A Wearable EEG Real-time Measure and Analysis Platform for Home Applications

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A Wearable EEG Real-time Measure and Analysis Platform for Home Applications*

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Abstract - **Scalp electroencephalography (EEG) is widely used to study human electrophysiological activity noninvasively. With the gradual improvement of the quality of the multi-channel bioelectric signal acquisition device, the volume and power consumption are gradually reduced, which makes it suitable for portable and wearable application. To ensure sufficient signal gain and acquisition accuracy, it is a huge challenge to effectively suppress external interference and obtain a better bioelectric signal. This paper presents a new kind of wireless EEG signal real-time analysis and acquisition system. The system can be wearable at home environment and wirelessly send the real-time EEG signal to the host. The results show that the system can collect EEG signal robustly. The noise of the test system is reduced by 60% through the design of the isolated circuit. The software algorithm also enables the ability to perform basic analysis of biological signals by using Python digital signal processing module. The system provides a new safety platform for human-machine interfacing, rehabilitation and mental disease monitoring at home.**

I. Introduction

An electroencephalogram is a bioelectric activity of a cerebral hemisphere, and an electrical amplifier is used to electrically amplify and record microorganisms generated in the human brain and obtain a graph [1]. The analysis and processing of EEG signals are of great significance in the diagnosis and treatment of certain brain diseases and in the brain cognitive science research field in clinical practice. At present, the physiological electrical signal acquisition device is developing in the direction of small size and high precision, and its application site has also entered the home and other general places from professional places such as hospitals, and it is mainly used for rehabilitation medical treatment, disease monitoring, and so on. Today, major medical electronics manufacturers around the world have introduced a number of outstanding products. For example, the "Active Two" bioelectric signal acquisition device produced by the Dutch BIOSEMI company can collect EEG and EMG signals of the electroencephalogram, but its size is large. It’s not suitable for portable use. In terms of amplifier selection, instrument amplifiers (AD620, INA128 series, etc.) are used for multi-stage mode amplification, and the analog filtering signal is preprocessed by conditioning the AD into a digital signal after conditioning. Each channel of an existing brain-electrical signal acquisition device (such as an electroencephalogram machine) must include an analog filtering and amplification module [2]. When the number of acquisition channels is large or the acquisition accuracy is high, the entire system volume will be large, which is not conducive to portable use. The acquisition device of EEG signals often has a complex system structure and a large size, and its acquisition channels cannot be flexibly configured [3]. Therefore, the current acquisition equipment still has the disadvantages that the high precision, portability and multi-channel cannot keep balanced.

For the existing lack of the acquisition equipment on the market, this paper uses high-precision analog-to-digital conversion chip, ADS1299 manufactured by Texas Instruments Company, to directly collect the raw EEG signals mixed with noise, thereby setting analog filtering and amplification circuits for each acquisition channel will not be needed, so that the system size and system power consumption can be reduced [4]. The collected raw EEG signal is sent to the Raspberry PI (MCU) through an isolation circuit, and then it will be processed by Python digital signal processing module to obtain the desired EEG signal and improving its quality. In this new platform, a coin cell battery to power the front-end system to improve safety level. Since the entire system is small in size and low in power consumption, the device can be portable and ideal for human-machine interfacing, rehabilitation and disease monitoring at home.

II. Materials And Methods

A. Overall System Design

The amplitude of the EEG electrical signal is at the microvolt level, which requires the resolution of the acquisition system to be high enough to collect signals below 1 μV, the preliminary choice is an acquisition chip with 24-bit resolution and a sampling rate more than 1 ksps [5]. The collected data is transmitted to the personal computer via WLAN. The scheme is shown in Fig. 1. The high-resolution acquisition front-end design solution mainly solves the problem of human raw data preprocessing and acquisition. The acquisition system converts analog signals to digital signals and uses Raspberry PI as the master controller to control the acquisition. The increase of lead extension and sampling rate will increase the requirement for the transmission rate of the communication interface, and the low-speed interface cannot meet the requirements of the system. The Wi-Fi network in the wireless interface can meet the system requirements [6]. The final solution for this system is the Wi-Fi network interface solution. With WLAN networking solutions, it can be applied to multiple sets of

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devices that are simultaneously collected under the same WLAN, it can make the equipment more flexible.

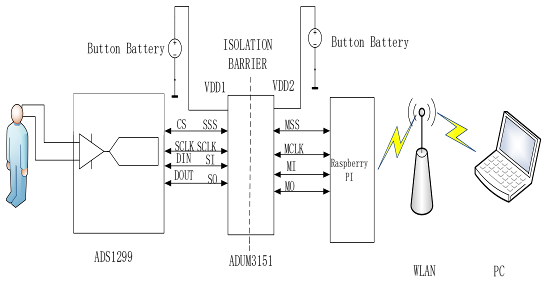

Figure 1. System Block Diagram

B. System Hardware Design

Serial Protocol Interface (SPI) data transmission protocol and add the necessary isolation in the hardware design. The isolation in electronic circuits is a method of preventing the flow of current between two parts [7]. It provides a mechanism for signal transmission between two points, but there is no current flow. The main reason for the isolation circuit is that the protection circuit is not damaged by dangerous voltages and currents. Isolating is a method to prevent current from flowing between the two communication points. In general, isolation techniques are used in two cases: the first case is that the presence of potential current surges could damage the equipment or endanger personnel, that is, there are conditions in the circuit that could damage the equipment or endanger the operator's high voltage or current [8] such as medical applications, motor control, bus isolation, I/O isolation and other aspects. The second case is that it must avoid the existence of different status and split ground loop interconnections. Generally, when there is a multi-system interconnection, there will be a potential difference between the grounds between different systems [9]. In this case, if we do not separate the two grounds, a ground loop and interfere with the entire system will exist. In both cases, isolation is used to prevent current flow, allowing data or power transfer between the two points. The general control system bus, communication system is controlled by the main control chip (MCU, ARM, DSP, etc.) signal transmission is achieved by the interface and the control system, and the application environment of the controlled system is usually more complex, there will be high voltage, lightning, large current [10]. And if it is directly connected to the main control system, these dangerous signals may destroy the entire system, which is extremely harmful to the entire application system. Based on above reason, isolation circuit is adopted in this design.

In the traditional isolation scheme, we generally use optocouplers, such as 6N137 and TLP521. Optocouplers achieve isolation through photoelectric conversion [11]. The application time is relatively long and the solution is relatively mature. At present, it is still the preferred product for many circuit designers, but the same optocoupler also has shortcomings such as low speed, high power consumption, LED aging, and unstable operation. Fig 2 shows the application of the ADUM3151 chip in this design. Magnetic isolation technology has developed in recent years and the chip-level transformer isolation technology is in use. Because of the adoption of high-speed iCMOS technology and chip-level transformer technology, there are many advantages in various aspects such as performance, power consumption, size, and speed. The input signal of the magnetic coupling digital isolator is modulated by a Schmitt trigger to adjust the pulse signal so that the input waveform can be a standard rectangular wave. Another magnetic coupling is also a unique DC correct function, the two sets of internal coils work as a pulse transformer, the change of logic level of the input port will cause a narrow pulse, coupled to the decoder by the pulse transformer, and then transform the waveform by a Schmitt trigger to output a standard rectangular wave. If the input logic level is stable more than 2μs, the correction circuit will generate a correct polarity correction pulse to ensure that the output signal of the transformer DC terminal is correct. If the decoder does not receive any correction pulse more than 5μs, it will consider that the input has been powered down or stop working. In addition, the power consumption of the magnetic coupling isolation series is only about between one of ten and one of sixty of the conventional optocoupler, and the speed can reach 150 M/s. Four channels can be integrated at most and the channel transform direction is flexible, which greatly shortens the development cycle. To construct a wide dynamic range system, the designer selects an ADC with good signal-to-noise ratio (SNR) first, and the SNR is usually related to the word length; the normal word length of the converter is 16 bits. However, if a higher dynamic range is required, other techniques such as using programmable gain amplifier, oversampling can be considered [11]. The ADS1299 is a low-noise, low-power, multichannel, simultaneously-sampling, 24-bit, delta-sigma (ΔΣ) analog to-digital converter (ADC) with an integrated programmable gain amplifier (PGA). This device integrates various EEG-specific functions that makes it well-suited for scalable electroencephalography (EEG) applications. The device can also be used in high-performance, multichannel, data acquisition systems by powering down the EEG-specific circuitry [15].

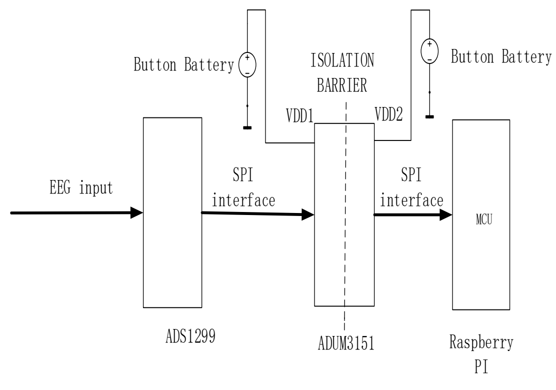

Figure 2. Isolated design block diagram

The wearable EEG real-time measure and analysis platform incorporates one ADS1299 EEG analog front end for EEG collection, a Raspberry pi as the MCU for communication. The designed EEG acquisition system as shown in Fig 3.

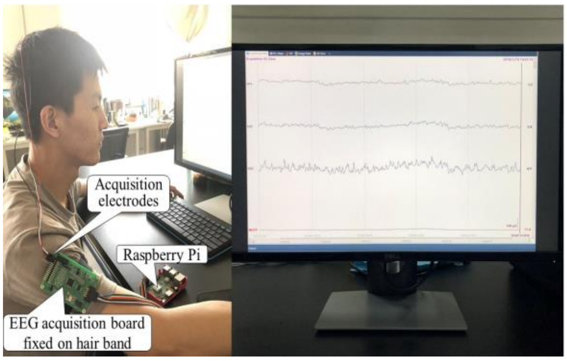

Figure 3. The designed EEG acquisition system

The reference voltage of ADS1299 is 4.5V, and the minimum resolution voltage is 0.536 μV. The amplitude of EEG signal in 0.001~0.1mV enables ADS1299 to process directly, thus eliminating the complicated conditioning circuit and reducing the volume of the acquisition circuit. The anti-interference ability of the circuit is improved on the basis of isolating circuit. The system adopts bipolar power supply and external crystal oscillator, which can implement the synchronous measurement of up to 8 channels. The hardware acquisition part is 7 cm long and 5 cm wide, small in size and easy to take. The system can be powered by a lithium battery inside the system and can work continuously for more than 10 hours when the battery capacity is 500mA.h. The main technical parameters of the EEG acquisition system are shown in the Table I

TABLE I. Main technical parameters of the EEG acquisition system

Performance Index	Parameters
CMRR/dB	110
Input Resistance/MΩ	100
Sampling Rate/Hz	250-4000
A/D bits,	24
Dimensions/cm*cm*cm	7*5*2
Weight/kg	0.25
Battery Capacity	500mA.h

C. System Software Design

Python is an object-oriented interpreted computer language with a large number of modules that can easy the program design and data processing, the digital signal processing of EEG can be achieved by the rich DSP modules in Python [12]. The data acquisition control and analysis processing of the EEG acquisition system are all completed on the Python platform, and the initialization of ADS1299 is also completed by Python as shown in Fig. 4. The device waits for the Python software running on the upper computer to send a command, the command is usually to obtain a display signal or performs an impedance test, selects an impedance test, when the device receives the command, the software system will enter an impedance test page, display the impedance value of each channel, compare the thresholds, and analyze whether the electrode of the device is worn, and then make it suitable for collection, if not, make some adjustments to make it suitable. When the impedance value of each channel is ideal, the manual acquisition and display signals are sent manually, and physiological signals can be collected, displayed, analyzed, and saved. This section outlines the procedure to configure the device in a basic state and capture data. This procedure is intended to put the device in a data sheet condition to check if the device is working properly in the user system. This procedure is recommended to be followed initially to get familiar with the device settings. When this procedure is verified, the device can be configured as needed. Some sample programming codes are added for the EEG specific functions. The ADS1299 provides flexible configuration control. The opcode commands are stand-alone, except for the register read and write operations that require a second command byte plus data. The chip selection signal (CS) can be taken high or held low between opcode commands but must stay low for the entire command operation (especially for multi-byte commands). System opcode commands are decoded by the ADS1299 on the seventh clock falling edge. The register reading and writing opcodes are decoded on the eighth clock falling edge. Be sure to follow SPI timing requirements when pulling CS high after issuing a command [15].

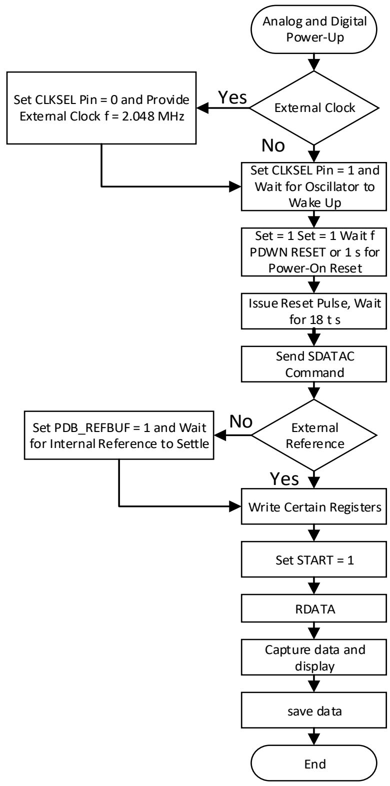

Figure 4. System initialization flow chart

The Raspbian is a kind of operation system designed for the Raspberry Pi and it is based on Linux, so we can control the hardware of Raspberry Pi by this Linux, also, we can use the python program language and its integrated development environment installed on the Linux to control the device connect to the Raspberry Pi. As is shown in Fig.5, when the Linux running on the Raspberry Pi starts, the shell script called auto boot script will boot the ADS1299 configuration module. This module is to configure the registers of ADS1299 in order to establish the connection between ADS1299 and Raspberry Pi, after the module configure ADS1299 successfully, the

ADS1299 will send raw data by SPI protocol to the Raspberry Pi, at the same time, the data reading module will receive the data and write it in a data file on Linux. The front program is a program include GUI and other function module, in the front program, the file reading module is to read the data file stored on the Linux, also, the date could be displayed on the remote PC by WLAN module, after reading the data file, the DSP module can process the date file read by file reading module, after processing, the processed data could be saved on the Linux or displayed on the remote PC. When it is necessary to change the mode of ADS1299, the parameter setting module can reconfigure the registers of ADS1299.

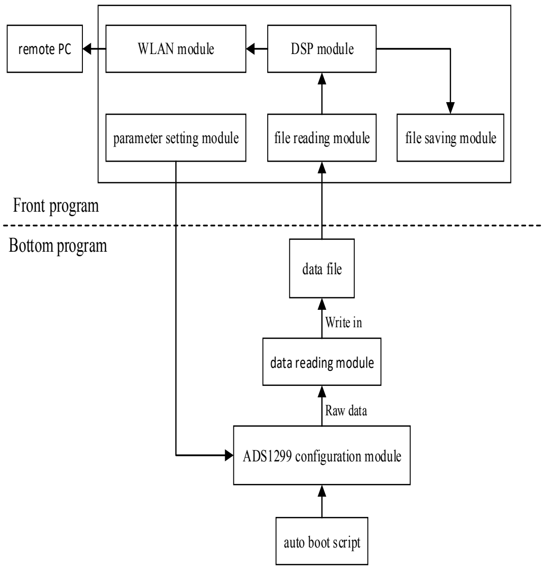

Figure 5. Software Block Diagram

According to the software block diagram, a python software program can be designed. Once the link is established, the program can send commands to the device, such as setting sampling rate, filtering, channel selecting, and so on. When the data collected by the device is transmitted to the host computer, the host computer decodes the data into real voltage data and pushes it to the display function program for waveform display [13]. The software also has the functions of impedance testing and data saving. Based on these functions, we designed a friendly and simple GUI that integrates these functions. In this GUI, a single-channel EEG signal whose length is 4 s is collected, shown as Fig.6.

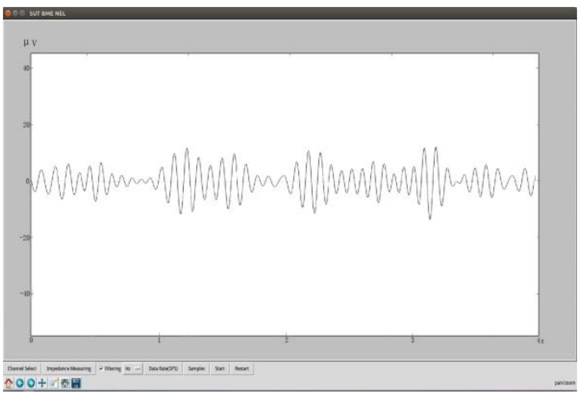

Figure 6. Python User Interface Demo

III. RESULTS AND DISCUSSION

A. Electrode impedance and system noise

Selection of electrodes and measurement of electrical impedance: ADS1299 provides two frequency options (7.8 Hz and 31.25 Hz) to measure the electrode impedance within the bandwidth of interest for EEG. There are four kinds of amplitude of current source (*ILeadoff*) options available 6 nA, 24 nA, 6 μA, and 24 μA. The electrode impedance measurement at these frequencies cannot be done simultaneously with EEG measurements. The voltage developed at the inputs depends on the impedance on each electrode and the current used for lead-off detection [14]. We denote the source impedance on positive electrode is Zp and the source impedance on negative electrode pin is Zm. The peak to peak voltage developed on channel input is the V_{PP}. calculation is shown in (1).

$$V_{PP} = 2 \times \left(ILeadoff \times Zp + ILeadoff \times Zm \right). \qquad (1)$$

ADS1299 also provides option to do electrode impedance measurement at frequencies outside the EEG bandwidth of interest. The frequency for this AC current source is set at a quarter of clock. For example, to do an AC lead-off detection at 1 kHz, the data rate for the device must be set at 4Ksps. These measurements can be done concurrently with the EEG measurement. Interface decodes commands in bytes and requires 4 clock cycles to decode and execute. Therefore, when sending multi-byte commands, assuming the clock is 2.048 MHz, 4 clock cycles is 1.96 μs. When clock is 16 MHz, one byte can be transferred in 500 ns. Therefore, a delay must be inserted so the end of the second byte arrives 1.46 μs later. In this later scenario, the serial port can be programmed to move from single-byte transfers per cycle to multiple bytes [15]. The electrode contact impedance was measured by electrodes. The impedance of the electrode changes over time under a current of 6 μA. The value of the electrode impedance will decrease over time. When the weak current of different frequencies is loaded, the electrode impedance will also decrease with the increase of the frequency. When we take the logarithm of the frequency as a variable, the result shows that the electrode impedance exhibits an approximately linear relationship with the frequency increase. The statistical results are shown in Fig. 7.

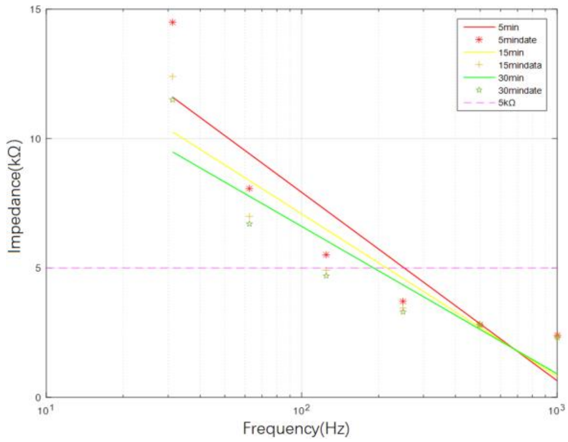

Figure 7. Electrode impedance with frequency at different times

Noise level test: we change the input mode as “input-short” and measure system noise in a suitable test environment. According to the data record in such an environment, the noise level of each channel of the discovery system is displayed. The system noise is only 0.47 μV under the condition with isolation circuit [16]. Detecting the common-mode rejection ratio of the device: input the differential-mode signal whose frequency is 10Hz, amplitude is U_D to the device, then input the common-mode signal to the device, and record the signal after increasing the input voltage K times, then store and replay the common-mode signal, so we can measure the Maximum amplitude U_C of each channel from the stored common-mode signal, moreover we can find out the maximum value and calculate common-mode rejection ratio (CMRR), as shown in (2).

$$CMRR = 20\lg K + 20\lg \frac{U_D}{U_C}. \tag{2}$$

This method measures the common-mode rejection ratio of the channel as 144 dB. Actual electrophysiological signal test: using the standard 10-20 electrode position, select the occipital lobe, and use the right ear mastoid as the bias electrode to make differential measurement. The type of electrode we used is medical AgCl wet electrode. Add conductive paste on the point to ensure that the electrode is in full contact with the scalp. Patient electrode impedances are known to decay over time. These electrode connections must be continuously monitored to verify that a suitable connection is present. The ADS1299 lead-off detection functional block provides significant flexibility to the user to choose from various lead-off detection strategies. Though called leadoff detection, this is in fact an electrode-off detection. Basic principle is to inject an excitation signal and measure the response to determine if the electrode is off. The methods differ in the frequency content of the excitation signal [15].

The EEG waveform shown in Fig. 6 is filtered by FIR filter achieved by software system. It can be seen that the waveform displayed in the GUI is clean, and most of the high frequency and power frequency interference are filtered out. The frequency spectrum is shown in Fig. 8. It can be seen that the subject’s EEG signal frequency mainly concentrates on 12 Hz. The design of the safety platform in this paper can meet the measurement requirements. This platform can acquire the EEG signal and store it on portable device, and display on remote computer through WLAN connection when necessary.

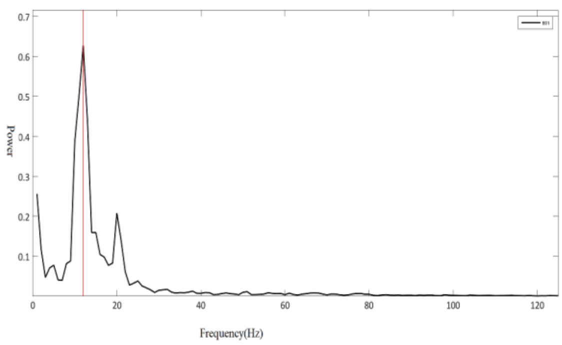

Figure 8. EEG signal spectrum diagram.

B. Isolated and non-isolated data statistics

The EEG signals were collected under isolated and non-isolated conditions. The sampling rate is 250 sps. The power spectrum of collected raw signal has been analyzed and we make a ratio whose value equals the ratio of isolated and non-isolated power spectral density. We intend to investigate whether there is a significant change in the power ratio of the alpha band under both isolated and non-isolated conditions. The power spectrum ratio of other frequency bands can also reflect the noise level of the acquisition system.

At the sampling rate of 250sps, as shown in Fig. 9, the red mark in the figure is the ratio value of the alpha frequency band. The results show that there is no significant attenuation of energy in the entire band under both, isolated and non-isolated conditions. The signal quality is not affected by isolated conditions.

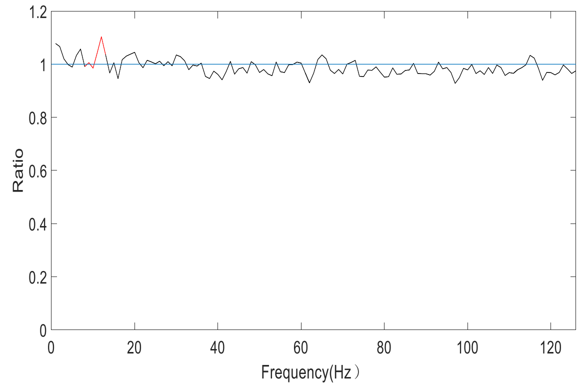

Figure 9. Power spectral density ratio

IV. CONCLUSION

In recent years, medical electronic devices have developed in the direction of high precision, low power consumption, and wearable. The design of the EEG acquisition system for wireless EEG signals proposed in this paper, chip selection, hardware circuit design, and software system are all designed around these aspects. While satisfying the basic requirements of the equipment, the high signal sampling rate, accuracy, low power consumption of the system operation, and small size of the entire device are also achieved [20]. Raspberry Pi is chosen as the main controller unit since Python can run well on it, also, Python has a large number of modules that can make it easy to process the digital signal of EEG. The ADS1299 chip is connected to Raspberry Pi, and the Raspberry Pi can receive and process the data from ADS1299 by Python program which includes abundant modules. Also, the remote display function between PC and Raspberry Pi can be achieved by the Wi-Fi network and the WLAN module programed by Python. This system can be used for human-machine interfacing, rehabilitation and mental disease monitoring at home.

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