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Study and Design of Distributed Badminton Agility Training and Test System

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Abstract: In order to improve the agility of college students, this paper designs a distributed agility training system. The system includes an upper computer and nine lower computers, in which the lower computer realizes the functions of data acquisition and communication with the upper computer and calculates the reaction time. The Android-based system software was installed in the upper computer to complete the functions of network connection, setting training times and showing the exercise time. In order to test the effectiveness of the equipment, nine university students were invited to complete agility training over 8 weeks with the help of agility training equipment in preparatory, enhancement and special stages. A *t*-test (Student's *t* test) was conducted on the test results at different positions on the front and middle and back areas of the court before and after the training. The results show that the agility of the experimental objects was significantly improved after training, from the midpoint to any point at the front, middle and back court ($p < 0.01$). This shows that using equipment designed to develop agility for long-term training can promote the sensitive quality in badminton learners.

Keywords: reaction time; embedded system; Android platform; badminton training; agility training; physical education; communication network optimization

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1. Introduction

Agility training is a training program in which the player makes the appropriate movements according to their coach's instructions or due to the guidance of auxiliary apparatus [1]. In badminton, players must accelerate, decelerate and change their direction of movement to return the incoming shuttlecock. Agility training can enhance athletes' action responses, such as start-up speed, backcourt cross-step return speed and returning to the frontcourt speed, and also enable athletes to make correct decisions, such as improving concentration to correctly anticipate the ball's landing point. Therefore, agility training is important to improve in competitive badminton [2]. The agility training apparatus has the characteristics of random placement and random light-up. The randomness of this training system can effectively regulate the flexibility of the trainer's cortical neural process. The trainer's decision-making ability in specific sports situations is enhanced to ensure that the trainer develops the best offensive and defensive skills, and reduces unnecessary movements, thus improving the agility quality of badminton players.

Wireless sensing sports equipment has been preliminarily applied in sports training [3]. For example, in golf training, a smart chip has been implanted in the club to obtain and transmit various data in real time, and the trainer analyzes the data transmitted to find out the deficiencies of the athlete, and help the athlete to better master the strength of the stroke and the degree of body tilt [4]. In December 2018, Luneng Football School introduced the wearable device "Sports Vest" from the Australian company Catapult, with the aim of combining it with the school's big data system to analyze players' sports performances and exercise load through the wearable device, and scientifically analyze data to help coaches evaluate the team's training intensity and quality [5]. The equipment designed in this paper includes several lower computers and one upper computer. The main research problems of the lower computer include data acquisition, communication with the upper computer and the calculation of motion time. The system software based on Android is installed in the upper computer to complete network connection, set training times and display the exercise time. Finally, a set of equipment for athletes to carry out agility training was developed, and the athletes' single reaction times could be recorded. We aimed to evaluate the players through the final data, find out the weak points of their return shots, and carry out special training [6].

At present, agility training in college badminton training still uses traditional mechanical equipment, such as hexagonal balls, a rope ladder [7], and marker cylinder [8]. Agility training apparatus, such as those based on high-precision laser sensors, spatial three-dimensional information-based vision machines [9], etc., are mostly bulky and inconvenient to carry. The visual response system used by Kuo KP reached a volume of 24 inches [10]. The FitLight Trainer produced in Canada is expensive and not suitable for efficient large-scale learning and training. An agile training instrument designed by Agus Rusdiana in 2021, although the randomness of training is achieved by hardware and software, cannot measure the integrated response time of training [11]. There is a single training and testing method for agility qualities in previous related studies, and there is a lack of studies that combining functional training and badminton agility qualities [12–14]. The portable device studied by Favorov, Oleg, can detect the movement time of prescribed movements well, but it lacks the most important randomness factor in agility training [15]; this is not the same as the agile training instrument studied in this paper, which can continuously train and improve the reaction ability of athletes by randomly starting the lower computer. Dieujuste can better study the changes in the blood oxygen of athletes during exercise by wearing portable devices [16]. Therefore, wearable devices to better monitor the changes in athletes' physical conditions in agile training is the focus of our next research work.

The agility training and testing device based on the embedded system and Android program studied in this paper is inexpensive and easy to carry out. The training method is unique and novel, the training content is interesting and rich, the training difficulty can be adjusted according to the athlete's performance, and the athletes' sports performance data were saved in real time for a later evaluation of the training to provide a reference basis.

2. System Design Overview

For the setup of the agility training apparatus, all the lower computers were placed on the badminton court, as shown in Figure 1. The athlete stands at the center point, the trainer enters the number of tests through the upper computer and clicks to start training, the center point of the lower computer will trigger an acoustic and optical alarm, and the athlete touches the sensing part of the photoelectric sensor with his hand to signal that they are ready at the center court. Then, the audible and visual alarms of the other eight lower computers will be triggered randomly to simulate the possible drop point, and the player will quickly start at the corresponding pace, run to the lower computer and touch the sensing part of the photoelectric sensor. The upper computer records the time from touching the lower computer at the central point to touching its own photoelectric sensor, which is used as the movement time of the first training and sent to the upper computer to complete data collection. Repeat until the number of training times entered by the trainer is completed. The overall scheme design of the system is shown in Figure 1.

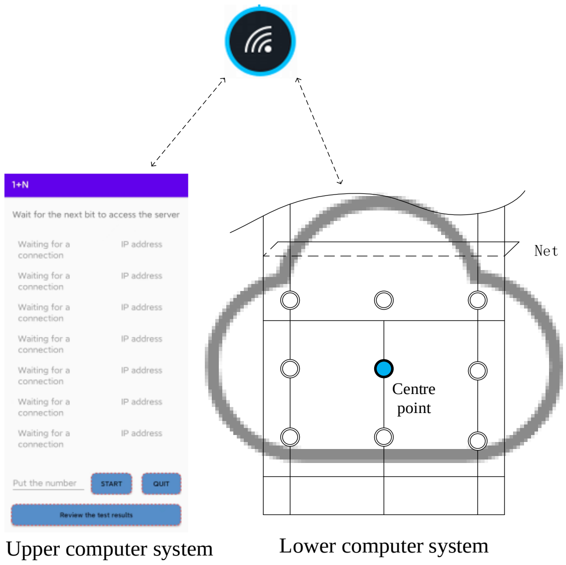


Figure 1. Overall system design scheme.

3. Touch Front-End Design

In the system, the STC89C52 chip is used as the controller [17]. The photoelectric sensor is used to detect whether the response signal is triggered. The ESP8266 wireless communication module is responsible for communication with the controller [18]. The LED and buzzer simulate the response signal. The power supply module is a rechargeable 12 V lithium battery with a capacity of 1050 mAh, while a voltage regulator circuit based on LM2596S and AMS1117 chips is used to regulate the power supply at 5 V and 3.3 V to ensure the normal operation of the controller and WiFi module. The touch front-end design diagram is shown in Figure 2.

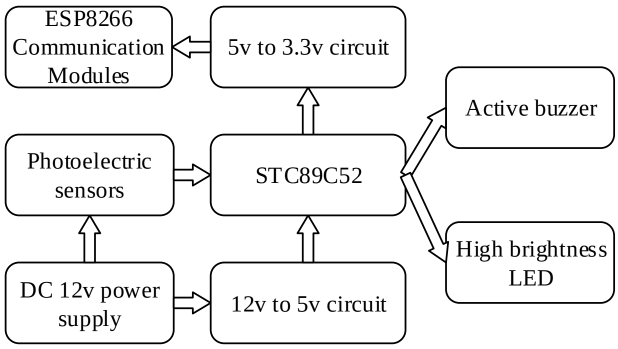


Figure 2. Touch front design.

3.1. Control Module Design

The controller is responsible for connecting the wireless communication module to the designated router. The ESP module creates a TCP client in STA mode and connects to the designated TCP server [19,20]. The controller is also responsible for sensing external trigger messages via the serial interface, displaying the signals acoustically, and storing the exercise time.

The main function initializes the serial interrupt, the timer interrupt, and the external interrupt, and then sends the command to connect to the AP site and the command to connect to the TCP server. Then, it waits in a loop for the information sent by the upper computer before responding to it. At the same time, the timer and external interrupt are turned on to start the clock and monitor the external trigger signal. The touch front-end (lower computer) software design flowchart is shown in Figure 3.

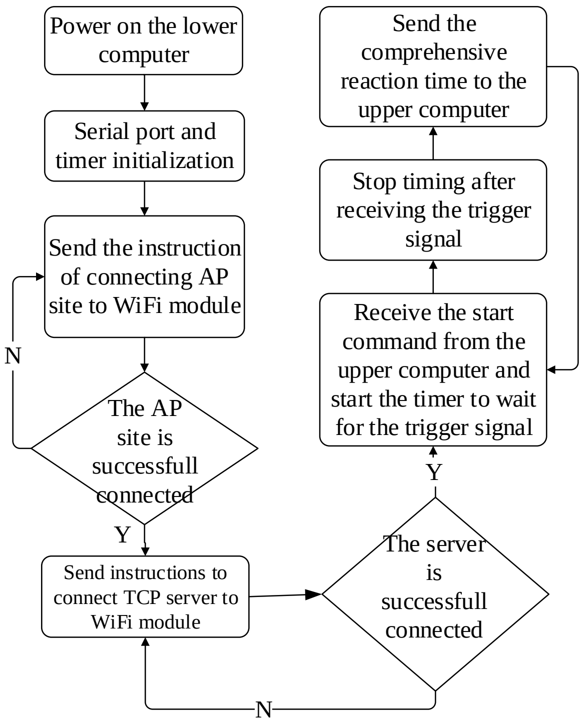


Figure 3. Touch front-end design flowchart.

The design adopts three interrupt sources in the controller—the external interrupt, serial interrupt and timer interrupt. When receiving instruction from the upper computer, the program turns on the external interrupt and timer in the serial interrupt to monitor the external interrupt. When the athlete triggers the photoelectric sensor, it turns off the timer interrupt and returns the data stored in the variable count, The main program calculates the comprehensive reaction time according to the variable count and the initial value register data of the eight-bit timer.

The working principle of timer T_0 in this design is that every time the crystal oscillator generates a pulse, the register TL_0 will be increased by one. When TL_0 overflows, TL_0 will be cleared, TH_0 will be increased by one, and a timing interrupt will be generated when TH_0 is full. That is, TH_0 and TL_0 form a 16-bit counter, which can be added from 0x0000 (0) to 0xffff (65,535). The controller of the system uses an 11.0592 Mhz crystal, the clock period is $1/12$ µs, and 12 clock cycles are one machine cycle, so T_{cy} is 10.85^{-6} s. The timer is a 16-bit timer with a machine cycle of 10^{-6} s, the required setting time is 50,000 µs, let the required time be t_0, the machine cycle is T_{cy}, the number of bits to be recorded is N, and the number of bits of the timer is x. The calculation process of comprehensive reaction time is as follows:

$$t = \frac{T}{20} + ((TH_0 * 256 + TL_0 - 2^x - \frac{N}{T_{cy}})) * 1.085 \tag{1}$$

3.2. Reaction Signal Simulation Module

During training, athletes need to be exposed to external stimuli (in real sports, the stimulus is where badminton may land and is felt by the eyes and transmitted to the brain) [21], so LED lights and buzzers were used during training.

3.3. Power Supply Module Design

Because the working voltage of different modules of the lower computer is different, and the battery voltage is 12 V, it is necessary to design a voltage-stabilizing circuit based on the LM2596S chip to convert 12 V voltage into 5 V voltage, so that the main controller can work normally. The voltage-stabilizing circuit based on the AMS1117 chip is designed to convert 5 V to 3.3 V, so that the communication module can work normally [22].

3.4. Design of the Monitoring Trigger Module

The photoelectric sensor used in this system is the PNP-NC-type sensor [23], When the sensor was connected, the collector and emitter were connected. At this time, the OUT signal line was connected with the emitter, that is, the positive pole of the power supply, and the signal output was high level [24]. Its monitoring distance is 1–200 mm (adjustable). The sensor needs to sense external trigger (masking) behavior during training and the trigger signal will be communicated to the external interrupt of the controller at a low level, thus allowing the program within the controller to operate accordingly.

4. System Communication Design

This system requires wireless connectivity and communication between the lower computers and the upper computer. The front-end system was connected to a designated router via the STA mode of ESP8266 module. Lower computers establish a client and transmit comprehensive response time data from each round to the upper computer in real time. When the user opens a WiFi hotspot via their mobile phone, the upper computer connects to the hotspot and uses JAVA Socket [25,26] technology to create multiple threads and implement TCP/IP based on the wireless connectivity and communication. This establishes wireless connectivity and communication within the LAN for the entire system.

4.1. Front-End Communication Design

The ESP8266 is a module that uses a serial port to communicate with an MCU (or other serial devices) and has a built-in TCP/IP protocol stack that enables conversion between the serial port and WiFi [27]. The communication module supports three data transmission modes: AP mode, STA mode and STA+WIFI&AP coexistence mode. Each mode also includes three sub-modes: TCP server, TCP client and UDP mode [28].

The wireless communication module is connected to the communication serial port of the controller. By programming the program in the controller, the wireless communication module sends out corresponding AT commands to achieve the functions of initialization, network connection and controlling the touch front-end system as a client to connect to the server side. The lower computer sends data to the server via the communication module and received data from the service port of the upper computer. The ESP8266 WiFi module operation instructions are shown in Table 1.

Table 1. ESP8266 WiFi module operation command.

Command Type	Grammar	Description
Setup commands	AT + CWMODE = 2	AP mode
Reboot command	AT + RST	Restart the communication module
Query commands	AT + CWLAP	Currently available APs
Connection commands	AT + CWJAP = "Name", "Password"	AP connection command
Sending orders	AT + CIPSEND = <num>	Sending bytes
Connection commands	AT + CIPSTART = TCP, IP address, port number	Connecting to a TCP server

The interaction of information between the WiFi module and the controller is important in the design of the lower computer. This is achieved by creating the function TxData(), which sends a single byte, implementing the function send_string_com(), which sends a string through the function TxData(),implementing the function send_string_com(), which sends ATSEND (send command) and appends the length of the sent character through the function send_string_ sendcom(), and finally, wrapping the three functions together to form a function that sends characters through the serial port. The above functions can be used to directly encapsulate a function to connect to an AP site by specifying the AP site name and password. In practice, it is possible to connect to an AP site with any name and password by simply modifying the specified string parameters. The same can be carried out for the function to send a command to connect to a TCP server using the function wrapped in the above implementation, which can then be called directly to connect to the specified TCP server site with the default parameters. It is only necessary to modify the IP address and port number in the specified string parameters to connect directly to the TCP server using this function.

4.2. Wireless Communication Design

The core function of the Android program design is to wirelessly connect and communicate [29,30], because only wireless communication within the local area network is required, which is all based on the design of JAVA Socket technology to create and implement wireless connectivity and communication based on the TCP/IP protocol [31]. The upper computer in this design completes the function of creating a TCP server and opens a listener waiting for the client to connect. To facilitate the management of individual clients, it is also necessary to create a SocketList to store the corresponding Socket channels of each client. The Android application needs to display the IP address of the local machine on the LAN, so that the client can connect to the specified IP address and port on the server. The system design uses the WiFiManager class to obtain the hardware WIFI information and then the IP address of the local machine. The wireless communication flow chart is shown in Figure 4.

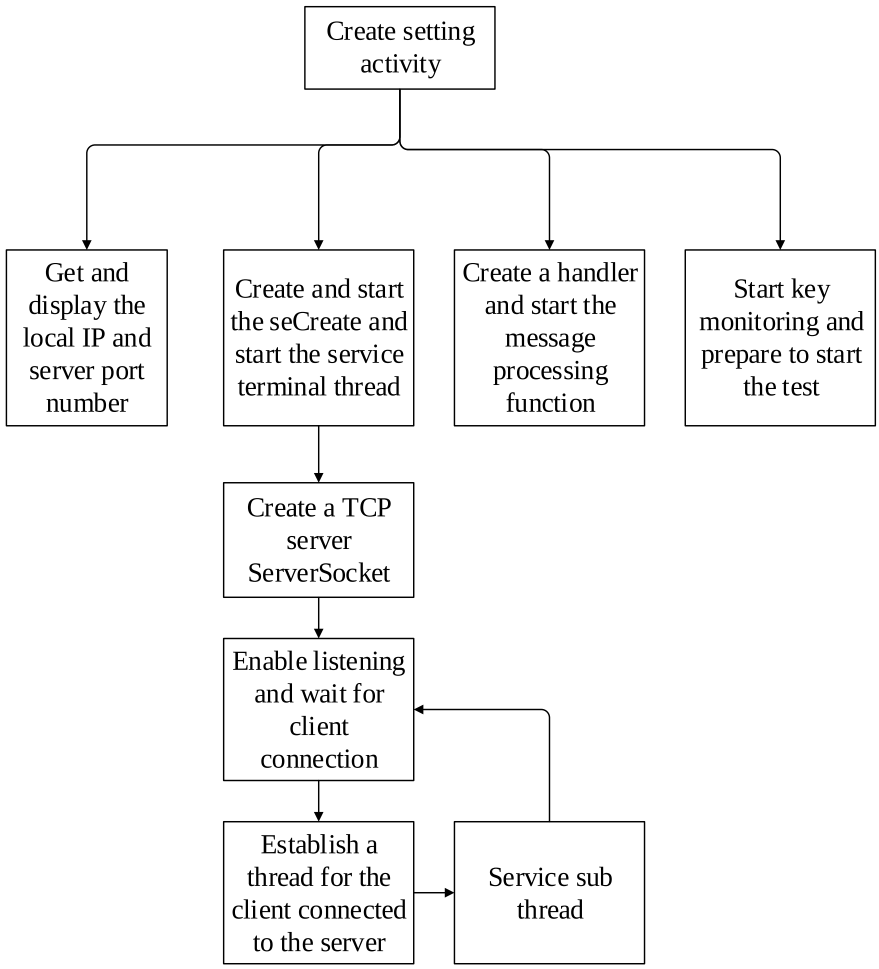


Figure 4. Wireless communication flow chart.

In order to obtain the local IP address, the system creates a WiFi Manager object to obtain the information of the WiFi hardware and passes this information to the WifiInfo object, and then receives the IP address from the get Ip Address object of the WifiInfo object. A service thread is created in the above thread for each socket channel to manage the communication. The run method of the service sub-thread is the function that handles the socket channel, including determining and acting on incoming messages and sending the specified messages. In the message handling function, the host forces the message sent by the sub-thread, i.e., the object, into a String type and assigns it to a String object, content, which is finally updated on the TextView component.

In the creation of the TCP Server, the upper computer creates a thread and opens it. After creating the server socket, the program enters a loop and waits for a connection from the client socket. Once a client connection is made, the program adds the connected channel socket to the list queue and creates a separate thread for this socket channel to handle the communication. The flow chart for creating the TCP server sub-thread is shown in Figure 5.

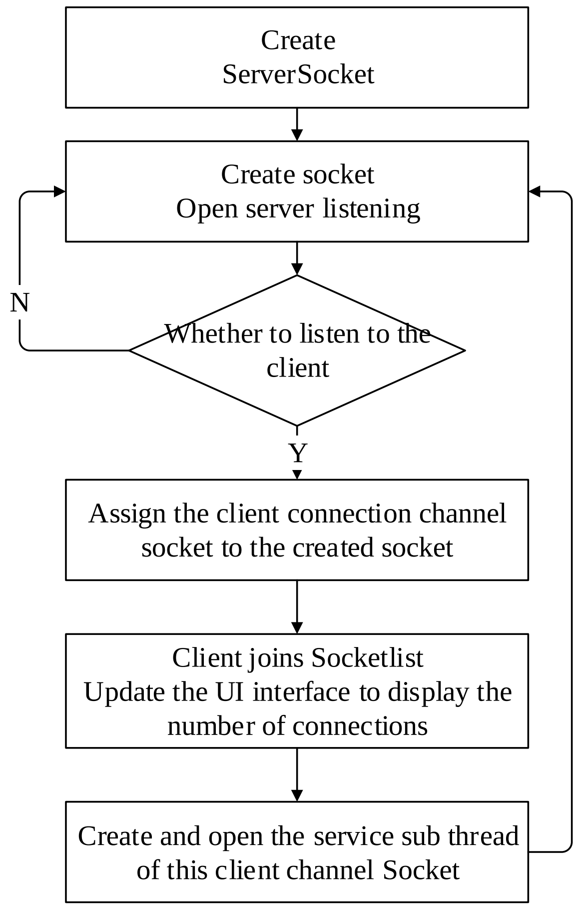


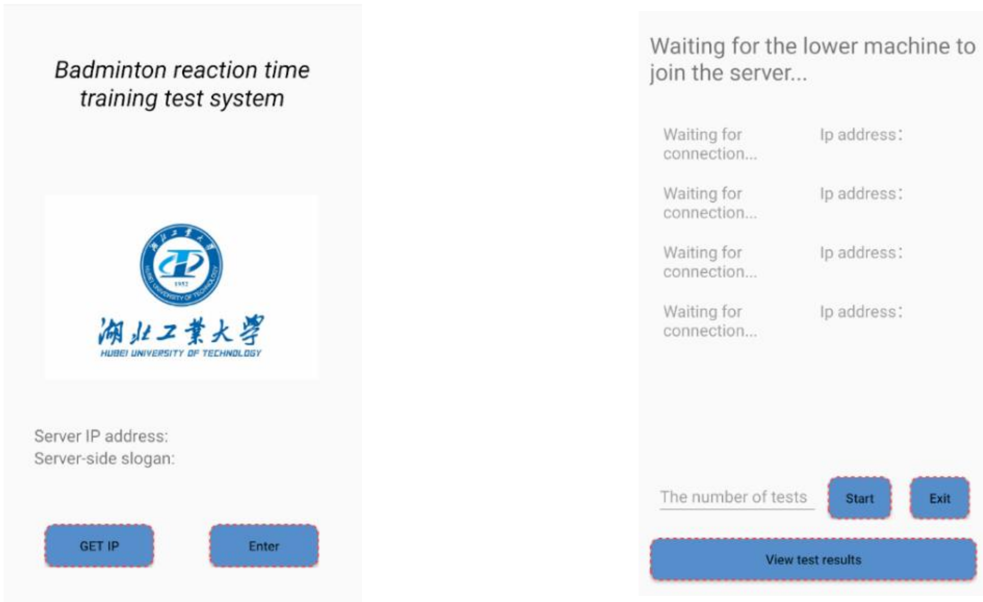
Figure 5. Flow chart for creating a TCP server-side sub-thread.

The main thread in this design is responsible for the UI response. If the network access is performed in the main thread, a forced shutdown will occur if the duration exceeds 5 s. The Handler is defined in the main thread but used in the sub-thread. In this design, the Handler is defined in the main thread and the HandlerMessage function receives messages from the sub-threads to perform the appropriate actions, including updating the UI.

5. Software Design

5.1. UI Interface Design for the Upper App

The UI interface design includes the design of static and dynamic layouts. Static layouts can be loaded directly for easy viewing and modification. Dynamic layouts require code control. The static layout includes text prompts, function buttons, and test result displays. The dynamic layout includes the display of the server IP address and port, the lower computer IP address display and the real-time display of the reaction time. According to the characteristics of the reaction time device, as shown in Figure 6a, the same hotspot as that of the lower unit is connected through a mobile phone to obtain the server IP address and service port number, indicating that the upper computer has successfully connected to the network. While waiting for the lower unit to join the server, the interface needs to be designed to show in real time whether the lower unit is connected to the server and to display the IP address of the connected lower unit into the interface for the user to view, as shown in Figure 6b.



(**a**) (**b**)

Figure 6. Design of the UI interface.

Some of the UI screens are shown in Figure 6.

5.2. Upper Computer Software Process Design

According to the characteristics of the sports agility training system, the upper computer waits for all touch front ends (lower computer) to be connected; the center point lower unit will be marked as 0, and the test point lower computer will be marked as 1–8, respectively, according to the connection sequence. The number N of tests is entered through the upper computer. After entering the number of tests via the App, click on Start Test. The upper computer will send the start flag character to the center point and wait for the athlete to trigger the center point, and then the lower computer will return the flag character. The controller calculates the reaction time and returns it to the upper computer, and the integrated reaction time can be viewed via the mobile phone terminal [32,33]. The flow chart of the upper computer design of the sports agility training system is shown in Figure 7.

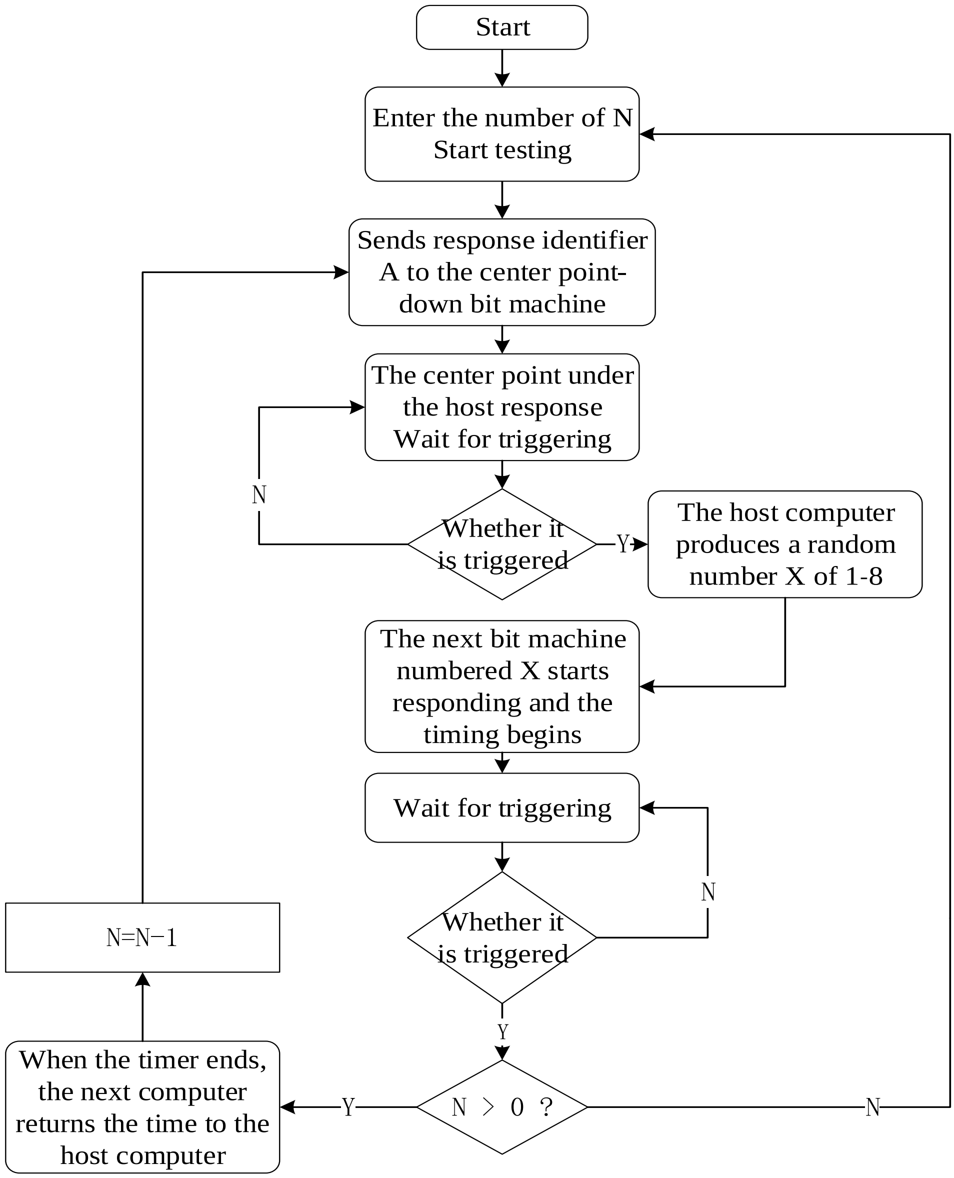


Figure 7. Flow chart of the upper computer software design.

6. Experimental Procedure and Data Analysis

6.1. Subjects of Study and Research Procedures

Nine or so male university students from the Hubei University of Technology were selected as the subjects of the study. All subjects were informed of the purpose of this test, the procedure, possible risks and related precautions. All athletes were free from injury and heavy training loads 1 week before the test. The basic profile of the athletes is shown in Table 2. The research procedures are shown in Figure 8.

Table 2. Basic information of the experimental subjects.

Name	Age (Years)	Weight (kg)	Height (cm)	T-Run (s)	36 m-Move (s)	Stand-Ups (pcs)
Trainer1	21	63.5	175	12.58	16.12	6
Trainer2	22	68.5	176	13.01	15.59	7
Trainer3	22	71.4	180	13.24	15.98	5

Table 2. *Cont.*

Name	Age (Years)	Weight (kg)	Height (cm)	T-Run (s)	36 m-Move (s)	Stand-Ups (pcs)
Trainer4	20	74.2	184	13.11	15.65	6
Trainer5	22	60.2	172	12.15	15.24	7
Trainer6	20	63.8	175	13.58	16.23	6
Trainer7	21	66.2	174	12.24	15.21	7
Trainer8	21	70.5	182	13.02	16.07	6
Trainer9	20	70.9	179	12.63	15.54	7

Note: where the T-run, 36 m move and standing push-up are measured three times each and the average is taken as the pre-training result.

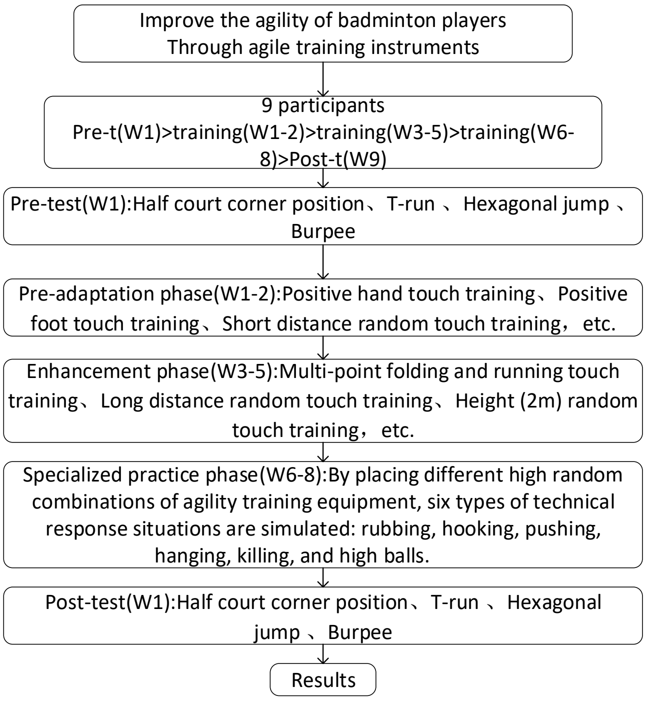


Figure 8. Research procedures.

6.2. Training Methods

In this study, the sensitive quality used to assess predictive decision-making ability, change in movement and change in direction ability [34], so the training content will be combined with the three attributes of the sensitive quality and badminton characteristics to develop. The content of the agility training is divided into three phases. Each phase is interlinked to promote each other, with the content arranged in the order of simple to complex. Each phase was developed using a detailed plan. Before and after the phase training was the mutual laying of the foundation, and the implementation of each phase training component is based on developing motor skills. Table 3 is the implementation plan for the specific training content of the three stages. Training methods and testing methods should avoid the same agility training methods in order to ensure that the athletes' test results improve after training because of the improvement of their own agility, not because the athletes have developed muscle memory by performing a certain agility training action for a long time, thus making the test results improve.

Table 3. Agility training schedule.

Training Phase	Training Content	Training Requirements	Training Purpose	Training Duration
Pre-adaptation phase	Positive hand touch training. Positive foot touch training. Short-distance random touch training.	This phase requires athletes to focus their attention and be able to reasonably coordinate their bodies in a small training environment.	Let athletes understand what agility training is, as well as the basic principle of the operation of the apparatus, and standardize the action of blocking the signal lights.	1–2 weeks 3 sets per session Each set is about 10 min
Enhancement phase	Multi-point folding and running touch training. Long-distance random touch training. Height (2 m) random touch training.	This phase requires the athlete to be able to control their body's center of gravity to complete more difficult movements.	The training content of this phase is reflected in the change in direction, jumping, balance control, etc., using different parts of the body to block the corresponding signal lights.	3–5 weeks 3 sets per session Each set is about 12 min
Specialized practice phase	By placing different random combinations of agility training equipment, six types of technical response situations were simulated: rubbing, hooking, pushing, hanging, killing, and high balls.	This phase requires the athletes to be able to combine the technical movements of volleyball in tandem to complete the blocking signal light.	The experimental subjects in this phase need to hold badminton rackets to complete various training exercises to achieve the effect of realistic simulation of court competition.	5–8 weeks 3 sets per session Each set of training is about 15 min

A part of the agility training is shown in Figure 9a, where the subject touches the apparatus in front of them with their hands. As shown in Figure 9b, the subjects held a badminton racket and performed a simulated pick-up game at the net. As shown in Figure 9c, the subjects waited for the signal lights at different heights such as the signpost and the ground to light up randomly, and then they quickly changed direction and sprinted to the reaction device and used their hands to block the sensing area where the sound and light were displayed to simulate a real badminton game [35].

(**a**) (**b**) (**c**)

Figure 9. Part of the training.

6.3. Test Method

The eight main directions of movement on the court are the left, middle and right of the front court and the back court, and the left and right of the middle court. The strategy of reacting and executing footwork against the opponent depends on the movements performed in these eight directions, which include striding, lunging, and cross-stepping on the front and back court, and the cross-step on the center court. Designing a center point with eight test points enables badminton players to complete their footwork faster and train to achieve greater acceleration. According to the characteristics of badminton, it is necessary to return to the center court quickly after each return stroke, as this allows the fastest reaction to the next stroke. During the game, the opponent will often hit the ball towards the sideline and the corners of the court so we consume as much of our physical strength as possible, so placing the test points on the sideline and the corners can train our agility and physical strength to the maximum extent, and at the same time, placing the instruments at different heights for training with the help of mechanical equipment is also more in line with the game scenario. The center of the lower computers was designed and placed in the center of the court according to the rules of motor skill formation and the specific characteristics of badminton, and the remaining eight test points were placed around the court to imitate the opponent's drop position [36]. At the same time, the agility training equipment was placed 40 cm from the ground with the help of a sign barrel. A diagram of the placement of the apparatus in the actual process is shown in Figure 10a,b.The physical diagram of the lower machine and the upper machine is shown in Figure 10c–e. The average combined reaction times at the eight test points before training are shown in Table 4.

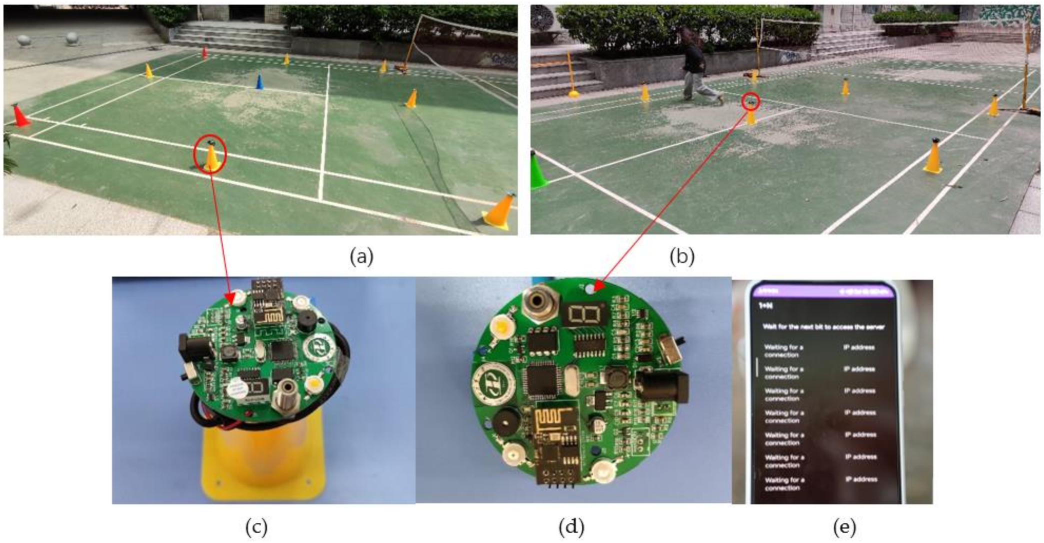


Figure 10. Physical and application scenarios of the agile training system.

Table 4. Combined response time at each point before training.

Name	1	2	3	4	5	6	7	8/s
Trainer1	2.67	2.01	2.57	2.11	2.09	3.12	2.58	3.23
Trainer2	2.58	2.15	2.68	1.95	1.89	3.12	2.21	3.11
Trainer3	2.66	2.07	2.61	1.86	1.98	3.05	2.38	3.17
Trainer4	2.59	1.98	2.66	2.03	1.88	3.02	2.34	3.05
Trainer5	2.45	2.12	2.58	2.01	1.87	3.11	2.42	3.37
Trainer6	2.71	2.17	2.72	2.19	2.15	3.21	2.19	3.04
Trainer7	2.75	2.24	2.64	2.18	2.16	3.18	2.23	3.25
Trainer8	2.62	2.10	2.60	2.07	1.96	3.07	2.35	2.98
Trainer9	2.50	1.94	2.52	2.06	1.99	3.15	2.37	3.21

Note: The values 1–8 in the table, respectively, represent the eight directions of this study: front left, front middle, front right, middle left, middle right, rear left, rear middle and rear right on the badminton court.

Before the test started, the subject stood 30 cm in front of the center point. After the test started, the subject backed up to the center point induction area, and then started the test. After touching the random lower computers, they quickly withdrew to the center point. They then continued to the next test. Each test did this 20 times per round, with a total of three rounds of testing and each round interval being 3–5 min. This was so we could take the average of the measured eight test points and obtain an accurate response time. The placement diagram of the lower computers is shown in Figure 10a and the actual test diagram is shown in Figure 10b. By comparing the reaction times of the subjects at the eight test points before and after training, the agility training apparatus designed in this paper can be verified as effective for improving the agility quality of badminton players [37]. At the same time, the data of T-running, hexagon jump and burpee support before and after training were analyzed using a T-test to judge the influence of agility training instruments on the agility of the experimental objects. In this regard, the p-value in the T-test, which is the probability, reflects the magnitude of the likelihood of an event occurring. Statistical p-values obtained based on the significance test method are generally statistically different at $p < 0.05$, statistically significantly different at $p < 0.01$, and extremely statistically different at $p < 0.001$. The meaning of this is that the probability that the difference between samples is due to sampling error is less than 0.05, 0.01, or 0.001.

6.4. Results and Analysis

After up to eight weeks of agility training, the subjects were tested on agility and the data were analyzed. The average combined reaction times for the eight test points after training are shown in Table 5.

Table 5. Combined response time at each point after training.

Name	1	2	3	4	5	6	7	8/s
Trainer1	2.07	1.74	2.11	1.88	1.75	2.54	2.01	2.32
Trainer2	2.11	1.84	2.20	1.71	1.65	2.61	1.97	2.54
Trainer3	2.14	1.71	2.12	1.56	1.73	2.60	1.87	2.73
Trainer4	2.04	1.65	2.09	1.68	1.61	2.56	2.05	2.61
Trainer5	2.15	1.78	2.12	1.75	1.63	2.74	1.95	2.68
Trainer6	2.21	1.75	2.23	1.81	1.94	2.59	1.86	2.64
Trainer7	2.25	1.79	2.19	1.74	1.80	2.52	1.92	2.58
Trainer8	2.12	1.73	2.23	1.85	1.60	2.58	1.94	2.66
Trainer9	2.03	1.62	2.07	1.80	1.74	2.49	2.03	2.40

Note: The values 1–8 in the table, respectively, represent the eight directions of the study: front left, front middle, front right, middle left, middle right, rear left, rear middle and rear right on the badminton court.

Table 5 shows that there is a significant difference in the combined reaction times of the experimental subjects when going to the front, middle and back areas of the court, with going to the middle and front areas being faster than going to the back court. The training program designed by Kuei-Pin Kuo was only six-point training, ignoring the training of the middle position of the forecourt and the backcourt, so the average movement time of the forecourt and the backcourt in the training results of this paper was about 0.4 s less than the average movement time of the forecourt and the backcourt in the training results of Kuo, Kuei-Pin [38]. The difference in the reaction times of the experimental subjects in the middle, front and back court can indicate that badminton players pay more attention to the incoming ball in the front and middle when returning the ball, so when the predicted location of the incoming ball is the middle and front court, the response action is more rapid; therefore, the comprehensive reaction time in the middle and front court is relatively short. When the response signal came from the backcourt, the subject backed up to the sensing area for the simulated return, and the leg muscle burst was weaker than the forward sprint burst initiated in the frontcourt, which also contributed to the difference in the combined response time in the front and back court.

As shown in Figure 11, after training with the device studied in this paper, the subjects' decision-making efficiency was significantly improved, integrated reaction time was significantly decreased, and reaction speed was enhanced, which is the same as the findings of Barnes M. [39], Craig B.W. [40], and Potteiger J.A [41]. They all concluded that long-term training with agility equipment increased the speed of transmission of various data in the higher centers of the brain, allowing trainers to accelerate their judgment. The results of the eight-week agility training intervention were similar to those presented by Chang [42] and Kao [43]. The reaction time function in the agility training component can find weak orientations and deficiencies in the stroke movements (forehand–backhand straight-line stroke, forehand–backhand diagonal stroke) of the experimental subjects in the fast change of direction for reinforcement training. The random signal function can stimulate the visual nerve, enhance the cortical excitation and improve the ability of pre-determination decision. At the same time, the training combined with the characteristics of badminton, simulating real scenes in competitive badminton matches, different heights and different distances, can well exercise the limbs, enhance the brain's control of the body, and coordinate muscles and nerves, thus improving the ability of the experimental subjects to change their movements.

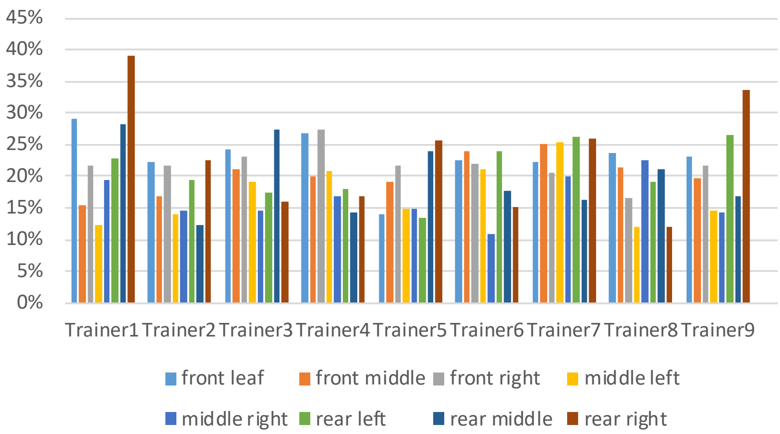


Figure 11. Rate of growth of combined response time at each point after training.

At the end of the training, the subjects were retested on their performance in the T-run, hexagonal jumps and burpees to determine changes in the three areas of anticipatory decision making, change in movement and quick change in direction. A comparison of the results of the indicators before and after training is shown in Table 6.

Table 6. Comparison of test results before and after training (n = 9).

Test Indicators	Pre-Training	Post-Training	*p*-Value
T-run (s)	12.91 ± 0.47	12.15 ± 0.54	**
Hexagonal jump (s)	13.39 ± 0.19	12.97 ± 0.15	**
Stand-ups (s)	5.62 ± 0.42	7.62 ± 0.42	**

Note: ** indicates a highly significant difference between the groups before and after the training of the subjects, $p < 0.01$.

Table 6 shows that after 8 weeks of training with the agility apparatus, the p-values were less than 0.01 compared to the pre-training period. The results show that the subjects' responsiveness improved very significantly after training.

Walklate, Benjamin M showed in their research that supplementing routine training with short-term sprint agility training can greatly improve the repeated sprint agility performance of national badminton players, which is similar to the principle of training with agile training instruments [44]. Agile response instrument training is used to improve the control ability of athletes' nervous systems in terms of body stability and flexibility through a series of training exercises. Zech Astrid (2010) also concluded through experiments that agility and balance training is effective in improving posture and neuromuscular control [45]. Through the continuous practice of different training movements, the ability of leg muscles to change direction and accelerate, the ability to control body balance under starting and buffering conditions, and the efficiency of upper and lower limbs cooperative operations can be improved to help practitioners improve their ability to generate force from different angles and seek reasonable forms of exercise, thus shortening the comprehensive reaction time. The six-week agility balance response training designed by Zemkov á E (2010) [46] and others is similar to our training content with the help of agility training instruments. Both of them are comprehensive training regimens for various agility abilities. The results show that the combination of agility and balance training under visual control improves dynamic balance, muscle contractility and agility.

6.5. Experimental Conclusions

(1) The subjects' reaction times to the front court, middle court and back court are obviously different, and going to the middle court and front court is obviously faster than going to the back court.

(2) At the end of the training, the subjects' reaction times at all points decreased significantly, indicating an effective increase in agility.

(3) Long-term badminton training using the agility equipment studied in this paper can provide a good boost to the subject's ability to make predetermined decisions, change movements and improve quick changes in direction.

7. Conclusions

We designed a distributed badminton agility training apparatus based on an embedded system that can realize the functions of free distribution, wireless communication and real-time display of reaction time. With the aid of the agility-training apparatus, the experimental subjects were trained for up to 8 weeks in badminton, and their data at various points of movement were analyzed after the training. The test results show that the use of agility-training equipment to develop a reasonable training plan and long-term training improve the agility quality of athletes.

With high accuracy, low power consumption and good portability, the agility equipment meets the requirements for the fast and accurate measurement of badminton players' reaction times, which significantly improves the reaction speed of college badminton learners and has certain application value. In the next step, we will further upgrade the agility-training equipment for the problems of limited training range and single function, and develop related wearable devices to monitor the athletes' body conditions so that it can be applied to many different sports training.

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