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Design, Fabrication, and Testing of a Sensor-Driven Table Tennis Trainer with Real-Time Feedback

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Abstract

This paper presents the design, fabrication, and testing of a sensor-driven training device for table tennis that provides real-time feedback. To identify ball trajectory and validate shots, the device uses infrared and sound sensors in combination with ESP32 microcontrollers in a master-slave arrangement. A goal-like structure attached to the table collects balls, while sensors assess whether a shot is valid, which is defined as a ball that bounces on the table before entering the goal. Visual feedback is provided via LED strips and an LCD display, guaranteeing that players receive immediate and intuitive performance information. Testing was done under three different conditions: infrared sensor only, infrared plus sound sensor in a quiet area, and infrared plus sound sensor in a noisy environment. The results demonstrated that, while a single infrared sensor reliably identified ball entry, it could not distinguish between valid and invalid shots. Combining infrared and sound sensors yielded complete accuracy in calm situations but dropped to 40% accuracy in noisy environments due to sound interference. The study addresses the lack of affordable, real-time training feedback systems for table tennis by proposing multi-sensor systems capable of distinguishing valid and invalid shots based on the contact between the ball and the table. This paper reports a validation of the proof-of-concept of a low-cost multi-sensor system, which focuses on the system's accuracy instead of comparison of human performance.

Keywords: Table Tennis, Sensor-Driven, Training Device, Shot Counter, Machine Design

1. Introduction

Recent advances in sports science have substantially enhanced the way athletes train, perform, and recover by integrating knowledge from physiology, biomechanics, psychology, and technology. Sensor-based systems, computer vision, and wearable devices have been widely adopted in various sports, providing real-time and objective insights into technical and tactical performance while simultaneously reducing the risk of injury [1]. Swimming, for example, uses underwater motion capture cameras to measure stroke efficiency, while computer vision and inertial sensors are applied in performance tracking [2]. In contrast, table tennis has not yet fully capitalized on such technological progress. As a sport characterized by rapid rallies, spin variation, and high accuracy, performance is determined by subtle technical differences that are difficult to capture through traditional methods such as manual observation or video analysis [3]. Although some image-processing and computer vision approaches have been applied, these systems are often complex, resource-intensive, and less suitable for routine training environments [4].

The rapid advancement of sports science highlights the role of technology in enhancing athlete training and performance, particularly in table tennis, where rallies, spin, and placement demand precision [5]. Studies show significant fluctuations in performance even within a single match, emphasizing the need for real-time measurement of accuracy and consistency to guide training [6]. The three-phase structure of table tennis rallies further illustrates the complexity of initial attack and counterattack, underscoring the necessity of precise performance indicators [7]. To address these needs, sensor technologies have been applied across sports, offering real-time kinematic analysis and objective feedback beyond traditional observation [8]. IoT-based systems such as Tac-Trainer demonstrate how sensor data and visual analytics support technical refinement and tactical adjustments in racket sports, including table tennis [9], while multi-target visual models show that combining advanced tracking algorithms with sensor data can significantly enhance performance monitoring for both professionals and beginners [10].

The integration of sensor technology has transformed sports training by enabling real-time feedback

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through motion sensors, wearables, and wireless networks, allowing athletes to optimize movement and reduce injury risks [11, 12]. In table tennis, where millisecond precision is critical, intelligent systems can capture biomechanical and performance data beyond human perception [13], reflecting the broader shift toward data-driven training for efficiency and safety [14, 15]. Wireless sensor networks extend this potential by synchronizing ball trajectory, racket angle, and body posture tracking [16, 17]. Meanwhile, AI-driven models achieve over 98% accuracy in detecting ball movement and stroke mechanics [18,19], and multi-sensor platforms effectively identify biomechanical inefficiencies to support skill development and injury prevention [20]. The importance of developing low-cost and accessible training devices has also been emphasized in related studies, such as the design of an economical 3D-printed robotic arm for educational purposes, which highlights the broader relevance of affordable technology-driven solutions [21]. These advancements demonstrate the versatility of combining sensors with intelligent algorithms, highlighting the need for tailored solutions in racket sports and motivating the development of a dedicated sensor-based training device for table tennis [15,18].

Building on these advancements and the lack of an affordable device to aid table tennis training, this study focuses on introducing a dedicated sensor-based device to validate shots. Unlike conventional training methods that rely heavily on an experienced coach's observation or expensive video-analysis systems, the proposed goal-based scoring system provides an objective, quick, and low-cost way to validate shot quality through a defined physical target. Furthermore, by requiring the ball to bounce on the table before entering the goal, the system requires the player to learn proper technique while giving live feedback based on the player's performance. The system aims to integrate and validate a reliable multi-sensor training system for table tennis, capable of distinguishing valid and invalid shots by combining infrared and sound sensors to improve accuracy. The system accuracy in this case is defined as the system's capability to correctly identify a valid shot, where a valid shot is one in which the ball first bounces on the table before it enters the goal. It also seeks to provide measurable performance data that assists players in monitoring and improving their skills, with testing designed to evaluate the device's reliability under both controlled and noisy training environments. Finally, the study aims to contribute to the broader field of sports science by demonstrating how sensor-based devices can enhance table tennis training, offering scalable insights for both recreational learners and professional athletes.

2. Methodology

2.1. Device Designing Process

The initial design of the sensor-based device was inspired by creating a device that is able to catch a coming ball hit by the player and count the number of balls the player is able to hit correctly, to give valuable feedback to the player on how well the player performed during training. The design of the device will have a goal-like structure at the edge of the table, so it will not interfere with the top of the table tennis table and will look similar to a soccer goal, as shown in Figure 1. The goal will function as a target that the player must try and make the ball go into, which helps to keep track of the valid shots taken by the player. The goal itself is intentionally made to look like a soccer goal since it allows the ball to enter from a wide range of angles and is still able to collect the ball being hit into the goal. This makes it easier for a new player to train in controlling where the ball should move, since the player is able to try different ways of hitting the ball and is still able to record the result.

Figure 1. Soccer goal.

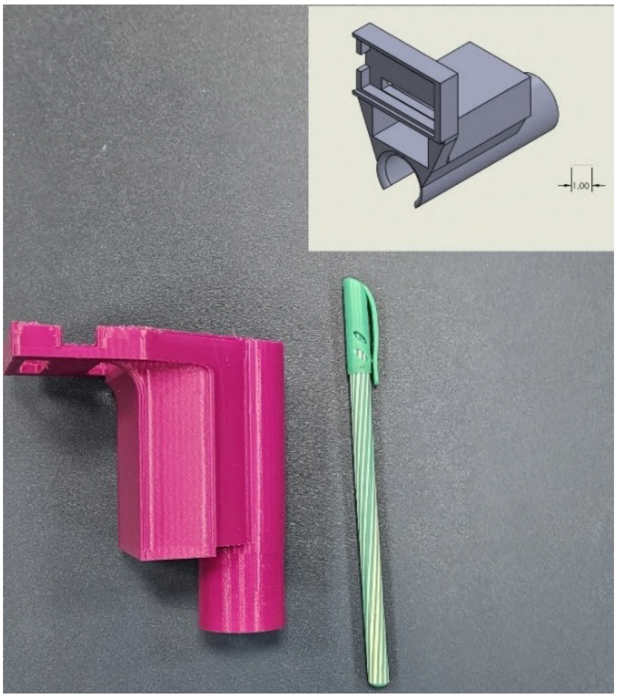
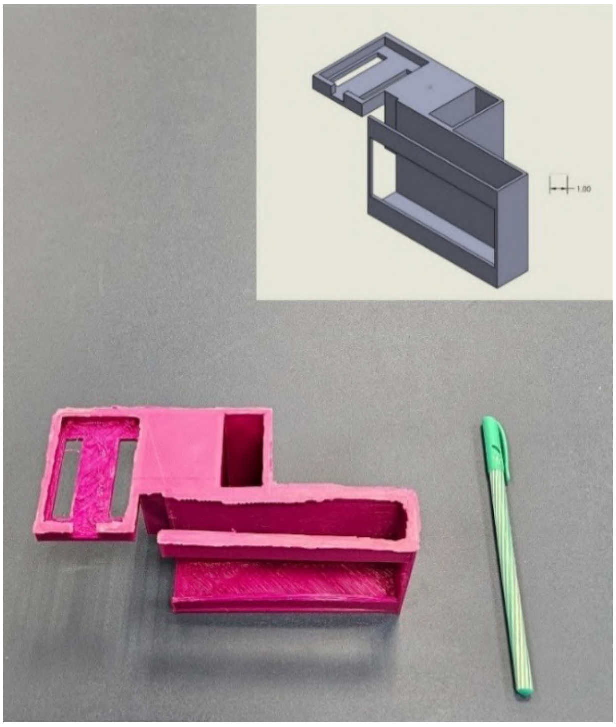
Other than that, to ensure the shot done by the player is a valid shot, a multisensory system will be used. The multi-sensor system will comprise of sensors that is able to detect when the ball hits the table and when the ball enters the goal. Two sensors are chosen for this; the first sensor is an Infrared (IR) sensor, which was selected to monitor whether the ball had passed into the goal or not. The second sensor chosen is a sound sensor, which will be used to detect whether the ball has made contact with the surface of the table or not, ensuring the shot made to the goal is a valid shot (bounce on the table) and not an invalid shot (direct entry into the goal). By utilizing multiple sensors, the device will be able to detect the validity of the shot done by the player more accurately, ensuring that the device will provide meaningful feedback to the player.

2.2. Device Manufacturing and Assembly

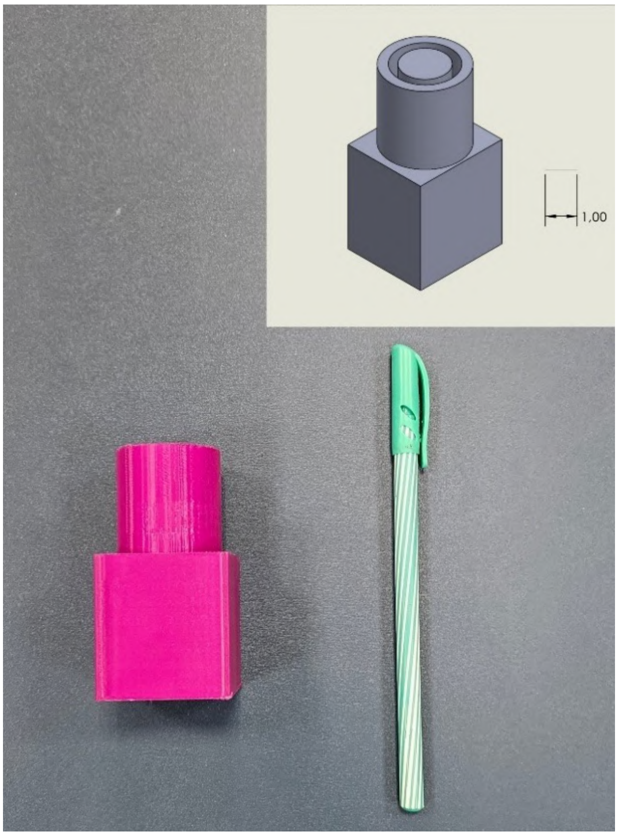
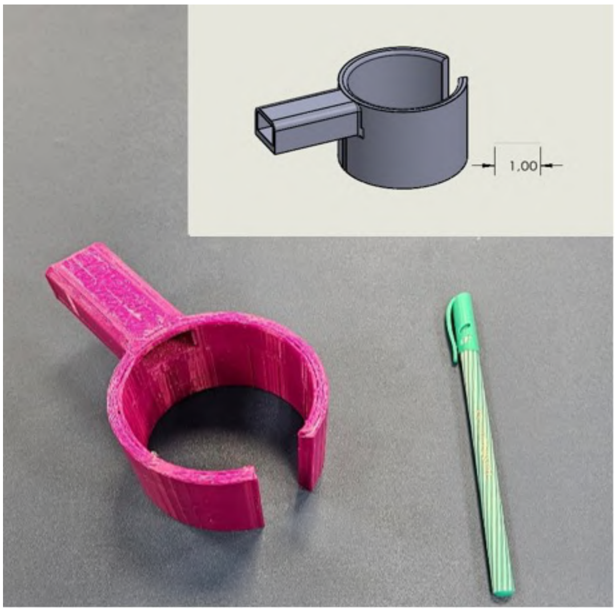
2.2.1. 3D Component Design and Its Function

Table 1 illustrates some 3D printed components created, and the use of each component. The component will be assembled together with the goal structure and sensor used in the system, with each component having a differ-

Table 1. 3D Components.

No.	Name and Image	Component Description
1.	**ESP32 slave holder** 	The ESP32 slave holder will be connected to the side of the goal. The holder will be used to hold the battery for the ESP32 and the ESP32 itself which will be connected to the IR and sound sensors.
2.	**Master ESP32 holder** 	The same as the ESP32 slave holder, the master ESP32 holder holds the battery and the ESP32. However, the master ESP32 holder will be connected at the side of the table, and it also holds a liquid crystal display (LCD) screen in front of it to show the score when the ball passes the goal correctly. The function of the ESP32 master is to process data from other ESP32's used on the goals and display the value of the ball that enters the goals correctly.

(continued on next page)

No.	Name and Image	Component Description
3.	**Goal Holder** 	The goal holder is used to mount the goals to the table safely without damaging the table. This holder will be connected to a G-clamp, which will hold the goal on the table securely, ensuring the goal does not move or fall during use.
4.	**Infrared (IR) sensor holder** 	For the infrared (IR) sensor, a holder for it has been created. This holder will be connected to the 2-inch pipe mounted on the mesh net hole created at the goal, so the IR sensor will be able to detect the passing balls that go inside the goal. The Infrared (IR) sensor will be placed inside the handle part of the holder and will be able to detect the ball that passes through the middle part of the holder.

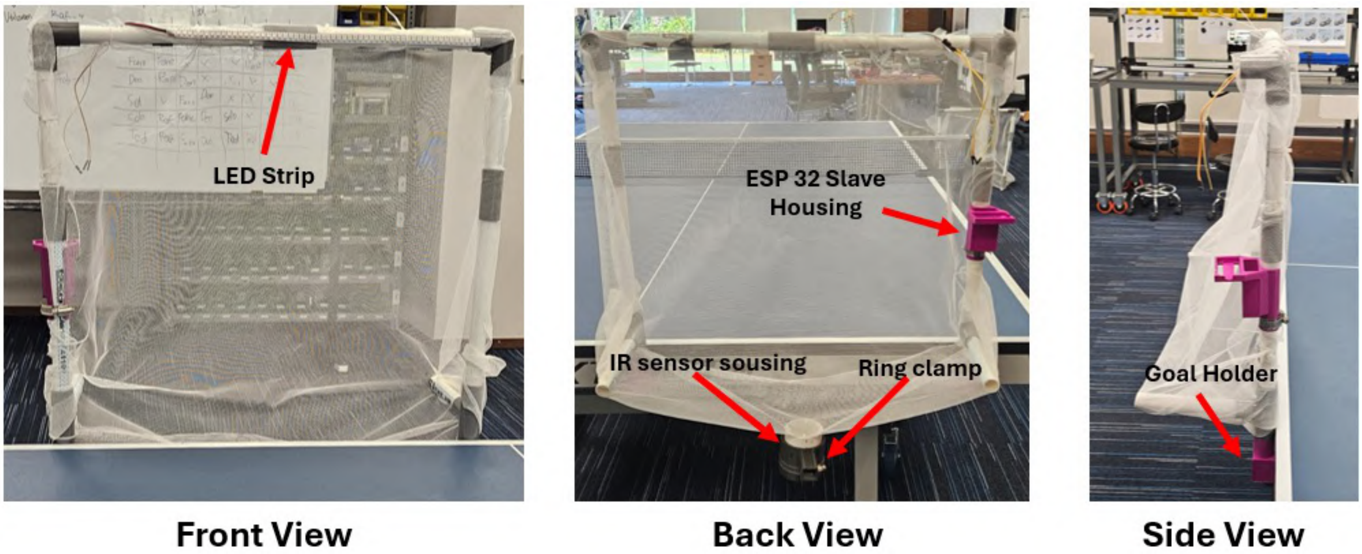


Figure 2. Goal structure components.

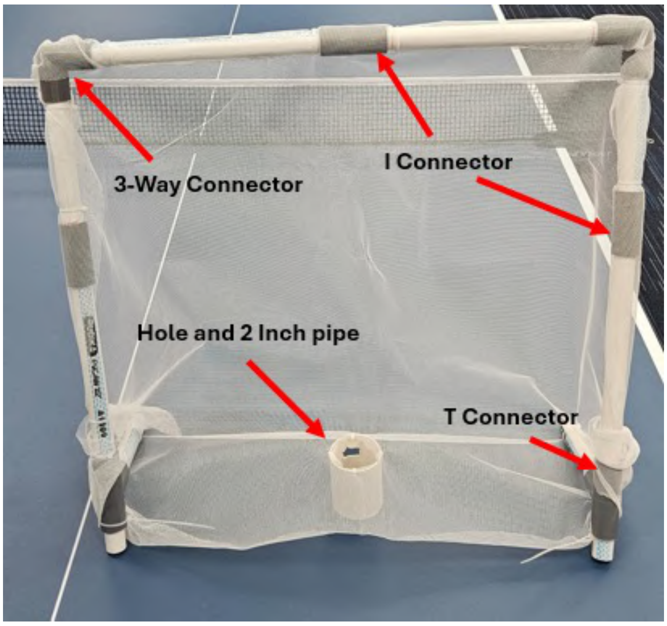


Figure 3. Goal structure overview.

ent function in either holding the electrical component or helping in holding the goal to the table.

2.2.2. Goal Structure

The goal structure of the device is made using a 1/2-inch PVC pipe and a connector joint. The PVC pipe is first measured and cut to a specific length based on the design set for the goal. The cut pipes are then assembled into a goal shape using the T, I, and 3-way connectors as shown in Figure 3. The overall goal opening has a width of around 56 cm, and a height of 54 cm from the surface of the table, which provides enough area to accommodate new players and more experienced players in training. After assembling the frame mesh net was then attached to the frame using zip ties to ensure that the ball shot at the goal will be captured effectively when using the device. A hole with a diameter of approximately 5 cm was then cut in the middle of the net inside the goal, as shown in Figure 3. A 2-inch pipe is cut with a length of 5 cm that has a 2x2 cm opening on its side (For an infrared sensor to detect the ball passing the pipe), and is attached to the hole using 4 small holes created on the side of the pipe and securing the pipe to the hole using zip ties.

Once the frame and net have been assembled, other components such as the sensor housing and LED strip are attached to the goal structure. The LED strip is attached along the top part of the goal structure using zip ties to provide visual feedback during training. While the IR sensor housing is mounted to the inside of the goal by attaching it to the 2-inch pipe, the ESP32 slave holder is attached to the side of the goal structure, as shown in Figure 2, both holder are attached to each part using a ring clamp. Lastly, the assembled goal structure is secured to the table using the 3D printed goal holder shown in Table 1 and a G-clamp to ensure the goal structure stability during use.

2.2.3. Electrical Component Wiring

The electrical system of the device was designed to connect and synchronize the sensors, LED strips, and microcontroller to give accurate scoring data. An IR sensor was attached to the inside of the IR sensor holder to detect the balls that pass through the goal, while a sound sensor is mounted on top of the table right behind the net to detect the sound the balls make when they hit the table. The two sensors are connected to an ESP32 microcontroller (ESP32 slave), which is mounted on the ESP32 slave hold-

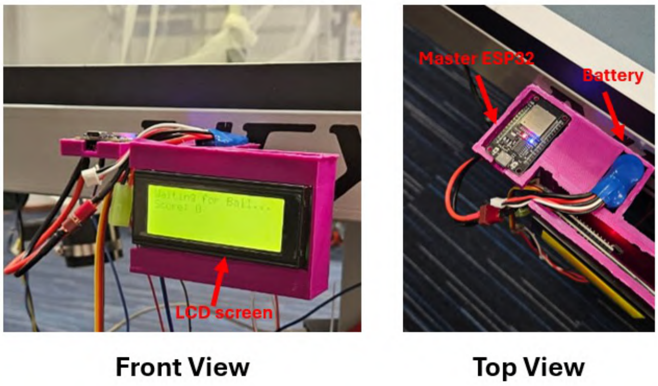


Figure 4. Master ESP32.

er at the side of the goal frame, serving as the main component in collecting data from each ball scored. An LED strip was also attached to the top of the goal and wired to the same ESP32 to provide visual feedback on when the player should shoot the ball at the goal.

To ensure neat and reliable wiring, AWG wires and jumper cables were used in combination with a terminal block to organize the power and ground connections. Each piece of data received by the ESP32 slave is transmitted to a master ESP32 placed on the side of the table, which is held by a G-clamp, as shown in Figure 4 and connected to a small liquid crystal display (LCD) screen, which displays the score of the player. Both the slave and master ESP32 microcontrollers are powered by a 7.4V ion battery, which makes the device more portable since it eliminates the need for the device to be connected to a power source using a cable. The setup allows the electrical components to work seamlessly, enabling the system to detect, validate, and display the score during training sessions, providing valuable feedback to the player during training.

2.2.4. Sensor, Software, and Electrical Configurations

The software system is built around the integration of sensors, microcontrollers, and LED-based visual feedback to create a responsive and interactive training tool. ESP32 microcontrollers were configured in a master-slave arrangement as the controller of the device. The master controller handles coordination, scoring, and player interaction, while each slave is assigned to a goalpost, monitoring its dedicated sensors, and controlling the LED strips attached to it. This division of responsibilities ensures modularity and responsiveness, while also simplifying debugging and software development.

The device employs two types of sensors: infrared (IR) sensors and a sound sensor. The IR sensors are mounted inside each goal to detect when the ball passes through the frame, serving as a key indicator of successful target entry. The sound sensor is positioned at the center of the table behind the net to capture the moment the ball contacts the table surface. The incorporation of sound sensing is further supported by recent studies that demo-

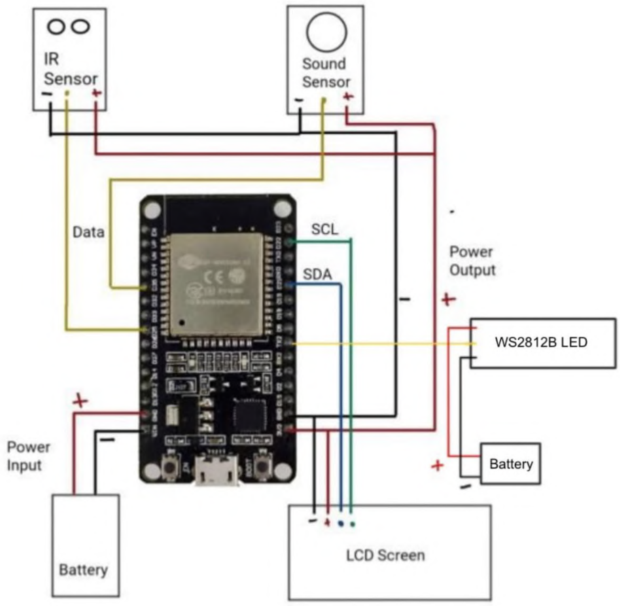


Figure 5. ESP32 wiring schematic.

nstrate the effectiveness of acoustic analysis for event detection, such as machine fault recognition using MFCC and machine learning techniques [19]. This dual-sensor configuration was intentionally designed to replicate real gameplay rules, wherein a valid point requires the ball to first strike the table before entering the goal. By integrating both inputs, the system can reliably differentiate between valid and invalid shots.

The electrical configuration follows a clear, modular wiring scheme, as shown in Figure 5. Each slave ESP32 is connected directly to its respective IR and sound sensors, as well as to the LED strip mounted on the goal. Power is supplied via a rechargeable 7.4V battery, which is distributed through a terminal block for neatness and stability. The LED strips use a programmable WS2812B-type interface, which is controlled through a single GPIO pin on the ESP32. This simplicity is one of the main reasons the FastLED library was used for LED control, it provides an efficient abstraction for sending color data to the strip while still allowing low-level timing control. On the master side, the ESP32 connects to an LCD display via I2C, which provides the player with real-time score updates, while also communicating wirelessly with the slaves using the ESP-NOW protocol, chosen for its low latency and lightweight implementation compared to Wi-Fi or Bluetooth.

The system is implemented on ESP32 microcontrollers programmed with the Arduino-Espressif PlatformIO SDK on top of FreeRTOS, combining Arduino's simplicity with OS-level task management for time-critical functions. Each slave initializes its LED strip via FastLED, sets default brightness/colors, and monitors sensors; interrupts capture IR triggers while polling functions read sound levels. A valid detection (sound followed by IR within a threshold) updates the LED strip to green and

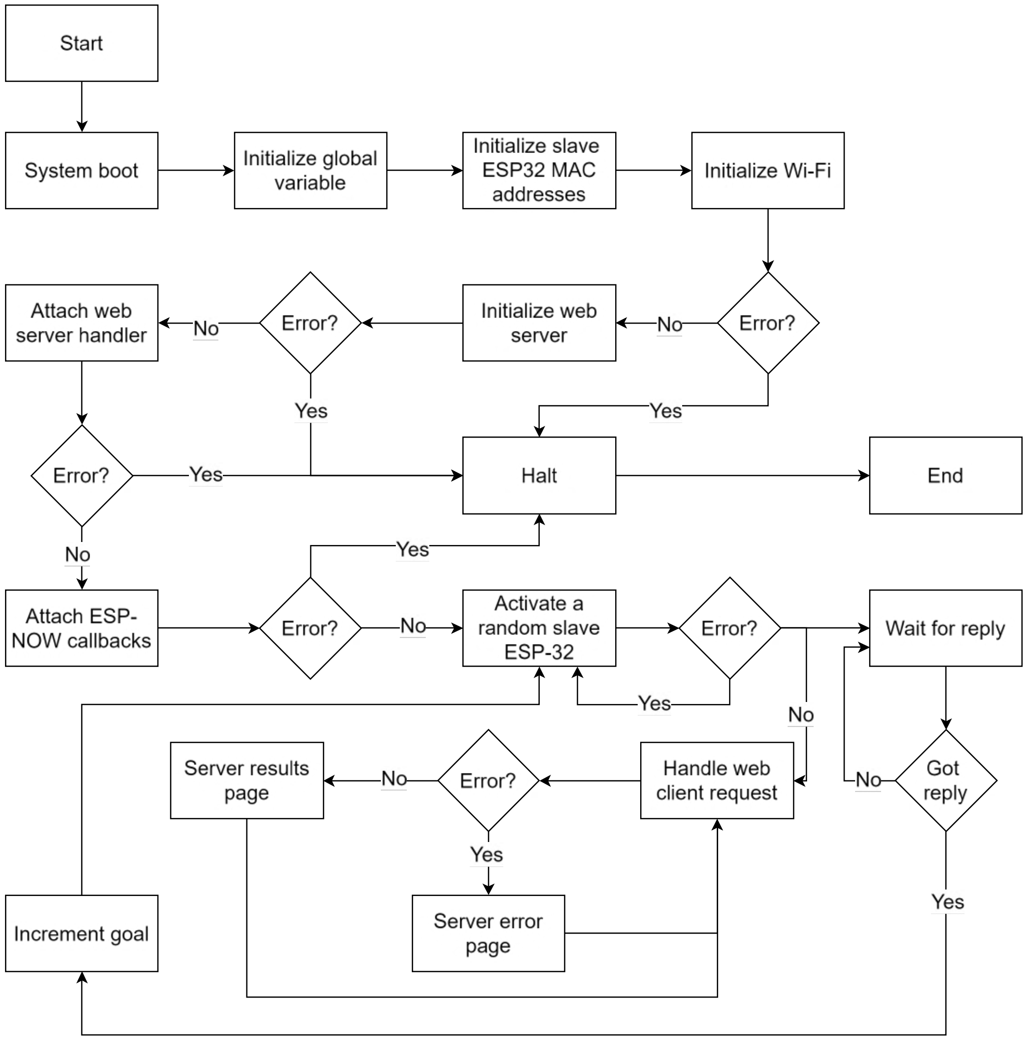


Figure 6. Flow diagram of a master ESP32 program.

sends a success signal via ESP-NOW; failures turn the strip red and send an error. The master ESP32 manages Wi-Fi, activates slaves, updates scores, and hosts the web server for user display, while slaves focus on goalpost sensor control and timing. The code is modularly split into two files for encapsulation, ensuring hardware-specific configurations remain separate. User feedback is provided through LED strips, LCD screens, and a web interface, enabling clear performance monitoring.

Figure 6 and Figure 7 display the flow of ESP32 master and slave configuration, respectively. The server uses the ESP random API to select and activate a random slave, which then lights its LED strip and displays an activation message on its 16×2 LCD. Using the FreeRTOS Task API, each slave monitors its IR and sound sensors through polling and interrupts to determine goal validity. A valid goal changes the LED strip to green, sends a success reply to the server, deactivates sensor monitoring, and prints a confirmation on the LCD. For invalid goals caused by timeout or missing sensor activation, the slave displays an error on the LCD, switches the LED strip to red, resets its state, and enforces a 3-second timeout between sound and IR signals to prevent miscounts.

The ESP32's communicate with each other through the ESP-NOW protocol, a data-link layer protocol used to send and receive data from other ESP devices. The protocol is favored compared to other protocols such as Wi-Fi, TCP/IP, and Bluetooth due to its real-time performance and ease of use.

2.3. Device Testing Method

To evaluate the reliability of the sensor-based training device, controlled tests were carried out focusing on goal detection accuracy and sensor reliability under different environmental conditions. Since the system integrates multiple sensors, the tests also aimed to validate whether using more than one sensor improves accuracy in distinguishing valid shots. Three testing methods were applied: (1) using only the infrared (IR) sensor to assess basic detection capability; (2) combining IR and sound sensors in a quiet environment to simulate a single-player setting; and (3) repeating the dual-sensor test in a noisy environment to replicate real-world conditions with multiple players and background noise.

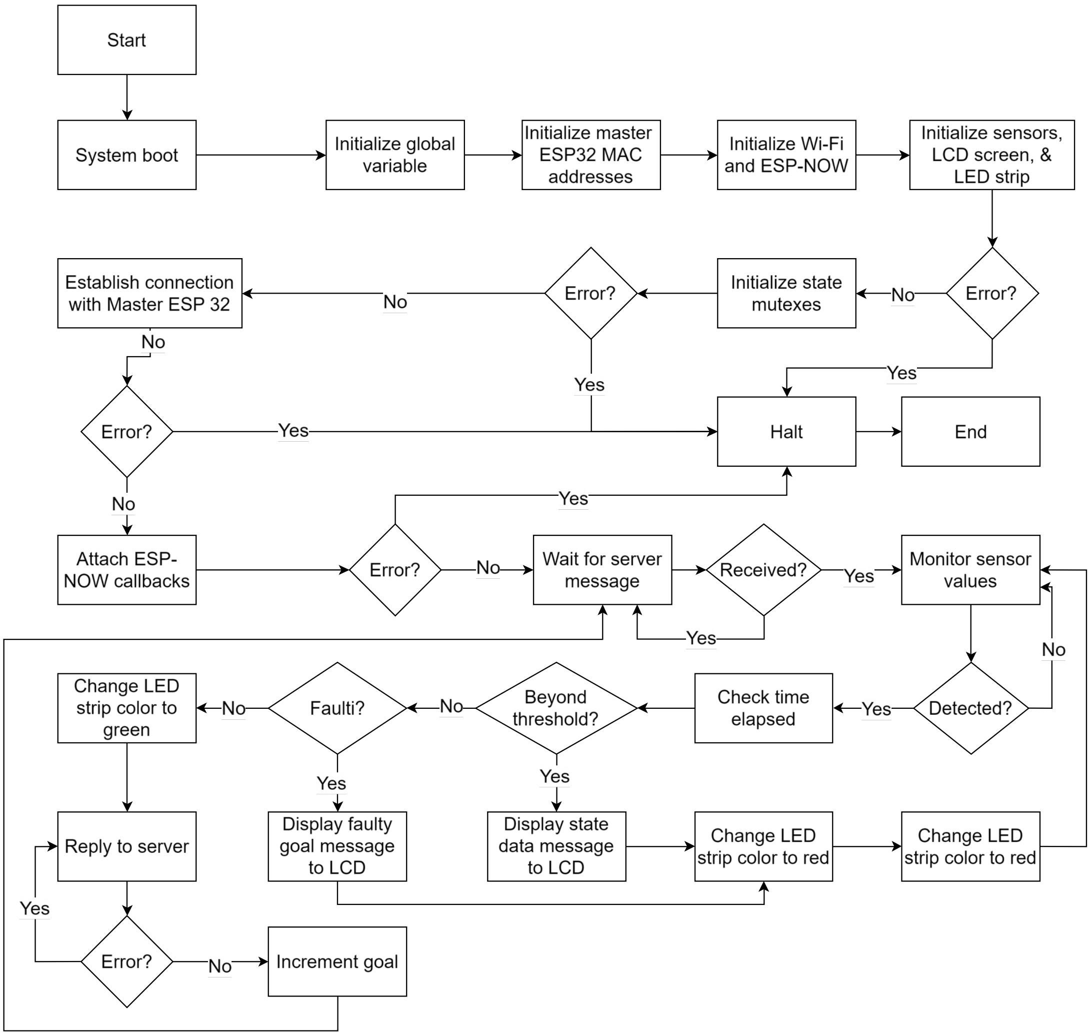


Figure 7. Flow diagram of a slave ESP32 program.

Each test involved 10 shots which consist of 5 valid (ball hits the table before entering the goal) and 5 invalid (ball goes directly into or misses the goal). This setup enabled a systematic evaluation of the system's ability to differentiate valid from invalid shots and highlighted its strengths and limitations across different scenarios. These tests were designed to test the functional correctness of the system to the detect accuracy of the conditions. Instead of inferring population differences in performances using inferential statistics, the experiment reports the performance indicators for a prototype device.

3. Result and Discussion

3.1. Prototype Outcome

The final design for the prototype is as shown in Figure 8, where the device utilises a PVC frame, 3D-printed sensor mounts and a goal holder, and an ESP32 microcontroller, which is used as the central processing unit of the device. As illustrated, the fully assembled training device is mounted on the table with all the components combined into a unified system. Where it is shown that on the side of the table, a custom 3D-printed housing holds the LCD screen, battery, and ESP32 microcontroller (The Master ESP32), all connected to one another through a wire connection, as shown in Figure 5. The LCD screen is used to display the player's score when a valid goal is made, which is when the ball first bounces off the table and then enters the goal, and is indicated by a green LED light turning on. The two sensors, in combination with the LED strip, are connected to a secondary Slave ESP32 mounted on the side of the goal structure, which is used to give information to the Master ESP32 if a valid goal is made and needs to be displayed on the LCD screen.

Once assembled, the system functions by using the sound sensor to detect whether the ball hits the table, followed by confirmation from the IR sensor to detect if the ball enters the goal. Furthermore, an LED strip is used to provide visual guidance to the player and act to tell the player if the player has hit the ball correctly into the goal, with it flashing green if the player makes the ball enter correctly (bounce of the table to the goal) and flashing red light if the ball enter incorrectly (goes into the goal di-

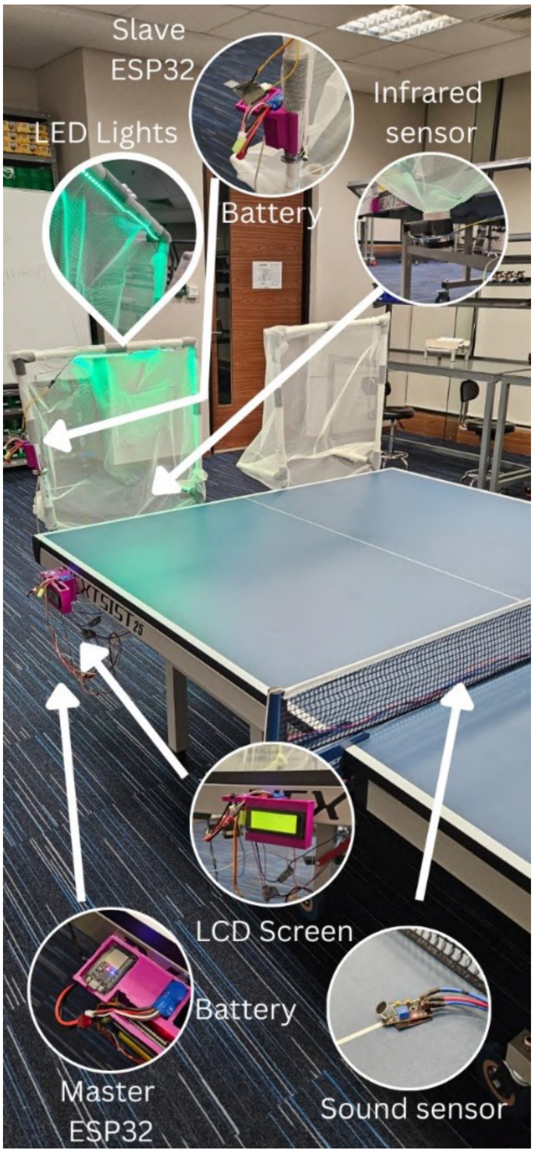


Figure 8. Fully assembled training device.

rectly). As a result, the device is able to be used for newer players to learn the basics of the table tennis game, while more experienced players are able to use the system to track the score/progress of their training in playing table tennis.

3.2. System Functionality

3.2.1. LED Power Management and Performance Analysis

The LED system plays a crucial role in providing real-time visual feedback to the player, indicating target goals and validating correct or incorrect hits. Each goalpost was equipped with a cut section of LED strip mounted on the top of the frame. These strips, based on WS2812B programmable LEDs, are controlled through the FastLED library on their respective ESP32 microcontrollers.

During initial testing, both LED strips were powered directly from the ESP32 boards. While this configuration worked for very short periods, it quickly revealed significant performance and thermal limitations. Each WS2812B LED typically draws about 60 mA at full brightness (white, 100%), and even with partial brightness settings and moderate colors, the cumulative load across dozens of LEDs per strip approached hundreds of milliamps. Since the ESP32 is not designed to supply such current directly through its onboard regulator, the microcontrollers began to overheat under load, and the LEDs showed signs of voltage drop, such as dimming and inconsistent color output.

To address the power distribution issues, the design implemented a more robust strategy by decoupling the components from a shared power source. Each goalpost was equipped with its own independent 7.4V rechargeable battery, which supplied power to both the LED strip and the corresponding ESP32 slave. This separation yielded significant improvements. Most importantly, it alleviated thermal stress on the ESP32 regulators, as they no longer had to handle the heavy current draw from the LEDs, which resolved overheating and ensured long-term stability. As a result, the LED strips received a dedicated and stable power supply, eliminating the flickering and voltage sag previously observed and allowing for consistent brightness and color accuracy. This approach also created a more balanced and modular system, where each goalpost functions as an independent unit, simplifying maintenance and preventing the overload of any single component.

3.2.2. Sensors Performance and Data Saving

To ensure continuous monitoring of the sensor's values, a separate FreeRTOS program task is allocated with the necessary priority to enable real-time updates and minimize desynchronization. As the sound sensor reading requires ADC sampling, which is considerably slower than reading the IR sensor, the task of reading the sound sensor and IR sensor is split such that the sound sensor uses a FreeRTOS task while the IR sensor is hooked up to an ISR that is loaded in the Slave ESP32's RAM. A mutual exclusion lock is also used to prevent race conditions when the Slave ESP32 switches between tasks.

Additionally, the data from the sensors is sent to the cloud in the form of a local web server hosted on the Master ESP32. The IP address of the local server is 192.168.4.1 on port 80, which users can connect to from their phones/computers using a browser after connecting to the Master ESP32's access point. The score of the current session is updated in real time using server-side events sent by the Master ESP32.

3.3. Device Testing Result

The device is tested following the procedure mentioned in part 2.3, where a series of tests are conducted using the sensor in different orders and different environmental settings, to test how well the device works at detecting a valid goal. Each test is conducted using 10 balls, where randomly 5 of the balls will hit the table and

Table 2. Ball counting with only infrared sensor.

Ball Number	Ball Hit the Table	Ball Counted or Not
1	Yes	Counted
2	Yes	Counted
3	No	Counted
4	Yes	Counted
5	No	Counted
6	No	Counted
7	No	Counted
8	Yes	Counted
9	Yes	Counted
10	No	Counted

Table 3. Ball counting with infrared and sound sensor in quiet environment.

Ball Number	Ball Hit the Table	Ball Counted or Not
1	No	Not Counted
2	Yes	Counted
3	No	Not Counted
4	Yes	Counted
5	No	Not Counted
6	Yes	Counted
7	Yes	Counted
8	No	Not Counted
9	Yes	Counted
10	No	Not Counted

the other 5 will not hit the table. These results are reported as configuration-level accuracy of the device's performance in validating valid goals. Given the binary device output and the absence of user-level sampling, inferential statistics are not applicable at this stage.

3.3.1. Ball Counting Using Only Infrared (IR) Sensor

Table 2 shows the data from the ball-counting test using only the IR sensor. From the test, using the 10 balls, all the balls were counted by the mechanism. However, this is a problem in the system since 5 of the balls do not hit the table and should not be counted as scores. This led to the device giving false positive results, where even invalid shots were counted as valid shots and given a score. While the device is useful in detecting that the ball has passed the goal, the single-sensor system is not sufficient to be used to assess training, since it is still only effective 50% of the time. Because of this, the device developed is equipped with another sensor, which is the sound sensor, to make it more accurate in detecting whether the ball has already bounced off the table or not before going into the goal.

3.3.2. Ball Counting Using Microphone and Infrared (IR) Sensor Without Noise

Table 3 shows data from the testing that was conducted previously using the two sensors (IR sensor and sound sensor in a quiet room with minimal sound). As shown in Table 3, 5 out of 10 balls were counted, and the other 5 balls were not counted. By utilising the sound sensor in combination with the IR sensor in the system, the device is able to detect if the ball has hit the table or not before entering the goal with full accuracy. The sound sensor confirmed that the ball had bounced off the table, while the IR sensor confirmed the ball's entry into the goal and counted it as a score. This demonstrates that using two sensors is necessary, as it improves the system's accuracy in detecting a legal shot (when the ball bounces off the table into the goal), ensuring that the device is able to provide reliable feedback to the player. A beginner is able to confirm that the shot they made is done properly and produces a legal shot, while a more advanced player is able to use the device to measure performance during training more precisely.

3.3.3. Ball Counting with Infrared and Sound Sensor in Noisy Room

Table 4 shows testing data similar to the previous testing using two sensors, but conducted in an environment with more background sound, with people walking and talking, simulating the usual table tennis training place. As a result, an increased number of goals were not counted by the system, and even some goals that should not have been counted were counted. This issue arises because the ambient noise frequently triggers the sound sensor, falsely indicating that the ball has touched the table. This led to a 3-second timer, which should start once the sound sensor detects an impact and expire before the IR sensor is triggered. As a result, the system reset prematurely, and the score was not updated despite the ball entering the goal correctly. Additionally, because of the premature trigger of the sensor, some balls that should not be counted, since they do not hit the table, are also counted. The addition of background noises leads to an increase in false positives being detected by the device, and out of the 10 balls tested, only 4 were correctly identified as either a correct or incorrect shot by the device, reducing the overall effectiveness of the device to 40%. To improve the overall accuracy of the device in such environments, the addition of a third sensor is needed to minimize false positives caused by background noise.

From all three tests conducted, it is found that using the infrared sensor is robust and efficient in counting the ball, but to validate the data further, another sensor needs to be used. In this case, the sound sensor is used to validate that the ball has already hit the table before it goes into the goal. However, the sound sensor has the drawback of being too sensitive to the surrounding sound, and further testing and adjustment needs to be conducted to prevent the sensor from picking up surrounding sounds. Additionally, a third sensor is needed in order to minimize the false positives experienced by the sound sensor that are caused by the background noise.

3.4. Device Limitation and Future Improvement

3.4.1. Noise Sensitivity

During the third test, where the device is tested in an environment with lots of noise, the device is shown not to perform or function properly. This leads to one of the limitations of the device as of now, where it only functions accurately in a quiet environment where the sound is only coming from the player using the device. This is a major drawback in the system since it is only able to function properly in a quiet environment, making it hard to be used in most training rooms with a lot of people. Because of this, during the development of the training device, a GY-521 accelerometer was tested to be used in combination with the other sensors.

By integrating an accelerometer and placing it bene-

Table 4. Ball counting with infrared and sound sensor in noisy room.

Ball Number	Ball Hit the Table	Ball Counted or Not
1	Yes	Counted
2	No	Not Counted
3	Yes	Counted
4	No	Not Counted
5	Yes	Counted
6	No	Counted
7	No	Counted
8	Yes	Not Counted
9	Yes	NotCounted
10	No	Counted

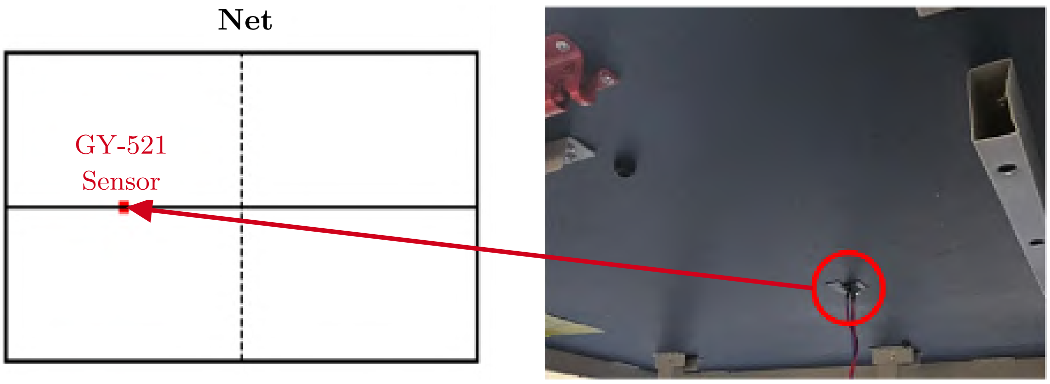


Figure 9. GY-521 accelerometer placed beneath the table.

ath the table, as shown in Figure 9, to detect the vibration from the ball's impact on the table, the system hopes to become more accurate in determining whether the ball has hit the table or not. This ensures that both the sound and vibration sensors need to be triggered first before the ball enters the goal, is detected by the IR sensor, and counted as a goal. In theory, this will make the system more accurate and reduce false positives when the device is used in a noisy environment. However, when the system is tested, it seems that the vibration sensor was not able to detect the vibration of any ball hit on the table. This is likely due to the vibration created by the ball's impact on the table being too weak, preventing the sensor from functioning as intended and leading to more false positives. Because of this, it is still more reliable for the device to have only two sensors, the sound sensor and the infrared sensor. However, to make the system more accurate, further testing is needed to test for a better vibration sensor other than the GY-521 accelerometer sensor, which is more suitable in helping to detect the ball impact more accurately.

During the development of the device, the goal structure was changed to improve the accuracy of goal detection and ensure that the ball goes in smoothly into the goal. As shown in the left image in Figure 10. The goal structure has been optimized by removing the back part of the structure, as highlighted in the figure. In the old design seen in the right image in Figure 10. There was a back support bar located inside the goal frame. This back support bar often caused the ball to bounce back out of the goal after the ball hit it, which led to the score not being counted, even though it should have been. Because of this, a new design for the goal structure was created, where the back part, as highlighted on the old design, is removed entirely. This led to the new design, where the entire back part of the goal is removed and only the neon mesh net is left on the back side of the goal structure. By using the new design, it significantly reduces the chance of the ball rebounding out of the goal after being hit by the player, which ensures that when the ball enters the goal, it will go in and pass the IR sensor and be counted as intended.

3.4.2. Coding Problem and Improvement

Some issues were detected during the software development, where some of the task scheduling suffered from race conditions, which caused the system to malfunction under specific circumstances such as network delays. Another issue found during testing is the limited power management capability of the Slave ESP32 where, during its inactive period (waiting for the signal from the Master ESP32), it is not set in power saving/sleep mode due to hardware and time constraints, reducing the power efficiency of the system. Additionally, the web server hosted by the Master ESP32 requires the user device to connect to the Master ESP32 as an internet access point client, limiting the device from accessing the wider internet while it is connected as a client. Lastly, the program is designed to only control a single Slave ESP32, which limits the flexibility of the system, as the user would be required to target the same goalpost, unlike in a real game.

One important improvement for future research could delve more into power management, where the Master Slave intercommunication could be designed such that it allows for the Slave ESP32 to be set to sleep mode during inactivity. Another source of improvement could allow for the Master ESP32 to be set as both an access point and station by integrating it with an external Wi-Fi router to enable the user device(s) connected to it to access the wider internet while still being able to access the web server. In addition, the reading of the sound sensor is monitored with program tasks using polling-based mechanisms, which could be further optimized by utilizing the ESP32's powerful hardware interrupt capabilities, eliminating the need for polling, which will further reduce the delay between sensor monitoring and output device control, such as the LED strip and LCD. Lastly, the system could be modified to handle multiple slave ESP32's, each controlling a single goal to enable a better user experience and better match the environment of a real table tennis game.

(a) (b)

Figure 10. Goal structure, (a) Old design ; (b) New design .

3.4.3. Future Analysis

The current work is focused on validating the proof-of-concept of a multi-sensor training system to validate valid shots in table tennis. Therefore, this paper is currently focused on improving the robustness of the sensing logic of the device. Future research will require user studies with repeated trials to evaluate the device's training outcomes across several conditions using appropriate inferential statistics. This future research will provide evidence of the effectiveness of the device in improving athlete's performance through a specific training method.

4. Conclusions

This study developed a novel sensor-based table tennis training device using IR and sound sensors with ESP32 microcontrollers, achieving 100% accuracy in detecting valid shots under quiet conditions compared to only 50% accuracy with a single IR sensor, but dropping to 40% in noisy environments due to the microphone's sensitivity. Tests with a GY-521 accelerometer showed that ball impacts produced vibrations too weak for reliable detection, highlighting the need for more sensitive alternatives. Hardware refinements, such as redesigning the goal to prevent rebounds and separating LED power from the ESP32, improved stability and scoring consistency, while FreeRTOS-based task management enhanced sensor synchronization. Overall, the device demonstrates strong potential as a practical training aid that provides real-time scoring and feedback, but future work should address noise resilience, power optimization, and multi-goal integration to create a more robust system for diverse training environments.

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