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# Portable muscle fatigue analysis system for sports training

Yuefeng Liu[1], Xiaodi Cai[1,3], Yu Fu[2]

**Abstract.** Portable muscle fatigue analysis system for sports training is to be studied. The portable muscle fatigue analysis system consists of hardware and software. Hardware system is made up of three modules: signal collection and wireless transmission module, data processing module and result display and data storage module. Software and its corresponding hardware module were used to code corresponding function modules. Then, system is detected by muscle fatigue analysis experiment on dumbbell lateral raise. Test results shows that there is the same variation tendency for parameters of bicipital muscle of arm and degree of muscle fatigue when doing dumbbell lateral raise. However, there are significant individual differences for muscle fatigue parameters. In conclusion, the portable muscle fatigue analysis system is verified reliable for sports training.

**Key words.** Sports training, muscular fatigue analysis, surface electromyographic signal, FPGA, portable muscular fatigue analysis system.

## 1. Introduction

When muscle motion function level was lowered by sports to a degree of insufficient energy for sports, it can be recovered by taking a long rest. This phenomenon was called muscle fatigue [1]. Muscle fatigue measurement was widely applied in various fields, such as sports field. Injury caused by excessive exercise can be avoided by assessing and monitoring muscle fatigue [2]. In human engineering field, muscle fatigue measurement can be used to avoid musculoskeletal fatigue related to working. In rehabilitation medicine field, muscle fatigue measurement and assessment can be used to guide recovering movement for rapid recovery [3]. Electromyographic signal was taken as parameter to study muscle fatigue in physical exercise. Automatic system was used as fatigue warning device for training to remain a best non-fatigue state and avoid muscle injury caused by excessive exercise.

It was convenient to acquire human electromyographic signal because surface

[1]Institute of Physical Education of Xinjiang Normal University, Urumqi 830054, China

[2]Sias International University, Zhengzhou, Henan, 450000, China; E-mail: siasyufu@yeah.net

[3]Corresponding author

electrode was featured noninvasive. Thus, surface electromyographic signal was frequently used for analyzing muscle fatigue [4]. There were many studies focused on this aspect at home and abroad. ICA and neural network was adopted by A. Subasi et al. [5] to identify and classify muscle fatigue. Median frequency of eletromyographic signal was calculated by Kang to measurement of human muscle fatigue [6]. Nowadays, off-line process has been adopted by most studies on muscle fatigue analysis. Generally, electromylgraphic collecting device could not analyze muscle fatigue [7], thus, it was inconvenient for daily muscle fatigue assessing and monitoring. Therefore, a practical portable real time muscle fatigue analysis system with low power dissipation was design based on surface electromyogram for daily training.

## 2. Hardware design for portable muscle fatigue analysis system

### *2.1. Signal collection and wireless communication module*

In the system designed, Ag-AgCl electrode was used to collect electromyographic signal. Surface electromyographic signal was a weak bio-electricity signal of alternating current, whose signal frequency energy was 20–500 Hz. Thus, enlargement and filtering was needed and the magnification factor was set as 500. To meet above requirement, the system was designed based on electromyogram transducers of AD8220 and OPA349E. And circuit of the transducer was shown in Fig. 1.

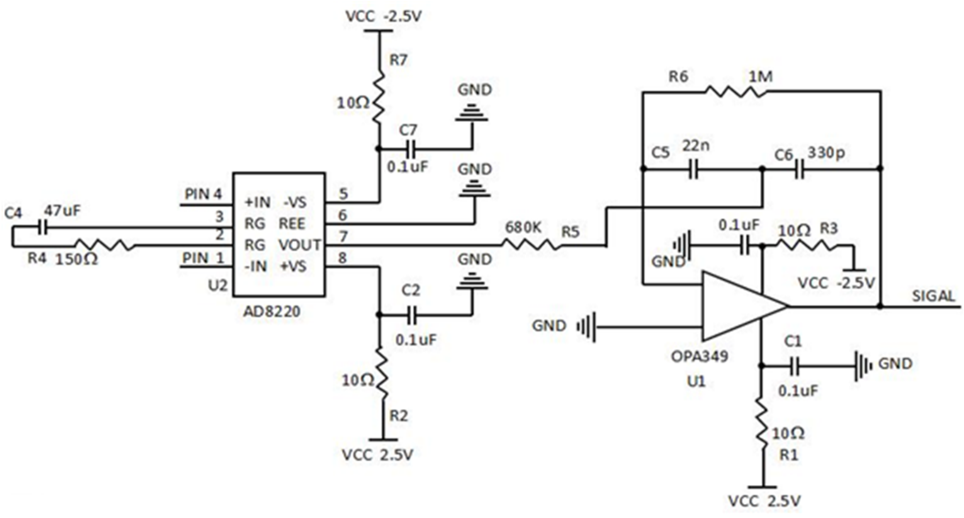


Fig. 1. Circuit diagram of enlargement and filtering

Synchronous sampling of 8 channels and delta-sigma analog-digital converter ADS 1198 of 16 bytes produced by TI company was selected. CSRBluetooth2.0 chip was used for wireless transmission. C8051F410 control center produced by Silicon Labs company was used for MCU control center. ADS1198 was used to connect

C8051F410 and SPI bus. UART was used to connect C8051F410 and wireless Bluetooth module. C2CK and C2D were used to connect C8051F410 and debugging tool. Meanwhile, in order to use as less devices on circuit board as possible, positive voltage of all devices in this system was set as 2.5 V. Thus, only one stability chip was needed for the whole system. Negative voltage corresponding to amplifier was –2.5 V, which can be obtained by voltage converter to convert 2.5 V.

### 2.2. Data processing module

Data processing module have to receive electromyographic signal of 6 channels and calculate parameters relevant to muscle fatigue in real time. To achieve this, FPGA was used to control this module and process signal. Core chip of FPGA chip was XC3S500E chip, whose configurable I/O pin was up to 232 which meet the requirement of system for multiply I/O interfaces. In order to achieve the best result of XC3S500E chip, supply voltages of 3.3 V, 2.5 V and 2 V should be inputted. Power supply chip AMS1117-1.2, AMS1117-2.5 and AMS 1117-3.3 V was adopted in this module, which greatly reduced circuit size and miniaturized system. For XC3S500E, there was a specified four-wire interface JTAG which can be used under any setting pattern when electrifying with XC3S500E.

### 2.3. Result display and data storage module

Result was displayed by LCD touch screen which also displayed variation tendency of muscle fatigue parameters in graphics. Data was stored in SD card for user to read. Chip of kernel series ARM 11 was selected for putting operation system conveniently. Data interface pin of SD card was connected to 10 K resistance and 3.3 V power supply then it was connected directly to data interface pin corresponding to S3C6410. Voltage of LCD touch screen was 5 V and electric current for driving LCD screen was around 1 A, a relatively large current value. For stabilize voltage and heat dissipation, LM2576 chip was used, whose power supply was shown in Fig. 2.

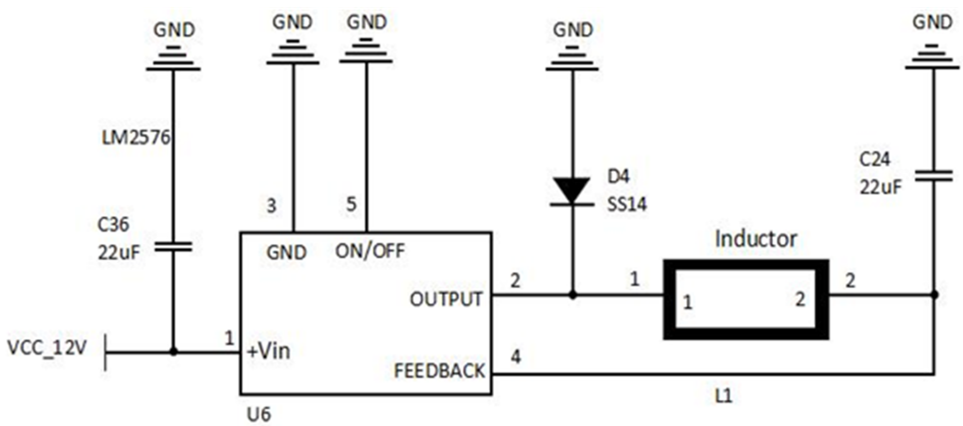


Fig. 2. LCD power supply

## 3. Software design for system

### 3.1. Signal collection and wireless transmission module

Surface electromyographic signal collected by transducer was converted into digital signal by ADS1198 which was controlled by C8051F410 through SPI bus. Then, digital signal was transmitted to wireless Bluetooth module through DART bus. This was the whole collection process. Finally, code was sent. Flow chart of the module was shown in Fig. 3.

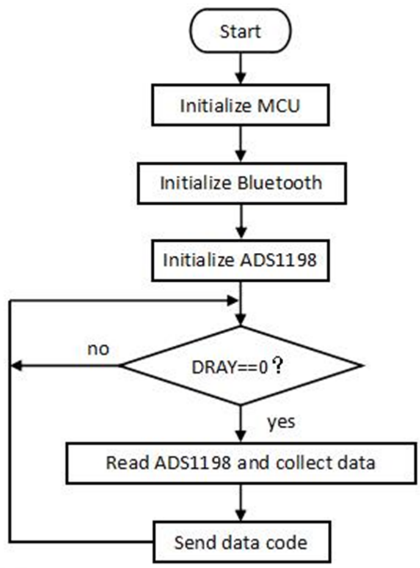


Fig. 3. Flow chart of data acquisition and wireless transmission module

### 3.2. Data processing module

Software in this module was made up of data receiving, data processing and data transmission. Data receiving was used to receive and parse data and extract original electromyographic signal of those 6 channels. Data processing was used to calculate data and parameter relevant to muscle fatigue. Data transmission was used to process the result and send original electromyographic signal code to display and storage module for storage. Software framework was shown in Fig. 4.

### 3.3. Result display and data storage module

Embedded operating system Windows Embeddd CE 6.0 was put into this module to display and storage data. Windows Embeddd CE 6.0 was featured good hardware compatibility, well reliability, strong communication ability, advanced power management system, friendly development environment and high security. Interface of

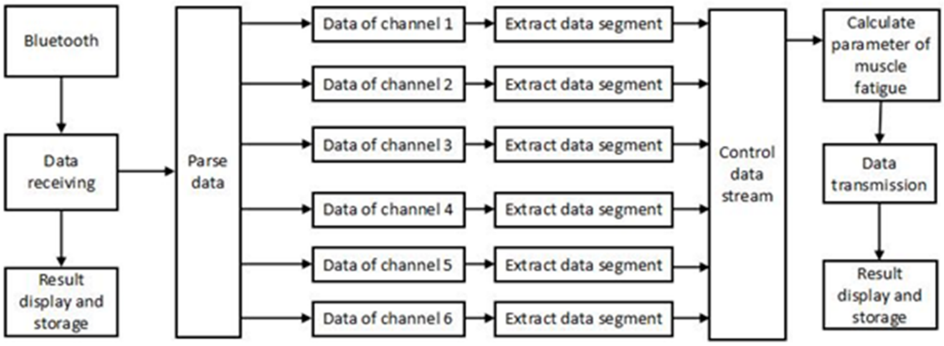


Fig. 4. Software framework of data processing module

serial device of Windows CE was a combination of communication-related function and drive program function for streaming I/O. In data display and storage module, data was received through two-way serial port- serial port COMl was responsible for receiving original eletromyographic signal and serial port COM2 was responsible for receiving data and processing parameter. There were buffer pools of 1024 bytes for those two serial ports, which was used to store those unread data in case it was lost. Totally, there were six channels for signal collection and six muscle fatigue parameters for each channel. Individual setting and display was adopted for user's convenient reading, which was achieved by drawing mechanisms of Windows CE. Besides, two documents were used to record original electromyographic signal and muscle fatigue analysis result respectively. And those documents were saved as format TXT.

## 4. Experiment of muscle fatigue analysis based on portable muscle fatigue analysis system

### *4.1. Experimental subject and method*

20 males with no medical history of muscle and skeletal muscle, no muscle injury lately, no unhealthy drug taken, no smoking history and no special preparation were selected as experimental subject and they were numbered from 1–20. Their basic information was shown in Table 1.

Table 1. Basic information of experimental subject for dumbbell lateral raise

| | |
|---|---|
| Age (years) | 24.72±2.35 |
| Height (cm) | 172.4±9.12 |
| Weight (kg) | 67.02±6.59 |
| Body index (kg/m$^2$) | 24.37±2.81 |

This was a static continuing contraction mode. Before experiment, place to put electrode should be swabbed by alcohol. Then, electrode was put on their bicipital muscle of arm. During the whole experiment, all experimental subjects should stand holding 2 kg dumbbell with forearm parallel to shoulder and their forearm should be vertical to their body. The experiment was finished once they failed to do the exercise properly.

### *4.2. Experimental result and analysis*

To quantizing relation of parameter and muscle fatigue, linear correlation analysis was conducted to all parameters. Function of linear relation was defined as $y(x) = ax + b$. Here, $y(x)$ denoted parameter value of the $x$th data segment, $a$ denoted the slope of fitting straight line and $b$ denoted intercept of straight line. Correlation coefficient was identified as function 1, for which $x'$ denoted mean value of $x$ and $y'$ denoted mean value of $y$. Correlation coefficient $r$ reflects the degree of fitting of straight line, through which monotonicity of data can be evaluated.

$$r = \frac{\sum_{i=1}^{n}\left(x_i - x^{'}\right)\left(y_i - y^{'}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - x'\right)^2}\sqrt{\sum_{i=1}^{n}\left(y_i - y'\right)^2}}. \tag{1}$$

Analysis result of fatigue of bicipital muscle of arm shown that slope of ZCR and MPF was negative and presented a downward trend for all experimental subjects except number 7. And slope of ZCR and MPF for number 7 was positive. Slope of RMS and IEMG was positive and showed rising trend for all experimental subjects. Slope of MDF was negative and showed a downward trend for all experimental subjects except number 7 and number 12. Slope of MDF for number 7 and number 12 was positive. Slope of Fl2 was positive and showed a rising trend for all experimental subjects except number 5. And slope of Fl2 for number 5 was negative. Thus, it can be concluded that this muscle fatigue analysis system was suitable for most people because 6 parameters related to muscle fatigue showed the same tendency in the fatigue process. However, it can be seen from above experiment that there were individual differences for muscle fatigue, which may be related to experimental subject's skin, muscle and power generation mode.

## 5. Conclusion

A portable muscle fatigue analysis system based on surface electromyopgram was developed by experimental, which was featured low cost, small in size and convenient to operation. Hardware and software design for this system was almost elaborated. This system was proved reliable by muscle fatigue experiment on dumbbell lateral raise. Not all degrees of muscle fatigue can be evaluated accurately because there were relative major individual differences, which should be improved in the future study.

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