Sensors and Materials, Vol. 35, No. 4 (2023) 1189–1210
MYU Tokyo

S & M 3239

Wireless Mesh Network and Its Application in Sports Agility Tests

Baohua Tan,[1,2] Kan Cao,[1,2] Enpu Wang,[1,2] Lu Xiao,[1,2]
Jingxin Nie,[3] Qinyang Wang,[4] Sitong Yang,[5*] and Lina Luo[5**]

[1]School of Science (School of Chip Industry), Hubei University of Technology, Wuhan 430068, China
[2]National "111 Research Center", Microelectronics and Integrated Circuits,
Hubei University of Technology, Wuhan 430068, China
[3]School of Electrical and Electronic Engineering, Hubei University of Technology, Wuhan 430068, China
[4]School of Arts & Design, Hubei University of Technology, Wuhan 430068, China
[5]School of Physical Education, Hubei University of Technology, Wuhan 430068, China

(Received September 12, 2022; accepted February 27, 2023)

Keywords: wireless mesh network, sports equipment, agility training

In view of the backward traditional training methods and the shortage of training funds in college sports, an agility training system based on a wireless mesh network is developed and evaluated. The network structure, initialization, and root node selection of the mesh network are described in detail. In the mesh network training scenario, the network topology is examined, and the response time and packet loss rate of the mesh network nodes are tested to demonstrate that the ad hoc network can transmit real-time data within the response time. The experimental data show that when the number of hops is $n \leq 2$ and the response time of the mesh network nodes is less than 300 ms, the packet loss rate is 0%. The wireless mesh network solves the problem that the traditional Wi-Fi network is limited by the communication distance. It also allows more lower-level computer nodes to access the network and expands the training coverage.

1. Introduction

Human society has entered an intelligent era, and the Internet of Things is being increasingly used in the environment, agriculture, and infrastructure construction. Many countries are also actively introducing electronic equipment into sports training to improve the performance of athletes.(1) Wang integrated cloud computing in the sports, fitness, and leisure industries, strengthening the research, development, and application of Internet of Things technology in the sports industry.(2) Liu and Li developed and designed a sports training information management system based on Internet of Things technology, which improved the intelligent management of sports training information.(3) University physical education departments still adopt traditional training methods in the agility training of students; current agility training equipment is still mechanical, and it is important to introduce modern training equipment.(4) The electronic

*Corresponding author: e-mail: sitongyang@hbut.edu.cn
**Corresponding author: e-mail: linaluo@hbut.edu.cn
https://doi.org/10.18494/SAM4113

ISSN 0914-4935
https://myukk.org/

products for assisting agility training designed in Canada named FitLight are expensive, costing 2000 dollars for a set of equipment, and are not suitable for general university training. Rusdiana developed an agility training apparatus that achieves a random function in training through hardware and software but does not measure the integrated response time of the user's training.(5) The slave machine in the agility training equipment developed by Wu uses Zigbee communication technology for the interaction with information, but Zigbee is a short-distance communication technology with a small communication range, which is only suitable for short-distance agility training.(6) Kuo *et al.* designed and developed an affordable visual response system for badminton training, but the overall system size is 24 inches, which is relatively large.(7)

In this study, we have designed an agility training system that is simple to operate, uses a randomized training mode, and contains audible signals and multicolored light functions. Because of its small diameter of about 8 cm, the system can be installed and configured anywhere, including on the floor, walls, or mechanical equipment. For large-field training, such as basketball half-court training, mesh networks can be combined with sports equipment to expand the range of training. The connection between the devices in the system is stable, which can solve the problem of the agility trainer being unable to be used because the routing device is not mobile or the network edge signal is weak. The agility training system is designed to improve performance in specific sports, shorten the reaction time, and improve speed endurance, coordination, and visual cognitive processing. The reaction time data collected by the system can be used to track and monitor the development of athletes. Therefore, it has important potential application value in the intelligentization of the college physical education curriculum.

2. Overview of Agility Training System

The system is mainly divided into a lower computer reaction training module and an upper computer software part, and the overall framework of the system structure is shown in Fig. 1.

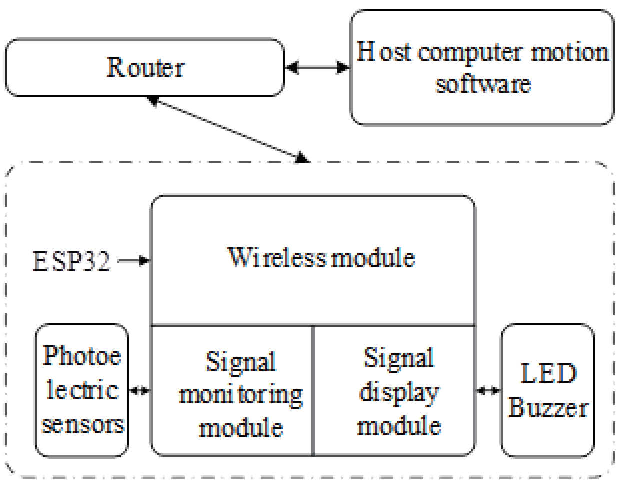


Fig. 1. Architecture of overall system.

2.1 Design of lower computer hardware

The system is mainly composed of a communication module, a signal display module, a signal monitoring module, and a power supply module. An ESP32 module, which is responsible for the functions of networking, communication, reaction time calculation, and control signal display, is used as the main controller in this system. A photoelectric sensor is used to detect whether the reaction signal is triggered, an LED and a buzzer simulate the reaction signal, the power supply module is a rechargeable 12 V lithium battery with a capacity of 1050 mAh, and a 12 V to 5 V converter module is used to supply power to the ESP32 module. An image of the lower computer of the system is shown in Fig. 2.

2.2 Design of lower computer software

The main software process in the ESP32 module is to first initialize the module hardware, system, and so forth. The user can set the network name and password for each lower computer. When a lower computer's own wireless network is turned on, other lower computers can connect with it according to its set name and password.[8]

In the program, after the node has finished networking, if the node is the root node, it will first create a transmission control protocol (TCP) client and establish a TCP connection using a socket, then create the tcp_client_read_task and tcp_client_write_task functions. In the tcp_client_write_task() function, the TCP connection is examined until it is successful. The root node first accepts data from the normal nodes in the mesh network and then sends the data to the host. In the tcp_client_read_task() function, data from the host is accepted and sent to the correct network node in the mesh network based on the MAC address. If the node is normal, the node_read_task and node_write_task functions are created; these functions wait for a message from the root node and transfer the motion data to the root node. Both the root node and the normal node create a wait task and turn on the light display and timer when they receive an open

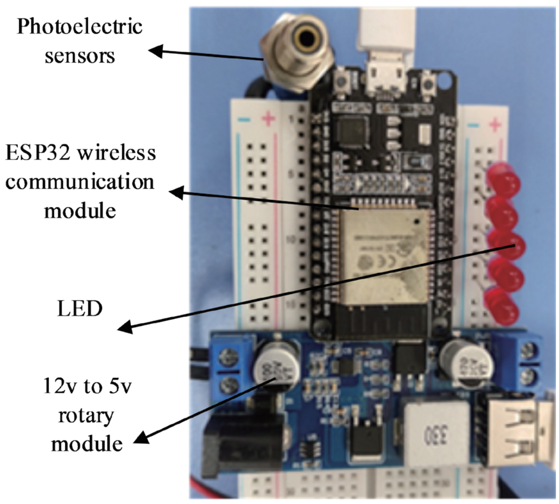


Fig. 2. (Color online) Image of the lower computer.

command from the upper computer. The function of the wait task is to listen to whether the trainer triggers the photoelectric sensor. When the trainer triggers the photoelectric sensor sensing area, the system turns off the light display and sends the reaction time data to the host computer via the write task.[9] A flow chart of the lower computer software is shown in Fig. 3.

2.3 Sports app design

2.3.1 Root node selection

The user interface (UI) in the system is divided into the static layout and the dynamic layout (which can also be called the interaction). The static layout can be loaded directly for easy viewing and modification. The dynamic layout requires code control. The static layout includes text prompts, function buttons, and the test result display. 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 response time.[10]

As shown in Fig. 4, according to the characteristics of multiple movements, we design three movement modes: standard mode (measuring the reaction time from the light display to the touch sensing area), synchronous mode (all lights are on at the same time and are touched in

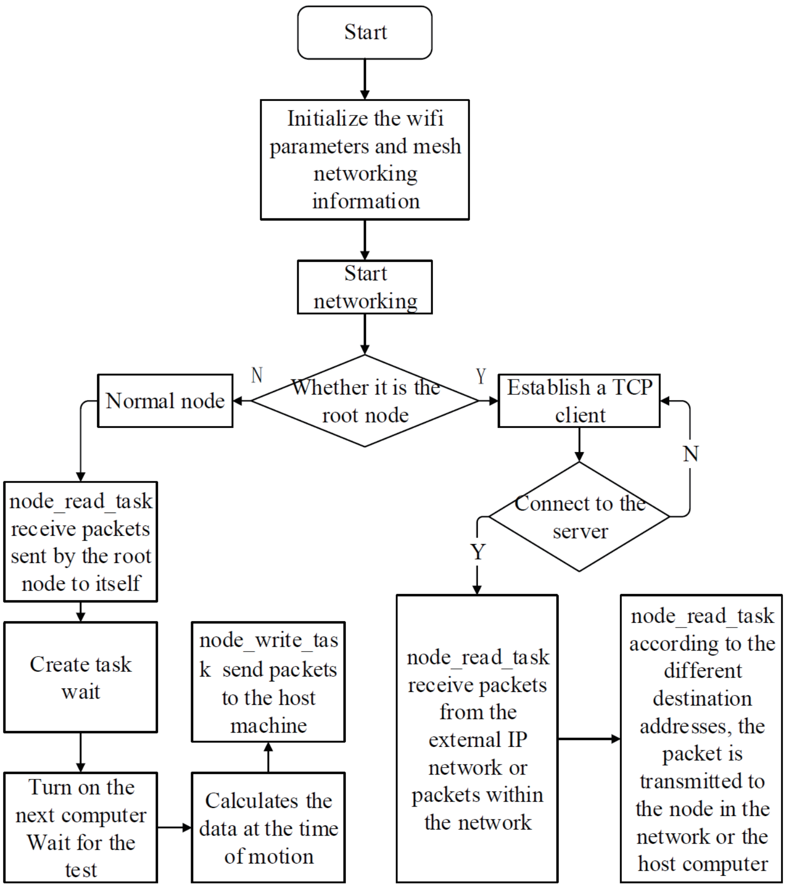
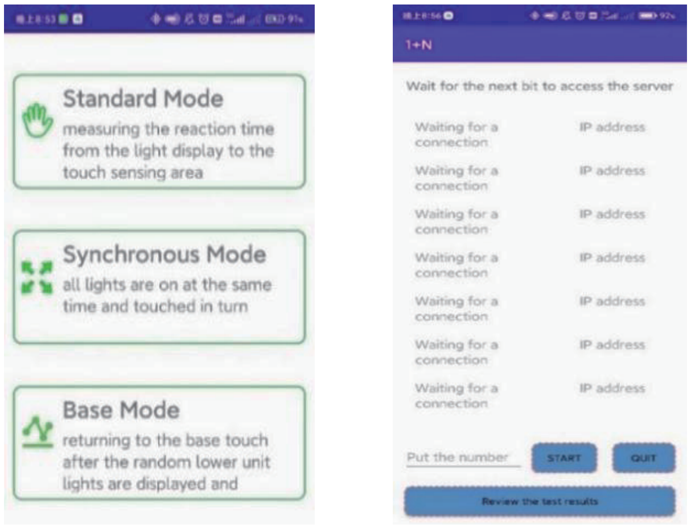


Fig. 3. Flow chart of lower computer software.



(a) (b)

Fig. 4. (Color online) Part of the sport app interface.

turn), and base mode (returning to the base touch after lower computer lights are randomly displayed and touched). At the same time, according to the characteristics of the device at the time of the reaction, the same hotspot as the lower computer is connected through a mobile phone to obtain the server IP address and service port number, indicating that the upper unit has successfully connected to the network. The interface must be designed to show in real time whether the lower computer is connected to the server and to display the IP address of the connected lower computer in the interface for the user to view.

2.3.2 Root node selection

Taking the base mode as an example, after the upper computer server is established, it is necessary to wait for all touch front ends to establish clients and communication connections with the server. During this time, the central point randomly marks a lower computer as 0 and the lower computer test points as 1–8 according to their order of connection after the number of tests, *N*, is entered through the sport app. Clicking the Start Training button on the mobile terminal screen causes the upper computer server to send a start command to the center point. When the athlete touches the light sensing area of the center point, the lower computer client sends a response command to the server. After the upper unit receives the signal, it randomly sends a flag character to the lower computer test point, which represents the random start of a lower computer, thus simulating an opponent's hitting direction, while the main controller turns on the sound and light display. When the athlete triggers the light sensing area again, the external interruption in the main controller is closed, and then the movement time for this training is sent to the upper computer server. Users can view the training time through their mobile device.(11) A flow chart of the training logic in the app operation is shown in Fig. 5.

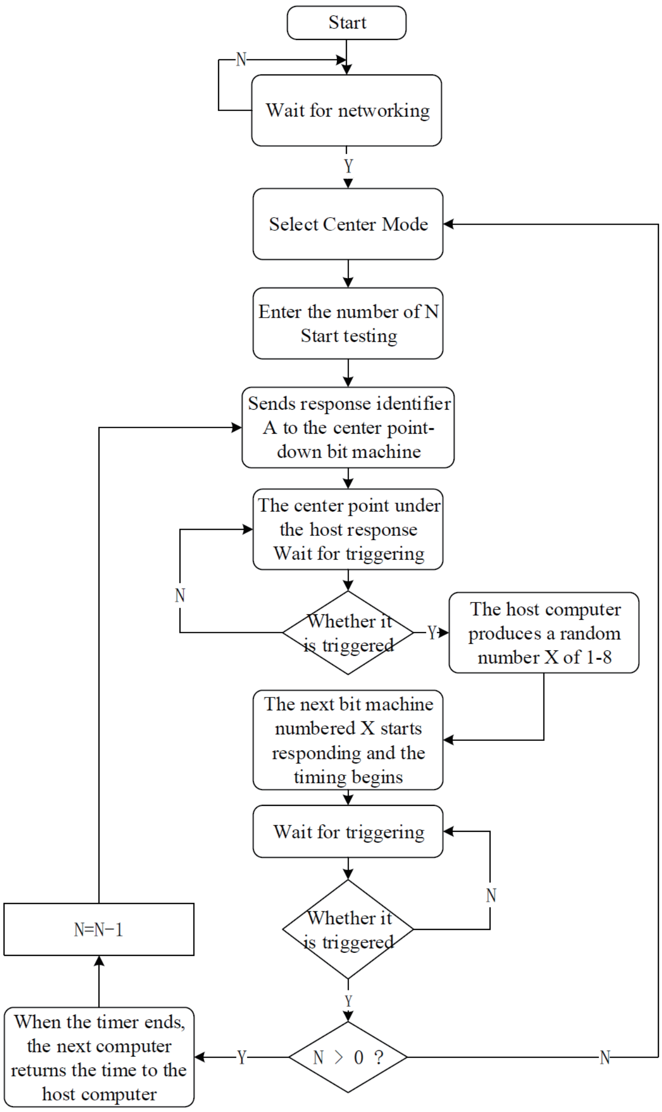


Fig. 5. Flow chart of app operation.

3. Wireless Mesh Networks

The mesh network in this design adopts the distributed network connection mode. All the lower computers in the local area network (LAN) can provide data to the higher machines through the network. There are wired and wireless connection modes, and the connection is stable. The ESP-mesh network uses the ESP chip with a routing function as the network terminal, and each independent terminal can communicate with the router to realize network transmission. Network discovery is a special function of the mesh network. The router automatically identifies the terminal with the strongest network signal and then connects to it. This ensures that damage to one terminal has no impact on the network of the whole system. As shown in Fig. 6, in the ESP-mesh network, multiple terminals are connected to each other, and

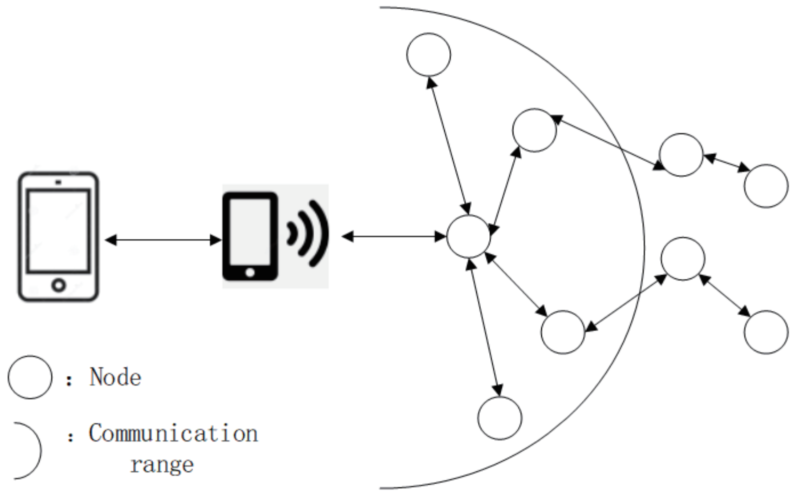


Fig. 6. Mesh network architecture based on ESP32.

Table 1
Comparison of mesh chips.

Main parameters	MT7620a	EFR32MG21
Operating voltage	12 V	3.8 V
Operating temperature	−40–80 °C	−40−80 °C
Transmitting power	18 dBm	20 dBm
Transmission distance	150 m	100 m
Low power consumption	Not supported	Supported
Receiving sensitivity	200 Mbps	150 Mbps

the information detected by the sensor is sent to the main terminal, which is the most stable in the network. The main terminal communicates with the mobile phone through the router.[12]

In the selection of mesh networking chips, power consumption and transmission performance are the main reference factors. The main chips on the market are MT7620a, EFR32MG21, and ESP32.[13] The relevant parameters of the three chips are shown in Table 1.

According to the information in Table 1, the ESP32 chip has the lower operating voltage and power consumption and meets our requirements in terms of the wireless rate, RF power, and transmission distance.

3.1 Network framework

Figure 7 shows a mesh network, where the nodes are connected to form a network. In mesh networks, different nodes have different degrees, for example, in Fig. 7, node A has degree 5, node F has degree 2, and node G has degree 1. Mesh networks are simple in structure, easy to wire, easy to scale, and relatively simple in the design of routing algorithms. Therefore, to support design reusability and system scalability, mesh networks are the most widely used topology in on-chip networks.[14]

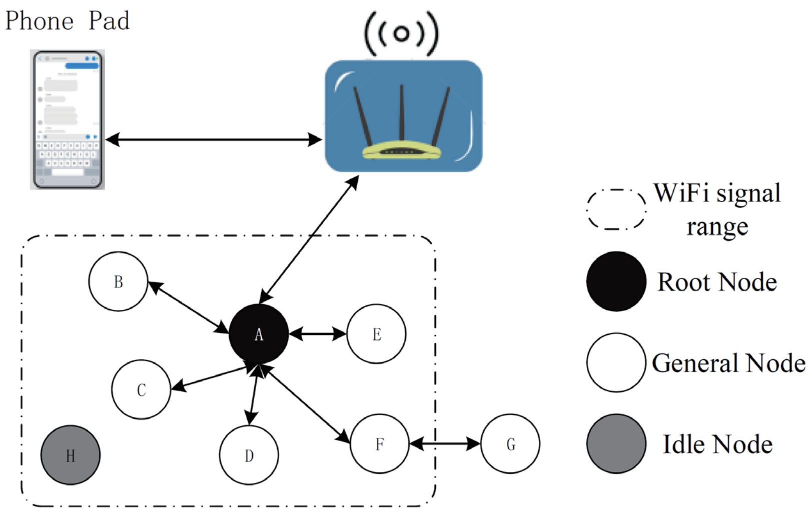


Fig. 7. (Color online) Network structure showing nodes.

Wi-Fi modules typically operate in two modes, AP and Station. In the AP mode, the node generates a LAN that allows other devices to access and thus interact with data. In the Station mode, the node acts as a terminal access point and can access other networks. In a Wi-Fi network, in the Station mode, a node can only connect to one server AP, but in the AP mode, multiple nodes can connect to it. The ESP32 has an AP+Station mode of operation, where a node is allowed to act as both a Station and an AP, by which multiple ESP32 nodes are connected wirelessly. The nodes in the training system network use the AP+Station mode.

Figure 7 illustrates the tree topology, in which nodes can establish multiple downlink connections through their AP interfaces and uplink connections through their Station interfaces to form a multi-parent tree mesh network.[15]

3.2 Network building process

3.2.1 Network initialization

The networking process mainly consists of the selection of the root node and the formation of the remaining layers. As shown in Fig. 8, at the start of the networking phase, each downlink device sends its MAC address and router received signal strength indication (RSSI) value via a Wi-Fi beacon frame.[16] The MAC address is used to identify the address of the lower computer at the mesh network device location and can indicate a unique device in the network. The router RSSI value represents the signal strength relative to the router. The automatic root node is selected in accordance with the signal strength. In the network establishment stage, each slave computer continuously scans the information from other slave computers within the communication range. When the RSSI value received by the lower computer from the messages broadcast by the other lower computers is greater than the current RSSI value, the lower computer records the information of the node and broadcasts its signal strength. After a

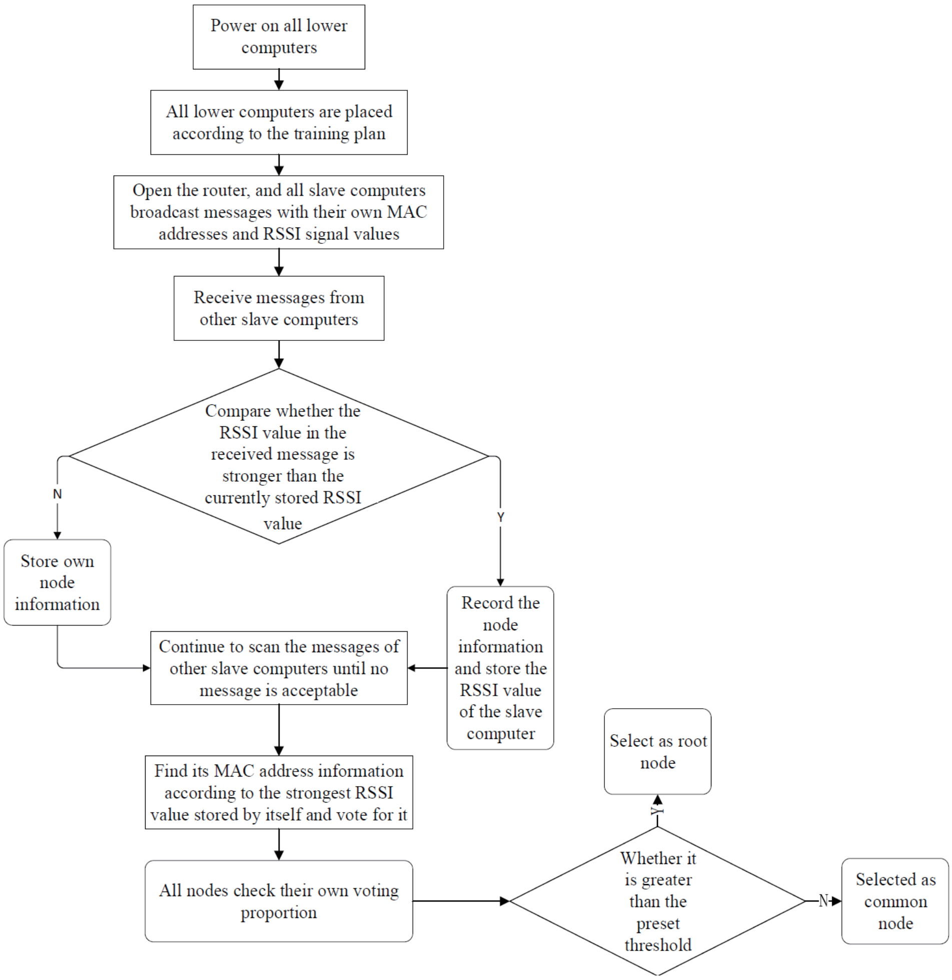


Fig. 8. Automatic root node selection flow chart.

minimum number of iterations, the beacon frame with the strongest router RSSI value is elected. When the number of campaign iterations designed by the program is reached, each slave machine counts the votes of all other slave machines to determine whether it is selected as the root node or must wait for the formation of the remaining root nodes. If the percentage of votes for a device is greater than a preset threshold, then the lower device becomes the root node.

RSSI ranging is a ranging-based positioning algorithm(17) calculated as

$$RSSI(d) = RSSI(d_0) + 10n_0 \lg\left(\frac{d}{d_0}\right) + x_\partial . \quad (1)$$

Here, $RSSI(d)$ represents the signal strength at distance d, the strength of the signal that can be received at a certain distance from the network terminal. $RSSI(d_0)$ represents the reference signal strength, the signal strength at the reference distance from the network terminal. n_0 denotes the transmission path loss factor. X_∂ is the signal decay factor of a Gaussian random variable and has a mean of 0 and a variance of σ.

RSSI is a negative value. The smaller its absolute value, the stronger the signal and the more stable the transmission. It can be divided into three intervals: −50 to 0 dBm, −70 to −50 dBm, and below −70 dBm, from high to low, corresponding to three levels of network data transmission quality. Generally, transmission with a signal strength less than −70 dBm is not considered in the actual network transmission.[18]

$$d = \frac{10^{\left(abs\left(RSSI(d)\right)-A\right)}}{10n} \tag{2}$$

Here, d is the distance from the lower computer to the router, A is the signal strength when the transmitter and receiver are 1 m apart, and n is the ambient attenuation factor. A and n are empirical values based on actual conditions and references, and suitable values of A = 59 and n = 2 were previously determined.[19] Figure 9 shows the relationship between the RSSI value and the actual distance.

3.2.2 Formation of other layers

Once the root node is connected to the router, the idle nodes within the range of the root node start connecting to the root node, thus forming the second layer of the network. Once connected, the second-layer nodes become intermediate parents (assuming the maximum number of layers allowed > 2) and therefore form the next layer. Referring to Fig. 7, nodes B to E are within the range of the root node. Therefore, these nodes form an upstream connection with the root node and become intermediate parents. The remaining idle nodes are connected to the intermediate parent nodes within the range, thus forming a new layer in the network. After connection, the free nodes become intermediate parents or leaf nodes, depending on the maximum number of layers allowed in the network. This step is repeated until there are no more idle nodes in the network or until the maximum number of allowed layers of the network is reached.

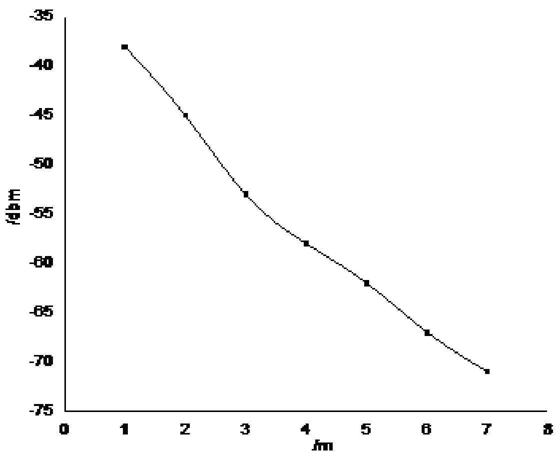


Fig. 9. Measured RSSI value versus distance d.

3.3 Node data frame structure

The Wi-Fi data frame consists of a MAC header, a frame body, and a frame check sequence. The frame body is the mesh data frame. The header contains the MAC addresses of the source and destination nodes, the Option field contains information about special types of mesh data frames, such as packets from external IP networks or broadcast packets, and the payload contains the actual application data. The specific component size of this data is shown in Table 2. The mesh data frame is used to transmit data in the wireless mesh, and since the mesh protocol is built on top of the Wi-Fi protocol, the mesh data frame used is fully contained in the Wi-Fi data frame. The relationship between the mesh and Wi-Fi data frames is shown in Fig. 10.

The MAC address is the data source address by which the data source nodes are distinguished. The start and end flags are set to facilitate the processing of data by managing the host computer.

3.4 Network maximum layer

The number of network layers determines the network quality. To prevent excessive network layers due to too many lower computers and mixed connections in the agility training system, the terminal of the last layer of the network is used as the end child. The terminals of the first and middle layers can be connected to the other two terminals, but the terminal of the last layer can only be connected to one terminal, thus enabling the maximum number of layers in the network to be controlled.

Table 2
TCP transmission message format.

Number	Name	Memory	Detailed description
1	Start sign	5 bytes	0xEF
2	Source port	16 bytes	MAC address of sending end
3	Destination port	16 bytes	MAC address of target node
4	Separation	6 bytes	0xFF
5	Reaction time data	7 bytes	Reaction time of single training
6	End marks	3 bytes	0xFFFFFF

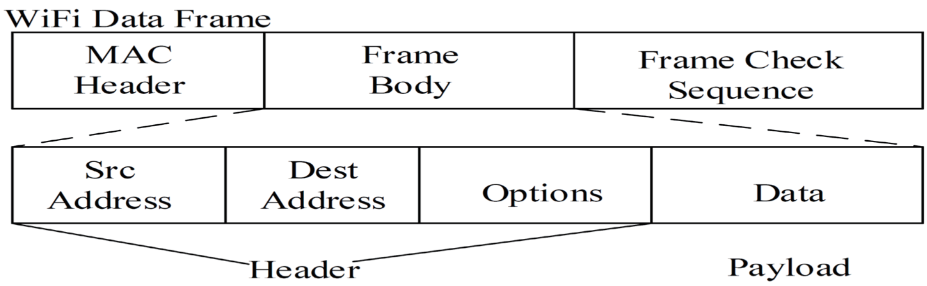


Fig. 10. Composition of Wi-Fi data frame.

4. Network Testing

4.1 Wireshark packet capture statistics

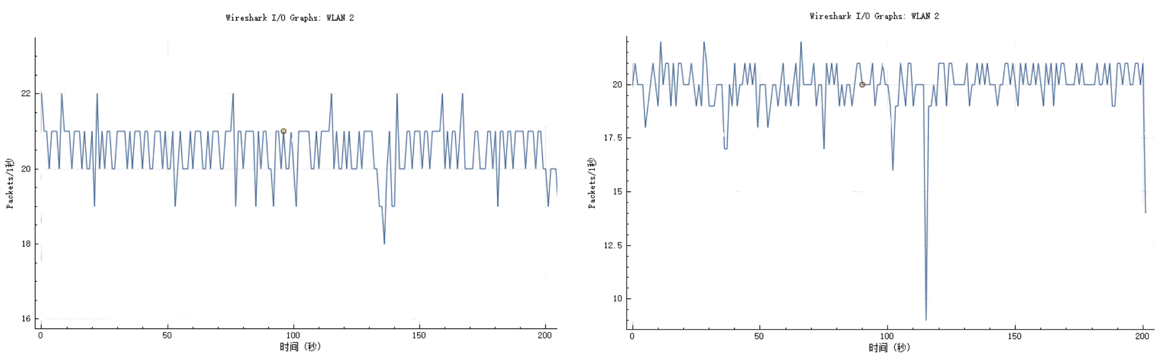
To test the transmission rate, we perform a mesh network multi-hop transmission test in which two nodes are placed in an open badminton court, one as the root node and the other as the test node. The network topology of test node -> root node -> router is implemented. We take the root node and implement the network topology of node -> router, and compare it with the above communication mode after networking. The distance between the leaf node and the router is 15 m. The root node is 10 m from the router.[20]

The test node sends packets to the upper layer machine, which connects to the router and opens a TCP server for the lower computer to connect to the root node. The IP address is 192.168.1.185 and the port number is 8082.

A statistical IO diagram of packet capture in the networking mode is shown in Fig. 11(a), where the horizontal axis is the time axis and the vertical axis is the number of packets received per second. On average, 21.08 packets per second (PPS) were received, with an average of 127 kB of data accepted per second. When the root node was removed, only the leaf node communicated with the router separately, and the independent communication quality between nodes and routers deteriorated because of the long distance. In this case, 19.5 PPS were received, with an average of 101 kB of data accepted per second. Figure 11(b) shows the statistical IO diagram of packet capture in normal mode.

4.2 Network topology

As shown in Fig. 12, the routing table of node D contains the MAC addresses of nodes D to J. The routing table of root node A can be divided into sub-tables for nodes B, C, and D, containing the MAC addresses of nodes B to K, nodes C to G, and nodes D to J, respectively. Figure 13 shows the routing table for the entire network, as printed out by the computer via the root serial port.



(a) (b)

Fig. 11. (Color online) (a) Packet capture statistics of mesh network. (b) Packet capture statistics of common network.

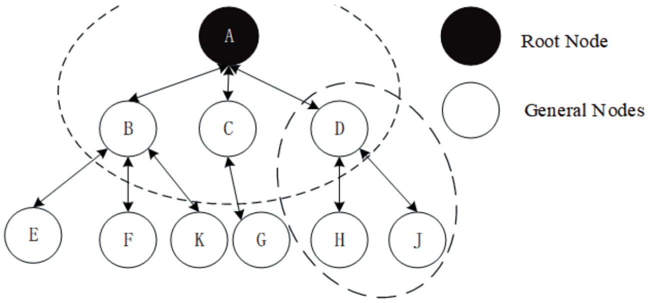


Fig. 12. Example of ESP-mesh routing table.

```
I (21557) mesh_main: Received Routing table[0] 7c:9e:bd:47:67:84
I (21557) mesh_main: Received Routing table[1] 7c:9e:bd:46:fd:0c
I (21567) mesh_main: Received Routing table[2] 94:69:7e:69:9b:a0
I (21567) mesh_main: Received Routing table[3] 7c:9e:bd:49:52:b0
I (21577) mesh_main: Received Routing table[4] 7c:9e:bd:47:1c:e8
I (21587) mesh_main: Received Routing table[5] 7c:9e:bd:49:09:74
I (21587) mesh_main: Received Routing table[6] 7c:9e:bd:47:be:90
I (21597) mesh_main: Received Routing table[7] 7c:9e:bd:47:48:00
I (21507) mesh_main: Received Routing table[8] 94:b9:7e:d2:f8:00
```

Fig. 13. Routing table of root node.

Fig. 14. (Color online) Actual field test chart.

In the actual test field test, the lower computer is placed as shown in Fig. 14. All the lower computers are opened in the whole mesh network, and a lower computer is randomly selected to access the main lower computer according to the serial port. Then, the routing table of the system can be found according to the serial ports of the main and lower computers.

Figure 15 shows the network topology in the actual training. The network topology of the entire agility training system can be obtained by comparing the routing tables of the master terminal, the secondary terminal, and the system routing.

As shown in Table 3, the MAC addresses of all subordinate machines are recorded through the serial port before the network is started.

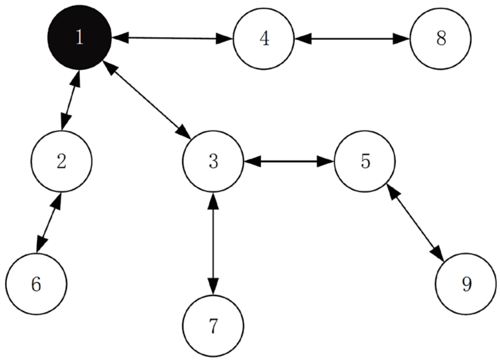


Fig. 15. Wi-Fi packets and mesh packets.

Table 3
MAC addresses of the lower computer.

Serial number	MAC address	Properties of nodes	Layer	Parent node
1	7c:9e:bd:47:67:84	Root node	1	—
2	7c:9e:bd:46:fd:0c	Parent node	2	7c:9e:bd:47:67:84
3	94:b9:7e:e9:9b:a0	Parent node	2	7c:9e:bd:47:67:84
4	7c:9e:bd:49:52:b0	Parent node	2	7c:9e:bd:47:67:84
5	7c:9e:bd:47:1c:e8	Parent node	3	94:b9:7e:e9:9b:a0
6	7c:9e:bd:49:09:74	Leaf node	4	7c:9e:bd:46:fd:0c
7	7c:9e:bd:47:be:90	Leaf node	4	94:b9:7e:e9:9b:a0
8	7c:9e:bd:47:48:00	Leaf node	4	7c:9e:bd:49:52:b0
9	94:b9:7e:d2:f8:00	Leaf node	4	7c:9e:bd:47:1c:e8

After the network is completed, a lower computer is randomly selected to examine the MAC address of the root node through the serial port, and the routing table of the training system network is obtained through the root node for comparison with the MAC table to determine the actual network topology.

4.3 Node response time

The response time is the time taken by the system to respond to a request, and for a single-user system, the response time is a good indicator of the system performance. In this article, the response time refers to the communication time between the primary terminal and the secondary terminal.[21] Specifically, it is the time taken for the sensor at the secondary terminal to be triggered and then transmit the signal to the primary terminal. In the ESP-mesh network, the sensor-mounted device with the ESP as the main control chip is called the lower computer of the system. With increasing number of lower computers, the number of network layers in the system also increases. The response time between all secondary and primary terminals is detected in different numbers of network layers, and the relationship between the number of network layers, n, and the response time t is obtained by taking an average value.

As shown in Fig. 16(a), when $n \leq 2$, the response time is less than 280 ms, and when $n \geq 4$, the response time is more than 310 ms, indicating that when the number of network layers is small, the master terminal can quickly respond to the information of the secondary terminal. However, with increasing numbers of lower computers and network layers, the response time of the master terminal to the secondary terminal increases. The response speed is relatively low.

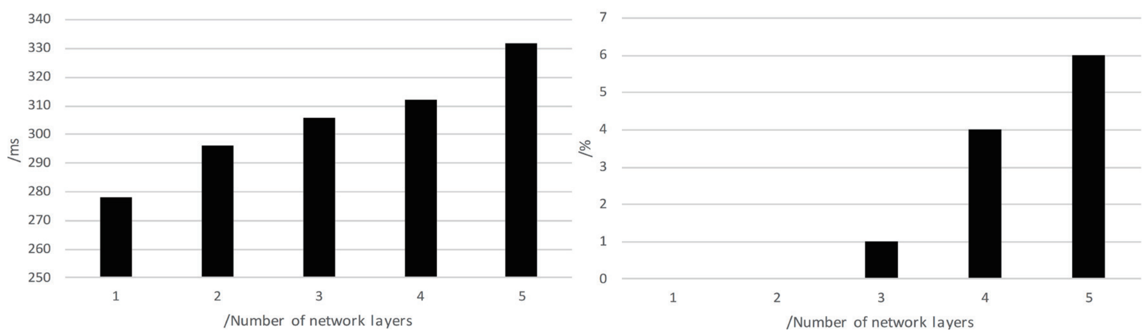
4.4 Packet loss rate

The packet loss rate is the ratio of the number of lost packets to the number of packets in the sent data during the test. It is calculated as [(input packets – output packets)/(input packets)] × 100%.[22] In the ESP-mesh network, when the number of network layers is increased to three or more, the communication between the secondary and primary terminals becomes complicated and may cause packet loss.

As shown in Fig. 16(b), when the number of network layers is one or two, the packet loss rate is 0%. However, when the number of network layers is more than two, packet loss occurs, and the greater the number of layers, the higher the packet loss rate. In the actual training process, the number of lower computers used is usually small, and less than 20 lower computers can meet the basic training requirements. Therefore, the network level in the ESP-mesh network is usually within four layers, and the packet loss rate between terminals is negligible and will not affect the agility training test.

4.5 Related information

In the process of network communication, various indicators affect the communication quality. As shown in Table 4, in addition to the response time and packet loss rate, the network



(a) (b)

Fig. 16. (a) Response time. (b) Packet loss rate.

Table 4
Relevant performance test data of wireless mesh network.

Performance	Time/packet loss rate
Time to last byte	280–350 ms
Loss tolerance	<1%
Networking time	10–15 s
Network access time of new node	<6 s
Re-election time of root node	<8 s
Re-access time of common nodes	<5 s

setup time, the time to connect to the lower computer, and the time to repair a fault of the primary or secondary terminal all represent the quality of the communication.

An increase in the number of lower computers leads to an increase in the number of network layers, and the construction of the network layer by layer increases the network construction time.(23)

5. Sports Tests

To verify the effectiveness of the agility training apparatus in the training of university sports students, 14 students were selected as experimental subjects on the basis of sports test data. Hubei University of Technology was used as the study site. The subjects were divided into a control group and an experimental group according to their training method. There were seven students in each group.

Before the test, all subjects were informed of the possible risks, purpose, process, and relevant precautions during the test. In addition, all subjects were healthy, had no serious illnesses, and had experienced no physical injury in the week before the test.

Before applying the agility training system, we evaluated the physical conditions of the 14 students in the two groups and simply carried out three agility training tests. A sample t-test was used to analyze the difference between the two groups of subjects. As shown in Table 5, the statistic $p > 0.05$ indicated that the results of the two groups of subjects were similar, i.e., there was no significant difference between the experimental group and the control group in terms of relevant physical conditions and agility. Thus, the grouping in this study met the experimental requirements and the subsequent experiments could be carried out.(24)

5.1 Agility training

The control and experimental groups both underwent agility training for 9 weeks, with four training sessions per week of 30 min each. The control group performed traditional agility training in phases, while the experimental group trained with the aid of the agility training apparatus. By comparing four test data of the control and experimental groups at the end of the training, the proposed agility training apparatus was verified to have a significant effect on improving agility. To ensure that the data obtained were valid, each test was conducted three times, then the results of the three tests were averaged. SPSS 21.0 was used to obtain the statistics, which were expressed as mean ± standard deviation, and independent sample t-tests

Table 5
Data sheet on the physical fitness of the experimental subjects.

	Control group (n = 7)	Experimental group (n = 7)	p-value
Age (years)	21.50 ± 1.21	21.25 ± 1.28	0.745
Height (cm)	179.57 ± 1.6	180.01 ± 3.3	0.580
Weight (kg)	70.74 ± 1.88	69.23 ± 1.37	0.136
Body fat (%)	15.38 ± 0.38	15.51 ± 0.29	0.535
BMI (kg m^{-2})	21.96 ± 0.97	21.27 ± 0.58	0.162
Pro agility test (s)	5.22 ± 0.52	5.12 ± 0.19	0.642
Hexagonal test (s)	7.88 ± 0.61	7.61 ± 0.58	0.227
T-run (s)	12.01 ± 0.41	11.90 ± 0.58	0.184
5 m three-way folding test (s)	9.35 ± 0.16	9.49 ± 0.28	0.293
505 agility test (s)	5.52 ± 0.37	5.36 ± 0.29	0.247
15 s standing push-ups (pc)	5.62 ± 0.42	5.57 ± 0.43	0.848

were conducted between the control and experimental groups before and after the experiment for the four indicators, with $p < 0.05$ indicating a significant difference.(25)

The traditional training was divided into three phases: pre-, mid-, and post-training. The pre-phase training includes sliding and running backwards, sitting, clapping to get up in small steps, and so forth. The aim of the training is to give students an understanding of basic agility training, to ensure that movements are completed quickly, and to establish basic movement patterns. The mid-stage training includes hexagonal training, T-running, the 505 agility test, and so forth. This stage focuses on directional training, changes of movement, and anticipation based on the fast completion of movements. The later stages of training are for strengthening and use mechanical equipment such as rope ladders, marker barrels, and straddles to increase the body's explosive power and coordination and further improve agility.

The training of the experimental group was divided into a warm-up phase and an intensive phase. The agility training was designed by consulting physiological and physical training experts, and a number of movements were developed with the aid of the agility training equipment and related mechanical devices. The warm-up phase consisted of a number of agility exercises including frontal touch training, hand and foot touch training, and random placement touch training. The intensive phase included hand and foot touch training, random folding touch training, and random height touch training. In addition, according to the different characteristics of the sports studied by the experimental subjects, the agility training equipment was placed in different positions, and various training methods were designed for special training. For example, in the training of badminton players, the lower computers of the agility training system were placed at nine test points on the field, and the trainer touching the random agility training device while holding the racket was used to simulate hitting a shuttlecock sent by the opponent. Also, in the badminton training, using a metal stand, the agility training equipment was placed at different heights in random combinations to simulate five types of technical response situations (ball hooking, pushing, hanging, killing, and high balls). In basketball, for example, about 15 agility training devices were randomly placed in a basketball half court, and the experimental subject touched the agility devices in a random order while holding a ball to improve their agility.

5.2 Experimental results and analysis

To investigate the differences between the control and experimental groups after training, a sample t-test was used to compare and analyze the data on the various abilities of the experimental subjects, and the results are shown in Table 6.[26]

The experimental group was trained using the agility training equipment, and the control group was trained using conventional training methods. After 9 weeks, the *p*-values for the 5 m three-way fold run and 20 s straddle jump were less than 0.01, indicating a highly significant difference between the effectiveness of the training of the experimental group and the control group. In addition, the *p*-value for the 15 s standing push-up and hexagonal ball response tests was less than 0.05, indicating a significant difference in the effectiveness of training between the experimental and control groups.

In the four different training programs, we tested and analyzed seven subjects in the experimental group, and the results before and after training were compared as shown in Fig. 17, from which it can be seen that the performance of the experimental group improved.

Table 6
Comparison of data between the control and experimental groups after training (n = 14).

Test item	Control group	Experimental group	*p*-value
5 m three-way fold run (s)	8.89 ± 0.10	8.64 ± 0.14	**
20 s straddle jumps (pc)	6.86 ± 0.40	7.52 ± 0.35	**
15 s standing push-ups (pc)	7.62 ± 0.42	8.14 ± 0.30	*
Hexagonal ball reaction test (s)	2.91 ± 0.14	2.67 ± 0.18	*

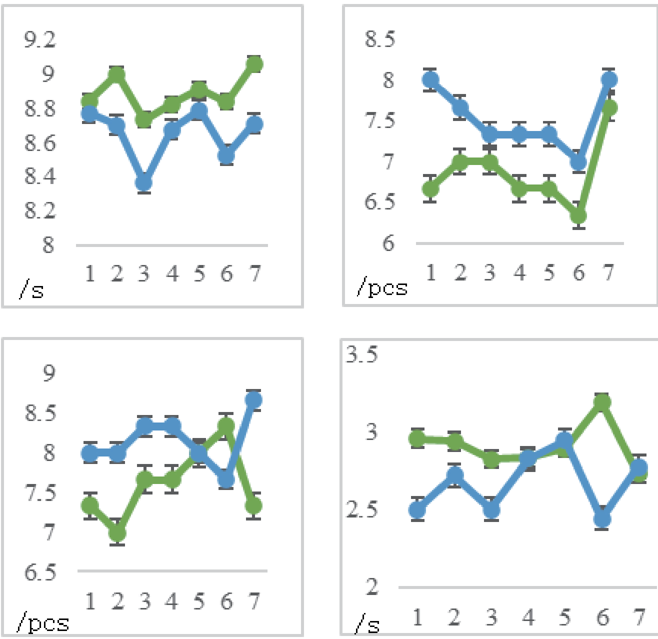


Fig. 17. (Color online) Comparison of test results for the seven subjects in the experimental group before and after training. The blue polyline represents the post-training and the green polyline represents the pre-training.

Numerous studies have shown that agility training improves the ability of athletes to change movement and direction quickly.(27,28) The random long-distance training and random fold running training in the experimental group can fully stimulate the lower limb muscles and improve the strength and flexibility of the muscles in the knees, hips, and ankles, thus improving the reactions of athletes.

The reaction time function of the agility training apparatus allows the identification of weaknesses in the subject's quick changes in direction and helps overcome these weaknesses, a facility that does not exist in traditional training. Therefore, training with the equipment resulted in greater improvement for the subjects in the experimental group. In this group, the random short-distance training, the frontal hand and foot touch training, and the combination of different exercises can fully activate the brain nerves and skeletal muscles at multiple levels, as well as coordinate the upper and lower limbs and enhance their explosive power.(29) The random signal function stimulates the functional state of the cerebral cortex and visual nervous system, allowing the test subjects' nervous system to better recruit motor neurons. Therefore, it can improve the physical coordination and anticipatory decision-making ability of the subjects more effectively than traditional training. The p-values for the 15 s standing push-ups and hexagonal ball response tests were both less than 0.05, indicating that after 9 weeks of agility training, the experimental group showed significant improvement in movement changes and anticipatory decision-making ability compared with the control group. This indicates that the changes in body composition and resting metabolic rate have an impact on the agility of athletes, as also reported by Zhao.(30)

6. Conclusion

In this study, badminton agility training equipment based on an ESP-mesh network was designed, and we introduced the design of the lower module, the upper computer application program, and the mesh network of the agility training equipment in detail. The Internet of Things technology was combined with badminton, and the experimental subjects were selected for the actual exercise test. According to the test results, the following conclusions were drawn:

1) On the basis of the development of the upper and low computers, the agility training system can realize random training, reaction time tests, real-time movement data viewing, and other functions. The mesh network can quickly perform ad hoc networking, realize multi-hop transmission, and quickly restore the network structure, and it has a low transmission delay. When the number of network layers is one, the response time of the nodes is less than 280 ms and the packet loss rate is 0%, which ensures the quality of network communication and satisfies the requirements of the agility training system.
2) We evaluated the proposed agility training equipment on two groups: a control group and an experimental group. The control group was trained by traditional agility training methods, while the experimental group was trained using the agility training equipment. The results show that the training performance of the control group in four different training programs is lower than that of the experimental group. Compared with themselves, the reaction ability of the experimental group was improved after training, which shows that the agility training

equipment can be applied in college courses and has a significant effect on improving the responsiveness of college students.

3) In follow-up research, we will consider adding blood oxygen and heart rate sensors to the lower computer, expanding the lower computer into wearable detection equipment, and monitoring athletes' physiological indexes in real time during agility training. In this way, we can improve the agility of athletes and optimize their training while safeguarding their health.

Acknowledgments

This project is co-funded by the Innovation Research and Development Project of the General Administration of Sport of China (22KJCX024), the Innovation Fund for Co-research Between Chinese Universities and Industries (2022BL052), the industry-school cooperative education project, China Ministry of Education (220900487303708), the National Fitness Key Research and Development Project of General Administration of Sport of China (2015B052), the Innovation and Entrepreneurship Program for College Students of the Ministry of Education of China (Grant no. 201810500024), the Major Project of Research on Philosophy and Social Science of Higher Education Institutions in Hubei Province (21ZD054), and the Major Project of Hubei Key Laboratory of Intelligent Transportation Technology and Devices in Hubei Polytechnic University (2022XZ106), and the Green Technology Leading Program of Hubei University of Technology (CPYF2018009).

References

1 W. J. Chen: J. Phys.: Conf. Series **1992** (2021) 4. https://doi.org/10.1088/1742-6596/1992/4/042026
2 P. Wang, G. H. Lu, and J. C. Feng: J. XI Phys. Edu. Univ. **35** (2018) 410. https://doi.org/10.16063/j.cnki.issn1001-747x.2018.04.005
3 Z. M. Liu and K. L. Li: Modern Electron. Tech. **40** (2017) 54.
4 K. Dong: J. Hum. Mov. Sci. **2** (2021) 4. https://doi.org/10.23977/jhms.2021.020415
5 A. Rusdiana: Songklanakarin J. Sci. Technol. **43** (2021) 448. https://doi.org/10.14456/sjst-psu.2021.58
6 T. Wu: Research and Development of Agile Trainer System Based on ZigBee Technology [D] (Ocean University of China, 2015).
7 K. P. Kuo, H. H. Tsai, C. Y. Lin, and W. T. Wu: Sensors **20** (2020) 6808. https://doi.org/10.3390/s20236808
8 F. Yue: Semiconductor Equipment Technical Reference Manual Chinese to English Practice Report [D] (Shanghai Normal University, 2017) H315.9.
9 D. Q. Li: Harbin Inst. Technol. **1** (2019) 1. https://doi.org/10.27061/d.cnki.ghgdu.2019.002435
10 W. Zhu: Harbin. Inst. Phys. Edu. **29** (2016) 187. G80-05
11 Y. L. Wang, C. D. Ni, K. H. Gao, and C. C. Dong: A Kind of Virtual-real Combination Reaction-time Exercise Test Experimental Device [P] China: CN211097434U (2020).
12 E. P. Wang, L. Xiao, X. Han, B. H. Tan, and L. N. Luo: IEEE Access **10** (2022) 84302. https://doi.org/10.1109/ACCESS.2022.3197285.
13 L. Kai: Research on Wireless Sensing Network Technology in Cabin Based on Spectrum Sensing [D] (Harbin Institute of Technology, 2017) 25–27.
14 Y. Meng, Z. L. Chen, H. Cheng, E. P. Wang, and B. H. Tan: Energies **16** (2023) 1299. https://doi.org/10.3390/en16031299
15 Z. Y. Guo, X. L. Ma, P. Zhang, and Z. Y. Liu: J. Phys. Conf. Ser. **1754** (2021) 1. https://doi.org/10.1088/1742-6596/1754/1/012129
16 X. Hu: Harbin Inst. Technol. **2** (2020) 1. https://doi.org/10.27061/d.cnki.ghgdu.2020.001141

17 Y. Yan, Q. Liu, X. Y. Zhao, and J. L. Mo: J. Kunming Univ. Sci. Technol. (Natural Sciences) **46** (2021) 1. https://doi.org/10.16112/j.cnki.53-1223/n.2021.01.08
18 Y. Kuang, Y. T. Wang, M. J. Wang, G. X. Li, M. Z. Li, and L. H. Zheng: Trans. Chin. Soc. Agric. Mach. **418** (2021) 52. https://doi.org/10.6041/j.issn.1000-1298.2021.S0.053
19 I. A. Muhammad, O. Thomas, K. Z. Uzair, and B. A. Muhammad: J. Sig. Inf. Process. **10** (2019) 29. https://doi.org/10.4236/jsip.2019.102004
20 B. Li, Z. G. Jin, and M. Y. Zhang: Comput. Eng. **34** (2008) 98. https://doi.org/10.3969/j.issn.1000-3428.2008.19.034
21 Y. D. Ni, D. Q. Lu, Q. Yu, Y. Z. Xu, and N. Xie: J. Shanghai Jiao Tong Univ. **55** (2021) 2. https://doi.org/10.16183/j.cnki.jsjtu.2021.S2.009
22 J. F. Zhong, H. J. Wang: Fire. Control. Command Control. **47** (2022) 55. https://doi.org/10.3969/j.issn.1002-0640.2022.02.010
23 R. D. Raut and K. D. Kulat: IEEE Conf. **1** (2011) 1. https://doi.org/10.1109/ICMSAO.2011.5775512
24 X. T. Zhao, Y. B. Zhang, and C. L. Ge: J. Capital. Univ. Phys. Educ. Sports **27** (2015) 249. https://doi.org/10.1093/acrefore/9780190236557.013.224
25 S.Y. Li, M. Yang, J. Z. Shi, Y. F. Wang, Y.Q. Shi, and L. J. Fu: China. Sports. Sci. Technol. **57** (2021) 18. https://doi.org/10.16470/j.csst.2021032
26 B. H. Tan, E. P. Wang, K. Cao, L. Xiao, L. N. Luo: Appl. Sci. **13** (2023) 1113. https://doi.org/10.3390/app13021113
27 J. Y. Liao: Guangzhou. Univ. Phys. Educ. **4** (2021) 1. https://doi.org/10.27042/d.cnki.ggztc.2021.000001
28 F. G. Ramadi, A. Juita, W. Welis: Adv.Social. Sci. Educ. Hum. Res. **464** (2017) 835. https://doi.org/10.2991/assehr.k.200824.186
29 W. B. Wu: Guangzhou Inst. Phys. Edu. **4** (2021) 1. https://doi.org/10.27042/d.cnki.ggztc.2021.000040
30 Y. F. Zhao: Study on the Difference between Sensitive Quality and Influence Mechanism of Physical Education Major and Non-sports College Students [D] (Shenyang Normal University, 2011).

About the Authors

Baohua Tan received his Ph.D. degree from Wuhan University of Technology, Wuhan, China in 2014. Since 2016, he has been a professor at the School of Science at Hubei University of Technology. His research interests include information, measurement, and control technologies. (tbh@hbut.edu.cn)

Kan Cao received his bachelor's degree from Jianghan University, Wuhan, China in 2020 and is currently studying for his master's degree at Hubei University of Technology, China. His research interests are in Internet of Things and sensor applications. (1761165925@qq.com)

Enpu Wang received his bachelor's degree from Shandong University of Technology, Dezhou, China in 2020. He is currently studying for his master's degree at Hubei University of Technology. His research interests are in embedded hardware development and sensor testing. (970981937@qq.com)

Lu Xiao received his bachelor's degree from Shaoyang Institute of Technology, Hunan Province, China in 2020 and is currently studying for his master's degree at Hubei University of Technology. His research interests include embedded system development. (2673942802@qq.com)

Jingxin Nie is studying for her bachelor's degree at Hubei University of Technology, Wuhan, China. Her research interests include public art and visual communication designs. (2967906376@qq.com)

Qinyang Wang is currently studying for her bachelor's degree at Hubei University of Technology, Wuhan, China. Her research interests include electrical automation and electronics technology. (1735023397@qq.com)

Sitong Yang received his bachelor's degree from Shandong Normal University, Jilin, China in 2002 and his master's degree from Wuhan Physical Education University in 2006. He is an associate professor in the Department of Physical Education at Hubei University of Technology. His research interests include sports performance statistics and sports agility training. (sitongyang@hbut.edu.cn)

Lina Luo received her Ph.D. degree from Beijing Sport University, China in 2012. She is an associate professor at the School of Physical Education, Hubei University of Technology. Her research interests include exercise effectiveness assessment, exercise, and exercise prescription. (linaluo@hbut.edu.cn)