Design and implementation of smart flying ball target based on APP

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Abstract. Home entertainment smart products have gradually become a hot topic. At present, home entertainment smart products are relatively simple to implement. They mainly use hardware or software methods to control and transmit information through Bluetooth or Zigbee. In order to solve the shortcomings of home entertainment intelligent products that lack intelligence and a single design method in the current market, this article uses embedded technology and Wi-Fi communication technology to design an intelligent flying ball target control system based on Android APP. Based on the hardware platform, the filtering algorithm and scoring algorithm of the flying target are studied. The flying target software system based on μC / GUI and μC / OS-III is written. The Android operating system is designed to connect to the flying ball target APP.

1. Introduction

1.1. Research background
Home entertainment smart hardware is a technology concept following the Internet of Things. Add intelligence and remote-control capabilities by adding relevant intelligent algorithms to the entertainment hardware platform [1]. When the product is connected to a wireless network, it can realize the function of loading Internet services, with added value such as big data [2]. With the increasing market demand of the Android platform and the rapid development of intelligent technology, software development based on the android operating system has become a new hot spot, and Android APP access to hardware devices has become a topic of much concern. This article is based on the concept of home entertainment intelligent hardware. In order to solve the problems in the implementation of the multi-sensor data acquisition system and intelligent platform control, and to achieve stable and easy-to-configure control between the embedded hardware system and the mobile APP platform, the intelligent flying ball target is designed. The design can enrich people's daily life and entertainment, so this design has important research significance and use value.

1.2. Research status
Intelligent hardware originated in the United States [3], and subsequently, Europe, Japan, and South Korea also participated in the development of intelligent hardware. At present, large companies in the United States, Europe, Japan, Korea and other countries and regions have established research
laboratories to specifically propose reasonable intelligent hardware protocol standards [4]. After years of development, a large number of international technical camps have appeared one after another. Intelligent hardware platforms based on the Internet have also developed rapidly. At present, Apple’s AirPlay and Google’s Google Home are more representative.

The concept of domestic home entertainment intelligent hardware started late, beginning at the beginning of this century [5]. With the popularization of Wi-Fi in the home, the current means of communication for most home entertainment smart products are based on Wi-Fi. Representative domestic smart hardware products for home entertainment are Xiaomi’s ‘Xiaomi AI Speaker’ and Alibaba’s home entertainment smart product ‘Tmall Genie’.

1.3. Research content
This design uses multi-sensor technology, embedded technology and short-range wireless communication technology to design a smart product for home entertainment. This product uses STM32 as the main controller, uses ultrasonic module and vibration sensing module MPU-6050 for data acquisition, and performs filtering algorithm research on the collected data. This design uses a scoring algorithm to comprehensively process the collected data and determine the score. The scoring algorithm has been researched. On the software side, the functions are implemented based on the μC/OS-III real-time operating system, and the user interface design and the Android-based APP design on the mobile terminal are performed through the μC/GUI [6]. The system uses Wi-Fi module to connect with the phone to establish a fast and stable connection. Finally, the flying ball target is debugged in different environments and the corresponding analysis is made.

2. Overall design of smart flying ball target
The smart flying ball target in this design belongs to the development design of home entertainment intelligent hardware, which is mainly divided into embedded hardware platform design, embedded software development and Android-based APP development.

The hardware platform mainly includes the main controller with Cortex-M4 as the core, data acquisition module, information output module, wireless transmission module and power module. The hardware structure of the system is shown in Figure 1.

![Figure 1. Structure of intelligent flying ball target hardware system.](image)

The embedded system software design is based on the μC/OS-III real-time operating system, and cooperates with the embedded system hardware to achieve the function of the flying ball target. The embedded software adopts modular design concept, and each module is divided into different tasks according to functions, and the operating system completes calls to different tasks. It is mainly divided into data collection tasks, scoring tasks, interface display tasks, voice tasks and wireless transmission tasks. The degree of coupling between tasks is an important factor affecting the complexity of the software, so when the system divides tasks, the degree of coupling between each task should be as small as possible. The flying ball target interface is designed based on μC/GUI, which is mainly used for human-computer interaction and display of other information.
In terms of remote control, this design uses Wi-Fi mode selection to set the Wi-Fi module connected to the flying ball target hardware as a hotspot. The mobile phone can search for hotspot signals and connect the flying ball target easily and quickly through a password. After the connection is completed, the flying ball target can be controlled by a mobile device such as a mobile phone.

3. **Intelligent flying ball target hardware design**

3.1. **Mechanical structure design of intelligent flying ball target**

Based on the analysis of the functions and design requirements of the flying ball target, the mechanical structure is designed. The overall shape of the smart flying ball target is designed as an isosceles trapezoid, with height of 20cm, average width of 11cm, and thickness of 5cm. The mechanical structure of the flying ball target can be divided into four parts: flying ball target panel, target, middle cover and back cover. Parts are made of ABS plastic through 3D printing to meet mechanical strength requirements. The appearance of the flying ball target panel is shown in Figure 2. The target composition and vibration direction after being hit are shown in Figure 3.

![Figure 2. Intelligent flyball target panel appearance schematic.](image1)

![Figure 3. Target structure and the vibration direction after being hit.](image2)

3.2. **Hardware circuit design of intelligent flying ball target**

According to the functional requirements of the intelligent flying ball target hardware platform, the hardware part of the embedded hardware platform designed in this paper includes the main controller, data acquisition module, data output module, remote control unit and power supply system. Among them, the main controller of the intelligent flying ball target uses a microcontroller STM32F407ZGT6.

3.2.1. **Electrical design of data acquisition unit.** The data acquisition unit is responsible for collecting data and uploading it to the main controller. Use MPU-6050 to detect whether the target is vibrating to determine whether the user has hit it. Use HC-SR04 ultrasonic sensor to detect the distance between the user and the flying ball target to obtain distance data.

3.2.2. **Electrical design of data output unit.** The data output unit is mainly composed of a 4.3-inch TFTLCD capacitive touch screen and voice module. The display is mainly used to display the user interface, user score data and battery power. The voice module is composed of the audio decoding chip VS1053, the audio driver chip TDA2822 and its peripheral circuits. The voice module should be able to emit a sound effect when the user hits the bull's-eye.

3.2.3. **Electrical design of remote-control unit.** The remote-control unit is used to complete the wireless communication between the mobile device and the flying ball target hardware platform, which is mainly realized through Wi-Fi. Use ATK-ESP8266 module [7] to establish a connection between a mobile device (Android phone or tablet with Android system) and the flying ball target.

3.2.4. **Electrical design of power module.** The power module consists of 18650 lithium battery and its peripheral circuits. Peripheral circuits include: lithium battery protection circuit using HX-S-01 module; Boost circuit using XL6009E module boost lithium battery, in order to meet the power....
requirements of TDA2822, the voltage is increased to 12V; Voltage regulator circuit using AMS1117-3.3 chip and LM2596 chip; A power supply detection circuit that divides the voltage of two power supply battery packs through a resistor divider circuit to obtain power.

4. Acquisition signal filtering and scoring algorithm design

4.1. Research on MPU-6050 filtering algorithm

After the flying ball target is subjected to external force, it will generate vibration, including the flying ball target bullseye vibration and flying ball target shell vibration. The flying ball target shell vibration is the main source of noise. The bullseye of the flying ball target is composed of spring. According to the statistical parameters of the spring vibration frequency in the related Literature [8], the MPU-6050 module fixed on the spring is subjected to the impact, and the vibration frequency is below 30Hz, which is higher than 0.5Hz. Here, the high frequency of the flying ball target response is taken as 50Hz. So, the flying ball target response frequency range: f = 0.5 ~ 50Hz. The vibration frequency of the flying ball target shell is generally higher than 90Hz [9]. When the vibration is higher than this frequency, it has exceeded the frequency response range of the flying ball target.

4.1.1. Filter selection. This design mainly uses filters to suppress the clutter of the flying ball target. We are concerned about the suppression of clutter and do not require the data to be strictly linear. So, we choose a Butterworth low-pass digital filter.

4.1.2. Butterworth filter performance index. Butterworth digital filters were proposed by British engineer Stephen Butterworth in 1930 [10]. Butterworth filter is a kind of electronic filter. On the Bode plot of the logarithmic diagonal frequency of the amplitude, starting from a certain boundary angular frequency, the amplitude gradually decreases with the increase of the angular frequency and tends to negative infinity. Butterworth filter performance index: \( \omega_c \) is the passband cut-off frequency, \( \omega_s \) is the stopband cut-off frequency, \( R_p \) (dB) is the passband ripple and \( R_s \) (dB) is the stopband attenuation. Butterworth low-pass filter characteristics are shown in Figure 4.

![Butterworth low pass filter amplitude-frequency characteristics](image)

**Figure 4.** Butterworth low pass filter amplitude-frequency characteristics.

Butterworth low-pass filter can be expressed as in Equation (1):

\[
|H(\omega)|^2 = \frac{1}{1 + (\frac{\omega_c}{\omega_p})^{2n}} = \frac{1}{1 + (\frac{\omega_p}{\omega_c})^{2n}}
\]  

(1)

Where \( \omega_c \) is the cutoff frequency, \( \omega_p \) is the edge frequency of the passband, \( n \) is the order of the filter, \( 1/(1 + e^2) \) is the value of \( |H(\omega)|^2 \) at the edge of the passband. When \( \omega = \omega_p \), according to:

\[
R_p = -10 \log |H(j\omega)|^2
\]  

(2)

and this yield:

\[
R_p = -10 \log \left| \frac{1}{1 + (\frac{\omega_p}{\omega_c})^{2n}} \right|
\]  

(3)

When \( \omega = \omega_s \), according to:

\[
R_s = -10 \log |H(j\omega)|^2
\]  

(4)
and this yield:

\[ R_s = -10 \log \left| \frac{1}{1 + \left(\frac{\omega_s}{\omega_c}\right)^2n} \right| \]  

(5)

According to the analysis of the signal characteristics of the flying ball target in the previous chapter, the Butterworth filter design index: the passband cutoff frequency is 50Hz, and the stopband cutoff frequency is lower than 90Hz. According to the Shannon sampling theorem \( f_s \geq 2f_m \), \( f_s = 200Hz \) is selected, the passband ripple is 1dB, and the stopband ripple is 15dB.

4.2. Research on scoring algorithm of flying ball target

The score is based on the distance between the serve and the flying ball target and the MPU-6050 inclination. The smaller the inclination angle and the further the distance, the greater the score value. It is known that the effective detection distance of the ultrasonic sensor is 0.02m ~ 4.5m. The design stipulates that the position of the serve is at least 0.5m from the flying ball target. When the distance is greater than 4.5m, the maximum detection distance of the flying ball target has been exceeded and it is judged as invalid. This design divides the distance into 40 gears on average. In the case of hitting the bull's eye, the score increases by 0.1 point for every 0.1 m increase in distance. That is, in the case of hitting the bull's eye, the score is 1 point when the distance to the flying ball target is 0.5m; the maximum point is 5 points when the distance is 4.5m.

The inclination angle is also an important factor for scoring. From the analysis, we can know the inclination range of MPU-6050. Let \( \theta \) be the maximum sum of the inclination angles sampled for each hit. Write:

\[ \theta = |\alpha| + |\beta| + |\gamma| \]  

(6)

where,

\[ \begin{align*}
\alpha & \in (-90^\circ \sim 90^\circ) \\
\beta & \in (-180^\circ \sim 180^\circ) \\
\gamma & \in (-180^\circ \sim 180^\circ)
\end{align*} \]  

(7)

The flying ball target samples a certain number of values each time during the scoring process, and then finds the maximum value of each set of sampled values. Then calculates the current score based on the maximum value. The maximum value calculation method is:

\[ \theta = \begin{cases} 
\theta & \theta \geq \theta_n \\
\theta_n & \theta < \theta_n
\end{cases} \]  

(8)

The \( \theta_n \) is the nth inclination value obtained by sampling the flying ball target. In this design, the sampling frequency of the flying ball target is set to 50Hz. After a hit event, due to the attenuation effect of the spring oscillator, the vibration frequency and amplitude of the spring oscillator will decrease significantly after 1s and the corresponding inclination angle will also be significantly smaller. Therefore, take \( n \) as 50, which is the inclination value within 1s after the sampling hit event occurs.

From the above formula, it can be known that in the ideal state, the minimum value of \( \theta \) is 0° and the maximum value is 450°. However, a large amount of experimental data found that when the flying ball hits the target, the minimum inclination of the flying ball target is about 30°, that is, when the flying ball hits the bull's-eye, the effective inclination angle is 30°, and the minimum inclination angle is selected here as 20°. At this time, due to the limitation of materials, the maximum inclination angle of a flying ball hitting the target is about 230°, and the maximum inclination angle is selected here as 240°. Let \( \theta_{\text{max}} \) be the maximum inclination angle and \( \theta_{\text{min}} \) be the minimum inclination angle, then the flying ball target scoring formula can be obtained:

\[ P = 1 + \frac{\theta_{\text{max}} - \theta_i}{\theta_{\text{max}} - \theta_{\text{min}}} (s_j - 0.5) \quad s_j \in (0.5, 4.5), \theta_i \in (\theta_{\text{min}}, \theta_{\text{max}}) \]  

(9)
Among them, P is the score of this hit. P effective data is rounded to one decimal place. The $\theta_i$ is the maximum inclination of this hit and $s_j$ is the distance between the serve and the flying ball target. And $l$ is the score compensation. The above formula also solves the problem of determining the effective data of the flying ball target.

5. **Main program design of intelligent flying ball target software**

This design chooses an application development method based on real-time operating system. $\mu$C/OS-III has the advantages of good real-time performance, easy development, and low requirements on hardware resources, which can meet the development requirements of flying ball targets [11]. This design software is based on $\mu$C/OS-III and $\mu$C/GUI. The operation flow of the main program design based on $\mu$C/OS-III is shown in Figure 5.

![Main sequence diagram](image)

**Figure 5.** Main sequence diagram.

This design divides tasks according to the functional requirements of the flying ball target. Including: data collection tasks, scoring tasks, user interface tasks, wireless module transmission tasks, voice system tasks and idle tasks. The data collection task is related to whether the flying ball target can collect user data in a timely and accurate manner, so it is set to the highest priority. The wireless control task allows users to operate the flying ball target at any time, so setting priority is second. The voice system tasks and user interface tasks are relatively low real-time and are set to a lower priority.

After the system power is turned on, the main control board device and other devices are initialized first, including on-chip peripherals and external interrupts. Then initialize the peripheral hardware, including: TFT-LCD, MPU-6050, ultrasonic sensor module and wireless control module. Then $\mu$C/OS-III calls the OSStatInit () function to initialize the operating system and calls OStatCreat () to create each task. The above two functions are performed in the start task OStat () respectively. After the above steps are completed, the system uses the OStat () function to enter the task scheduling phase.

6. **System debugging**

6.1. **Installation of flying ball target**

Assemble the flying ball target, assemble the circuit board and other sub-modules into the 3D printer case, and fix the corresponding component modules. The flying ball shell is shown in Figure 6. After the flying ball target is installed, power on and restart the system. The overall effect is shown in Figure 7. It can be seen from the figure that the flying ball target can start normally, the graphical interface is clear, and the flying ball target works well.
6.2. Flying ball target inclination verification

In the study of the scoring algorithm, we envisage using the inclination of the MPU-6050 to simulate the number of rings of a conventional shooting target after the flying ball target is hit by a table tennis ball. The closer the contact position of the ping-pong ball to the target when it collides with the target, the smaller the inclination angle. The above speculation needs to be verified by experiments.

The purpose of this experiment is to verify how the inclination of a ping pong ball hits a flying target from different angles under the same conditions. This experiment is divided into four groups. Each group changed the angle between the flying ball target and the horizontal plane under the same experimental conditions, and simulated the flying ball from different directions. In the first set of experiments, the flying target was parallel to the table. In the second set of experiments, the angle between the flying target and the table was 30°. In the third set of experiments, the flying ball target made an angle of 60° with the table. In the fourth group of experiments, the flying ball target made a 90° angle with the desktop. Experimental steps: Place the flying target on the table, and place the table tennis 1m above the flying target. Lower the ping-pong ball one meter above the flying ball target, hit the flying ball target vertically, and record the tilt angle displayed by the flying ball target. Each group of experiments was performed 10 times, and the experimental data were recorded. The experimental data are shown in Table 1.

| Experimental group | Experimental data |
|--------------------|-------------------|
| First group        | 81° 80° 78° 82° 79° 77° 83° 81° 80° 79° |
| Second group       | 94° 97° 98° 100° 97° 96° 97° 99° 101° 96° |
| Third group        | 117° 114° 119° 117° 116° 115° 120° 119° 115° 117° |
| Fourth group       | 131° 134° 129° 135° 134° 133° 136° 135° 137° 133° |

According to the above data, it is found that when the angle with the table is different, the data obtained by the flying ball target is different, and it has a linear relationship with the angle. The error of each group of data does not exceed 5°. Based on the analysis of the above experimental data, this experiment verified the previous conjecture.

6.3. Communication debugging between flying ball target and mobile phone

First set the Wi-Fi working mode, and use the AT+CWMODE command to set it. Among them, 1 is STA mode, 2 is AP mode, and 3 is STA + AP mode [12]. After the module is set to mode 2, you need to use AT+CWSAP command to configure the route. TEST_ESP8266 is set here as the name of the wireless access point. The encryption method used to connect to the router is WPA2PSK, the channel number is 1, and the password is 123456. After the route is set, restart with AT+RST to take effect.

Then, set it as the connection mode of the wireless access point, 0 is single connection, that is, the ESP8266 module allows only one client to access, and 1 means multiple connections. This design allows multiple clients to access at the same time, so set to 1. Then, open the UDP server to monitor and start multiple connections: AT+CIPMUX = 1. Finally, establish server: AT+CIPSERVER = 1.
After sending these four instructions, turn on the phone’s Wi-Fi search function and you can see the corresponding Wi-Fi information. Click on the connected Wi-Fi, the phone will automatically enter the password input interface, and then manually enter the password: 123456 to connect to the flying ball target. Enter the mobile phone connection interface, type a string of characters on the screen and click send, and you will receive the characters sent by the mobile phone on the flying ball target interface. Experiments show that the connection between the flying ball target and the mobile phone meets the expected requirements. The effect of sending information by mobile phone is shown in Figure 8.

![Figure 8](connectESP8266.png)

**Figure 8.** APP effect diagram of mobile phone

7. Summary
This design chooses STM32F407 as the main controller, and built the hardware platform including the main controller module, the data acquisition module based on MPU-6050 and ultrasonic sensors, the human-computer interaction module based on TFTLCD and VS1053, wireless communication. Modules, etc. Then, use μC/OS-III and μC/GUI to build an embedded operating system on the STM32 processor, and implement the specific functions of the smart flying ball target based on the hardware platform and related algorithms. Including the overall design of the main program, the programming of other modules and the design of the APP based on Android. The functions of each module were debugged. The hardware modules of the flying ball target work normally, and the interface part of the flying ball target is displayed clearly. After hitting the target with the flying ball, the system can quickly calculate the data to give a score and accurately report the target. In terms of wireless control, the flying ball target is connected stably. Achieve the use of mobile phones to control flight targets and check scores.

References
[1] Li Z and Liang Q 2013 *IEEE Transactions on Smart Grid* **4**(1) 13-20
[2] Liu W and Leng Z B 2016 *ZigBee-based Smart Home Control System Electronic Technology and Software Engineering* (14) 140-1
[3] Garcia F C C, Creayla C M C and Macabebe E Q B 2017 *Procedia Computer Sci.* **105**(1) 248-55
[4] Chen T, Gao X and Chen G 2016 *J. Parallel & Distributed Computing* **96**(3) 45-74
[5] Li G 2016 Status and Development Trend of Smart Home *China New Telecommunications* **18**(19) 67
[6] Fu X 2016 Research on UI Design of Smart Phone APP Based on User Experience *China High-tech Enterprises* (17) 24-5
[7] Li X, Lu R and Liang X 2011 Smart community: an internet of things application *IEEE Communications Magazine* **49**(11) 68-75
[8] Liu X X and Wang Z 2010 Effect of mass of vertical vibration spring on vibration period *University Physics* **29**(11) 51-54
[9] Liu Y 2014 *Research on Plastic Vibration Processing and Sample Forming Integrated Testing Machine and Its Application* (Hangzhou: Zhejiang University)
[10] Huang T, Wang H J, Fan Y H and Miao X F 2008 Design of Butterworth Digital Filter Based on MATLAB *J. Yan an University (Natural Science Edition)* (3) 45-8
[11] Meng Q P, Zhai G Y and Zhu Q B 2014 *Radar and Countermeasure* (2) 59-61
[12] Ferdoush S and Li X 2014 *Procedia Computer Science* **34**(3) 103-10