

## Research Article

# Engineering Design and Prototyping of an Automated Shuttlecock Feeder with Programmable Court-Zone Targeting

P. E. Punithan <sup>a</sup> • R. Ramakrishan <sup>a</sup> • G. Nallavan <sup>a</sup> • K. Jayanarasimhan <sup>b,\*</sup><sup>a</sup>Department of Sports Technology, Tamil Nadu Physical Education and Sports University, Chennai, Tamil Nadu, India | <sup>b</sup>Department of Mechanical Engineering, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamil Nadu, India**ABSTRACT**

Manual multi-shuttle badminton drills can introduce variability in feeding rate and placement, reducing training standardization and complicating objective evaluation. Automated, programmable feeder with zone-based metrics can address this limitation. To design and validate a low-cost, automatic nine-shot shuttlecock feeder that delivers shuttlecocks to predefined court zones with controllable speed, direction, and timing. The prototype combined a wooden frame with 3D-printed dropper/ejector components and a dual-wheel launcher fixed at 30°. An ESP32 coordinated two DC motors (launch wheels) and three servomotors (dropper, ejector, and horizontal aiming). Nine-shot programs targeted a 3×3 court grid (left/center/right × front/mid/rear). The feeder was mounted 1.10 m above an indoor regulation court and 1.30 m from the net. For each zone, 12 feather shuttlecocks were launched (108 trials). Dual-camera video (60–120 fps) captured trajectory and top-view landings; Dartfish tagging and planar-homograph calibration converted pixel coordinates to court distances (mean spatial error <3%). All nine programs were executed successfully and produced distinct zone-specific landing distributions. Landing-distance variability was low (coefficient of variation <12% across programs), indicating strong repeatability under fixed settings; rear-court programs showed longer mean distances with similarly tight dispersion. Feeding reliability was 100% across 108 launches, with no blocking, double-feeding, or missed shots. Flight time and estimated near-field launch speed changed consistently with the programmed motor settings. The proposed feeder enables repeatable, structured multi-shuttle training and provides a practical framework for quantifying zone-delivery performance, with future work directed toward refining closed-loop targeting.

**KEYWORDS** automation • ESP32 • embedded systems • learning innovation • sports engineering • skills development • training technology

**ARTICLE CITATION**

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## 1. INTRODUCTION

Badminton is widely regarded as one of the fastest racket sports and is characterized by a highly intermittent match structure in which brief, explosive rallies are interspersed with short recovery periods. Elite play typically alternates ~5–7 second of high-intensity actions (strokes, rapid accelerations/decelerations, and directional changes) with ~11–15 second of rest, placing substantial demands on both anaerobic power and aerobic recovery while requiring precise stroke execution and rapid tactical decisions [1], [2]. Notational analyses further indicate that the modern game has become increasingly time-pressured, with higher shot frequencies at the highest competitive levels [3].

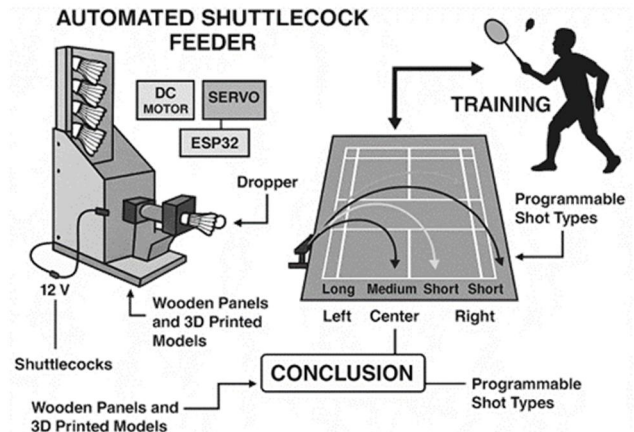
To replicate these constraints in practice, high-performance programs commonly use multi-shuttle (multi-feeding) drills, where a feeder delivers consecutive shuttles at high frequency to varied court locations to increase action density and train technical execution under fatigue [4], [5]. Empirical work shows that multi-feeding can impose very high internal and external loads, and that changes in interval prescription can meaningfully alter metabolic responses during these drills [6]. However, in many training environments, multi-shuttle drills remain manually fed; because shuttle delivery in “multi-feeding” is typically continuous and randomized by a coach, feed tempo and placement are operator-dependent, which can reduce session standardization and complicate objective performance comparisons across time [7].

Several automated badminton shuttlecock feeders have been reported in the literature, including wheel/roller-based launchers, pneumatic systems, and spring- or impact-driven mechanisms combined with gravity-fed or rotary delivery. For example, roller-based launchers can achieve high initial shuttle speeds through frictional contact between dual rollers and the shuttlecock [8]. In addition to the launching mechanism, these systems differ in their control strategies: some rely on fixed embedded control, whereas others incorporate wireless or IoT-enabled modules to support adjustable operation and programmable feeding patterns (e.g., microcontroller-based designs with wireless control) [9]. Patented designs also describe automated shuttle launchers capable of varying frequency, trajectory, and speed for training purposes [10]. Related work on badminton training robots and automated training devices further reflects ongoing efforts to reduce dependence on a human partner or feeder. However, many solutions remain expensive or operationally complex for routine coaching use [11].

Recent developments increasingly incorporate computer vision for shuttle tracking, calibration, and outcome assessment. Vision-based systems have been used to detect shuttle landing outcomes (e.g., in/out classification), demonstrating both feasibility and the practical challenges of tracking a small, fast-moving

object under realistic conditions [12]. Nevertheless, in many feeder-focused studies, vision is applied primarily for basic identification or limited calibration rather than for systematic, zone-based evaluation of landing accuracy against predetermined target areas on the court. This limitation is particularly important in badminton because the shuttlecock’s geometry and aerodynamic behavior make consistent placement difficult. Unlike ball projectiles, shuttlecocks experience very high drag and are highly sensitive to small variations in launch conditions. Aerodynamic studies model the shuttlecock as a conical skirt behind a hemispherical dome and show that design features (including gap structure and porosity) strongly influence drag and flow behavior [13]. Consequently, performance metrics that report only shuttle speed or mean landing distance are insufficient to characterize the zone-specific placement accuracy required for structured multi-shuttle training.

Despite these advances, to the best of our knowledge, low-cost, programmable badminton shuttlecock feeders have not been rigorously evaluated using a zone-based framework with statistically meaningful measures of spatial accuracy and repeatability. To address this gap, the present study proposes a low-cost, programmable badminton shuttlecock feeder and a zone-based evaluation methodology to quantify landing accuracy and repeatability under controlled multi-shuttle training conditions.



**Figure 1.** Framework study for automated shuttlecock feeder

The main contributions of this work are as follows: (1) the design and implementation of a programmable, automatic nine-shot badminton shuttlecock feeder; (2) the development of a zone-based experimental framework for evaluating landing accuracy on a regulation court; (3) statistical analysis of shot performance using confidence intervals, radial error, and spatial dispersion measures; and (4) experimental validation demonstrating stable operation and repeatable delivery despite the shuttlecock’s complex aerodynamic behavior.

This work builds upon our prior conference publication, which introduced a prototype shuttlecock feeder and reported an initial evaluation of selected shot

parameters [14]. The present study extends that work by implementing a programmable nine-shot feeding system and by providing a zone-based experimental framework with statistically grounded measures of landing accuracy and repeatability.

## 2. LITERATURE REVIEW

### 2.1. Shuttlecock Aerodynamics, Flight Behavior, and Launch Mechanisms

The aerodynamic characteristics of shuttlecocks during play were investigated by Chen et al. [15] through an analytical study of shuttlecock trajectory. Drag and shuttlecock orientation—two critical factors in feeder machine design—were shown to influence the parabolic flight path significantly; however, their study focused primarily on the shot trajectory. Shuttlecock type also affects aerodynamic performance. Alam et al. [16] reported differences in drag and flight stability between feather and synthetic shuttlecocks, highlighting the need for adaptability to different shuttle types and corresponding motor-speed adjustments in feeder design. Tan et al. [17] designed and tested a prototype launcher to evaluate shuttle performance under controlled conditions, underscoring the importance of consistent, repeatable launch conditions for reliable performance assessment.

Yousif and Yeh [18] developed a badminton training device incorporating an impact mechanism. Their work provides useful concepts for feeder systems that require dynamic control of launch velocity and angle, aiming to reproduce human-like shots through controlled impact force and direction. De Alwis et al. [19] proposed a shuttlecock feeding machine capable of reproducing a range of common badminton shots. Their prototype demonstrated coverage of rear-, mid-, and short-range shots across the left, center, and right court zones. The system supported both manual and randomized shot selection via push-button input, corresponding to nine programmed shot types. Similarly, Aslam et al. [20] introduced a portable and adjustable shuttlecock launcher that improved usability, mechanical reliability, and portability compared with prior designs. As in the present work, their system enabled controlled feeding and launching by coordinating servo-driven dropper and ejector mechanisms via microcontroller-based logic.

More recent designs by Kusuma et al. [21] further inform the present study. The Kinesthetic launcher supports athlete training through multiple shot types and reliable mechanical control. At the same time, Sholichin et al. [22] demonstrated an Arduino-based, servo-driven feeding and launching mechanism that aligns closely with ESP32-based implementations. De Alwis et al. [19] also reported selecting an ejection mechanism based on measured error using a newly developed test apparatus; they further evaluated agreement between experimental

and simulated results and assessed shuttlecock damage. Karamuz et al. [23] developed a programmable experimental station for automatically launching badminton shuttlecocks using two speed-controlled DC motors to spin an aluminum ring, with remote control integration to improve usability. Saeab and Phiphitphibunsuk [24] designed a 3D-printed shuttlecock launcher prototype primarily fabricated from PLA.

Motor-driven projectile launchers developed for cricket balls offer relevant insights into DC-motor actuation and driver-based control, although they are not specific to badminton [25], [26]. These studies emphasized the regulation of launch force and direction using DC motors and motor drivers, which is directly transferable to shuttlecock feeder design. Embedded microcontrollers such as ESP32 and Arduino boards are commonly used in these systems. Model-based DC motor speed control has been proposed to maintain constant launch speeds, and the working principles of Arduino relevant to the ESP32 programming environment adopted in this project [27].

### 2.2. Control, Sensing, and Vision-Based Performance Assessment

Hsiao and Ik [28] introduced an AIoT (artificial intelligence of things)-enabled badminton serving machine featuring MCU-based control, with programmable APIs enabling precise serving and integration with computer vision through automated positioning and calibration. Beyond launch mechanisms, several studies address training outcomes and sensing/measurement technologies. Nirmaladevi et al. [29] examined a training program for para-badminton athletes and associated biomechanical parameters. In sports-object tracking, Huang et al. [30] proposed TrackNet, a deep learning model based on heatmaps for accurately tracking small, fast-moving tennis balls.

Related research on shuttlecock tracking, recognition, and trajectory prediction demonstrates that learning-based and vision-based methods can reliably detect and track small, high-speed objects during play. These approaches demonstrate that neural networks and heatmap techniques can extract shuttle position and flight path information from video sources. Trajectory modeling and prediction further enable analysis of shuttle flight behavior and landing conditions, while automated detection and multisensory methods can improve measurement accuracy and stability. Collectively, these methods support the development of automated, data-driven systems for badminton training and assessment [31]–[33]. Foundational literature in sports performance analysis establishes key measures related to precision, repeatability, and skill evaluation [34]–[37]. Research on projectile launching systems also clarifies repeatable impact mechanisms, propulsion control, and launch dynamics [38], [39]. For feeder-machine development, integrated electromechanical design, camera-based

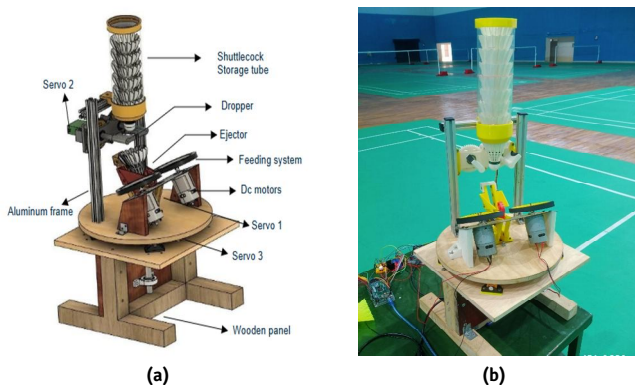
measurement, and motor control are theoretically supported by references in mechatronics, robotics, computer vision, and control engineering [40], [41].

Prior research and commercial shuttlecock feeder machines predominantly use high-speed motors driving rotating wheels to impart velocity to the shuttlecock [19]–[22]. These systems are typically automated or embedded-controlled, with limited parameter adjustment, such as wheel speed and feed rate. Despite these advances, many existing devices offer restricted programmability and only a small set of shot types. Consequently, most designs emphasize shuttle delivery rather than generating objective data on shot placement, trajectory consistency, or landing precision. This reveals a clear research gap: the need for a programmable, experimentally validated shuttlecock feeder capable of generating realistic shots and assessing objective performance. Accordingly, this project aims to develop an automated shuttlecock feeding system with adjustable mechanical and control features. By consistently delivering shuttlecocks under controlled conditions, the proposed approach is intended to help athletes identify technical deficiencies and improve overall performance.

### 3. MATERIALS AND METHODS

#### 3.1. System Architecture

The automated shuttlecock feeder system was designed to deliver shuttlecocks to specific areas of the badminton court through a controlled, predetermined process. This capability enables precise measurement of shot execution, directional accuracy, and launch speed. To minimize operational errors and ensure consistent launch conditions across repeated trials, the system integrates mechanical components, electronic circuitry, and embedded control within a unified embedded design.



**Figure 2.** (a) CAD model and (b) Feeder machine prototype. The CAD design is used to verify dimensions and alignment, while the prototype is built using a wooden frame and custom components (a shuttle holder and a dropper mechanism).

The feeder's mechanical structure was designed using CAD modeling software to plan the component layout,

ensure structural rigidity, and achieve a compact configuration for the feeding and launching mechanisms. The CAD model guided prototype fabrication and assembly, ensuring that all dimensions remained consistent throughout development. Figures 2a and 2b present the CAD design and the final prototype used for experimental analysis.

The system provides programmable control of key operating parameters, including the shuttlecock feeding sequence, launch-wheel speed, and shot direction. By adjusting these parameters, a range of shot types and target locations can be evaluated automatically and with high precision.

The feeder comprises three major subsystems: (i) a mechanical subsystem for shuttlecock storage, feeding, and dual-wheel launching; (ii) an electronic control unit incorporating an ESP32 microcontroller, motor drivers, sensors, a display, and a power supply; and (iii) a software subsystem that coordinates timing, motor speed, and servo actuation to supply shuttlecocks safely and continuously for experimental testing.

#### 3.2. Mechanical Design of the Shuttlecock Feeder

A wooden base panel supports the feeder structure, ensuring stable operation. The upper base is mounted on a circular wooden plate with a 300 mm diameter and 12 mm thickness, serving as the mounting surface for the ejector and feeding subsystems. To increase structural strength and reduce vibration during operation, frame components are secured using screw-type fasteners and brackets.

For directional control, the upper base is mechanically coupled to the lower base and actuated by a 15 kg-cm torque servo motor (Servo-3) positioned between the base and the rotating upper structure. This servo drives the launcher assembly's left-right rotation to achieve controlled shot placement.

Functional components, including the shuttle holder, dropper unit, motor-mount supports, and ejector mechanism, were fabricated using fused deposition modeling (FDM) 3D printing with PLA filament. The shuttlecock dropper assembly was designed to enable continuous feeding while maintaining shuttle stability, thereby minimizing unintended motion that could degrade launch accuracy. To ensure consistent fabrication quality and controlled printing parameters, the DC motors were mounted on custom 3D-printed brackets produced in-house using a desktop FDM printer. Figure 2 shows the assembled prototype.

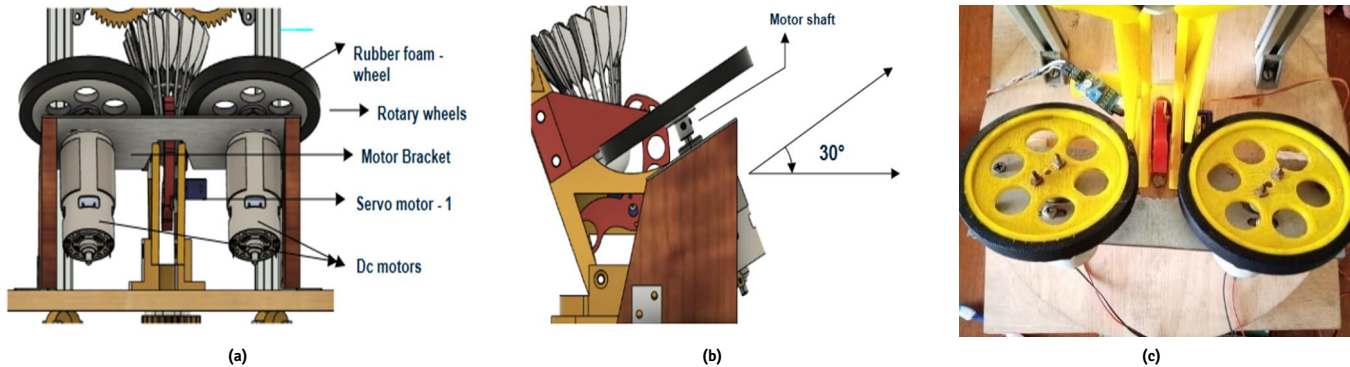
#### 3.3. Launching Mechanism

The launcher assembly was mounted at a fixed vertical angle of 30° to produce stable shuttlecock motion while keeping the mechanical design simple. Shot distance was controlled by automatically adjusting the launcher wheel speeds, and lateral targeting across different court zones was achieved using a servo-driven aiming mechanism. The

launch angle was selected based on preliminary evaluations to ensure stable and repeatable trajectories.

The motors were supported by a custom-designed steel bracket fabricated from 1.5 mm-thick sheet steel and precision-cut to the specified dimensions. This thickness provides adequate structural strength and

reduces vibration at high rotational speeds. Slotted holes in the bracket allow adjustment of the inter-wheel spacing, ensuring continuous wheel–shuttlecock contact during acceleration and accommodating variations in cork size.



**Figure 3.** Shuttlecock launching mechanism

Two identical 3D-printed wheels were fitted with an outer rubber-foam layer to increase friction and reduce slippage at high rotational speeds. This layered construction improves grip and promotes more uniform force transmission at the wheel–cork interface. Each wheel has a 100 mm diameter (a 90 mm PLA core with a 5 mm rubber layer) and a 10 mm width. Based on initial trials using standard feather shuttlecocks, an adjustable inter-wheel spacing range of 30–35 mm was established.

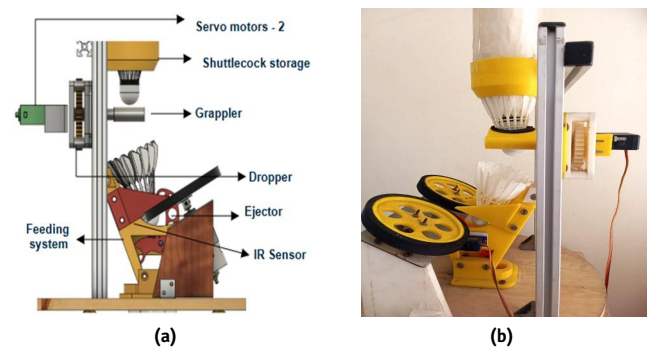
Each wheel is coupled to the motor shaft via a 5 mm form-fit connection and rotates continuously during operation. Wheel alignment was carefully evaluated during assembly to ensure symmetric rotation and consistent launch direction. Wheel rotational speed was estimated from prior PWM–RPM calibration tests rather than measured directly during each trial.

### 3.4. Shuttlecock Feeding and Ejection System

The shuttlecock feeding system retrieves individual shuttlecocks from a vertical storage magazine and accurately delivers them to the launch zone. As shown in Figure 4, the mechanism comprises two coordinated subsystems—a dropper and an ejector—each actuated by an independent servo motor.

The dropper uses a dual-rotation grabber to extract a single shuttlecock from the magazine while retaining the remaining shuttlecocks in the stack. The dropper is driven by Servo Motor 2, which enables controlled grasping and release. After release, the shuttlecock lands on the ejector platform, and the dropper returns to position to secure the next shuttlecock in the stack. An infrared (IR) sensor mounted near the ejector detects the presence or absence of a shuttlecock. Once a shuttlecock is detected, the ejector rotates backward to align it with the launcher wheels and then moves forward to feed it into the launching mechanism. Prior to formal trials, feeding

reliability was evaluated through more than 100 test cycles, with no shuttle crossover observed.



**Figure 4.** Dropper and ejector mechanisms of the shuttlecock feeding system.

The embedded program regulates servo speed and motion sequencing, enabling coordinated operation of the dropper and ejector. The control logic specifies the actuation order and delay intervals to ensure consistent single-shuttle release and repeatable placement before launch, thereby minimizing feeding errors during subsequent experiments.

### 3.5. Hardware Specifications

Table 1 summarizes the hardware specifications employed in the system, including component type, key parameters, power requirements, operating voltage range, control-signal type, and the functional role of each module, to ensure integration compatibility and operational stability.

As indicated in Table 1, the system adopts a centralized control architecture based on the ESP32, which drives the actuators via PWM/digital signals, where a DC motor serves as the primary propulsion unit for the launching mechanism and multiple servos handle

shuttlecock release, injection, and directional aiming; meanwhile, an I2C-based LCD provides the monitoring interface, and a multi-rail power design (12 V as the main supply with regulation for 6 V/5 V/3.3 V loads) ensures power sufficiency and mitigates disturbances induced by dynamic loads during operation.

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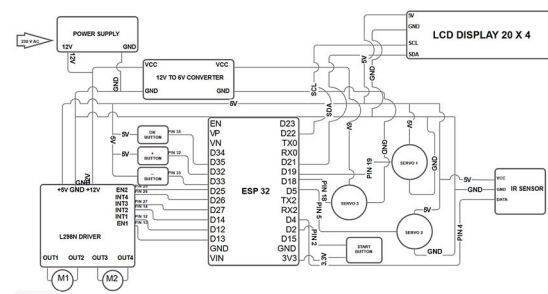
**Table 1.** System Specifications

Component	Model/Type	Key Specifications	Rated Power	Operating Voltage Range	Control Signal Type	Functional Role
Controller	ESP32	240 MHz processor, PWM frequency up to 20 kHz	~0.8 W (typical)	3.0–3.6 V DC	Digital / PWM	Central system coordination and shot control
DC Motor	RS-775	18,000 rpm (no-load), ~1.2 N·m stall torque	~150–200 W (peak)	9–18 V DC	PWM (via driver)	Shuttlecock propulsion via dual-wheel launcher
Motor Driver	L298N Module	Dual H-bridge, up to 2 A per channel,	~25 W (max dissipation)	Motor: up to 46 V DC, Logic: 5 V DC	PWM / Digital	Wheel motor speed and direction control
Servo Motor- 2 (Dropper)	Tower Pro MG996R	180° rotation, 9.4 kg·cm torque	~5–7 W	4.8–7.2 V DC	PWM	Controlled release of the shuttlecock from the holding mechanism
Servo Motor-1 (Ejector)	Tower Pro SG90	0–180° rotation, 1.2 kg·cm torque	~2–3 W	4.8–6.0 V DC	PWM	Ejection of the shuttlecock into the launcher wheels
Servo Motor- 3 (Direction)	RDS3115 MG (Dual Shaft)	0–180° rotation, 15 kg·cm torque	~8–10 W	6.0–7.4 V DC	PWM	Left–right rotation of the feeder base for directional targeting
LCD Display	LCD2004 with I <sup>2</sup> C Interface	20×4 characters, PCF8574, yellow backlight	~1 W	4.5–5.5 V DC	I <sup>2</sup> C (Digital)	Displays system status, selected mode, and shot parameters
Power Supply	Mean Well HDR-60-12	Output:12 V DC, 4.5 A	60 W	90–264 V AC input	—	Primary power supply for motors and control circuitry
Voltage Converter	LM7806 Linear Regulator	Fixed 6 V DC output	~5 W (with heat sink)	Input: 9–24 V DC	—	Voltage regulation for the directional servo motor
Camera	Action Camera	1080p resolution, 60 fps	~4–6 W	—	Digital	Video recording

As indicated in Table 1, the system adopts a centralized control architecture based on the ESP32, which drives the actuators via PWM/digital signals, where a DC motor serves as the primary propulsion unit for the launching mechanism and multiple servos handle shuttlecock release, injection, and directional aiming; meanwhile, an I2C-based LCD provides the monitoring interface, and a multi-rail power design (12 V as the main supply with regulation for 6 V/5 V/3.3 V loads) ensures power sufficiency and mitigates disturbances induced by dynamic loads during operation.

**3.6. Electronics and Control Hardware Configuration**

The proposed shuttlecock feeder’s electrical and control system integrates power regulation, embedded control, motor drivers, sensors, and a user interface to enable automated, programmable feeding. The overall control architecture centers on an ESP32 microcontroller that coordinates timing, actuation, sensing, and user interaction across all subsystems.

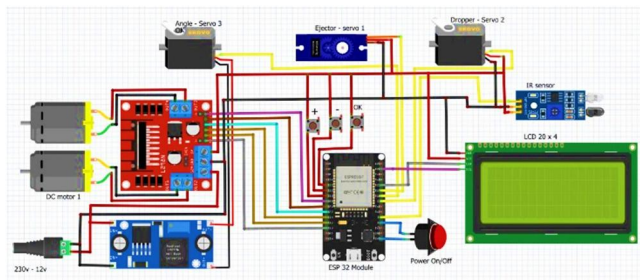


**Figure 5.** Electrical schematic of the ESP32-based shuttlecock feeder control circuitry

The system is supplied by a 230 V AC mains source that is converted to a regulated 12 V DC rail. An L298N dual H-bridge motor driver module powers the DC motors directly from the 12 V supply. A linear LM7806 regulator with a heat sink provides a regulated 6 V supply for the servomotors. The ESP32 controller, LCD, IR sensor, and user input circuitry are powered by regulated 5 V and 3.3

V rails derived from onboard regulators and DC-DC converters. All modules share a common goal of maintaining signal integrity and reliable operation.

Figure 5 illustrates the electrical interconnections among the controller, motor drivers, sensor, display, and input devices. To support repeatability and ease of implementation, the schematic identifies signal lines, power rails, and module connectors. Figure 6 presents the corresponding practical wiring layout used during hardware integration and experimental evaluation.



**Figure 6.** Practical wiring layout of the control hardware connections.

System operation is governed by the ESP32 microcontroller, which generates PWM signals to regulate DC motor speed and to control servo motor positioning. The dual-wheel launching mechanism uses two independently driven DC motors, each connected to a L298N motor driver, enabling adjustable launch velocity and differential wheel-speed control for directional and trajectory tuning. Mechanical functions are actuated by

three servo motors, including those responsible for shuttlecock feeding/ejection and horizontal angle adjustment of the launcher assembly.



**Figure 7.** Electronics implementation of the prototype system.

Multiple push-button inputs provide user interaction, including shot selection, parameter increment/decrement, confirmation, and system start-up control. A 20 × 4 LCD module with an I<sup>2</sup>C interface displays real-time operating parameters and system status information. An infrared (IR) sensor detects the presence of a shuttlecock and coordinates the feeding and launching sequences. Figure 7 illustrates the control electronics implemented for the feeder system.

To ensure consistent hardware integration, Table 2 details the ESP32 GPIO interface mapping used in this study, including pin assignments, module connections, signal types (digital, PWM, and I<sup>2</sup>C), and the functional role of each signal.

**Table 2.** System Specifications

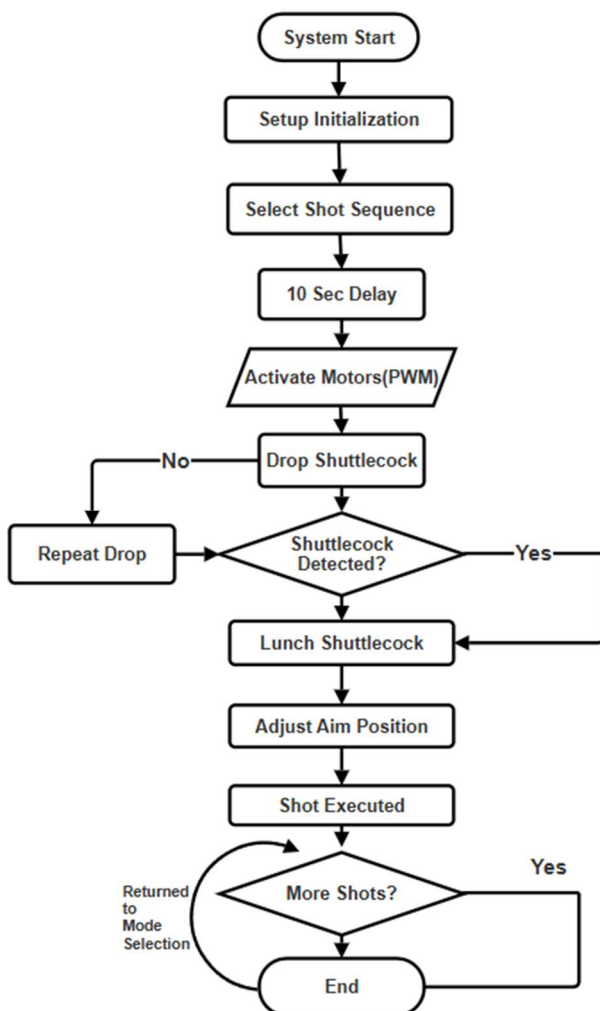
ESP32 GPIO PIN	Connected Module	Signal Type	Descriptions
GPIO 12	L298N IN1	Digital Output	Motor 1, clockwise direction control
GPIO 13	L298N EN1	PWM Output	Motor 1 controls the speed of the motor
GPIO 14	L298N IN2	Digital Output	Motor 1 anti-clockwise direction control
GPIO 26	L298N IN3	Digital Output	Motor 2 clockwise direction control
GPIO 27	L298N EN2	PWM Output	Motor 2 controls the speed of the motor
GPIO 25	L298N IN4	Digital Output	Motor 2 anti-clockwise direction control
GPIO 19	Servo 1 (Ejector)	PWM Output	Controls the shuttlecock launching system
GPIO 4	Servo 2 (Dropper)	PWM Output	Controls the shuttlecock feeding mechanism
GPIO 18	Servo 3 (Angle)	PWM Output	Adjusts direction angle (left-right)
GPIO 21	LCD SDA	I <sup>2</sup> C Data	LCD communication
GPIO 22	LCD SCL	I <sup>2</sup> C Clock	LCD communication
GPIO 35	OK Button	Digital Input	Confirmation input
GPIO 32	“+” Button	Digital Input	Parameter increment
GPIO 33	“-” Button	Digital Input	Parameter decrement
GPIO 15	Select Button	Digital Input	Menu input
GPIO 2 / GPIO 5	IR Sensor	Digital Input	Shuttlecock presence or absence detection
VIN / 5V	Power Input	—	Power supply in ESP32

ESP32 GPIO PIN	Connected Module	Signal Type	Descriptions
GND	Common Ground	–	Shared ground line

### 3.7. Control Firmware and Program Flow

The shuttlecock feeder is controlled by an ESP32 microcontroller, which serves as the primary controller for all motors, sensors, timing, and sequencing. The control firmware was developed using the Arduino IDE and an Arduino-compatible programming language. The Arduino IDE was used to write, compile, and upload the firmware to the ESP32.

The program follows the standard Arduino structure, consisting of two main functions: `setup()` and `loop()`. The `setup()` function executes once at start-up to initialize all devices and establish consistent initial conditions. During initialization, the DC motors and servomotors are set to predefined positions or states to ensure uniform mechanical starting conditions prior to operation.



**Figure 8.** Flow chart of the Shuttlecock feeder program

Figure 8 illustrates the operating sequence of the control firmware, from initialization through shuttle release, presence verification, motor activation, directional

adjustment, and launch execution using the specified PWM duty cycles.

The `loop()` function runs continuously and governs the feeding and launching sequence. The dropper servo and infrared (IR) sensor operate in coordination to control shuttlecock delivery. The dropper servo releases a shuttlecock into the ejector path, and the IR sensor confirms its presence. If detection is unsuccessful, the dropper repeats the release action. Once the shuttlecock is detected, the ejector servo advances it through the gap between the two rotating launcher wheels, accelerating it to the prescribed launch speed. A directional servo located at the base adjusts the horizontal aiming angle to target the left, center, or right court zones.

Different shot types are assigned to each target zone, with predefined program sequences corresponding to rear-, mid-, and front-court shots. To support training variation, the control logic provides both sequential and randomized operating modes. User input is provided via push buttons for parameter increment/decrement and mode selection. Following shot selection and start confirmation, a 10-second delay is applied to allow the player to prepare before the launch cycle begins.

### 3.8. Shot Program Parameters & Target Zone Definition

To evaluate launch accuracy and repeatability, nine-shot programs were developed based on three horizontal target regions (left, center, and right) and three court-depth zones (front, mid, and rear). Each program controlled the shuttlecock's flight trajectory and intended landing location through a unique combination of directional servo angle, wheel speed, and feeding delay. The court was marked using standard badminton lines to provide fixed reference points for measuring landing distance and placement accuracy.

**Table 3.** Programmed parameters for all nine target zones

Shot ID	Target Zone	Servo Motor 3 Angle (°)	Wheel PWM	Feed Delay (ms)
S1	Front-Left	5	63	800
S2	Front-Center	90	50	800
S3	Front-Right	175	63	800
S4	Mid-Left	35	73	900
S5	Mid-Center	90	67	900
S6	Mid-Right	145	73	900
S7	Rear-Left	45	230	1000
S8	Rear-Center	90	205	1000
S9	Rear-Right	110	230	1000

Table 3 summarizes the programmable variables for all nine target zones used in the experimental evaluation.

These parameters were held constant throughout testing to ensure comparability across trials.

### 3.9. Experimental Objectives and Shot Execution Techniques

The automated feeder's shot-programming approach was designed to meet two objectives. First, it aimed to generate specific shot types in a controlled and repeatable manner so that shuttlecock landing distance and location could be recorded with high accuracy. Second, it aimed to demonstrate that the feeder can deliver structured and variable shot sequences suitable for badminton training.

During experimental testing, each shot program corresponding to a given target zone and distance range was executed under identical operating conditions. This enabled a systematic evaluation of distance consistency, directional accuracy, and landing dispersion for predefined servo angles, wheel speeds, and feeding intervals.

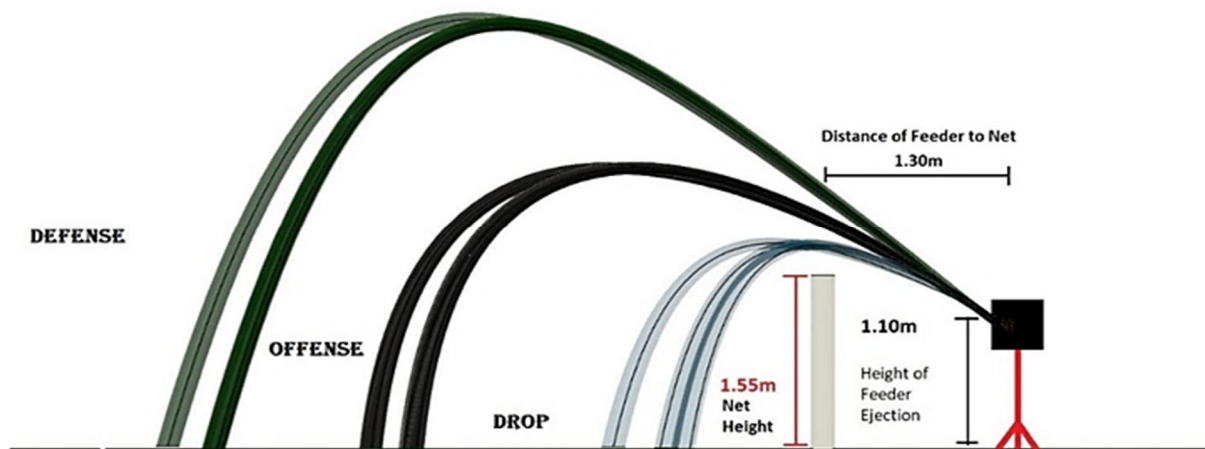
For training applications, the individual shot programs were organized into sequences with selectable parameters. The system can execute shots either sequentially or randomly, producing variation in shot direction and depth without requiring continuous user input. This supports realistic training scenarios that

combine left-, center-, and right-hand placements with front-, mid-, and rear-court shots. The Results section provides a quantitative assessment of shot accuracy, repeatability, and landing behavior.

### 3.10. Experimental Setup and Test Protocol

The automated shuttlecock feeder was mounted on a stand 1.10 m above the court surface and positioned 1.30 m from the badminton net along the court's longitudinal centerline. Experiments were conducted on an indoor badminton court (13.4 m × 6.1 m) at the TNPESU University campus.

The court surface was divided into 9 target zones according to predetermined shot sequences. For each zone, 12 shuttlecocks were launched using standard feather shuttlecocks (Kawasaki King Kong 700, speed 77; feather skirt with a composite cork base), resulting in 108 trials per experimental run. Shuttlecocks were inspected after each block of trials and replaced if visible skirt deformation or cork damage was observed. The firing sequence remained fixed throughout all trials to ensure consistent data collection under identical operating conditions. Shot programs were executed in zone-specific blocks to maintain repeatable conditions across repeated trials.



**Figure 9.** Experimental setup for the shuttlecock feeder machine.

All experiments were conducted indoors under stable air conditions, with no measurable cross-drafts or external airflow disturbances. The ambient temperature during testing ranged from 26 to 28 °C, and lighting was kept constant for all recordings to minimize visual-tracking variability and environmental effects (Figure 9).

### 3.11. Data Acquisition System

During the feeder experiments, shuttlecock motion and landing locations were recorded using a dual-camera setup. Two digital cameras were deployed to capture both the flight trajectory and the landing area. Camera II was mounted above the court to obtain a top-view recording of landing positions within the target zones, whereas

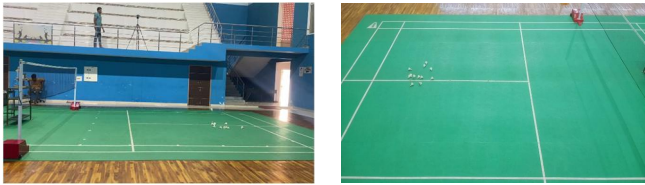
Camera I was aligned with the feeder direction to capture the shuttlecock's trajectory. To minimize motion artifacts and vibration during testing, both cameras were secured on stable stands.



**Figure 10.** The Camera I set up was used to measure the shuttlecock's flight path distance.

Shuttlecock speed measurements were primarily recorded at 120 frames per second (fps) to provide improved temporal resolution for short-range motion analysis. In addition, several trials were recorded at 60 fps to capture overall motion and landing patterns.

Video recordings supported frame-by-frame analysis and motion tracking at a fixed frame rate (60 fps) and a resolution of  $1920 \times 1080$  pixels. Camera coordination was achieved by initiating both recordings simultaneously and subsequently verifying synchronization during post-processing using a visual marker event captured by both cameras. An initial calibration test was performed to confirm appropriate camera placement and viewing angles.



**Figure 11.** Camera II top-view configuration used for landing-zone capture.

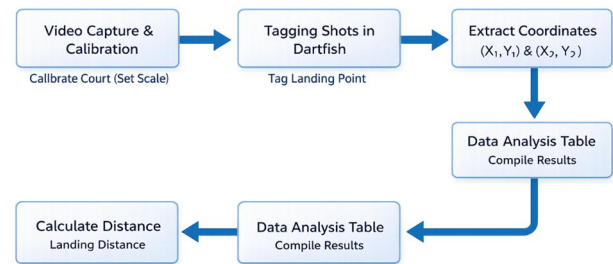
To enable spatial measurements, fixed reference markers were installed on the badminton court at known coordinates based on standard court dimensions. These markers served as calibration points for converting pixel coordinates to real-world distances. Pixel-to-distance conversion was performed using court reference markers and planar homographs calibration, yielding a mean spatial error of less than 3%. Calibration was verified during each testing session to maintain measurement accuracy and reduce systematic error; accuracy was further confirmed by measuring known court distances.

### 3.12. Vision Coordinate Extraction Using Dartfish

Shuttlecock launch speed was determined via frame-by-frame video analysis. The shuttlecock was tagged at the launcher exit and again after traveling a known reference distance of 1 m. Video was recorded at 120 fps, enabling precise identification of the start and end frames. The frame difference between the two tagged positions was used to compute elapsed time, and shuttlecock speed was calculated by dividing the known travel distance by the measured time interval. The reported speeds, therefore, represent near-field translational velocities measured over a 1 m segment immediately after launch and do not correspond to the theoretical wheel-exit speed.

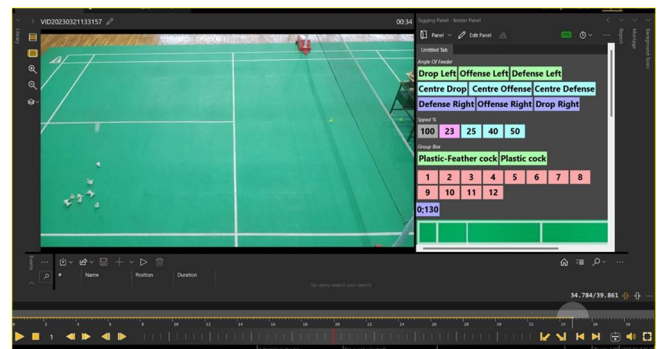
Figure 12 summarizes the workflow used for video-based landing analysis. The procedure begins with video capture and court calibration, in which the badminton court is defined as a reference region using official dimensions. Shuttlecock landing locations are tagged in Dartfish at the exact impact frame, and the corresponding Cartesian coordinates  $(x_1, y_1)$  and  $(x_2, y_2)$  are extracted. These coordinates are compiled into a data table, and the

landing distance is computed using the Euclidean distance metric.



**Figure 12.** Workflow for shuttlecock shot-location analysis

Figure 13 presents the Dartfish motion analysis interface used during the experiments. The calibrated badminton court is displayed in the main video frame, and the tagging panel appears on the right. The panel records shot type, feeder angle selection, speed parameters, shuttlecock type labels, and test sequence numbers. Using this interface, each shuttlecock landing event was identified at the impact frame.



**Figure 13.** Shuttlecock landing-position tagging using Dartfish software.

When an event was tagged within the calibrated court area, Dartfish automatically recorded the x-y coordinates, event time, and label. This standardized tagging procedure ensured consistent data collection across trials and enabled straightforward export of coordinate data as comma-separated values (CSV) for subsequent statistical analysis.

## 4. RESULTS AND DISCUSSION

### 4.1. Landing Distance, Repeatability and Flight Speed

The results were evaluated on a standard badminton court in an indoor sports facility. Throughout testing, operational performance and observed constraints were recorded. A total of 9 shot types were used in 108 launch trials, and the landing location of each shuttlecock was recorded for evaluation. Across all regions, higher programmed motor speeds produced greater shuttlecock travel distances.

**Table 4.** Repeatability statistics of shuttlecock landing distance

Shot ID	Target Zone	Mean (m)	SD (m)	CV (%)	95% CI (m)
S1	Front-Left	3.33	0.21	6.31	3.20 – 3.46
S2	Front-Center	3.10	0.36	11.61	2.88 – 3.32
S3	Front-Right	3.18	0.10	3.14	3.12 – 3.24
S4	Mid-Left	5.07	0.29	5.72	4.90 – 5.24
S5	Mid-Center	5.10	0.28	5.49	4.94 – 5.26
S6	Mid-Right	5.04	0.39	7.74	4.81 – 5.27
S7	Rear-Left	6.06	0.32	5.28	5.88 – 6.24
S8	Rear-Center	6.14	0.15	2.44	6.06 – 6.22
S9	Rear-Right	6.42	0.15	2.34	6.33 – 6.51

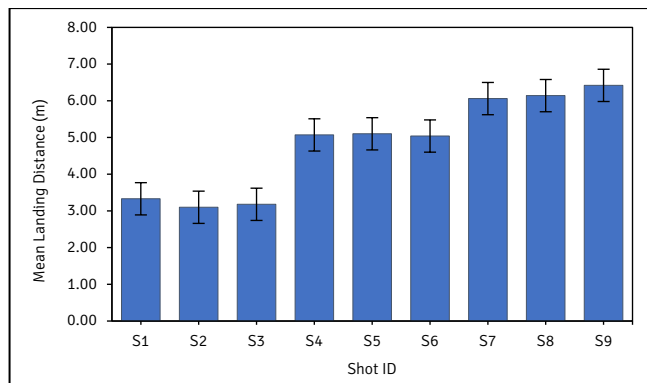
**Figure 14.** Repeatability of shuttlecock landing distance across shot programs (mean  $\pm$ SD; n = 12 trials per condition).

Figure 14 presents the mean landing distance with standard deviation error bars for all nine shot programs. The relatively small error bars across all conditions indicate low variability and strong repeatability of the shuttlecock landing distance under fixed programmed settings. Rear-court shots exhibit both higher mean distances and a tighter spread compared to several front-court shots. To further quantify the repeatability beyond visual inspection, the coefficient of variation (CV) was calculated for each shot program, with all values remaining below 12%. This indicates high shot-to-shot distance repeatability, confirming the consistency of the motor and servo control settings.

**Table 5.** Average shuttlecock flight interval time and estimated launch speed for each shot type and motor speed setting

Shot ID	Target Zone	Motor Speed (%)	Interval time (s)	Shuttlecock Speed (m/s)
S1	Front-Left	25	1.04	3.20
S2	Front-Center	25	1.08	2.87
S3	Front-Right	25	1.04	3.06
S4	Mid-Left	50	1.44	3.52
S5	Mid-Center	50	1.32	3.86
S6	Mid-Right	50	1.44	3.50
S7	Rear-Left	100	1.60	3.79
S8	Rear-Center	100	1.64	3.74
S9	Rear-Right	100	1.61	3.99

Compared with other shuttlecock launching systems, the repeatability performance observed in this study is competitive. In an arm-type badminton launching machine, Sakai et al. [42] reported an initial shuttlecock speed of 36.0 m/s, a maximum flight distance of approximately 9.2 m, and landing dispersion characterized by a standard deviation of 0.30 m along the shot direction and 0.17 m in the lateral direction. The magnitude of longitudinal dispersion in that study is comparable to the landing-distance variability reported here (SD = 0.10–0.39 m), although their evaluation explicitly quantified lateral dispersion as an additional accuracy dimension.

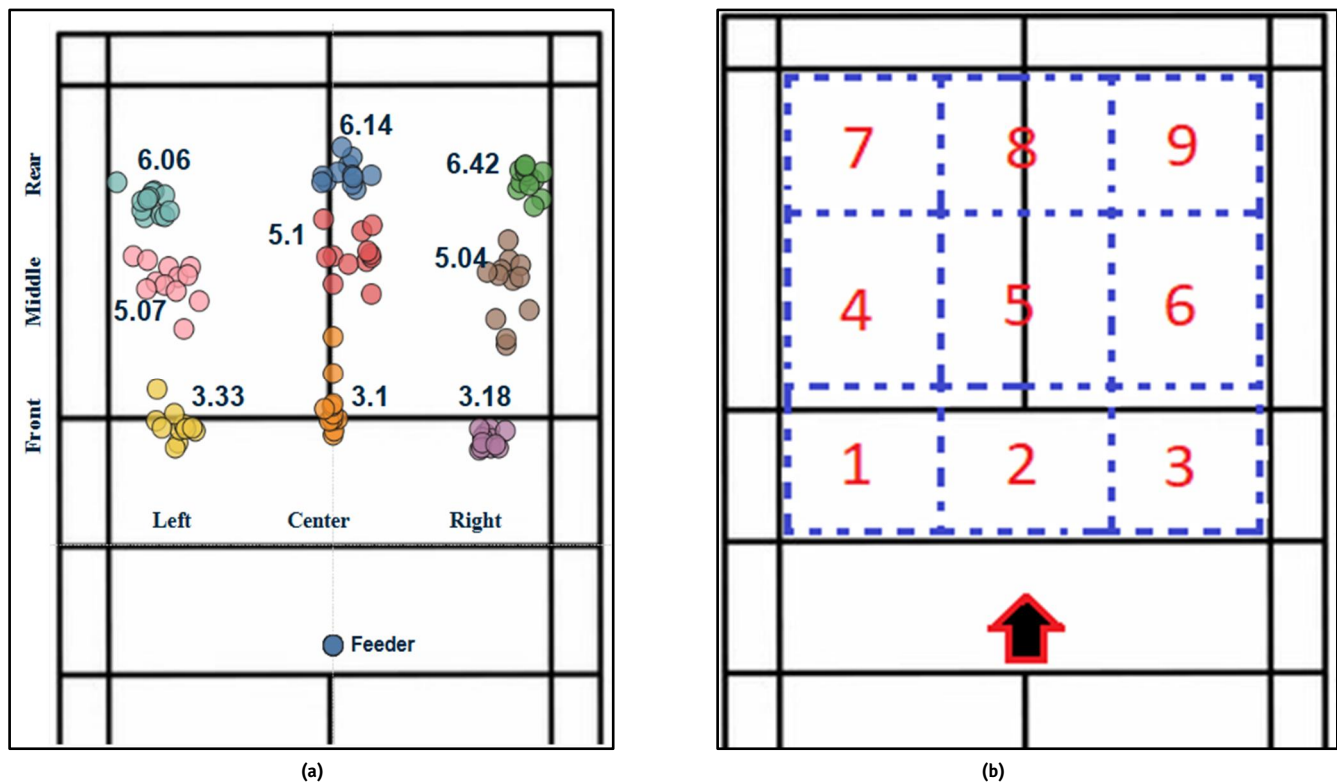
#### 4.2. Targeting Accuracy and System Reliability

Targeting performance was assessed using distance-based deviation together with the two-dimensional (2D) landing distribution, allowing accuracy (mean deviation per zone) and repeatability (within-zone dispersion) to be interpreted in the same court-plane representation (Figure 15). Notably, in human badminton short-serve research, landing location is often considered an unreliable proxy for accuracy because the shuttle is typically intercepted before it lands; trajectory-based descriptors (e.g., net clearance and apex) are therefore preferred for match-like serve evaluation. In contrast, for an automated launcher whose objective is explicitly zone

delivery, the landing distribution remains a direct and operationally meaningful outcome metric.

Compared with prior shuttlecock training/launching prototypes that commonly emphasize trajectory determination and general system feasibility (often without a standardized, zone-wise 2D error map), Fig. 7(a) provides an explicit zone-resolved depiction of landing outcomes with annotated mean deviations [9], [11]. This presentation aligns with broader calls in shuttlecock evaluation research for well-defined, consistent testing methodologies, including dedicated launcher-based testing to support repeatable, comparable measurements

[43]. Complementing recent “serving machine” evaluations that report performance via target-hit demonstrations in continuous-shot protocols, the 2D zone map in Figure 15(a) makes both systematic bias (mean deviation) and repeatability (cluster compactness) visible at a glance. The depth-dependent variation observed across zones is also qualitatively consistent with the strong role of shuttlecock aerodynamics and launch-condition sensitivity during flight, as characterized experimentally and via trajectory modeling in prior aerodynamics work [19].



**Figure 15.** (a) Two-dimensional shuttlecock landing distributions with mean deviation per target zone. (b) Shot-zone indexing and program-to-zone mapping (arrow indicates launch direction).

System reliability was evaluated over 108 launch trials (nine shot programs, 12 attempts each), with no blocking, double-feeding, or missed launches observed (i.e., 100% feeding reliability, 0% missed rate). Reliability is particularly important in shuttlecock launchers because the feeding mechanism is a critical subsystem that advances shuttlecocks from the dispenser to the ejection unit in a controlled manner [44]. Figure 15(b) summarizes the zone indexing and program-to-zone mapping used for this evaluation.

## 5. CONCLUSION

An automated shuttlecock feeder was designed and experimentally evaluated for programmable badminton training. The system delivers shuttlecocks to predefined court zones with controlled speed, direction, and timing, enabling repeatable multi-shot drills without manual

feeding. The mechanical design integrates CAD-based modeling, 3D-printed components, and lightweight frame elements. Shot direction and launch parameters are controlled using servo motors and dual DC launcher motors governed by an ESP32 microcontroller.

Experimental testing using high-speed video and motion tracking showed that the system successfully executed all nine programmed shot types, producing distinct landing distributions consistent with the intended target zones. Performance was evidenced by relatively uniform landing distances, low distance variability, and zone-specific landing patterns. Flight time and estimated launch speed varied as expected across motor configurations. No jamming or misfeeding occurred in any of the 108 trials, indicating reliable and stable feeder operation under the test conditions.

The results demonstrate that the proposed feeder provides controlled and repeatable shuttle delivery to

predefined court zones, supporting structured badminton practice. Future work may include expanding the range of shot variations, integrating closed-loop feedback to improve targeting precision, coordinating feeder output with player response, and developing mobile control applications to enhance system functionality.

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#### CONFLICTS OF INTEREST

The authors declare that no conflicts of interest are associated with this study. All aspects of the research were conducted with the utmost integrity and transparency.

#### DATA AVAILABILITY

The datasets utilized and analyzed during this research are available from the corresponding author upon reasonable request.

#### ETHICAL STATEMENTS

The authors confirm that the study complied with all applicable local laws, ethical standards, and institutional guidelines, including obtaining approval from relevant ethics committees.

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