Intelligent Health Management based on Photoelectric-Inertial Fusion Perception Tennis Sports Device

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Abstract

Nowadays, Scientific and technological innovation is reshaping the paradigm of sports development and health governance with unprecedented efforts. Intelligent wearable health management tennis equipment is based on photoelectric technology, sensing technology and artificial intelligence technology. Through the combination of software and hardware, data was accurately collected by the device through multi-modal fusion, the collected motion data and physiological data were analyzed in real time by the device using intelligent algorithms, and high performance and an ultra-low power wireless connection hub were provided for the device by NRF52840. The overall system framework of the equipment was mainly introduced in this paper. The progress results of photoelectric-inertial fusion sensing were summarized in this paper, and the shortcomings and future development of the project at this stage were expounded in this paper.

Keywords

NRF52840; Photoelectric Sensor; Data Fusion Processing; Tennis Sport.

1. Introduction

(1) National policies empower the development of intelligent sports equipment

With the popularization of the concept of national health management, the demand for scientific sports is increasing, and the national fitness strategy is accelerated, and the intelligent transformation of the sports industry is promoted. In this context, the national policy continues to empower the development of intelligent sports equipment: the National Fitness Plan (2021-2025) clearly proposes to promote the deep integration of artificial intelligence, big data and national fitness, the“14th five-year plan” sports development plan even lists “Intelligent sports” as a key area, emphasizing the acceleration of intelligent sports equipment research and development and industrial application.

(2) Photoelectric-inertial fusion sensing system boosts sports industry development

The breakthrough of Internet of things, artificial intelligence and sensor technology is driving the evolution of traditional sports equipment to intelligence. However, due to the lack of real-time biomechanical feedback, traditional rackets lead to low training efficiency and high risk of sports injury The existing intelligent products also face bottlenecks such as insufficient intelligence, poor system compatibility and high cost, which restrict the popularization and application of technology. At present, the research and development of intelligent tennis racket technology in foreign countries is leading. Although it started late in China, it has made remarkable progress in the field of sensor integration and communication technology. It is worth noting that the application of multi-modal

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fusion detection and deep learning technology is still in the exploratory stage, and it is urgent to deepen the core technology research. Based on the national strategic needs and technical pain points, this paper aims to break through the key technical bottlenecks of intelligent tennis rackets and promote the high-quality development of the industry.

2. System Design Framework

(1) This project is a complete system

The system is based on a variety of new photoelectric sensors to collect the movement and physiological data of tennis players, and uses intelligent algorithms for multi-dimensional data processing, nRF52840 is used as the wireless connection center to achieve the purpose of real-time feedback of sports data. If conditions permit, the cloud platform can be used for data backup and processing to provide basis for medical decision-making and health management of sports personnel, to enhance the effect of exercise. The system block diagram is shown in Fig 1:

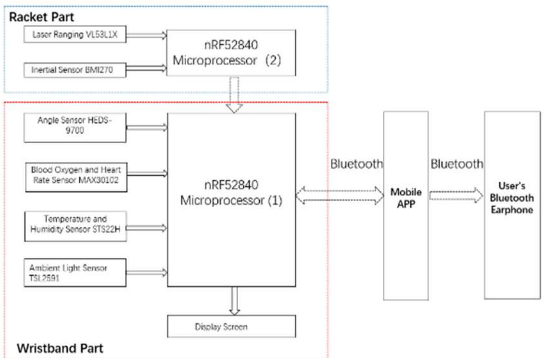

Fig. 1 System principal frame diagram

(2) Hardware design

To ensure the integration of equipment, cost-effective and low power consumption, the system uses photoelectric sensor as the core hardware configuration [2]. The sensor set is shown on the table below:

Type	Model	Performance
Laser range finding	VL53L1X	50Hz refresh rate
Inertial measurement	BMI270	500Hz sampling
Angle encoding	HEDS-9700	±1°accuracy
Ambient light	TSL2591	0-88,000 Lux
Physiological testing	MAX30102 +DS18B20	Heart rate and digital temperature sensor

Fig. 2 Sensor selection

- Power management system

Polymer Lithium Battery + monocrystalline silicon solar panel dual-mode power supply, TP4054 charge management +XC6202LDOregulator, TVS/PPTC/Max811 for overvoltage and overcurrent protection.

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- Display module

Round high-definition IPS LCD bare screen.

Fig. 3 Outline drawings

(3) Software design

The system adopts the edge-cloud collaborative architecture and constructs a three-layer closed loop of data perception, fusion processing and feedback.

- Data perception layer

Multi-sensor synchronous acquisition [5].

Adaptive sampling rate control.

- Data fusion processing

Kalman filter noise reduction + space-time alignment to eliminate multi-sensor bias.

Space-time alignment (pre-processing) [3].

Time Alignment

Cubic spline interpolation was performed on the low-frequency laser data (100Hz) to match the IMU data timestamp (500Hz):

$$z_{laser}^{(t)} = Spline\left(z_{laser}, t_{IMU}\right) \tag{1}$$

Hardware synchronization: the RTC timer controlled by the core marks the time of data acquisition (error < 0.1 MS).

Spatial alignment

Dynamic calibration: the initial transformation matrix is calculated by the preset swing motion (such as vertical down), Kalman filter [4] (state optimal estimation), State equation (take the position of the hitting point as an example)

$$\begin{gathered} X_k = \begin{bmatrix} p_x \\ v_x \\ a_x \end{bmatrix} = A_{X_{k-1}} + w_k \left(State\ Prediction\right) \\ Z_k = H_{X_k} + v_k \left(Observation\ Model\right) \end{gathered} \tag{2}$$

- Data feature extraction

Peak value detection by threshold method (acceleration ≥8g to identify hitting time), The convolutional neural network (lightweight CNN) Model [1] (200 MS sliding window) classifies a variety of hitting actions in real time, A two-dimensional evaluation system was constructed by fusing physiological data.

3. Project Outcomes

(1) A 3D simulation of the hardware design is shown in Fig. 4

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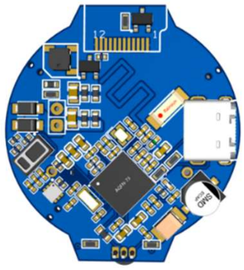

Fig. 4 3D simulation of hardware design

(2) Software design block diagram

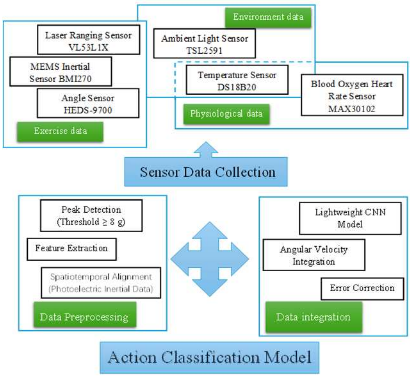

Fig. 5 Software design block diagram

(3) Simulation effect of data preprocessing algorithm

Data acquisition and processing are the top priorities of the whole system operation. Based on Kalman filter algorithm using MATLAB tennis racket multi-sensor data fusion simulation system, the results are as follows:

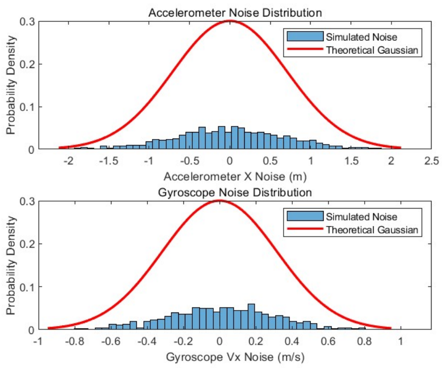

Fig.6 Noise distribution

The simulation system simulates the tennis swing motion by generating a composite trajectory including circular motion and linear motion. On this basis, the measurement noise is added to the accelerometer and gyroscope, respectively, a reasonable covariance matrix of process noise and measurement noise is set to simulate the real sensor characteristics.

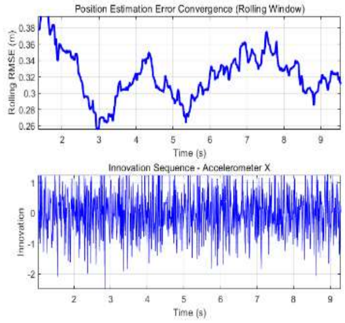

Fig. 7 Filtered Data

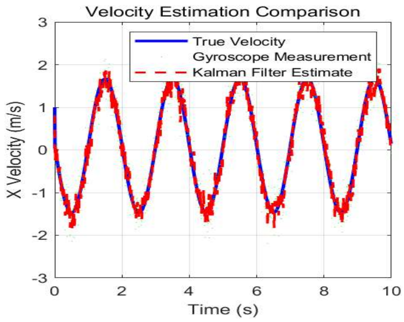

Fig. 8 Velocity Estimation Comparison

The performance evaluation shows that the data fusion method significantly improves the accuracy of state estimation, and the improvement degree of position estimation on each coordinate axis reaches a significant level, the effectiveness and practicability of Kalman filter in multi-sensor data fusion of tennis racket are fully verified.

4. Shortcomings and Prospects

(1) Shortcomings

Although the existing system theoretically achieves multi-sensor fusion and embedded real-time analysis, it still faces many limitations. The racket sensor disrupts the mechanical balance of traditional rackets, which leads to resistance from professional players. The algorithm bottleneck lies in the confusion of motion scenarios; the environmental adaptability is weak. The breakthrough path requires collaborative innovation in hardware and algorithms.

(2) Prospects

The core of the future lies in redefining the technical concept: no longer limited to motion classification, but building a digital twin of competitive performance, a cognitive model for perceiving and judging effects; using advanced materials and technologies to embed this system deep within sports equipment, optimizing biomechanical energy efficiency without being noticed. This evolution not only reshapes the paradigm of intelligent sports equipment but also establishes a quantitative assessment standard of "human motion entropy change" for sports science.

5. Conclusion

This paper systematically introduces and briefly analyzes the intelligent health management tennis sports equipment based on photoelectric-inertial fusion perception. It integrates a variety of new cost-effective photoelectric sensors and adopts advanced intelligent algorithms to process and analyze the collected motion data and physiological data. This scheme closely aligns with the era proposition of "National Health Management", constructs a closed-loop ecology of "technology improvement-

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health monitoring-scientific fitness" for tennis, and contributes to the in-depth practice of the "Healthy China" strategy in the sports field.

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