Research on Energy Expenditure Detection Based on Three-Dimensional Acceleration

Qi Luo

Abstract The physical activity energy expenditure mainly refers to the part of the body energy which is used for muscle contraction to mechanical work. With the improvement of living standards, people's diet structure has changed enormously. Basing on it, the three-dimensional acceleration monitoring system to monitor the physical activity energy expenditure and daily actions is proposed in the paper. Hardware Design and The mechanism of accelerometer assessing movement energy were also proposed in the paper. The system is based on three-dimensional acceleration transducer MMA 7260QT and microprocessor MSP430F149.

Keywords Physical activity energy expenditure · MMA 7260QT · Three-dimensional acceleration · MSP430F149

1 Introduction

The physical activity energy expenditure mainly refers to the part of the body energy which is used for muscle contraction to mechanical work. With the improvement of living standards, people's diet structure has changed enormously. Many chronic diseases such as hypertension and diabetes mellitus have happened usually. One reason leading to this result is that people take fewer sports so that their energy expenditure is reduced. The detection of the physical activity energy expenditure is much important to forecast physical activity and improve movement way. In clinical medicine field, some diseases such as hyperthyroidism need to monitor the patient's energy expenditure. In the athletic training field, measuring

Q. Luo (✉)
School of Educational Information Technology, Central China Normal University, Wuhan 430079, China
e-mail: ccnu_luo2008@126.com

Q. Luo
College of Sports Engineering and Information Technology, Wuhan Sports University, 430079 Wuhan, China

P. Salmon and A.-C. Macquet (eds.), *Advances in Human Factors in Sports and Outdoor Recreation*, Advances in Intelligent Systems and Computing 496,
DOI 10.1007/978-3-319-41953-4_14

physical activity is also need to improve athletes' training. In addition, the physical activity energy expenditure is also applied in nutrition and labor physiology fields [1–5].

Basing on it, the three-dimensional acceleration monitoring system to monitor the physical activity energy expenditure and daily actions is proposed in the paper. The system is based on three-dimensional acceleration transducer MMA 7260QT and microprocessor MSP430F149.

2 Three-Dimensional Acceleration Transducer MMA 7260QT

The MMA7260QT low cost capacitive micro machined accelerometer features signal conditioning, a 1-pole low pass filter, temperature compensation and g-Select which allows for the selection among 4 sensitivities. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. Includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

Features as follows:

- Selectable Sensitivity (1.5 g/2 g/4 g/6 g)
- Low Current Consumption: 500 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2–3.6 V
- 6 × 6 × 1.45 mm QFN
- High Sensitivity (800 mV/g @ 1.5 g)
- Fast Turn On Time
- Integral Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- Pb-Free Terminations
- Environmentally Preferred Package
- Low Cost.

Typical Applications as follows:

- HDD MP3 Player: Freefall Detection
- Laptop PC: Freefall Detection, Anti-Theft
- Cell Phone: Image Stability, Text Scroll, Motion Dialing, E-Compass
- Pedometer: Motion Sensing
- PDA: Text Scroll
- Navigation and Dead Reckoning: E-Compass Tilt Compensation
- Gaming: Tilt and Motion Sensing, Event Recorder
- Robotics: Motion Sensing.

Figure 1 is Pin Connections and Fig. 2 is Simplified Accelerometer Functional Block Diagram.

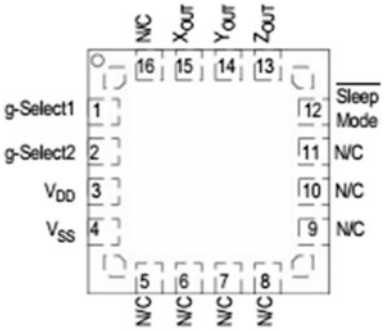

Fig. 1 Pin connections

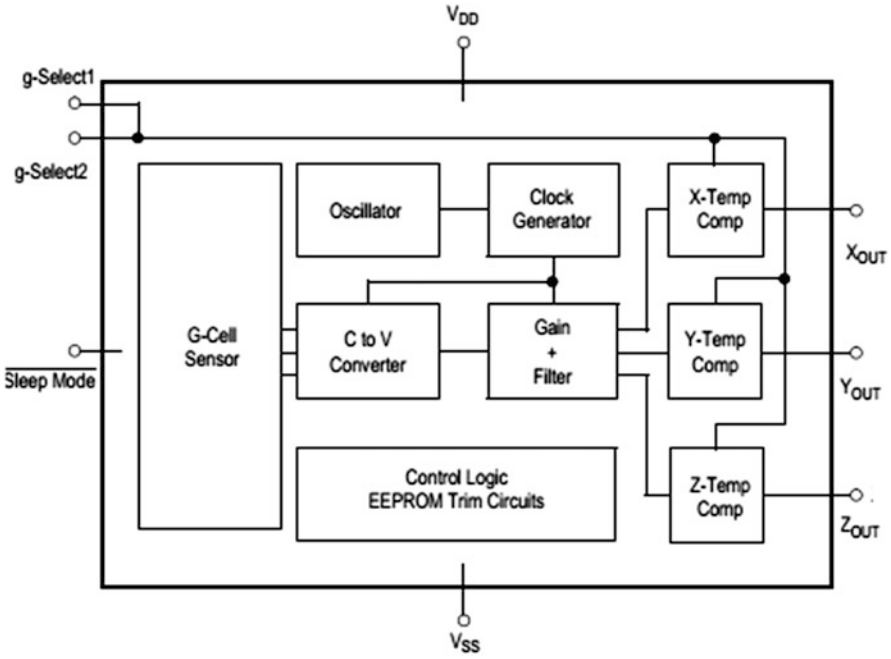

Fig. 2 Simplified accelerometer functional block diagram

3 MSP430F149

The Texas Instruments MSP430 family of ultralow-power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low power modes is optimized to achieve extended battery life in portable measurement applications. The device

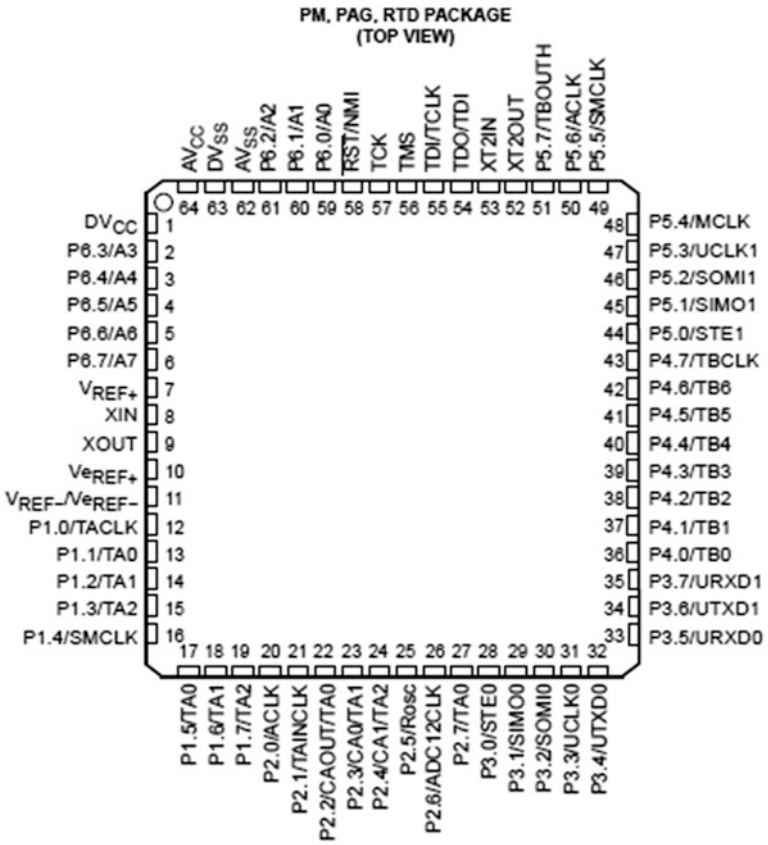

Fig. 3 Pin connections

features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that attribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 6 μs.

The MSP430x13x and the MSP430x14x(1) series are microcontroller configurations with two built-in 16-bit timers, a fast 12-bit A/D converter (not implemented on the MSP430F14x1 devices), one or two universal serial synchronous/asynchronous communication interfaces (USART), and 48 I/O pins.

Typical applications include sensor systems that capture analog signals, convert them to digital values, and process and transmit the data to a host system. The timers make the configurations ideal for industrial control applications such as ripple counters, digital motor control, EE-meters, hand-held meters, etc. The hardware multiplier enhances the performance and offers a broad code and hardware-compatible family solution. Figure 3 is MSP430F149 Pin Connections.

4 The Mechanism that Accelerometer Assess Energy of Movement

Speed acceleration is the rate of change that the velocity of the object varies over time, is physical quantities that describe the size and direction of the velocity of the object. Acceleration sensor is an electronic device that can measure acceleration.

There are two kinds of Accelerometer: one is the angular accelerometer, is improved by gyro (angular velocity sensor). Another is linear accelerometer.

Acceleration of the movement of objects is a space vector. On the one hand, if we want to accurately understand the motion state of objects, we must measure the component on its three axes. On the other hand, in the status of cases that we don't know the motion of an object in advance, we only use multi-dimensional acceleration sensor to detect the corresponding acceleration signal. At the same time, with the rapid development of science and technology, the traditional one-dimensional acceleration sensor has been unable to satisfy increasing high sensing information requirements in the measurement, control and information technology and other areas [6, 7].

There are many different kinds of accelerometers. From the measured principle, it can be divided into piezoelectric effect type, capacitive type, inductive type, strain type, piezoresistive type and surface acoustic wave type, etc. From the measured dimensions, it can be divided into one-dimensional model, individual two-dimensional model, a handful of three dimensional type [8].

The human body movements not only have dynamic characteristics such as physical activity, as well as static features such as the weight load. However, all forms of exercise can eventually be attributed to muscle contraction and energy consumption caused by heat dissipation and physical work. When we do exercise, the sugar, fat and protein oxidation in our body do reaction with oxygen in our body, produce carbon dioxide and water, releasing energy at the same time. More exercise, oxygen consumption will be increased, and within certain limits, the oxygen consumption of the subjects of the muscles is proportional to the power of muscle per unit time, and cardiac output caused by muscle motion is proportional to oxygen consumption. Therefore, we can use the oxygen consumption of unit weight and unit time to represent the energy of movement [9].

Bouten and Sauren [10], in a three-dimensional acceleration sensor research, used three-dimensional acceleration sensor placed perpendicular by three one-dimensional piezoresistive sensor as well as its supporting data processing software to measure the body exercise.

The results are as follows: in internal reliability test of the repetitive experiments and instrument, the offset and sensitivity of three-dimension acceleration sensor in each measurement direction are the same.

And three-dimension acceleration sensor has excellent linear relationship between output and energy consumption ($r = 0.95, p < 0.001$).

Whether in the high intensity and low intensity experiment, the inconsistencies between output and energy consumption of three-dimension acceleration sensor are smaller than one-dimensional acceleration sensor.

Relative to the one-dimensional acceleration sensor, the superiority of three-dimension acceleration sensor is very obvious, and its output value is closer to the objective true value.

At present, we use the following formulas 5–1 to calculate energy of sports,

$$EE_{tot} = EE_{act} + SMR \tag{1}$$

We can use respiratory gas analyzer to measure the amount of the oxygen consumption and carbon dioxide generation, and calculate the total energy consumption of body EE_{tot}. And we can measure AMR (Sleeping Metabolic Rate) of subjects in quiet sleep in a respiratory chamber.

Bouten and Westerterp [11] etc. considered that the effect of heat EE_{diet} generated after dinner should be considered. So the exercises in the experiment are arranged in 1.5 h or 2 h after dinner, as a result, EE_{diet} can be rule out. Thus, $EE_{tot} = EE_{act} + SMR$, the final EE_{act} by this method can be considered the true value of body motion.

We can worn the exercise measuring device based on three-dimension acceleration on the rear waist, the output of accelerometer are been amplified, filtered and shaped through data processing apparatus, then integral of absolute value taking 30 s as intervals can be calculated and obtain output AO_X, AO_Y, AO_Z in X, Y, Z axis.

$$AO_X = \int_0^t |a_x| dt \tag{2}$$

$$AO_y = \int_0^t |a_y| dt \tag{3}$$

$$AO_z = \int_0^t |a_z| dt \tag{4}$$

$$AO_{tot} = AO_X + AO_Y + AO_Z \tag{5}$$

Since AO_X, AO_{tot}, EE_{act}

$$EE_{act} = -0.176 + 0.085\, AO_X \tag{6}$$

$$EE_{act} = 0.104 + 0.023\, AO_{tot} \tag{7}$$

where, EE_{act} denote the energy consumption, unit: (J/min/kg), AO denote the accelerometer output units: times/min.

The conversion relationship between Joule and one thousand Ka Lula, as formulas 5–8

$$1\,\text{kcal} = 4184\,\text{J} \tag{8}$$

Large number of experiments proves that, the absolute value of body acceleration versus time integral and energy or oxygen consumption is a linear relationship. And provides a specific theoretical basis for the accelerometer assess human's movement.

In this study, three-dimensional accelerometer used to output AO_X, the linear relationship model of energy consumption EE_{act} used to calculate the energy consumption of the person what during exercise.

5 Hardware Design

Energy Expenditure Detection based on Three-dimensional acceleration is composed of portable measuring device and computer data processing device. Portable measuring device consists by the sensor signal acquisition and processing controller is respectively linked together with the acceleration sensor, temperature sensor, pulse sensor, and the wireless signal transmission module. Computer data processing device that connected by the wireless consists of computer and wireless signal receiving module that connected to the computer, portable movement measuring device and computer data processing device connected to each other through wireless, Fig. 4 shows the specifics.

In the above technical solution, the portable measuring device provided with large capacity memory, keyboard and LCD monitor, USB interface. They are linked together with the data port of the sensor signal acquisition and processing controller's. Three-dimensional acceleration sensor built into the portable measuring device, pulse sensor and the temperature sensor is provided in the bottom plate of the portable measuring device.

Computer data processing device management the data written to the database firstly (the data through wireless receive or USB receive), respectively to analysis energy consumption, Motion gesture, health consultants, etc., and combined with pulse, temperature to do a health state of motion analysis and processing, provide recommendations of health exercise, for example, recommended type of movement, time, etc.

This design has simple structure, convenient operation, low cost testing, and low power consumption. By fast data processing, it can provide rationalization guidance of health exercise for individuals. Physical activity energy monitor through measuring the waveform of three-dimensional acceleration, identify the type of human body exercise, to set up a motion energy consumption mathematical model and

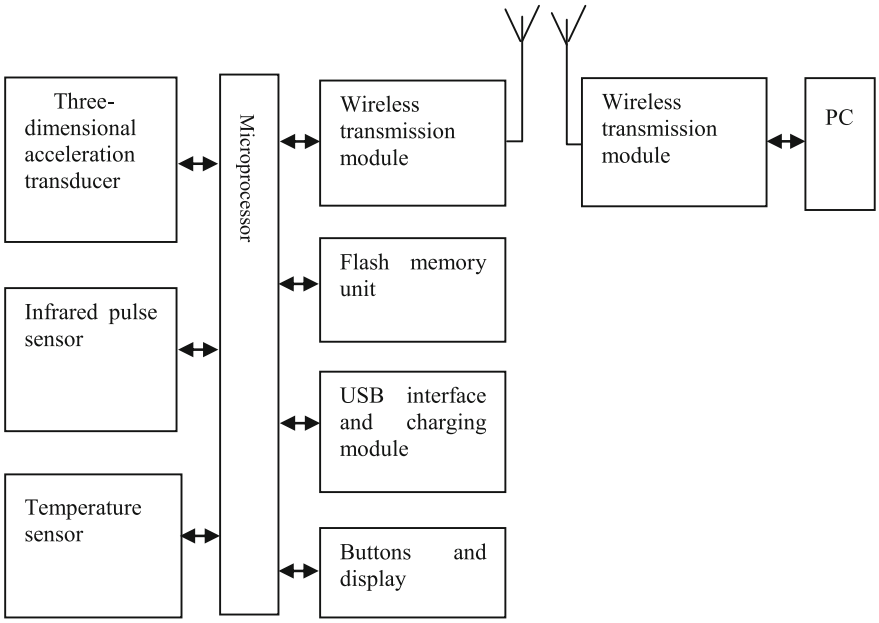

Fig. 4 The structure of energy expenditure detection based on three-dimensional acceleration

basic relations of human motion energy consumption and motion type, and acceleration, pulse, temperature, height, age, gender, etc., it can automatically select the corresponding mathematical model to carry out real time monitoring and to calculate the energy consumption.

6 Conclusion

Basing on it, the three-dimensional acceleration monitoring system to monitor the physical activity energy expenditure and daily actions is proposed in the paper. Hardware Design and The mechanism of accelerometer assessing movement energy were also proposed in the paper. The system is based on three-dimensional acceleration transducer MMA 7260QT and microprocessor MSP430F149.

Acknowledgments This paper work is supported by 2015 58th Chinese Postdoctoral Science Foundation (No. 2015M580655, Research and Application of College Students' Sports Energy Expenditure Model).

References

1. Grace, T.W.: J. Am. Coll. Health[J]. **45**(6), 243–251 (1997)
2. Davies, J., McCrae, B.P., Frank, J., et al.: Identifying male college students' perceived health needs, barriers to seeking help, and recommendations to help men adopt healthier lifestyles. J. Am. Coll. Health [J] **48**(6), 259–267 (2000)
3. Ware, Jr JE , Snow, K.K, Kosinski, M. et al.: SF-36 Health Survey Manual and Interpretation Guide [J]. New England Medical Center the Health Institute, pp. 1–12. Boston (1993)
4. McFarlane, A.H., Neale, K.A., Norman, G.R., et al.: Methodological issuesin developing a scale to measure social support [J]. Schizophr. Bull. **7**, 90–100 (1981)
5. Levine, H.M., Basham, R.B., Sarason, B.R.: Assessing social support: the social support questionnaire [J]. J. Pers. Soc. Psychol. **44**(1), 127–139 (1983)
6. Kerem, Shuval, Eyal, Weissblueth, Mayer, Brezis, et al.: Individual and socioecological correlates of physical activity among Arab and Jewish college students in Israel [J]. J. Phys. Act. Health **6**(3), 306–309 (2009)
7. Nuala M. Byrne, Jarrod D. Meerkin, Raija Laukkanen, et al. Weight Loss Strategies for Obese Adults:Personalized Weight Management Program Vs [J]. Standard Care, 2006
8. Loney, Tom, Standage, Martyn, Thompson, Dylan, et al.: Objectively assessed physical activity: which is right for public health [J]. J. Phys. Act. Health **8**, 62–70 (2011)
9. Carter, S.M., Rychetnik, L., Dietetics, PGradDip Lloyd, B et al.: Evidence, ethics, and values: a framework for health promotion [J]. Am. J. Public Health **101**(3), 465 (2011)
10. Bouten, C.V.C., Sauren, A.A.H.J.: Effects of placement and orientation of body-fixed accelerometers on the assessment of energy expenditure during walking [J]. Med. Biol. Eng. Comput. **35**, 50–56 (1997)
11. Bouten, C.V., Westerterp, K.R.: Assessment of energy expenditure for physical activity using a triaxial accelerometer [J]. Med. Sci. Sports Exerc. **26**(12), 1516–1523 (1994)