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Design study of an integrated test system of free combat training aids based on singlechip

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Abstract. Functions of current free combat training aids are unitary. Thus based on the MSP430 singlechip, this study designed a kind of integrated test system for free combat training aids, aiming to provide a versatile exercising and test platform for athletes. First of all, the adopted software and hardware in design were introduced. Then the design of hardware circuit and the program flow of software design were elaborated. Finally, the whole system was debugged. The designed integrated test system in this study was mainly composed of MSP430F247 singlechip, an ultrasonic wave sensor module and a liquid crystal module, etc. The system collected signals through the ultrasonic wave sensor and the air pressure sensor. The MSP430F247 singlechip was responsible for data calculation as well as displaying results through liquid crystal. The wireless communication module was connected with the upper computer and the user database was constructed for data management and query. Tests of modules and the whole system indicated that, the designed free combat system met ideal requirements, which also made up for the deficiency of current free combat training aids and improved the practicability and maneuverability.

Key words. MSP430 singlechip, free combat training system, sensor, upper computer, system debugging.

1. Introduction

Free combat training aids are popular in gyms. Follows aspects should be considered in selection of exercise equipment. Firstly, it should be popular. Secondly, it should be safe that exercisers will not be injured during exercising. Thirdly, it is reasonably priced and does not occupy much space [1–2]. Therefore, this study aims to design a kind of free combat training equipment that is perfect for gym.

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2. Literature review

Modern free combat training aids are integrated by exercising and testing. The back of the target surface of free combat training aid is connected with a air cylinder. When the surface is hit by users, the air is compressed and the target moves backward, thus a distance of buffer is formed, which can protect the fist [3–4]. The boxing strength can be reflected by changes of the air pressure in air cylinder. Signals of the air pressure changes are collected by air pressure sensors. After analog to digital (A/D) conversion, the boxing strength can be known [5]. In the designed system in this study, ultrasonic wave sensors were installed on top of the target, thus to detect the distance between the fist during boxing through reflected waves. Thus the speed could be calculated according to the specific value of distance difference of every two measurement and the time used. Among various speed values obtained, the maximum value was defined as the boxing speed. Therefore, the free combat training aid designed in this study could not only be used for boxing training, but could be used to test the reaction time, boxing speed and boxing strength. Such system overcame shortcomings of traditional free combat training aids, and its gas buffer could protect users.

3. Research method

3.1. Design of hardware circuit

The system designed in this study was mainly composed of MSP430 singlechip, MPS20N100D-S air pressure sensor module, SC63X75 air cylinder, HC-SR04 ultrasonic wave sensor module and 12864 liquid crystal module. MSP430 singlechip was the core module of the whole system, as shown in Fig. 1.

Ultrasonic wave sensors were responsible for collection of distance signals and air pressure sensors mainly collected air pressure signals. Collected signals were sent to the singlechip for calculation of boxing speed and strength. Meanwhile, the reaction time was obtained by timer B in the singlechip. The MSP430 singlechip not only stored measurement data in FLASH, but also sent them to 12864 liquid crystal module for display. Operating principles of the system are shown in Fig. 2. Overall structure of the free combat training aid is shown in Fig. 3.

3.1.1. Design of power circuit: As shown in Fig. 3, MSP430 single chip as well as the amplifier in differential amplification circuit requires ± 5 V of power supply. Therefore, 220 V of alternating current power supply was not suitable in the circuit design and should be used after coherent processing. Design principles of the power circuit is shown in Fig. 4.

LM7805 was a $+5$ V integrated regulator and its maximum output current was 1 A. According to the law of conservation of energy, the input and output power of power supply stays the same in ideal conditions. However, the output power is usually smaller than the input power in real life due to the loss caused by each component.

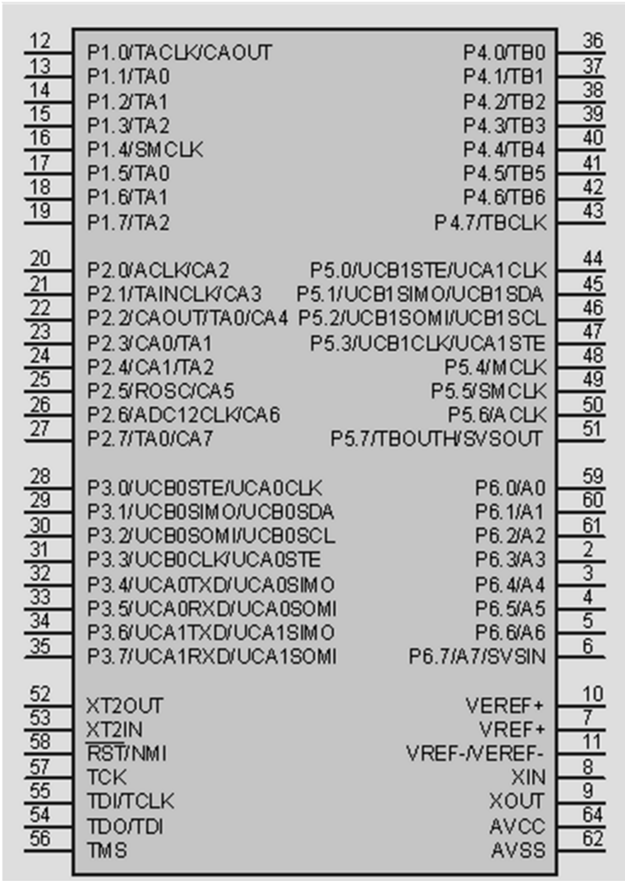

Fig. 1. Pin figure of MSP430F247 singlechip

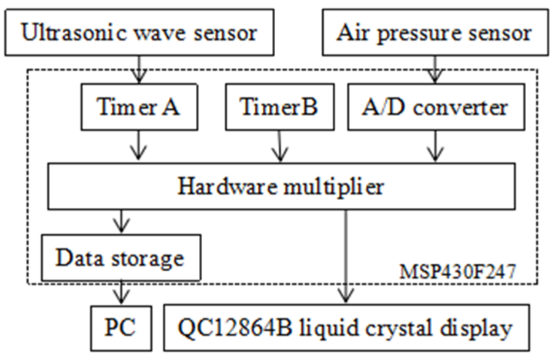

Fig. 2. Working principles of the free combat training system

The differential pressure of direct current between LM78 and LM79 before and after voltage stabilization was 2∼3 V. Thus, under positive and negative dual power,

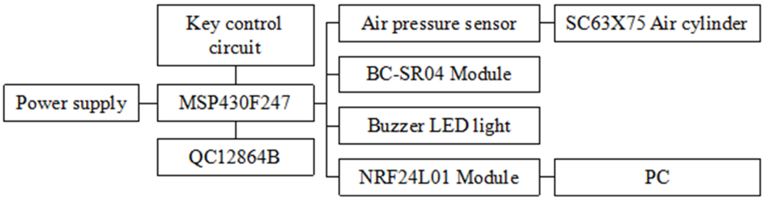

Fig. 3. Structure of the free combat training aid

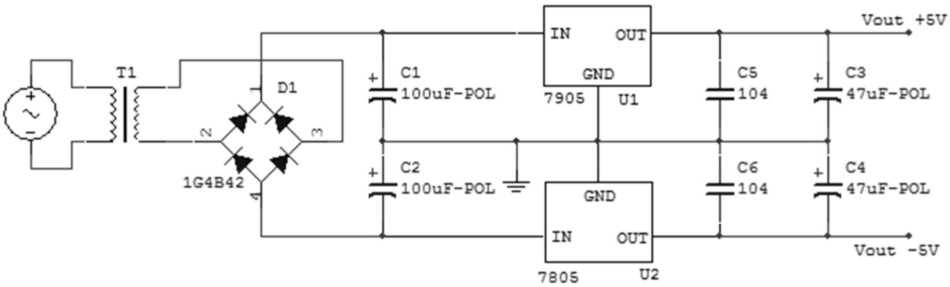

Fig. 4. Design principles of the power circuit

it should be 5∼6 V. Connection of the output end with capacitance could eliminate the ripple, thus the output direct current could be relatively stable. In addition, it had buffer effect on impact load.

3.1.2. Design of peripheral auxiliary circuit: Peripheral auxiliary circuits should be designed before the usage of MSP430 singlechip, such as reset circuit and clock circuit etc., in which the clock circuit was used to produce clock signals. The singlechip contained a low-speed crystal oscillator (LFXT1) and a high-speed crystal oscillator (XT2). Its external circuit is shown in Fig. 5.

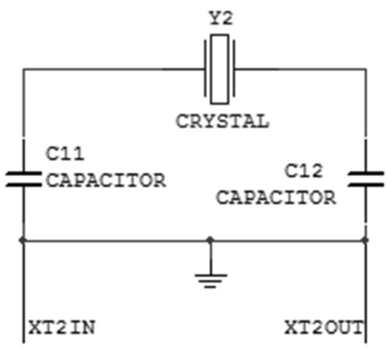

Fig. 5. Crystal oscillating circuit

MSP430 singlechip had two kinds of signals that could reset and initialize the equipment, which are power on reset (POR) signals and PUC signals. When the

MSP430 singlechip was powered on, the singlechip could produce POR signals if the reset pin RST/NMI was added with low electrical level. MAX708 was a kind of control chip of power supply for microprocessor, which could simultaneously output high level effective and low level effective reset signals [6]. Besides, MAX708 could monitor power supply signals and provide early warning of voltage drop for the singlechip. Thus the outage could be safe and parameters could be stored. The scheme of the reset circuit is in Fig. 6.

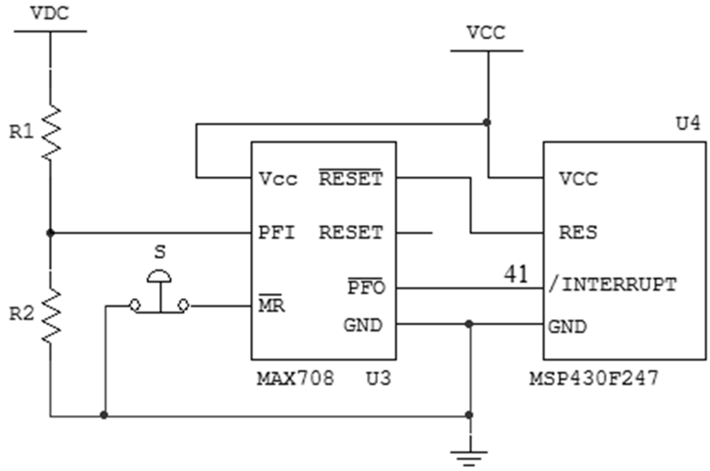

Fig. 6. Reset circuit

3.1.3. Circuit design of speed measurement: Ultrasonic waves are characterized by strong directivity and slow energy decrement and can propagate for a long distance [7]. Therefore, distances were measured using ultrasonic waves in this study. In the design, HC-SR04 ultrasonic wave sensor was used for speed measurement and the measurement accuracy reached 3 mm. The HC-SR04 distance measurement module included an ultrasonic wave emitter, a receptor and a control circuit. Its basic operating principles included three steps. Firstly, TRIG was used through input/output port to measure distances. Secondly, the module automatically emitted eight square waves in 40 kHz and it was automatically detected whether there was signal return. Thirdly, if there was signal return, a high level was output through the input/output port. The time of duration of high level was the time of ultrasonic waves from emitting to return. The measurement distance = high level time × sound velocity (340 m/s)/2. Wiring of the ultrasonic wave sensor is shown in Fig. 7.

3.1.4. Circuit design of boxing strength measurement: In measurement of boxing strength, the air pressure sensor was used to detect the voltage change in air cylinder. The maximum pressure air cylinder could bear was 320 kg; the boxing strength of normal people was around 250 kg. During boxing, the air was pressed while the piston would not rebound immediately, thus the maximum air pressure in the air cylinder could be maintained for a period of time. Thus the air pressure sensor had enough time of reaction.

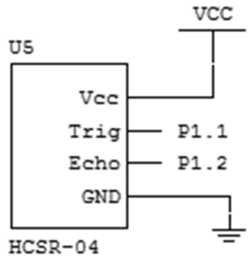

Fig. 7. Wiring of the ultrasonic wave sensor

The air pressure sensor used in this study was a SMD packaging product, which had good repeatability and long-time stability. Its internal circuit structure is shown in Fig. 8.

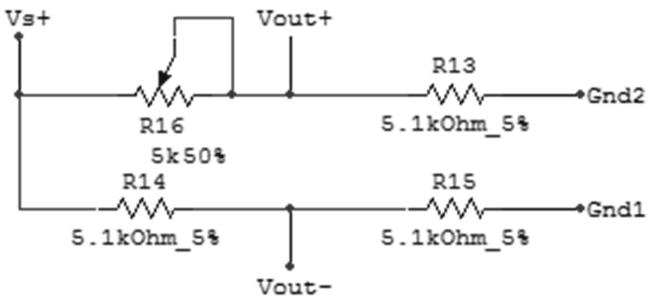

Fig. 8. Internal circuit of MPS20N1000D-S

Hardware circuit of the air pressure sensor is shown in Fig. 9. Output signals of Vout+ and Vout- were differential signals. Because signals were in millivolts, samples should be selected and amplified. Obtained positive analog signals were input in P6.0 port for analog-digital conversion. Thus the pressure value could be obtained after relevant calculation.

3.1.5. Analysis of sensor errors: Sensors were used in several parts of the designed free combat system in this study. Changes of factors, such as temperature, humidity and pressure, etc., could result in certain measurement errors. Therefore, analysis and adjustment of measurement errors in the design could reduce errors and improve accuracy, thus to further improve the systematic stability.

Propagation velocity of ultrasonic waves was mainly affected by temperature. Thus temperature correction was required for measurement of ultrasonic wave speed:

$$v = 331.4 \times \sqrt{T/273 + 1} \approx 331.4 + 0.067T\,\mathrm{m/s}\,.$$

In the above equation, v refers to the propagation velocity and T is the air temperature. Calibration curve could be used for error correction of pressure sensors.

First of all, standard weight was added on the target surface and multiple times of measurement was performed. Then standard input-output curves were drawn to obtain a characteristic curve:

$$F(x) = \frac{y_2 - y_1}{x_2 - x_1} x = kx\,.$$

In practical measurement process, the standard output could be obtained by substituting the input value to the input-output function

$$F(x_0) = kx_0\,.$$

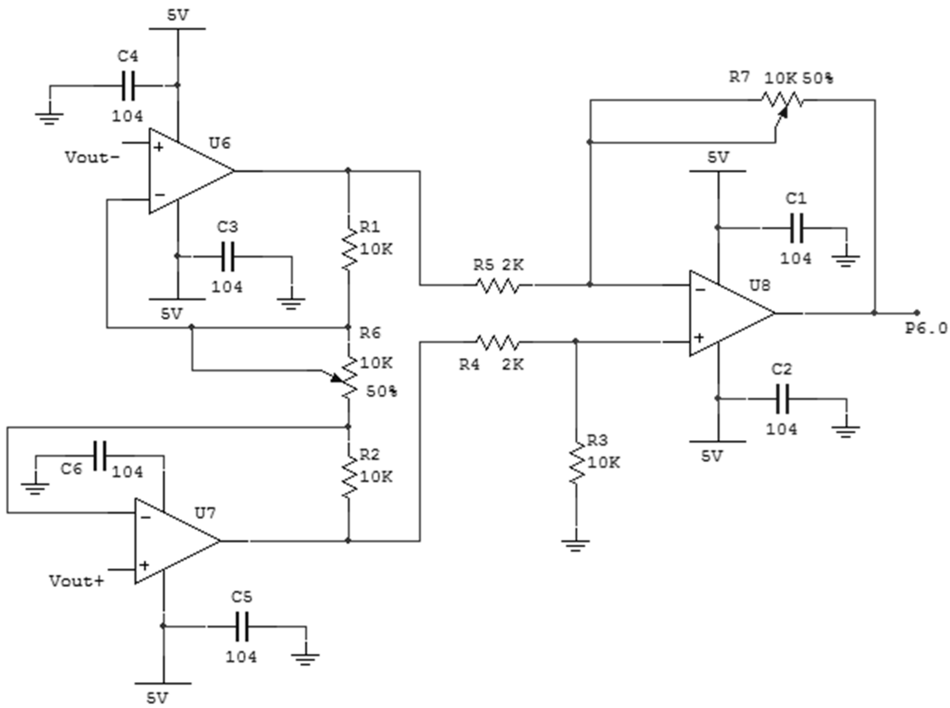

Fig. 9. Differential amplification circuit

3.1.6. Design of display circuit: QC12864B liquid crystal was used in the display module. 12864 refers to the number of lattice of 128×64 lattice liquid crystal module; its resolution ratio was 128×64. The function of key reminder circuit was to control the whole test process. Design principle of the key reminder circuit is shown in Fig. 10. As shown in the figure, the key was driven by P3.0 port and connected with a pull-up resistor. The electrical level of P3.0 port was continuously examined by the scan-round program. When low electrical level occurred, the key was pressed.

Serial peripheral interface (SPI) bus was used for central processing unit (CPU) and peripheral equipment in this study. The SPI bus of singlechip supported the host mode and the slave mode, and it had independent shifting register, bumper and interrupt functions in receiving mode and sending mode. It could programme and control the polarity and phase of clock as well as the frequency of clock under the state of host mode [8].

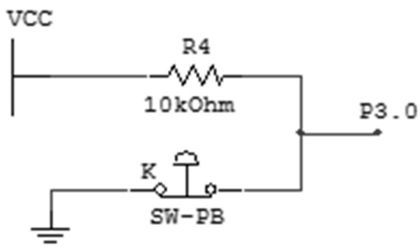

Fig. 10. Wiring diagram of the key

Communication between the system and PC was through the nRF24L01 module, which was a monolithic wireless transceiver chip operated in 2.4∼2.5 GHz general ISM frequency band. The wireless communication module included emission and reception these two parts and the operating principles are shown in Fig. 11.

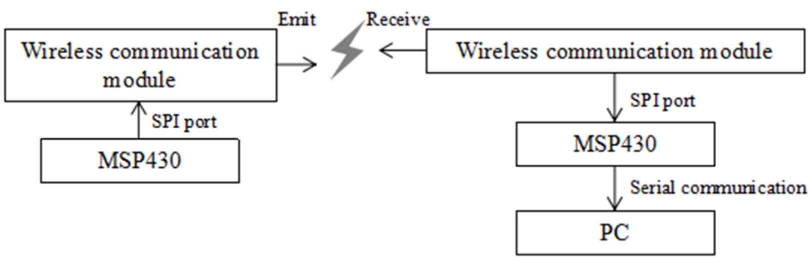

Fig. 11. Operating principles of wireless communication

3.1.7. Software design: IAR FOR MSP430 was a kind of programming and debugging environment that could be used in MSP430 singlechip. Developers could connect target boards through JTAG and the program could be debugged directly in IAR environment. Register values could be checked at any time and programming windows of C language and assembler language could switch at any time, etc.

Modularized programming concepts were used in the design. Consistent program interfaces were beneficial for debugging, correction and maintenance of the program. C language was mainly used for programming in the design of free combat training system. Besides, IAR program compiler was used for editing, debugging and compiling of C language. MSP430 singlechip emulator was used for simulation of the program.

The software part in the system was mainly composed of the main program and several interrupt service subroutines. The flow chart of the main program is shown in Fig. 12. The interrupt service subroutine was composed of following parts: the subroutine of ultrasonic speed measurement; the subroutine of boxing strength measurement, which collected the variable quantity of air pressure; a timing program of timer; the subroutine of wireless communication. Besides, there was also a display subroutine. Design texts of subroutines were not further elaborated in this study.

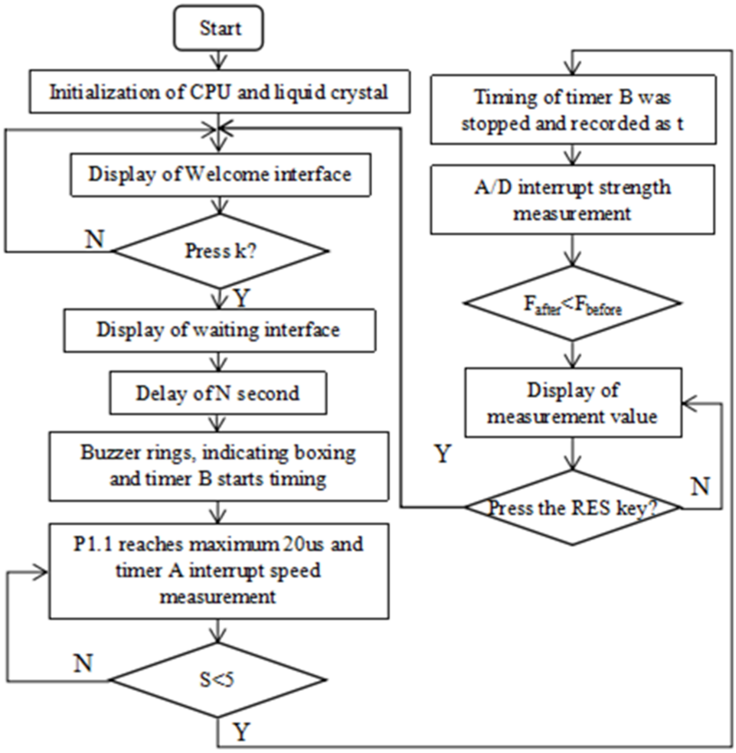

Fig. 12. Flow chart of main program

4. Debugging results and analysis

4.1. Configuration of development environment

IAR software was installed in computer and then set up. Specific steps are as follows:

IAR software was started and a new project was constructed according to Project> Create NewProject. Then in pop-up dialog box, address that should be stored was selected and then a new project was constructed.

Then the Workspace window was entered and the Debug configuration was defaulted. No correction was needed, or the program debugging could not be performed.

After that, a new file was built according to File>New>File and then saved for programming.

Finally, project options were set up and Projects>Options was selected after the finish of programming. Under the option of Device of General Options, the MSP430F247 singlechip was selected; then FET Debugger was selected under the option of Driver of Debugger for hardware simulation.

In MSP430 target board, debugged source program was loaded and hardware circuit was connected and checked. After that, mechanical framework was installed and fixed, i.e., the whole system could be tested.

4.2. Debugging and debugging result analysis

Firstly, the system was powered on. Then the display of Welcome interface could be seen. The k button was then pressed and the program entered the waiting time. After N seconds, the buzzer hinted boxing and the tester could prepare for the boxing at that time. At that moment, contents of liquid crystal display are as shown “Acousto-optic hint will be prompted after 3 second, please prepare to punch”.

When the buzzer rang, the tester began to punch. During that that, the reaction time, boxing speed and boxing strength of the tester were test at the same time. The test was over when the fist hit the target surface. Test performance was then displayed, as shown in Fig. 13.

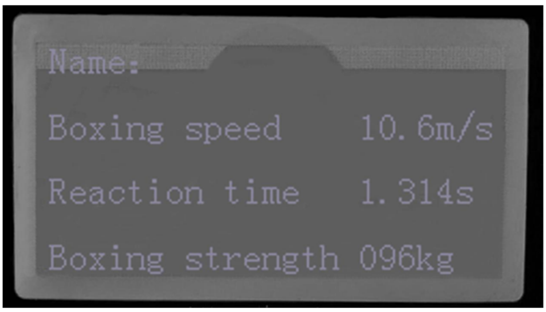

Fig. 13. Display interface of test performance

After the interface of test performance, it was also displayed that, Press RES to retest, reminding the tester to perform another test.

5. Conclusion

On the basis of theories of singlechip as well as the design methods of traditional free combat aids, we have basically understood design theories and principles of the free combat training system. Through the design of the integrate test system of free combat training, advantages and deficiencies are discovered to improve the ability of solving problems. Moreover, through module test as well as the test of the whole system, appropriate components are selected to improve the measurement accuracy, thus to improve the maneuverability and practicability of the training equipment.

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