity, V_y (ms^{-1})**	**Resultant velocity, V_o (ms^{-1})**	**Deflection angle, ∠P (°)**
30	100	16.85	6.90	18.20	67.73
40	100	14.44	7.43	16.24	62.78
30	110	19.26	7.43	20.64	68.90
40	110	16.86	7.96	18.64	64.72
100	100	0.00	10.61	10.61	0.00
110	110	0.00	11.67	11.67	0.00

Finalizing θ = 10º, 30º for low and high angle respectively along with combinations of motors' PWM in table above, the figures below illustrate the experimental results:

Fig. 29 Experimental result (1).

Fig. 30 Experimental result (2).

Fig. 31 Experimental result (3).

The perceptible disparity between the theoretical calculation and the experimental data is within the expectation. Despite the disparity, 3 obvious falling points of the shuttlecocks can still be determined. Reasonings are depicted in a way that both results are obtained under different conditions in which the theory is done ideally whereas the experimental data is obtained under practical conditions. For theoretical calculation, external factors have been neglected for the ease of processing. However, these external factors still bring significant effect to the results. The next section describes the assumptions which lead to the disparity.

A. Assumption

1. No air resistance, friction, and other forms of energy loss.

   Air resistance, also known as drag, slows down the speed of a shuttlecock as it moves through the air. The amount of drag on an object is determined by its shape and surface texture, as well as the density and viscosity of the fluid (in this case, air) that it is moving through. The shuttlecock has a unique shape with feathers, which produce a large amount of drag and affect the speed. The shuttlecock speed also affected by the direction and strength of the wind.

   The relationship between air resistance and a shuttlecock's speed is inverse. As the speed of the shuttlecock increases, the amount of air resistance it encounters also increases. This results in a slowing down of the shuttlecock's speed.

   Since the equation applied to figure out the required resultant velocity is only valid under ideal condition in which there is no existence of air resistance and friction, the theoretical value obtained would be smaller than actual value to fire the shuttlecock to desired positions. Similarly, the x-component and y-component velocities' theoretical values are expected to be less than actual input values.

2. Linear characteristic between the relationship of motor voltage and rotational speed.

   The relationship between the voltage applied to a DC motor and its rotational speed is typically direct and linear. Increasing the voltage applied to a DC motor will generally result in an increase in its rotational speed, and decreasing the voltage will result in a decrease in rotational speed.

   However, the relationship between the voltage and the speed of a DC motor is not always linear, it could be non-linear, especially in the case of high-performance motors.

   There are several factors that can affect the relationship between the voltage applied to a DC motor and its rotational speed:

   a. Motor internal resistance: The internal resistance of a motor affects the relationship between voltage and speed. A motor with a lower internal resistance will have a stronger relationship between voltage and speed than a motor with a higher internal resistance.
   b. Load torque: The load torque on a motor can also affect the relationship between voltage and speed. A motor under a heavy load will require more voltage to achieve the same speed as a motor under a light load.
   c. Motor constant: The motor constant (K) which is the ratio of the torque produced by the motor to the current flowing through the motor, also affects the relationship between voltage and speed. A motor

with a higher motor constant will have a stronger relationship between voltage and speed than a motor with a lower motor constant.

d. Friction coefficient: The friction coefficient (B) also affects the relationship between voltage and speed. A motor with a higher friction coefficient will require more voltage to achieve the same speed as a motor with a lower friction coefficient.

e. Back emf constant: The back emf constant (E) is the voltage generated by the motor when running at a specific speed. A motor with a higher back emf constant will require less voltage to achieve the same speed as a motor with a lower back emf constant.

f. Temperature: The temperature also affects the relationship between voltage and speed, as a motor will produce less power and torque at higher temperatures.

g. Power supply: The quality of the power supply also affects the relationship between voltage and speed, as a poor power supply can cause voltage fluctuations that can affect the speed of the motor.

Despite the possibilities of having non-linear characteristic exhibited in the relationship between motor voltage and its rotational speed, linearity is assumed to ease the theoretical calculation.

3. Linearity of motor speed under load conditions.

The relationship between a DC motor's rotational speed and the load condition is typically inverse. As the load on the motor increases, the rotational speed of the motor decreases and as the load decreases, the rotational speed increases. The load torque on the motor is directly proportional to the load condition. When the load on the motor increases, the load torque also increases, which in turn causes the motor to work harder to maintain its speed, resulting in a decrease in the rotational speed.

It's worth noting that the relationship between the load condition and the rotational speed of a DC motor is not always linear, it could be non-linear, especially in the case of high-performance motors. However, since the weight of wheels and shuttlecocks are so light to be negligible, linearity of DC motor’s rotational speed under different load condition is assumed.

4. Perfect collision and energy transfer.

A perfect collision, also known as an elastic collision, is a type of collision in which the total kinetic energy of the colliding objects remains constant before and after the collision. In an elastic collision, the total kinetic energy of the system is conserved and the objects will rebound with the same kinetic energy and opposite velocities that they had before the collision.

This means that the sum of the kinetic energy of the colliding objects is conserved, as well as the total momentum of the system. In addition, the collision between the objects is assumed to be collision with no external forces acting on the objects, and no energy is lost due to internal friction, heat, or sound.

In this context, assumption is made that the kinetic energy is fully transferred from the wheels to the shuttlecock without any energy lost due to friction, heat, sound and etc.

B. *Limitation*

1. Size vs loading capacity.

The size of a badminton robot trainer and its shuttlecock loading capacity are two separate but related factors.

Size of a badminton robot trainer typically refers to the physical dimensions of the robot, such as its length, width, and height. Shuttlecock loading capacity, on the other hand, refers to the number of shuttlecocks that the robot can hold and shoot out in a certain period of time. The loading capacity is often measured in terms of the number of shuttlecocks that can be held in the robot's loading cylinder and the number of shuttlecocks that can be shot out per minute.

Generally, as the size of the badminton robot trainer increases, it can have a larger shuttlecock loading capacity, as it can hold more shuttlecocks and shoot out more shuttlecocks per minute, but it depends on the design, features, and construction of the robot.

If the badminton robot trainer is designed to be portable and compact, the loading capacity might be sacrificed to achieve the aim.

2. Fixed feeding source.

The designed badminton robot trainer is unable to move around the badminton court to serve the shuttlecock from different positions which will improve the standard of the training. Instead, it is fixed at the centre of the opposition’s court to provide the fixed and randomized shuttlecock feeding training from a fixed position.

3. Wall socket plug required.

There are several disadvantages to using a wall socket plug power supply:

a. Limited mobility: A wall socket plug power supply is typically limited to the location of the nearest electrical outlet, which can limit the mobility of the device it is powering. This can be a problem if you need to move your device to another location or use it in a location without easy access to an electrical outlet.

b. Voltage fluctuations: Power supplies that plug into a wall socket are often subject to voltage fluctuations, which can cause problems with the device being powered. Voltage fluctuations can cause the device to shut down, or cause damage to the device's components.

Power interruption: Power interruption can happen due to various reasons like power outage, maintenance of power grid, etc, which can cause the device to shut down and lose data or settings.

C. *Advantage*

1. Adjustable firing angle.

There are several types of badminton shots that players use to hit the shuttlecock in a game:

Clear: A clear shot is a high, deep shot that is hit from the back of the court. This shot is used to put the shuttlecock in a position where the opponent cannot reach it easily.

Drop shot: A drop shot is a shot that is hit softly and with a low trajectory, close to the net. This shot is used to catch the opponent off guard and force them to move forward.

Drive: A drive shot is a fast, flat shot that is hit with power. This shot is used to force the opponent to hit the shuttlecock in a weak position.

Smash: A smash is a powerful shot that is hit with a downward motion. This shot is used to end the rally quickly by hitting the shuttlecock out of the opponent's reach.

Net shot: A net shot is a shot that is hit with precision and aimed at the opponent's side of the net. This shot is used to disrupt the opponent's rhythm and force them to make mistakes.

Lobe shot: Lobe shots are high and deep shots that are hit with a lot of topspin. This shot is used to create a difficult return for the opponent by making the shuttlecock dip quickly when it reaches the opponent's side of the court.

Having the adjustable firing angles, the badminton robot trainer is able to deliver more types of shot as compared to those products available in the market. The shots are clear shot, drive shot, and net shot to different positions of the court.

2. Great development potential.

Looking at the current developing phase of the badminton robot trainer, there is a great potential lurking within it, waiting for evolution. Amelioration may take place in terms of its height. Having its height adjustable electronically through the uploaded program, more shots can be achieved, including a drop shot and a smash shot. A variety of combination shots may be performed by the robot, blossoming its potential into leading technology in sports field.

V. Problems Encountered & Future Improvement

There are several problems faced throughout this project, which are mainly focusing on prototype making of our Capstone project. The first problem we faced is getting the spinning wheels needed for the ball-firing mechanism of the robot trainer. We could not get the spinning wheels with the suitable rim diameter (100mm) with a rim hole diameter of 5mm to be attached to the DC motors' shaft. Therefore, we come out with the solution of 3D printing out the rim of the spinning wheels. Besides, the glue that we used to attach the rubber sheets to the rim for the friction of the shuttlecocks and the wheels is not that suitable. Next, the casing of the badminton robot trainer was made with cardboard since we did not have enough budget to get the extra acrylic board to make the casing.

For future improvement, we can improve our badminton robot trainer design by adding more ball-firing angles such as right cross ball, and left cross ball, which suit the training for intermediate or professional badminton players. The shuttlecocks storage of this robot trainer can also be improvised by using large-capacity rotational ball storage. A movable stable stand with non-slip wheels can also be added to the robot trainer to make it portable and can be moved anywhere. Last but not least, the stability of this badminton robot trainer can also be enhanced by using a harder material than cardboard as the casing.

Conclusion

In conclusion, an automation-based badminton robot trainer is designed which could help badminton players at beginner levels conduct their self-training. This badminton robot trainer can feed the shuttlecocks in different directions and trajectories. This badminton robot trainer can successfully feed the ball to the user with high accuracy. This badminton robot trainer is also successfully built within a reasonable budget while maintaining the high quality of the robot trainer. All the objectives of this project are achieved. By having this badminton robot trainer, players do not need to rely on partners or coaches as the speed of shuttlecock feeding of the robot operates supersedes humans and also prevents typical human errors in terms of technique, and positioning whilst improving the overall quality of training.

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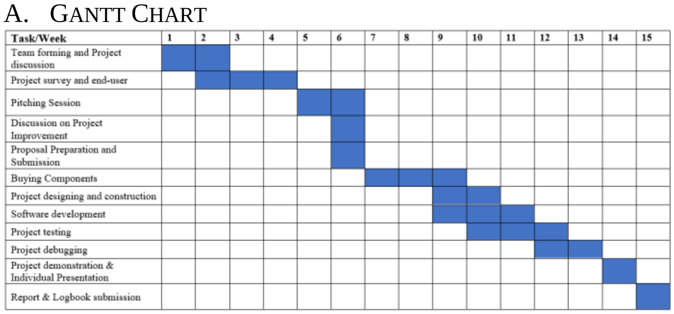
Appendix

A. Gantt Chart



B. Milestone

Milestone	Details	Completion of week	Status
Group forming	• Briefing on Capstone Project • Confirm group members and group leader • Research based on the theme given	Week 1	Done
Project discussion and submission of project title	• Discuss a project based on: 1. Problem statement 2. Objectives 3. Possible outcomes • Meeting with facilitator to confirm the project	Week 2	Done
Conduct marketing survey and look for end-user	• Prepare a google form to conduct a survey • Finding an end-user	Week 3 – Week 4	Done
Pitching	• Conduct an online pitching session with facilitator and end-user	Week 5	Done
Submission of proposal	• Modify design based on feedback from survey and end-user • Submit the finalized proposal	Week 6	Done
Designing and testing project	• Design project including hardware and software • Testing and debugging the project	Week 7 – week 11	Done
Final report preparation	• Prepare a final report • Record details about the project and its application	Week 12 – week 13	Done
Demonstration	• Demonstrate the working project	Week 14	Done
Submission of all reports	• Submit the finalized report	Week 15	Done