An auxiliary system for rehabilitation training

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Abstract. In this paper, aiming at the problem of sports injury in squatting, the development of squatting training assistant system based on MPU9250 is proposed and designed. The system uses embedded technology, through the cloud architecture of recurrent neural network to analyze data, realize the monitoring of squat training, return the results to the mobile APP end, realize the correction and guidance of each action, and display the user's rehabilitation in real time. Through the system test, the results show that the system has the characteristics of stable performance, accurate detection, convenient and portable.

1. Introduction

Squat as a very common exercise in fitness, some studies show that squat exercise is a good means to promote knee rehabilitation, such as cruciate ligament postoperative rehabilitation. However, incorrect squatting posture may lead to forward movement of knee joint and excessive force on meniscus [1]. With the development of human-computer interaction applications, motion acquisition and analysis technology and related applications have become a hot research topic. However, due to the limited factors of hardware, the progress of computer interaction has not made a leap. Motion recognition technology generally adopts image processing technology, which has certain practicability for the overall analysis of motion, but it is not suitable for convenient, Low-Power Embedded Applications [2]. In recent years, the popular Kinect somatosensory technology also has the problems of large volume and high power consumption of sensors and processors.

In this paper, based on the concept of Internet of things, through the combination of embedded hardware and application layer software, a wearable and convenient device is developed, which can interact with the user's mobile APP and help the user squat training.

2. Overall framework design of the system

The overall design of the system is shown in Figure 1. The STM32F103 MCU is used as the core controller of the hardware level, and the nine axis attitude sensor JY902 is used to collect the attitude data of users during squatting movement. Through the serial communication function of STM32, the data is transmitted to the Bluetooth communication HC-05 module. The Bluetooth module sends the data to the mobile APP through frequency hopping spread spectrum technology, and the mobile APP operates the Bluetooth components as the Bluetooth host to connect the Bluetooth slaves of the left and right knees and waist, respectively, to obtain the user's squatting posture data, and then transmits the data to Alibaba cloud server through the Message Queuing Telemetry Transport (MQTT) protocol. The MQTT server is built by using the Linux operating system of Alibaba cloud server. It is mainly used to extract the characteristics of the data, calculate the specific results by using deep learning technology and eigenvalue analysis, and send them back to the mobile APP for use in the supply layer.
3. Statistics training times and analysis of the squat movement posture accuracy and evaluation, using WEB related technology to achieve the sports rehabilitation training auxiliary system information view and control.

3. System hardware design

The main body of the bottom hardware is composed of a waist data acquisition device and two knee data acquisition equipment groups. Each knee device is composed of bending sensor, STM32 MCU and HC-05 Bluetooth communication module. The waist device is composed of nine axis attitude sensor, STM32 MCU and Bluetooth communication module. The hardware level is composed of three modules, namely sensor module, control module and communication module [4]. The underlying device is used to collect multi-dimensional monitoring data during training, and then send the data to the transit data controller through MQTT.

3.1. Sensor module

The sensor module uses JY902 nine axis attitude sensor based on MPU9250 chip to collect three dimensions of acceleration, angular velocity and magnetic field acceleration. After Data Management Platform (DMP) processing, the quaternion can be used to calculate Euler angle (pitch angle, heading angle, roll angle) [5]. A total of 12 dimensions of motion attitude information can be obtained. Flex4.5 bending sensor is a kind of sensor for measuring deflection or bending angle. The surface of the sensor is a kind of resistance element sensitive to bending angle. Different bending degree will change the resistance value of the resistance element, and the bending angle value can be obtained by Analog to Digital (ADC) voltage conversion.

3.2. Control module

STM32f103C8T6 MCU is used as the control module of the hardware core controller. The MCU is responsible for receiving the motion attitude data collected from the sensor. The serial communication protocol is used to realize the data exchange between the core microprocessor and the main sensor.

3.3. Communication module

If the WIFI communication module is used, it is necessary to provide users with an intuitive interface with strong operability, so it must be combined with the Organic Light Emitting Diode (OLED) screen, which will increase the cost and volume. The coverage and reliability of WIFI data transmission in different locations are inconsistent, which will lead to poor user experience. Considering the efficiency of data transmission, most wearable devices use Bluetooth as the communication module to access the mobile communication network. Using the reliable data processing ability of mobile communication network, the data is processed and uploaded to the server.
4. System software design

4.1. Data processing

As shown in the data processing flow chart in Figure 2, the data collected by the bottom layer sensor is the initial data, which is affected by the temperature drift phenomenon caused by the sensor noise signal and the external temperature, so that we can not intuitively obtain the acceleration, angular velocity and magnetic field acceleration, as well as the angle and distance in the three directions of x, y and z axis. By using the good computing ability of STM32, the first-order complementary filtering algorithm, Kalman filtering algorithm and hardware design of the original data are carried out to remove static and dynamic errors [7] [8], and then the original data is converted into feasible transfer data.

This paper studies the squatting posture data of different experimenters for many times, as shown in Figure 3. After analysis, it can be concluded that: when the action is normal, except for the angular velocity x-axis has a small fluctuation, the other values are relatively stable; when the action moves back and forth, the acceleration x-axis, angular velocity x-axis, angle x-axis (pitch angle) and magnetic field y-axis fluctuate obviously; when the action amplitude is too large, the acceleration y-axis fluctuates obviously The angular velocity y-axis, angular z-axis (roll angle) and x / z-axis of magnetic field fluctuate greatly. A total of 8 dimensions are used: acceleration y-axis, angular velocity x / y-axis, pitch angle, roll angle, magnetic field height x / y / z-axis as transfer data. After the transfer data is input into the installed recurrent neural network model, the final data is finally formed.

4.2. Motion detection algorithm

When users squat, there are three common states: normal movement, excessive amplitude and back and forth shaking. Using LSTM (Long Short Term Memory) long-term and short-term memory network, a squat movement detection algorithm is built to detect different squat states. First,
initialization constants are NORMAL and EXTENT_BIG, BACK_FORTH, CAMBER and COUNT respectively indicate that the movement is normal, the amplitude is too large, the front and back sway, the start of a squat and the squat count. Then, when the quotient of the sum of the two knee bending sensor voltages divided by 2 is greater than the CAMBER, it means that a squat is started, count plus 1. Finally the collected data of squat movement are input into LSTM neural network model to calculate the results. Figure 4 shows the LSTM neural network training model.

![Figure 4. LSTM neural network training model](image)

As shown in the figure, we assume that the measured value of the six axis sensor at the current time is \( x_i \), the parameters of the input layer and the hidden layer are \( W_{ih} \) and \( W_{hh} \), respectively, and \( t \) is the current time. The output of the hidden layer can be expressed as equation (1).

\[
a_h^t = \sum_{i=1}^{I} W_{ih} x_i^t + \sum_{h=1}^{H} W_{hh} b_{h}^{t-1}
\]

(1)

In formula (1), \( b_{h}^{t-1} \) represents the output value of the hidden layer at the previous time, that is, the output value of the hidden layer can be obtained from the output value of the input layer, which is formula (2).

\[
b_h^t = f_h(a_h^t)
\]

(2)

By introducing the parameter value \( W_{hk} \) of the output layer and the output value of the hidden layer, the output value of the output layer represented by matrix \([a_{k0}, a_{k1}, a_{k2}]\) is obtained as equation (3).

\[
a_k^t = \sum_{h=1}^{H} W_{hk} b_h^t
\]

(3)

After the result of the output layer is obtained, the squat action state is judged. When \( a_{k0} \) is greater than NORMAL, the action is normal. When \( a_{k1} \) is greater than EXTENT_BIG, it means that the amplitude is too large. When \( a_{k2} \) is greater than BACK_FORTH, which means shaking back and forth.

4.3. Design of alicloud architecture

As shown in Figure 5, first of all, build an Elastic Compute Service (ECS) cloud server through alicloud platform to reduce the development of hardware architecture. Cloud server mainly integrates cloud data processing services, database services, WEB services and MQTT services. Cloud data processing is an important hub of data processing in the training process. Cloud database realizes master-slave relation table. WEB services provide mobile APP data access requirements, and MQTT establishes a real-time data channel for the data in the training process [6].
Use Alibaba cloud server to build MQTT server, send the original data to the python script side, run the deep learning model, analyze the data to get the results, and according to the application layer protocol, complete the message control every five squats, send the a character to the APP side of the hand through MQTT protocol, and then control the APP to send user prompt instructions. When the prediction result is squat posture data and needs to be alarmed, b or z will be sent according to the situation, which respectively means that the squat amplitude is too large and the shaking is frequent, and then the APP will be controlled to send user prompt instructions.

4.4. Design of mobile APP
Through Android stpdo development platform for mobile APP development, call the MQTT server built by alicloud platform to realize data communication with alicloud platform, and use WEB related technology to realize the view and control of information of sports rehabilitation training auxiliary system [7] [8]. The module breakdown diagram of mobile terminal system is shown in Figure 6.

5. System results and test results
According to the above software and hardware design, a complete auxiliary system of sports rehabilitation is realized, and each module can operate normally. The display result of mobile APP is shown in Figure 7, and the physical sketch of squatting is shown in Figure 8.
In order to test the performance and effectiveness of the system designed in this study, two groups of tests are set up to observe the accuracy of the system for the analysis of several squatting movements. The test results are shown in Table 1.

| number | Action times | Number of false positives | Test accuracy | Correct times of action | Number of action errors | Action success rate |
|--------|--------------|----------------------------|---------------|-------------------------|-------------------------|-------------------|
| 1      | 50           | 10                         | 80%           | 38                      | 12                      | 76%               |
| 1      | 50           | 12                         | 76%           | 38                      | 12                      | 76%               |
| 2      | 50           | 9                          | 82%           | 43                      | 7                       | 86%               |
| 2      | 50           | 9                          | 82%           | 36                      | 14                      | 72%               |

In the verification of the feasibility of the system development, the recognition error rate is relatively low, because the acceleration, angular velocity and magnetic field height are always in a fluctuating state in the process of movement, there will be occasional error.
6. Conclusion
In this paper, a long-term and short-term memory network based on LSTM is proposed to complete the squat movement detection task, and the detection accuracy reaches 82%. A squat movement auxiliary system based on MPU9250 is designed. The experimental results show that the system can achieve good detection results in rehabilitation training and other detection tasks. Compared with other detection systems, the system has better accuracy and reasoning speed, and has good application performance in sports rehabilitation training.

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