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RESEARCH ARTICLE

Design of an Agile Training System Based on Wireless Mesh Network

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ABSTRACT Given the problems of using traditional training methods and insufficient funds in college sports agility training, the agility training system based on Wireless MESH Network is developed. The lower computer realizes the automatic networking between nodes based on the ESP-MESH network, and describes the networking process, intra-group communication and network management of the MESH network in detail. When the number of network layers ≤ 2, the node response time is about 300ms, and the packet loss rate is close to 0, it is proved that the Wireless MESH Network can transmit network data in real-time. The upper computer adopts the software design based on Android, which can view the agility training time of each point in the movement. In this paper, 10 university sports students were trained in stages for up to 9 weeks with the aid of an agility apparatus. After the training, the ability of rapid direction change, movement change and decision-making related to agile quality was significantly improved compared with those before the training ($p < 0.01$). The experimental results show that agile coaches are practical in improving college students' agility.

INDEX TERMS Agile training, reaction time, physical education, communication network optimization, wireless mesh network.

I. INTRODUCTION

Different scholars have come up with different definitions of the concept of agility in recent years, with Lin *et al.* defining agility as the ability of a player's body to rapidly change its displacement trajectory through adjustments in direction and speed in response to the external source of stimulus signals occurring [1]. Ratamess *et al.* considers agility as the ability of an athlete to rapidly change movement in the face of stimuli, and it is a complex motor ability that requires a high degree of integration of multiple physiological systems and physical elements [2]. Some scholars have further enriched its connotation by arguing that agility encompasses balance, coordination and responsiveness to environmental change in addition to speed, and that agility requires the collaboration of the whole system and individual characteristics cannot fully represent this ability [3], [4]. Sensitivity is important for athletes to win, Zhang Peicheng believes that in addition to the proper use of technique and tactics, sparring athletes also need strong sensitivity to cope with the high-intensity practical combat [5]. In volleyball, tennis, badminton or other games, there are often characteristics such as fast offensive and defensive transitions, short hitting times and variable ball flight trajectories, so athletes need to move quickly to react, block the net and hit and dunk the ball, which requires athletes to have outstanding special sensitivity [6]. At the same time, athletes can compensate for the shortcomings of their bodies due to genetic factors by improving agility, reduce the risk of injury and prolong their careers [7].

With the rapid development of modern computer information technology, people's lives have been greatly improved and enhanced, and the field of physical education and sports

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training will also usher in the era of intelligence. Agility training departments in universities still use traditional training, with most of the training equipment being marker barrels, pole wraps, soft ladders etc [8], so it is necessary to upgrade the training equipment and methods. Agility training equipment that already exists such as the FITLIGHT Trainer agility response training system from Canadian is expensive and not suitable for large scale training in universities. Agus Rusdiana's agility training equipment designed in 2021, although randomised through hardware and software, does not measure the combined response time of the user's training [9]. A ZigBee-based agility training device developed by Wu Tao is not networkable between devices and has a limited training range [10]. Wireless MESH Network are less used in sports, so applying wireless self-organising network to agility training expands the scope of training, expands training methods and better enhances agility training for university students. It also improves the robustness and flexibility of the network by avoiding the problem of poor communication quality due to the distance of individual lower computer nodes from the router.

Therefore, this paper designs an agility training apparatus with randomisation, movement time calculation and networking capabilities for use in university teaching and training to improve the agility of students.

II. OVERALL SYSTEM DESIGN

The system is mainly composed of two parts, the upper and lower computer, the system wireless network topology is a tree topology, the system structure diagram is shown in Figure 1. The lower computer node is responsible for the collection, calculation and forwarding of data during the integrated response. The Wireless Mesh Network formed by the ESP32 module increases the coverage area and robustness of the wireless network. The root node of the lower computer is connected to the upper computer by Wifi and is responsible for establishing and maintaining the Wireless MESH Network, storing global routing information, transmitting data sent by the remaining nodes to the upper computer and returning control commands from the upper computer. The upper computer is mainly responsible for sending commands and for the coaches to view the athletes' reaction time information in real time, and to set the number of training sessions for agility training through the mobile app [11].

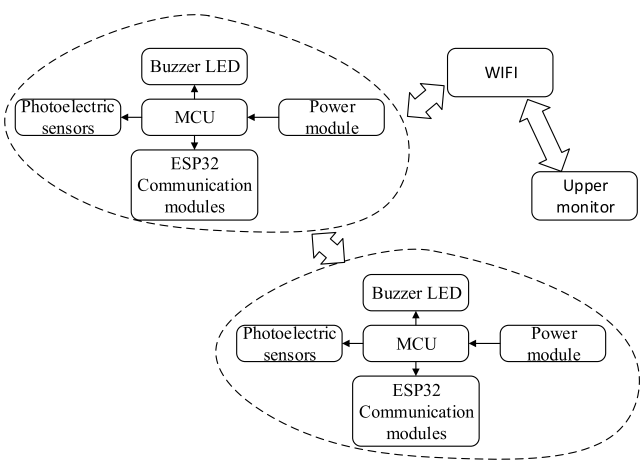

FIGURE 1. System architecture diagram.

III. LOWER COMPUTER SYSTEM DESIGN

A. HARDWARE CIRCUIT DESIGN

The system uses the STC89C52 chip as the main controller, a low-power, high-performance CMOS 8-bit microcontroller operating at up to 35MHz with 8K bytes of system-programmable Flash memory. It contains three 16-bit timers/counters, four external interrupts, a 7-vector 4-stage interrupt structure and a duplex USART [12]. The main controller is responsible for interacting with the ESP module by the serial interface, sensing external trigger messages, displaying the signals acoustically and calculating the integrated response time.

As each module of the lower computer has different requirements for voltage, it is necessary to design different voltage conversion circuits for stable voltage conversion. In this system design, the operating voltage of the photoelectric sensor is 12v, the operating voltage of the main controller and the audio-visual display module is 5v and the operating voltage of the wireless transmission module is 3.3v. A voltage regulator circuit based on LM2596S and AMS1117 chips is used to stabilise the power supply at 5V and 3.3V for the stable operation of each module of the lower computer [13].

The ESP32 is designed and developed by the Chinese company. The ESP32 is designed and developed by China-based Lexin as a standalone system running applications or as a slave device to the host MCU, providing Wi-Fi and Bluetooth functionality via SPI / SDIO or I2C / UART interfaces. Designed for mobile devices, wearable electronics and IoT applications, the chip offers a high level of low power performance including fine resolution clock gating, power saving mode and dynamic voltage regulation.

When the buzzer is in working condition (1.5-15V DC operating voltage), the multi-harmonic oscillator is activated and the impedance matcher pushes the piezoelectric buzzer to sound, outputting an audio signal of 100-500Hz. The power value of the LED used in this design is 1W and the luminous brightness is between 80-90Lm. A stimulus signal is simulated when the LED is illuminated and the buzzer is sounding at a lower computer test point and the athlete needs to get to this test point quickly and trigger the infrared sensor to simulate a training session.

The photoelectric sensor used in this system design is PNP-NC type, when there is no signal trigger, it sends out the same voltage as the VCC power line, at this time output line and power line VCC connected, output high level. When there is a signal trigger, the output line will be in a suspended state, at this time the VCC power line and output line are disconnected, output low level. Its operating voltage

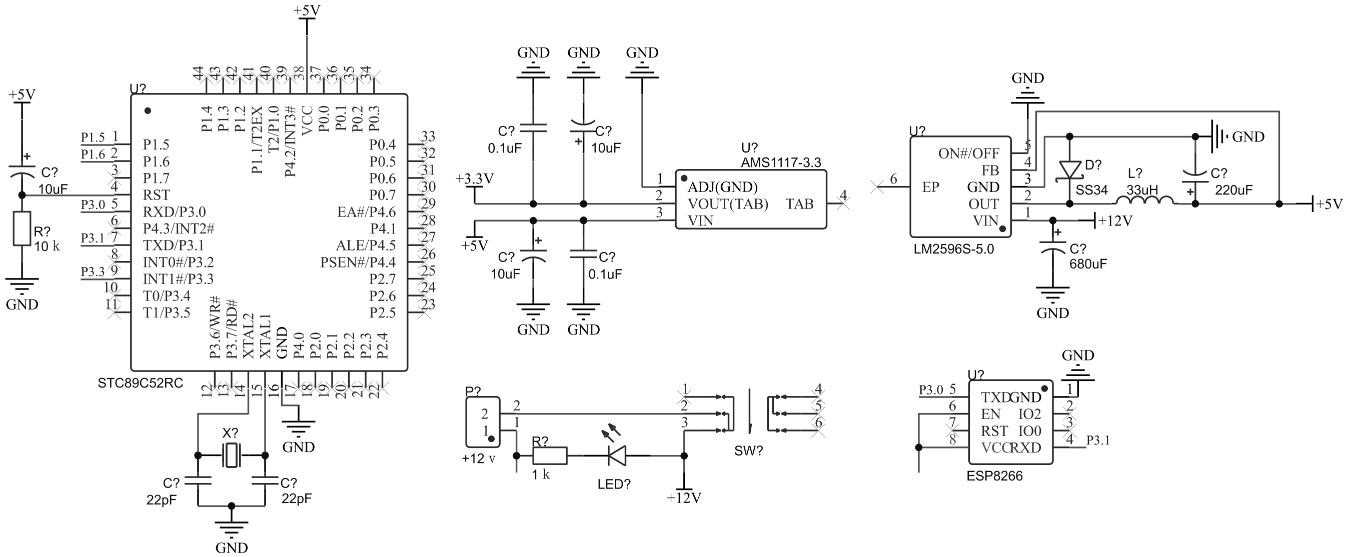

FIGURE 2. Core module circuit of the lower node.

is 10-24V DC, no load current is less than 10mA, the maximum load current is 50mA, switching frequency is 100Hz and monitoring distance is up to 1-200mm (adjustable). The sensor needs to sense external triggering (masking) behavior during training and the trigger signal is communicated at a low level to an external interrupt in the main controller, thus allowing the program within the main controller to operate accordingly [14].

B. SOFTWARE DESIGN

The interaction of information between the communication module and the main controller is important in the design of the lower computer program. This is achieved by creating the function TxData() that sends a single byte, implementing the function send_string_com() that sends a string through the function TxData(), then the function send_string_com() that sends "a" comprehensive response time and the function send_string_sendcom () appends the length of the sent character, and finally, the three functions are wrapped together into one function for sending characters on the serial port. At the same time, the serial port interrupt function which the microprocessor receives information from the serial port, the function will judge the received bytes and pre-set bytes to do the corresponding operation, to achieve the role of the upper computer control and communication of the lower computer.

In addition, the system design also uses two interrupt sources of the main controller: external interrupt and timer interrupt, the initialization of the three interrupts is completed at the beginning of the program, and the serial port interrupt waits for the upper computer to send the flag character, when the serial port finishes receiving a frame of data, the main controller opens INT0 with timer/counter0 interrupt (T0), after accepting the test command from the upper computer, it starts timing and store the data in the variable count until the external interrupt is triggered (the interrupt pin signal generates a jump (low → high)). In the external interrupt response function the timer interrupt is switched off, the timing stops and the external interrupt and timer interrupt are switched off. The main program calculates the integrated response time based on the variable count and the eight-bit timer initial value register data [15].

The external interrupt and timer interrupt will be opened at the same time when the lower computer receives the signal from the upper computer, and when the athlete touches the infrared sensing area, the interrupt will stop and the main program will start to calculate the reaction time. The timer in this design is a 16-bit timer, the crystal frequency is 11.0592Mhz, the clock cycle is 1/12 μs, and 12 clock cycles for a machine cycle, so the machine cycle is 10.85^(−6) s.

TH_0 and TL_0 are the high and low octets of the register respectively, the machine cycle is T_{cy}, the number of this system needs to be noted as N, the number of bits of the timer is x, and the response time t is calculated as shown in (1).

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

IV. UPPER COMPUTER SYSTEM DESIGN

Based on the functional characteristics of the agile training apparatus, the software design of the host computer is divided into two parts, the first part is the establishment of a TCP service port for the lower computer client to connect and achieve real-time communication. The second part is the manual input of the number of times to achieve the effect of random training by the lower computer and to record the integrated reaction time.

A. COMMUNICATION DESIGN

According to the purpose and basic requirements of the design, the upper computer needs to design an Android program that can run in the Android system environment. However, to be able to communicate wirelessly, the device running the program must have the hardware facility of a wireless network adapter and be able to connect to an existing WIFI local area network. The core function of the Android program design is wireless connectivity and communication. Since only wireless communication is required within the LAN, JAVA Socket technology is usedin the design to create and implement wireless connectivity and communication based on the TCP/IP protocol [16]. The system communication flow chart is shown in Figure 3.

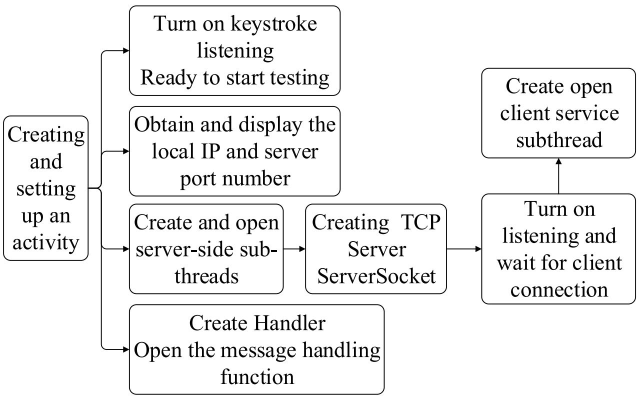

FIGURE 3. System communication flow chart.

Java is a language that can be used for network programming and is closely integrated with the Internet Web, providing two powerful network support mechanisms: classes for URL access to network resources and classes for communicating with sockets to meet a wide range of user requirements. The socket is bound to a specific port so that the TCP layer knows which application to provide the data to. To complete the functional requirements for creating a TCP server, the program needs to create a server-side socket—a TCP server, using the ServerSocket class and turn on listening for client connections. Once a client connects, a thread is created to handle the connection between the client-side and the server-side to handle the client's message interaction separately [17].

B. RESPONSE TRAINING SIMULATION DESIGN

According to the characteristics of the sports agility training system, the upper computer waits for all lower computers to complete networking, and the root node of the lower computer will obtain the MAC address of all sub-node lower computer, which will identify the lower units according to the unique MAC address and communicate with them through the root node. Enter the number of tests by the upper computer app N Afterwards, click to start the test. The upper computer sends the start flag character to the random lower computer and the data is forwarded through the root node,

FIGURE 4. Agility training equipment.

while the main controller opens the timing interrupt and serial interrupt waits for the athlete to trigger and then closes the timing interrupt and serial interrupt, the main controller calculates the reaction time and returns it to the upper computer, waits for the athlete to trigger the lower computer and then the lower computer returns the flag character and the movement time data and views the integrated reaction time through the mobile phone terminal [18]. The flowchart of the upper computer design of the sports agility training system is shown in Figure 5. The agile training process is shown in Figure 4 (a), (b) for the lower computer, (c) for the upper application, and (d) for the display screen.

V. WIRELESS MESH NETWORK

Wireless MESH Network is a new form of network developed on the basis of the Wireless Ad-Hoc Mesh Network which does not need any infrastructure support, the nodes form a multi-hop wireless network by self-organizing [19]. A comparative analysis of existing research papers in the field of Wireless MESH network and Wireless Ad-Hoc MESH Network is shown in Table 1.

According to the characteristics of the Wireless Ad-Hoc Mesh Network, we can find that the network topology is in the process of real-time changes due to the high mobility of nodes, so the research bases are mostly on unmanned aircraft swarms, urban vehicle systems and military communication systems, etc. For example, the vehicle-mounted self-organising network [20], the coordinated operation of military multi-UAS [21], the development of a wireless self-organizing network communication system for rescue and disaster relief [22], etc. The current research hotspots are active and passive routing protocols, which are intended to build more stable networks. The Wireless MESH Network are generally fixed nodes, and in terms of network topology, mesh networks are more stable, and generally only change when interference changes and nodes are accessed and withdrawn. Now, there are still gaps in research in the field of sports, so applying wireless self-organizing networks to

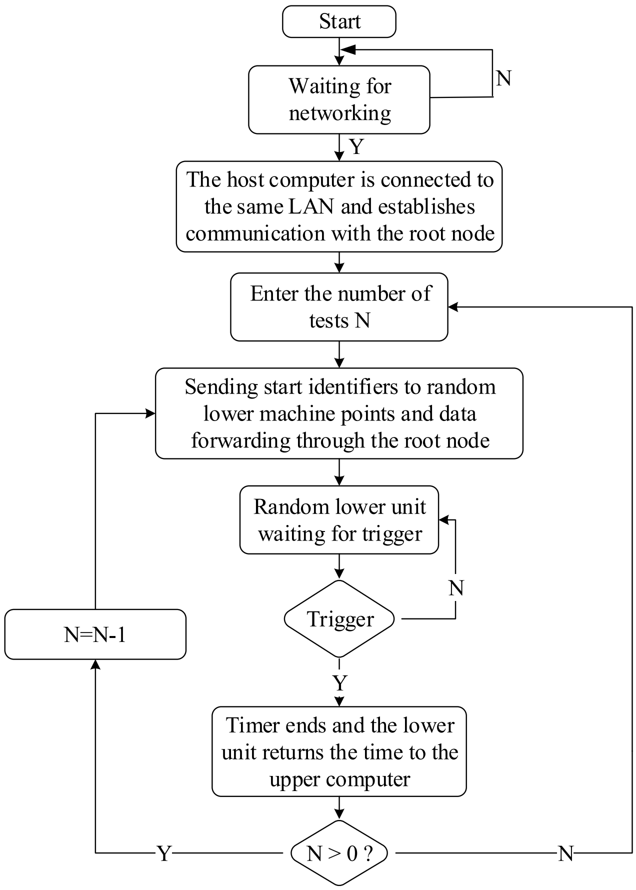

FIGURE 5. Low chart of the upper computer design.

TABLE 1. Comparative analysis of the related studies in the field of wireless mesh network and wireless Ad-Hoc networks.

Wireless Ad-Hoc Mesh Networks		Wireless Mesh Networks	
Direction	Features	Direction	Features
MANET VANET FANET	Centerless, self-organizing, with distributed algorithms; Dynamically changing network topology; Poor security,et.	Node Deployment; Cluster routing algorithms; Multipath routing discovery algorithm	High spectrum efficiency; Strong coverage; High scalability; High reliability

agile training can be a good way to improve the robustness, destructiveness and flexibility of the network.

A traditional infrastructure WiFi Network is a single point to multipoint network. Multiple sensor devices communicate directly with each other and with external devices via the router. As all sensor devices need to be directly connected to the router, they cannot communicate beyond the router's range, while the communication signal gradually fades with increasing distance and the quality of communication is

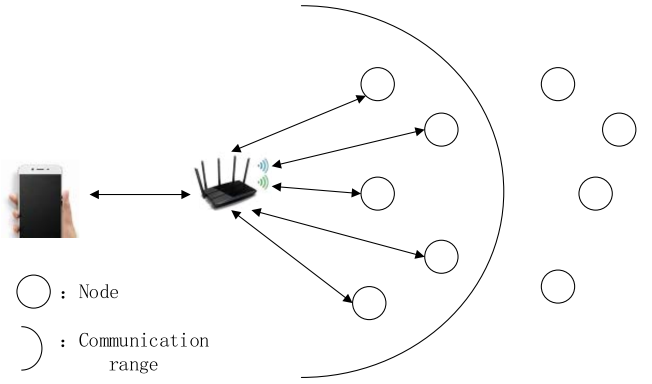

FIGURE 6. Traditional WIFI network architecture.

relatively poor for devices further away from the router. The number of devices allowed in the network is limited by the access capacity of the router and can easily be overloaded. The increased number of sensor devices can also cause problems such as poor communication quality [23]. An illustration of the network architecture is shown in Figure 6.

The ESP-MESH network differs from the traditional Wi-Fi network in that the sensor devices in the network do not all need to be connected to the router, but can be connected to neighboring sensor devices. Each sensor device is responsible for relaying data from the connected devices. The ESP-MESH network has a much wider coverage area as it is not limited to the location of the router and all sensor devices can be interconnected as long as one sensor is connected to the router. Also, as it is no longer limited by the capacity of the router access, the ESP-WIFI-MESH network allows more sensor devices to be connected and is not easily overloaded [24]. An illustration of the network architecture is shown in Figure 7.

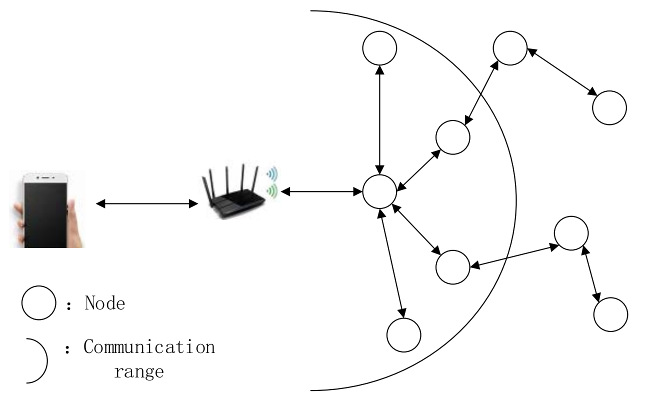

FIGURE 7. Schematic diagram of the mesh network architecture based on ESP32.

A. NETWORK PREPARATION

ESP-MESH network must initialize the LwIP and Wi-Fi software stack before it can start up properly. This is done through the ESP_ERROR_CHECK(nvs_flash_init())

function and ESP_ERROR_CHECK(esp_netif_init()) function to initialise the non-volatile repository and the underlying TCP/IP required stack respectively. The system creates STA and AP mode network interfaces for the node, disables the DHCP server and client, and enables the client only when the node confirms that it has been selected as the root node. The function mdf_wifi_mesh_init() is used to initialize the ESP-Mesh netweorks, register the MESH event handlers, set the main parameters such as the maximum number of network layers, the root node push percentage, the router name and password, and the channel, and finally call esp_mesh_start to start the ESP-MESH network.

B. NETWORKING PROCESS

The ESP-Mesh network is built layer by layer, starting from the root node. The most critical and fundamental part of building a MESH network is to select the most suitable parent node for the downstream nodes and establish a stable and high quality upstream connection. The MESH network node periodically sends WIFI beacon frames containing key information such as node type, current node level, maximum network level, the total number of current network nodes and maximum number of downstream connections allowed. The node sends a beacon frame to broadcast its information, and if an idle node listens to the beacon frame, it will add the node to its list of potential parents, and the idle node will select the best node to establish an upstream connection and join the MESH network according to the rules. The RSSI (Received Signal Strength Indicator) indicates the strength of the connection signal between a potential parent node and the currently idle node threshold determination mechanism. To prevent weak connections from forming between nodes: if a node detects that the RSSI value of an upstream node's beacon frame is less than a preset signal strength threshold, it will ignore the upstream node when establishing an upstream connection [25]. The automatic root node selection flowchart is shown in Figure 8.

Received Signal Strength Indication RSSI ranging is a ranging-based positioning algorithm [26], which completes signal ranging and positioning based on the relationship between signal spatial propagation attenuation and transmission distance, calculated as

$$RSSI(\mathrm{d}) = RSSI(\mathrm{d_0}) + 10\mathrm{n_0}\lg(\frac{\mathrm{d}}{\mathrm{d_0}}) + \mathrm{x}_\partial \qquad (2)$$

in equation (2), $RSSI(d)$ represents the signal strength at a distance d the signal strength in dBm that can be received at the distance from the source. $\mathrm{RSSI(d_0)}$ denotes the reference distance d_0 the signal strength received at the reference distance. n_0 denotes the transmission path loss factor. $X\sigma$ 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.

Test the communication quality under different signal strengths. In the ESP32 program, the designer sends 20 packets to the server every second. Use NetAssist software on the PC to establish a TCP server with an IP of 192.168.1.185,

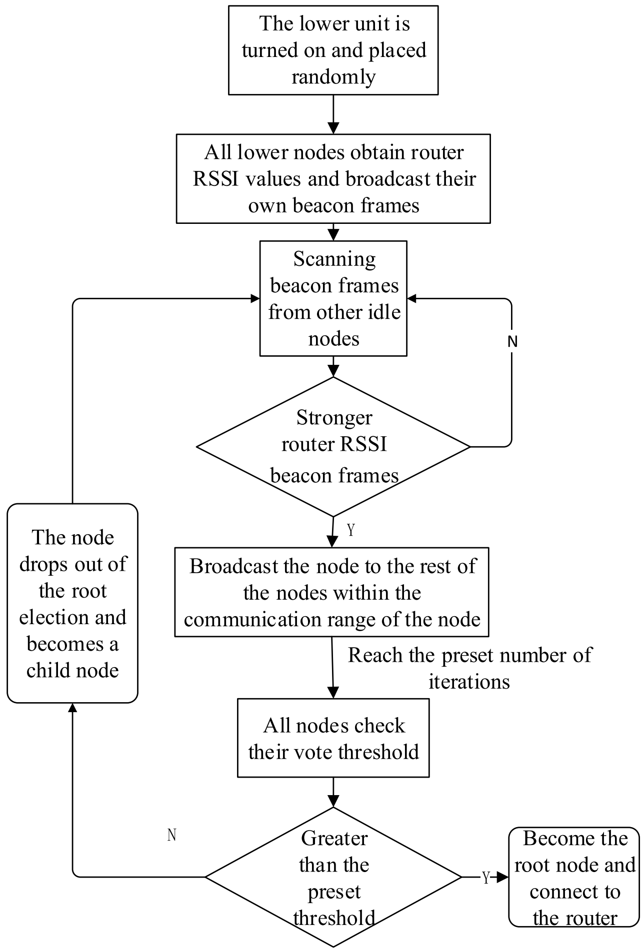

FIGURE 8. Flow chart for automatic root node selection.

the port number is set to 8082. Start the mesh node, and the node will continue to upload data. Wireshark software is used to capture packets and analyze network conditions. The IO chart of packet capture statistics is shown in the figure. The abscissa is the time axis and the ordinate is the number of packets received per second.

Generally between −50 and 0 dBm, the signal strength is very good, the stronger the communication quality, the more stable the signal transmission. This is shown in Figure 9, according to statistics, when the signal strength value is 35, 19.7 PPS packets per second are received. Between −70 and −50 dBm, the signal strength is slightly better, the use of perception is slightly worse, but the experience has no significant impact, and the transmission performance meets the general requirements. This is shown in Figure 10, according to statistics, when the signal strength value is −55dBm, 18.9 PPS packets per second are received. Below −70 dBm the signal is poor, the perception of use is poor and the transmission performance is not so good. This is shown in Figure 11, according to statistics, when the signal strength value is 75, the quality of the communication is very unstable, and in many cases, the number of packets received is less

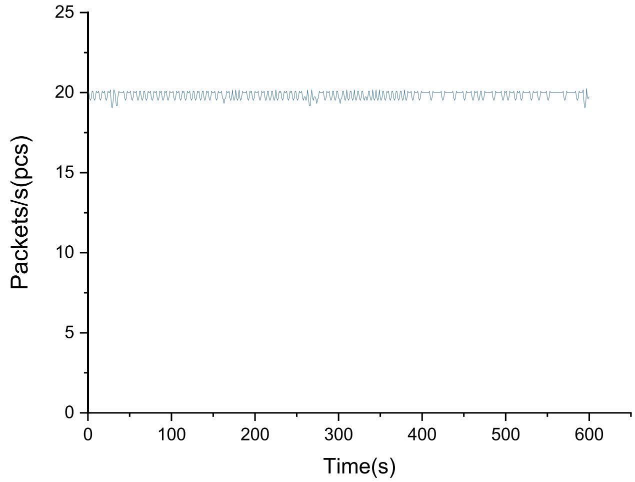

FIGURE 9. Wireshark packet capture statistics at RSSI = −35.

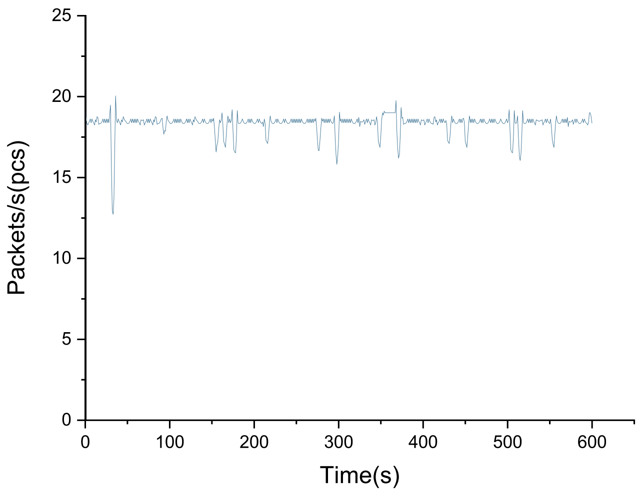

FIGURE 10. Wireshark packet capture statistics at RSSI = −55.

than 10, the signal transmission rate of the network is the key to the performance of the network [27].

Upon the successful election of the automatic root node, it will be connected to the router and all lower unit devices within the range of the root node will start connecting to the root node, thus forming a layer 2 network. Upon successful connection, the lower computer in the layer 2 network will become intermediate parent nodes. The remaining lower computer will connect to the intermediate parent node within the communication range and form a new layer. This is done until all downlink devices have joined the MESH network or have reached the maximum allowed layer of the network.

As shown in Figure 12, at this point the root node is within range of the free node G. Since the root node A is at the shallowest layer in the network, it will be the preferred parent of the node G. When choosing between candidate parents located at the root node and the second layer, the root node will always take precedence as the preferred parent.

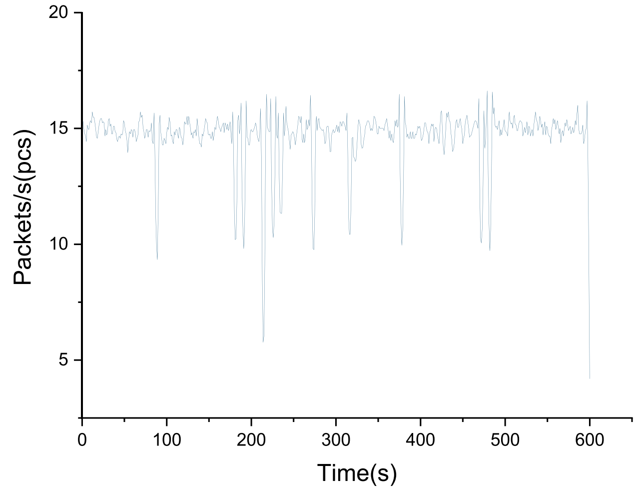

FIGURE 11. Wireshark packet capture statistics at RSSI = −75.

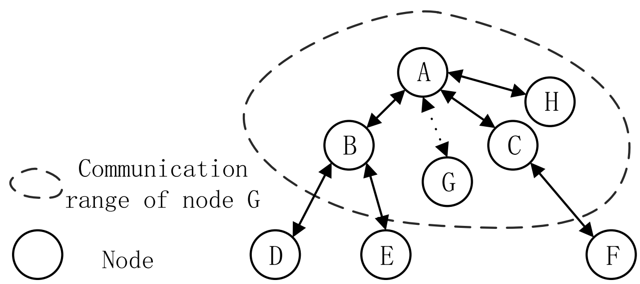

FIGURE 12. Preferred parent node selection.

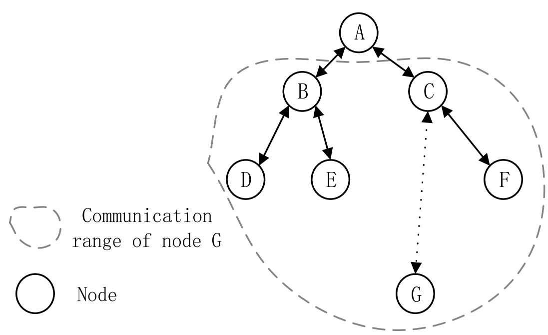

FIGURE 13. Preferred parent node selection.

As shown in Figure 13, the shallowest node in the range of the idle node G contains the node B and the node C. The number of children of the node B is 2 and the number of children of the node C is 1, so the node C will be the preferred parent of the idle node C. If there are multiple candidate parents on the same layer, the candidate parent with the fewest children will be the preferred parent. This helps to balance the number of downstream connections of nodes on the same layer.

To prevent the network from exceeding the maximum allowed tier, nodes on the maximum allowed tier will become leaf nodes after they have completed their connections. In this way, other idle nodes will not be able to form connections with the leaf nodes on these maximum allowed tiers and therefore will not exceed the maximum allowed tiers. However, if the idle node is unable to find another potential parent node, it will remain idle indefinitely [28].

C. INTRANET COMMUNICATION

Once the network is successfully formed, all subordinators in the MESH network maintain their routing tables to find the correct transmission path for each packet passing through the device and to deliver the data efficiently to the destination node. the routing table of a subordinate in the parent position in the MESH network will contain the MAC address of all nodes in the device's subnet, as well as the device's own MAC address. MESH network uses the routing table for forwarding to determine whether incoming packets should be forwarded upstream or downstream [29].

The esp_mesh_send (const mesh_addr_t *to, const mesh_data_t *data, int flag, const mesh_opt_t opt[], int opt_count) function is used to send packets over the MESH network, either to any device on the network or to an external IP network — the host computer. The parameter const mesh_addr_t *to indicates the packet destination address, which is divided into the MAC address of the node in the network and the IP address of the external network. When a packet is sent to an external IP network, the packet is first transmitted to the root node and then passed from the root node to the external network, where the IPv4:PORT is written into the parameter. The parameter const mesh_data_t *data is a pointer to the packet to be sent, where the transmission type is of P2P type. The parameter int flag is set to MESH_DATA_P2P when the packet is sent to a node inside the mesh, or MESH_DATA_TODS when the packet is sent to an external IP node. If the root node sends a packet from an external IP network to an internal ESP Mesh device and needs the internal device to reply to the packet, the identifier MESH_OPT_RECV_DS_ADDR needs to be added to the destination domain address. The intra-group packet forwarding flow diagram is shown in Figure 14.

The specific packing format of a mesh data frame is shown in Table 2. The data frame contains a start flag, a MAC address, a separator sequence, the data content, and an end flag.

In the agile training system, the Mesh network is mainly used to upload the motion-time data collected by the nodes and to send the lower computer start-up commands, so the user meshs data frame of the root node is shown in Figure 15.

D. NETWORK MANAGEMENT

1) PARENT NODE FAILURE

If the root node is disconnected from the network due to a power failure or equipment failure, the node of the second layer will detect the root node failure and disconnect from it in time. The node of the second layer will actively try to reconnect with the root node. However, after several failed connections, a new round of the root node elections will be initiated. According to the root election process, the nodes with the strongest RSSI value in the second layer will be elected as the new root node, while the remaining the nodes of the second layer will form an upstream connection with the new root node, or with its adjacent parent node if the nodes of the second layer is not in the root range. If the root node and the nodes in the following in layers (root, second layer and third layer nodes) are disconnected at the same time, the nodes in the shallowest layer that are still working properly will initiate the root node election. It has been tested in practice that if the root node is abnormal, the network detects the problem and generates a new root node in less than 10 seconds [30].

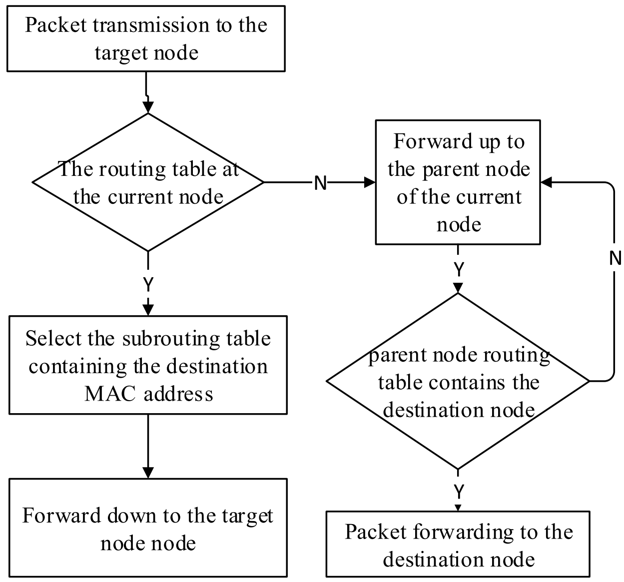

FIGURE 14. Flow chart of packet intra-group forwarding.

TABLE 2. Message packing format.

Number	Name	Memory	Detailed description
1	Start sign	5 bytes	0xFF
2	Mac address	6 bytes	Destination Node
3	Separation	6 bytes	0xFF
4	Data content	8 bytes	Data during exercise
5	End marks	3 bytes	0xFFFFFF

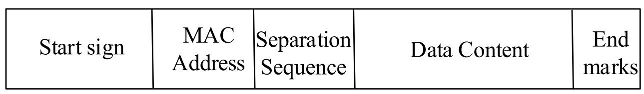

FIGURE 15. Data frames.

2) INTERMEDIATE PARENT NODE FAILURE

If an intermediate parent node is disconnected from the network due to a failure, the child nodes connected to it will make multiple attempts to reconnect with that parent node.

After several failed reconnection attempts, each child node starts scanning for potential parents.

If more than one potential parent node is available, each child node will select a new parent according to the preferred parent rule and form an upstream connection to it. If a parent node is abnormal, within 5 seconds of testing the child node will detect the problem and connect to the new parent node [31].

3) ROOT NODE SWITCHING

Root node switching is the act of explicitly initiating a new election process, where a node with a stronger router RSSI is elected as the new root node. This can be used to counteract the degraded performance of the root node. The MESH network does not automatically switch root nodes unless the root node is disconnected from the network. Even if the RSSI value of the root node is reduced to the point where it must be disconnected, the root node will remain continuously connected.

When the current network needs to trigger a root switch, the root node must explicitly call the esp_mesh_waive_root() function to trigger a new election. At the moment the root node will ask all nodes in the network to send and scan beacon frames using the broadcast, at which point it will remain networked. According to the root selection rules, if another node receives more votes than the current root node, the root switching process will be initiated, otherwise, the root node will remain unchanged.

The newly selected root node sends a switch request to the current root node, and the original root node returns a response notification indicating that it is ready to make the switch. Once the response is received, the newly selected root node will disconnect from its parent node and quickly form an uplink connection to the router, becoming a new root node in the network. The original root node will disconnect from the router while maintaining all downlink connections and entering an idle state. The previous root node will start scanning for potential parents and select the preferred parent [32].

4) ASYNCHRONOUS POWER-ON RESET

The MESH network may be affected by the order in which nodes are powered up. If some nodes in the network join after the networking is complete, the final topology of the network may differ from the ideal situation when all nodes are powered up simultaneously. If the root node already exists in the network, a newly joined node will not become the new root node, even if its router RSSI is stronger. Instead, the delayed node, like any other idle node, will join the network by connecting to its preferred parent.

When a newly joined node forms an uplink and becomes an intermediate parent, it can also become the new preferred parent of other nodes, i.e. shallow nodes.

5) PARENT NODE SWITCHING

Parent switching is when a child node switches its upstream connection to another parent node at a shallower level. Parent switching is automatic, which means that a child node will automatically change its uplink connection if a potential parent node at a shallower layer becomes available. All potential parents will periodically send beacon frames, thus allowing the child node to scan for the availability of the parent node at the shallower layer. to ensure that each connection has a good RSSI value and that there are minimal layers in the network.

E. NETWORK PERFORMANCE ANALYSIS

1) NETWORK TOPOLOGY

To obtain the actual network topology after the networking is completed, the MAC address of all the lower computers are recorded, the routing table of the root node and all the parent nodes that are in the network layer 2 are viewed through the serial port,and compared with the MAC address to determine the network topology of the agile training system. MAC address as a unique identification of the device solidified in the hardware system. The MAC address of the subordinate machines is shown in the TABLE 3.

TABLE 3. **Table of MAC addresses of the lower unit.**

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

After all the lower computers are placed on the training site according to the training requirements, they are switched on and wait for the networking to be completed. A randomly selected lower computer obtains the root node information via the serial port, finds the root lower computer and again obtains the routing table for the entire agile training system via the serial port. The root node routing table is shown in Figure 16.

The network topology of the agile training system was finally obtained by looking at the root node and parent node routing tables and comparing them with the recorded MAC addresses. This is shown in Figure 17.

When data transmission between the target and source nodes is not within the scope of direct communication, communication can be achieved using intermediate node relays

```
<MESH_EVENT_ROUTING_TABLE_ADD>add 1,new: 8
<MESH_EVENT_ROUTING_TABLE_ADD>add 1,new: 9
sent publish returned meg_id=52148
sending routing table to [0] 7e 9e:bd;47;ic:e8: sent with err code: 0
Received Routing table [0] 7e:9e:bd:47:1c:e8
Received Routing table [1] 94:b9:7e:e9:9b:a0
Received Routing table [2] 7c:9e:bd:47:67:84
Received Routing table [3] 7c:9e:bd:47:be:90
Received Routing table [4] 7c:9e:bd:49:52:b0
Received Routing table [5] 7c:9e:bd:47:48:00
Sending routing tabie to [2] 7c:9e:bd:47:67:84: sent with err code:0
Received Routing table [6] 7c:9e:bd:49:09:74
Sending routing tabie to [3] 94:b9:7e;e9:9b:a0: sent with err code:0
Received Routing table [7] 94:b9:7e:d2:f8:00
Sending routing tabie to [4] 7c:9e:bd:49:52:b0: sent with err code:0
Received Routing table [8] 7c:9e:bd:46:fd:0c
Sending routing tabie to [6] 7c:9e:bd:47:67:84: sent with err code:0
Sending routing tabie to [7] 7c:9e:bd:47:67:84: sent with err code:0
Sending routing tabie to [8] 7c:9e:bd:47:67:84: sent with err code:0
```

FIGURE 16. **Root node routing table.**

FIGURE 17. **Network topology of the training system.**

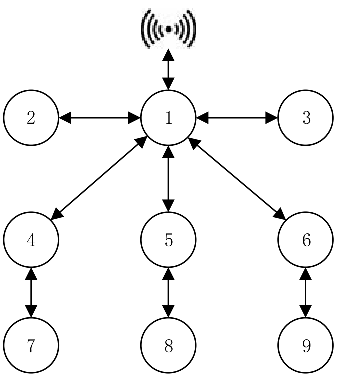

FIGURE 18. **Network topology of the training system.**

As shown in Figure 18, node 7 in the diagram cannot communicate directly with node 1 but can communicate via path 7 to 4 into 1.

As shown in Figure 19. When we change the location of the mobile hotspot and view the root node and parent node routing information again, we can see that the network topology has changed, this is because the RSSI values of all the nodes in the lower computer have changed and the node with the strongest RSSI value has been re-elected as the root node, followed by the rest of the nodes making new network connections according to the rules, forming a new topology.

FIGURE 19. **Network topology of the training system.**

2) RESPONSE TIME TEST

The response time is the time difference between sending a packet to a leaf node of the MESH network endpoint and receiving a return message from the root node [33]. The response time from the root node device to the end device is tested at different network layers by continuously adding devices with self-assembling capabilities between the end lower sensor devices to form a network structure with different hop counts. Each set of tests was repeated 20 times, and the relationship between the number of hops n and the response time t between the root node device and its destination node device was obtained after taking the average value, as shown in Figure 20.

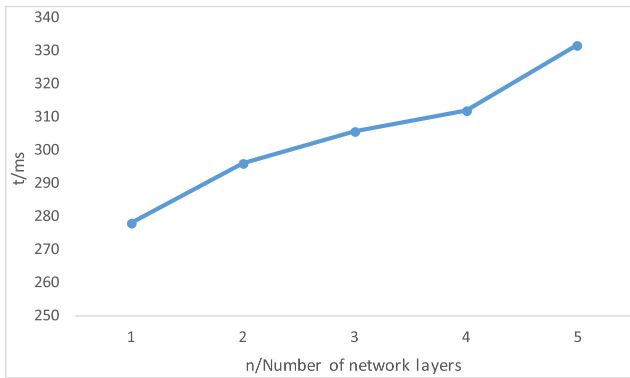

FIGURE 20. **Network layers versus response time.**

It can be seen that when $n \leq 2$, the response time is short, less than 300ms, while when the number of network layers reaches five, the response time of communication between the root node and the leaf node reaches about 330ms. Therefore, too many network layers will lead to more data forwarding and longer response time in the MESH network, which will eventually cause the communication quality to degrade. The number of agile training system lower devices is generally less than 15, limited by the range of sports fields, the number of network layers will not exceed four, so the response time of nodes forwarding data will not be too long and will not have an impact on training.

3) PACKET LOSS RATE TEST

The packet loss rate is the ratio of the number of packets lost in a test to the number of data sets sent [34]. In agile training MESH network, when the number of network layers reaches three or more, the root node and leaf nodes communicate with each other or the parent node and leaf nodes communicate with each other requiring forwarding by other nodes. Therefore, an excessive number of network layers will lead to a large number of retransmissions of messages in the network and a serious decrease in communication efficiency. The packet loss rate at different network layers is shown in Figure 21.

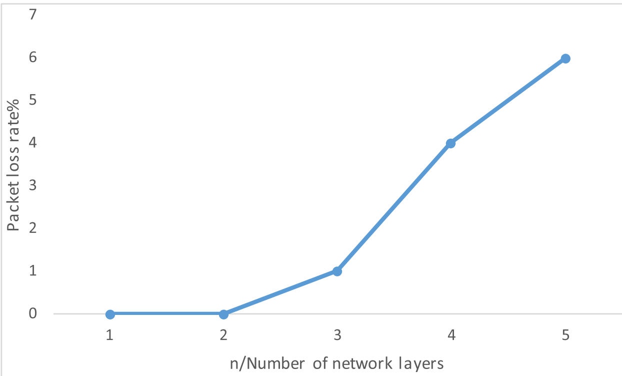

FIGURE 21. Network layers versus packet loss rate.

When the number of network layers is n = 2, the packet loss rate is almost 0. As the number of network layers increases, the packet loss rate gradually increases and reaches about 6% when the number of network layers n = 5. The agile training system generally has less than 15 devices in the lower computer, the number of network layers does not exceed three, and the data transmission volume is small, so the packet loss rate of data forwarded by the nodes is low and does not affect the training.

4) RELEVANT PERFORMANCE PARAMETERS

Testing of the MESH network's networking performance, including networking time, new node join time, root node failure cure time, and sub-node failure cure time The test results are shown in Table 4.

TABLE 4. Mesh network related performance parameters.

Performance	Time/Packet loss rate
Network build time	8s-15s
Node join time	<10s
Root node failure repair time	<10s
Sub-node failure repair time	<5s
Node response time (in three layers)	280ms-350ms
Packet loss rate (within three layers)	<1%

VI. EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

A. SUBJECTS AND TEST METHODS

Ten male students from the School of Physical Education of the Hubei University of Technology were selected as the subjects of the study. All subjects were informed of the purpose of the test, the procedure, the possible risks and related precautions. All athletes were free from injuries and heavy training loads 1 week before the test. The basic profile of the athletes is shown in Table 6.

TABLE 5. Test action statistics table.

Classification	Test index
Fast change of direction	T-run test 4×10M folding run 36m moving run
Change of movement ability	Metric movement 20 seconds of repeated straddle Cross quadrant jump Kneeling jump up Standing Push-ups
Pre-judgmental ability	Hexagonal jump Hexagonal reaction ball Y-responsiveness test

Zhao Xitang's research on the quality of athletic agility has divided it into the ability to anticipate decisions, change movements and quick changes of direction [35]. According to the different abilities, there are different agility tests. The T-run test, the three-point toss run, the 20-second repeated horizontal jump, the 15-second standing push-up and the hexagonal reaction ball were selected to reflect the agility of university men. Test action statistics are shown in Table 5. The physical form and specific agility qualities of the students were measured before the experiment. The students' specific agility qualities were measured after the experiment. SPSS 21.0 was used for the statistics, and the data were expressed as mean ± standard deviation. T-test was conducted for each index of agility quality, and P-value was used for all differences between groups, with $P < 0.05$ indicating a significant difference [36].

B. TRAINING METHODS

General agility aims to develop the body's ability to coordinate a variety of movements, while special agility is more related to the sport in question, such as the initiation and braking of basketball and volleyball. Closed and open agility can be divided into closed and open agility, with closed agility being the ability to perform a fixed movement in a fixed position on a defined route and a predictable environment, with the aim of optimising the movement pattern and the speed of the fixed movement, which is also used as a coordination quality in some theories [37]. The training is divided into three phases with different content. By asking physiology and physical training experts for advice, the agility training content is designed in a targeted manner and several training movements are developed with the help of agility training equipment and related mechanical equipment. Closed agility was combined with open agility to enhance the agility training. Some of the training diagrams are shown in Figure 22. The training schedule is shown in Table 7.

TABLE 6. **Data sheet on the physical fitness of the experimental subjects.**

Name	Age (years)	Height (cm)	Weight (Kg)	1 (sec)	2 (sec)	3 (pcs)	4 (pcs)	5(sec)
Wang**	21	175	62.3	13.28	9.31	5.33	5.33	3.53
Xiao**	20	176	66.3	13.12	9.47	5.67	5.00	3.45
Cao*	21	178	67.5	13.16	9.25	6.33	5.67	3.43
Yuan**	21	179	64.9	13.31	9.40	5.67	5.67	3.35
Duan**	20	180	68.9	12.83	9.22	5.67	6.00	3.31
Wang**	20	179	68.0	13.14	9.30	5.33	6.33	3.77
Xiao**	20	178	67.2	13.19	9.50	6.67	5.33	3.30
Tian**	21	184	70.5	12.93	9.46	6.00	5.33	3.51
Chen**	21	180	71.5	13.05	9.15	6.33	5.33	3.69
Meng*	21	181	72.4	12.97	9.27	5.00	6.00	3.41
Average	20.60	179	67.95	13.10	9.33	5.8	5.6	3.47
Standard deviation	0.49	2.41	2.91	0.14	0.11	0.49	0.39	0.15

Note: 1: T-run test; 2: Three-point folding run; 3: 15s standing push-ups;4: 20s repeated horizontal jump;5: Hexagonal reaction ball
15s standing push-ups and 20s repetitive horizontal jumps Three separate tests averaged for the final score

(a) Frontal hand and foot touch training (b) Net picking training (c) Badminton full court simulation training

FIGURE 22. **Part of the training.**

C. RESULTS AND ANALYSIS

At the end of the training, the subjects were retested on the T-run test, 5m three-way turn back run, the 20-second repetitive straddle jump, the 15-second standing push-up and the hexagonal reaction test to determine the changes in the subjects' ability to change direction quickly, anticipate decisions and change movements. The comparison of the results of the indicators before and after training is shown in Table 8.

Table 8 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, indicating a highly significant improvement in the subject's responsiveness after training.

After the training, it can be seen from Figure 23 that the T-run, 5m three-way turn back run and hex ball response test was reduced by 7.63%, 5.47%,and 16.43% respectively compared with before training. The 20s span jump and 15s standups improved by 22.41% and 33.39% respectively compared with before training. The training of agile training instruments is based on the traditional training methods, adding randomness. It requires that the trainer's nervous system highly matches the physical activities, and the hand, eye and brain should be flexible. By continuing this high-intensity stimulation, the trainer's response ability can be effectively improved. The random placement and random signals of agile training equipment can realize the training of different distances, different heights and different movement modes, and realize different needs in combination with the movement characteristics of different movements.

Short distance random placement training and hand and foot touch training in agile training can enhance the stability of the limbs, the coordination ability between muscles and the control ability between nerves and muscles, to improve the predictive decision-making and physical coordination ability of the tester. Therefore, after the training, the test results of the subjects' the 20s repeated crossing and hexagonal ball test will be improved. The six- week agile balance response training designed by zemkov á e and others is similar to the training content with the help of agile training instruments. Both of them are comprehensive training for a variety of agile abilities. The results show that the training combining agility and balance improves the dynamic balance under visual control, improves the ability of muscle contraction, and better

TABLE 7. Data sheet on the physical fitness of the experimental subjects.

Training phase	Training objectives	Training content	Training sets
Foundation Stage	Establishing basic movement patterns under fast completion conditions and improving fast neuromuscular coordination.	Speeding and intrinsic directional training movement variation exercises: random hand and foot touch training, short distance random reaction training, random fold and run training, etc.	1-2 weeks 2-5 sets per session 3 times a week
Enhancement phase	Practice with elements of strength and speed of movement based on quick completion of movements.	Exercises with variation in elements such as directionality, speed ,and responsiveness: kneeling up touch training, Random long distance reaction training, turn around random touch training, etc	3-5 weeks 2-5 sets per session 3 times a week
Specialized phase	To improve the accuracy and anticipation of movements based on the development of elements such as explosive power.	Different movements are designed according to the characteristics of different sports: badminton is combined with the placement of equipment at random heights on the basketball, basketball with the use of nets for wide range training, etc.	6-8 weeks 2-5 sets per session 3 times a week

TABLE 8. Comparison of test results before and after training (N = 10).

Test indicators	Pre-training	Post-training	P-value
1(sec)	13.10±0.15	12.10±0.08	**
2(sec)	9.33±0.11	8.82±0.11	**
3(pcs)	5.60±0.39	7.47±0.43	**
4(pcs)	5.80±0.49	7.10±0.52	**
5(sec)	3.47±0.15	2.90±0.12	**

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

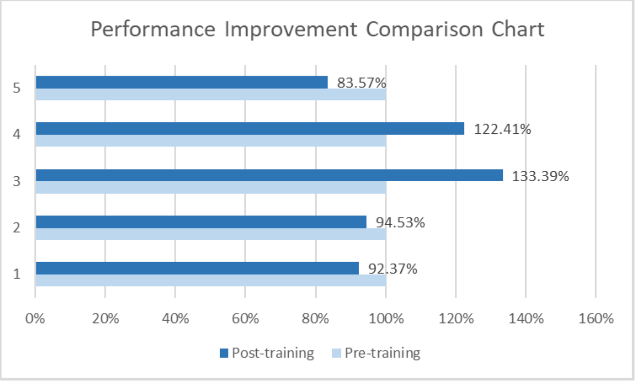

FIGURE 23. Comparison chart of performance before and after training.

improves agility [38]. Astrid *et al.* also concluded through experiments that agility and balance training are effective in improving posture and neuromuscular control [39].

The long-distance random placement point training, random turn back running training and random height training are the training combining speed, body disguise and coordination, and reaction ability, so as to improve the coordination and movement effect of muscles in all links of athletes' movement process, and help the direction change and acceleration in different training methods, body coordination under braking and buffering conditions, and the speed and power of upper and lower limbs' movement. Therefore, after the training, the test results of the 5m three-way turn back run and T-run will be improved.

Training according to the characteristics of different movements can transform complex body movements into regular behaviors. The brain controls muscles, joints and bones to cooperate to complete the established movement procedures, strengthen muscle memory, and flexible joints, enhance the efficiency of foot movement, and better control the whole body's power and coordination. Therefore, after the training, the test results of the subjects' 15s standing and lying support tests will be improved. Mohr *et al.* tested the agility before and after Volleyball Teaching and proved that training combined with sports has a good effect on improving agility [40]. Rogozhnikov *et al.* used fit light for basketball training. The results showed that the number of errors in dribbling decreased by nearly half, about 43.6% [41]. This is mainly because the use of agile training equipment can not only improve the neuromuscular connection but also improve the athlete's touch.

VII. CONCLUSION

The paper designs a distributed agile training device based on an embedded system and an Android program. The paper describes the design of the lower computer module and upper computer App of the agile trainer, as well as the networking process and networking rules of the MESH network, and tests the topology, response time and packet loss rate of the mesh network. Through nine weeks of agility training, the following conclusions are drawn:

1) The experimental results show that the random distributed agile trainer based on esp-mesh designed in this paper can realize the functions of free distribution, wireless connection, communication and real-time display of comprehensive response time, and can be well applied to college physical education.

2) The experimental results show that using the ESP-MESH based random distribution training designed in this paper, the agility quality data of experimental subjects have been significantly improved. This shows that, compared with the traditional training methods, the agile trainer designed in this paper can effectively improve the agility quality of college students.

3) By constructing the MESH network based on the ESP32 communication module, the response time is about 300ms and the packet loss rate is about 6% when the number of network layers is ≤ 3. It proves that the lower computer nodes can transmit data in motion in real-time through Wireless MESH Network. It also demonstrates that the lower computers can access the network via power-up, which is very convenient and allows more lower computers to access the network, thus extending the training coverage better than the traditional ''one-to-many'' type of agility training apparatus.

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