The design of sports energy expenditure measuring device based on three-dimensional motion sensor

Chun Jiao¹, Ming Tang²
Xi’an Peihua University, Xi’an, China

Corresponding author and e-mail: Chun Jiao, 2024988445@qq.com

Abstract. The effectiveness of the measurement method based on accelerometer for human sports energy expenditure has been confirmed by research in recent years. In this paper, combined with the overall design requirements of micropower consumption and miniaturization, this paper describes the design scheme of a portable measuring device that uses three-dimensional accelerometer to measure sports energy expenditure. The general design idea of the measuring device and the implementation method of main functional units are discussed in detail.

1. Introduction
Daily physical exercise or training can improve human health. Moderate physical exercise can reduce the early mortality rate of adults by 20% to 30%, which can reduce the incidence of chronic diseases such as coronary heart disease, type 2 diabetes and stroke by 50% [1]. Exercise can also slow muscle decline, maintain bone health and promote child growth. In the process of exercise health management, whether it is to study the relationship between exercise and health or disease, or to conduct sports intervention or conduct personalized sports guidance research, objectively and accurately assess the energy consumption during human exercise is a key issue.

In recent years, with the development of microelectronics and computer technology, more and more researchers have begun to use accelerometers to study the assessment of sports energy expenditure. Researchers have demonstrated through a large number of scientific experiments that the integral value of body motion acceleration versus time is linear with energy or oxygen consumption. That is, the accelerometer output is highly correlated with the energy consumption [2][3][4][5]. This provides a specific theoretical basis for the use of accelerometers to assess human exercise energy consumption.

The three-dimensional accelerometer can simultaneously measure the vertical, front-back and lateral human motion accelerations, and has obvious advantages in sensing motion type and exercise intensity, and can more accurately reflect the actual movement of the human body. The reliability and validity of using three-dimensional accelerometers to assess energy consumption has also been confirmed by more and more studies [6-9].

2. The System Design
As shown in Figure 1 and Figure 2, the measuring device of sports energy expenditure is a battery-powered portable single chip application system. The measuring device can collect, process and store human motion information in the motion field, monitor the motion state, and calculate the sports energy consumption generated during the human body motion. At the same time, the sports
intervention function can be completed by the control program and function programs built in the measuring device.

![Hardware structure diagram of the measuring device](image1)

**Figure 1.** The hardware structure diagram of the measuring device

![Software structure diagram of the measuring device](image2)

**Figure 2.** The software structure diagram of the measuring device

Since the measuring device needs to continuously monitor and record the motion information at the sports site, its field usability has high requirements on the overall micropower consumption design of the system. That is, the entire system should have low static power consumption and low, controllable dynamic power consumption to extend the use time of the measuring device. At the same time, the measuring device should be small in size and light in weight, which is convenient for the athlete to wear and does not affect the normal exercise. Therefore, micropower consumption and miniaturization design are important contents and difficulties of this system. Component selection, circuit design, and software design in the system should be closely related to micropower consumption and miniaturized design.
3. The Central Control Unit

The central control unit of the system uses TI’s new 16-bit microcontroller MSP430F5419. Compared with the earlier models of the MSP430 series of microcontrollers, MSP430F5419 integrates more functional modules. The integration is further improved, the micropower characteristics are more prominent, the functions are more powerful, and the cost is significantly reduced.

MSP430F5419 integrates four independent serial interfaces, a 12-bit precision multi-channel A/D conversion module, 128KB of program memory and 16KB of RAM, enabling efficient data acquisition without the need for a dedicated A/D converter chip [10]. It has an RTC real-time clock module that provides available time coordinates for the system and provides reliable time stamp for the orderly storage of relevant data. The system does not require an additional clock chip, which improves system integration. MSP430F5419 also provides an on-chip CRC check module based on the CRC-CCITT standard, which provides technical guarantee for further improving the reliability of data storage and transmission.

MSP430F5419 features outstanding micropower consumption with five low-power modes that can be woken up from low-power modes in as little as 5μs. Its hardware and software architecture are designed for low-power applications. Its internal RAM controller can choose to retain RAM data or shut down RAM directly, depending on the needs of the different low-power modes. Each of its internal functional modules can be turned off by software operation when idle. At the same time, MSP430F5419 interrupts and subroutine calls have no hierarchical restrictions. It is beneficial to design the control program and function programs based on the interrupt structure, and further reduce the system power consumption from the software design level.

4. The Motion Sensor

ADI’s ADXL345 chip is a motion sensor that monitors the three-dimensional acceleration of human motion. ADXL345 features threshold monitoring and motion acceleration measurement with a maximum range of ±16g and a bandwidth of 1.6KHz. It can output a 16-bit two-complement digital signal that can resolve tilt changes of less than 1.0° and can sense the presence or absence of motion [11].

Because ADXL345 has built-in A/D converter, it can directly output the digital signal in the complement form, which eliminates the signal conditioning unit that realizes the amplification, shaping and filtering functions in the system, which simplifies the system design and saves the board space. The amplitude range of the human body motion acceleration signal is -12g to +12g, and the frequency range is 0Hz to 20Hz. ADXL345 is selected as the three-dimensional acceleration sensor to meet the measurement range required by the system.

At the same time, the power supply range of ADXL345 is 2.0V to 3.6V, support SPI serial interface, so its power supply range and interface form can be matched with MSP430F5419, the two can be directly connected. As shown in Figure 3, when connected in SPI mode, both chips work in master-slave mode. MSP430F5419 is used as the master to provide the clock signal and ADXL345 is the slave.

![Figure 3](image-url)
four modes of operation: bypass mode, FIFO mode, flow mode and trigger mode, which can effectively reduce the load of MSP430F5419. ADXL345 has a complete interrupt mechanism and provides two interrupt output pins, INT1 and INT2, which can be used to set the interrupt output in combination with different operating modes. In this system, ADXL345's low-power mode, interrupt mechanism, and interrupt-based control program and data receiving program are combined to achieve motion state monitoring and motion acceleration measurement with lower power consumption.

In order to further reduce the error and improve the system accuracy, in the sports energy calculation program, the three axial acceleration outputs of ADXL345 should be temperature compensated in combination with the actual ambient temperature value measured by the temperature measurement unit in the system.

ADXL345 is available in an LGA package that is optimized for miniaturization and its volume is only 3mm x 5mm x 1mm.

5. The Data Storage Unit

Considering storage capacity, power consumption, volume and cost factors, the system selects ATMEAL's FLASH data storage chip AT25DF641. Its operating voltage is 2.7V to 3.6V, and the standby current is only 25μA. Its storage capacity reaches 8M bytes [12]. AT25DF641 supports SPI serial interface, which saves space and reduces switching noise during high-speed data transmission.

Since the supply voltage and interface form of AT25DF641 can be matched with MSP430F5419, the two chips can be directly connected. When connected using the SPI serial interface, both chips work in master-slave mode. MSP430F5419 is used as the master to provide the clock signal, and AT25DF641 is the slave. In order to further increase the storage capacity, the system simultaneously connects two AT25DF641 chips through one SPI serial interface. The enable pins of each AT25DF641 chip are controlled by different pins of MSP430F5419 to realize time division multiplexing of two AT25DF641 chips.

The flow chart of the data storage program is shown in Figure 4.

![Flow chart of the data storage program](image)

**Figure 4.** The flow chart of the data storage program

This system uses the MISTY1 encryption algorithm to design a special data encryption program. The information segment of each frame of data can be data-encrypted, and the information segment and the data segment of each frame of the stored data are subjected to CRC check, which further increases the reliability and security of data storage.

The flow chart of the data encryption program is shown in Figure 5.
6. The Power Supply Unit
The power supply unit is an important part of the hardware design of the system. The output quality of the power supply unit will directly affect the accuracy and reliability of the system.

In this system, the design of the power supply unit must meet the following requirements:
1) It can output high quality power supply voltage. The output ripple is small, the electromagnetic radiation is low, and the voltage regulation effect is good;
2) The input voltage range is wide. It can meet a wide range of changes in battery voltage from the input;
3) The power supply efficiency is high. It can effectively reduce unnecessary energy loss;
4) Miniaturization. There are few external components and no large capacitance or large inductance.

The power supply unit of this system uses Maxim’s DC-DC converter MAX1556. Its quiescent current is only 16μA, its output current can reach 1.2A, and its conversion efficiency can reach 97% [13]. The 1.8V, 2.5V, 3.3V or adjustable output voltage can be selected via the pin. Its input voltage range is 2.6V to 5.5V, which is very suitable for powering the system with lithium ion battery or 2 to 3 alkaline batteries. MAX1556 is also available in a tiny 10-pin TDFN (3mm x 3mm) package.

7. Conclusions
In this paper, with the design principle of micropower consumption and miniaturization, the design scheme of the measuring device for assessing sports energy expenditure based on three-dimensional motion sensor is expounded. The measuring device can collect, process and store human motion information in real time on the sports site, and can quantitatively evaluate the human sports energy consumption. It is an intelligent instrument suitable for family or individual sports health management.

Acknowledgement
This work was supported by Shaanxi Natural Science Fund Project (2018JM7037025).
References

[1] Department of Health, Physical Activity, Health Improvement and Prevention. At least five a week: Evidence on the impact of physical activity and its relationship to health. 2004.

[2] Meijer, G.A., Westerterp, K.R., Koper, H. Assessment of energy expenditure by recording heart rate and body acceleration[J]. Medicine and Science in Sports and Exercise, 1989, 21: 343-347.

[3] C.V.C. Bouten, K.T.M. Koekkoek, M. Verduin. A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity[J]. IEEE Trans. Biomed. Eng., 1997, 44: 136-147.

[4] Scott E., Crouter•James R, Churilla. Estimating energy expenditure using accelerometers[J]. Eur J Appl Physiol, 2006, 98: 601-612.

[5] Troiano, Richard P., Berrigan, DAVID. Physical Activity in the United States Measured by Accelerometer[J]. Medicine & Science in Sports & Exercise, 2008, 40: 181-188.

[6] Juliette Hussey, Kathleen Bennett, et al. Validation of the RT3 in the measurement of physical activity in children[J]. Journal of Science and Medicine in Sport, 2009, 12: 130-133.

[7] Meredith A. Perry, Paul A. Hendrick, et al. Utility of the RT3 triaxial accelerometer in free living: An investigation of adherence and data loss[J]. Applied Ergonomics, 2010, 41: 469-476.

[8] Tanaka, Hidenori; Kawamata, Tomoyuki; et al. Evaluation of the Physical Activity of Anesthesiologists in the Operating Room During Daily Work Using a Triaxial Accelerometer[J]. Archives of Environmental & Occupational Health, 2015, 70: 77-80.

[9] ROWLANDS, ALEX V.; YATES, THOMAS; et al. Sedentary Sphere: Wrist-Worn Accelerometer-Brand Independent Posture Classification[J]. Medicine & Science in Sports & Exercise, 2016, 48: 748-754.

[10] TEXAS INSTRUMENTS. MSP430F543x, MSP430F541x Mixed-Signal Microcontrollers. TEXAS INSTRUMENTS data sheet, 2018.

[11] Analog Devices, Inc. 3-Axis, ±2g/±4g/±8g/±16g Digital Accelerometer ADXL345. Analog Devices data sheet, 2009.

[12] Atmel Corporation. 64-Mbit, 2.7V Minimum Serial Peripheral Interface Serial Flash Memory AT25DF641. Atmel datasheet, 2010.

[13] Maxim Integrated Products. 16µA IQ, 1.2A PWM Step-Down DC-DC Converters MAX1556/MAX1556A/MAX1557. Maxim data sheet, 2011.