Research on Acoustic Target Establishment and Reporting System Based on TDOA

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Abstract

In order to improve the catching rate and measuring accuracy of the automatic target-reporting system for acoustic and electrical positioning,an automatic target-reporting system based on high-frequency shock signal acquisition of projectiles was designed according to the requirements of military training.The principle and structure of the system are analyzed,and the software and hardware of the system are designed,which lays a foundation for further development and design.

Keywords

Equipment support;automatic target reporting;shock location.

1. Introduction

The automatic target-reporting system can be roughly divided into the following types: double-layer electrode short-circuit sampling system, target-reporting system based on image processing technology, optical fiber coding positioning target-reporting system, photoelectric sensing target-reporting system, electrode-embedded target-reporting system and acoustic-electric positioning target-reporting system. Compared with other target-reporting systems, the acoustic-electric positioning and target-reporting system has the advantages of low production cost, high measurement accuracy, fast target-reporting speed and all-weather operation[1].In the actual shooting range testing environment, the traditional electret capacitive acoustic sensor is vulnerable to the complex environment of shooting range, which causes the system to trigger incorrectly, and has a certain impact on the normal operation of the testing system. Therefore, the piezoelectric ultrasonic sensor with higher frequency band and faster response is proposed as the receiving sensor of shock wave signal, and the projectile coordinate measurement system is designed according to the actual test requirements.

2. System Measurement Principle

When a projectile moves at supersonic speed, the gas around the projectile is disturbed and flows around the projectile to form a compression wave. When the compressed wave collides with the airflow, the pressure, density and temperature around it will suddenly rise, which will cause the airflow around it to be compressed suddenly. The compressed wave is called shock wave.

The working principle of the shock location system is that the shock wave produced by the supersonic projectile in flight acts on the ultrasonic sensor to produce pulse signals, and the microphone array converts the pulse signals into electrical signals, and then analyses and processes them to get the arrival time value of each microphone. Then, the time difference of arrival (TDOA)and microphone array are used in advance according to the principle of time difference of arrival(TDOA)and microphone array. The collision coordinates are calculated by the mathematic model established by the array model. In this paper, a four-element L-type positioning model is adopted.

3. System Overall Scheme Design

3.1 Overall Design

The overall scheme is shown in Figure 1.The system is designed according to the test requirements of the automatic target-reporting system and the theory of passive acoustic positioning test technology. The system is mainly divided into five parts: sensor array, shock signal processing system, time acquisition and control system based on MSP430, wireless communication module and host computer.

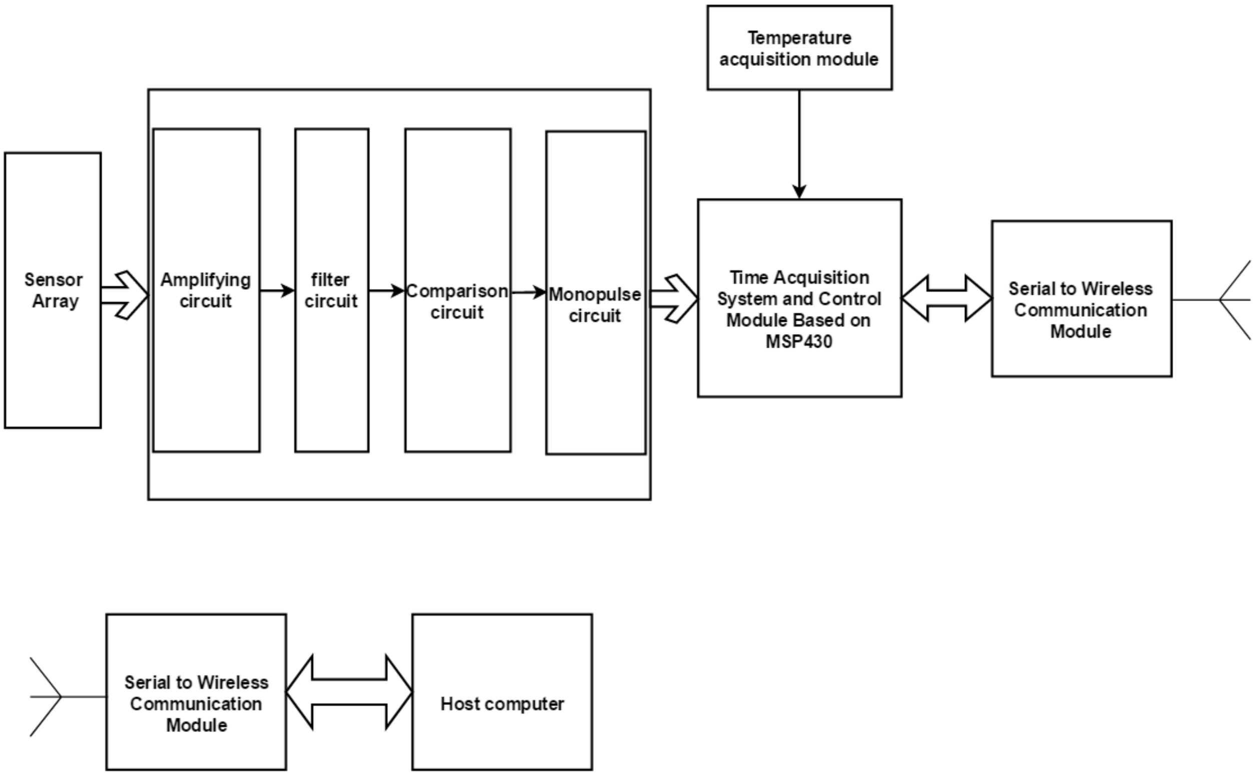

Fig.1 System Overall Scheme

Each part can be divided into several modules. The specific contents are as follows:

(1) The sensor array is a four-element L-shaped target array. When the conical shock wave of the projectile passes through the four sensors, they can detect four simulated shock signals of the projectile respectively.

(2) Shock signal processing system is composed of analog circuit and digital circuit. The analog circuit part completes the amplification, filtering and comparison of the shockwave signals of projectiles and transmits them to the digital circuit part. The signal processing is transformed into high-precision pulse sequence by a bistable flip-flop-flop.

(3) The time acquisition and control system based on MSP430 collects the time data of multi-channel pulse sequence arrival and the temperature data of the experiment site, and sends the collected data to the upper computer through serial port to wireless module.

The wireless communication module is composed of two wireless sending/receiving modules and a serial port to USB module to realize long-distance data transmission. Because the lower machine target machine is partially distributed in the target attachment, and the upper machine must be in a safe shelter of several hundred meters, or even thousands of meters, so the data is transmitted through the wireless communication module. One wireless communication module is connected with MSP430 through serial port, the other is connected with PC through serial port to USB module.

3.2 Component Selection Design

3.2.1 Sensor Selection

Shock wave of projectile has the characteristics of single transient, and the reliability of sensor triggering determines whether it can capture effective signals. Considering the characteristics of sound wave and the harsh environment in the field,the special use environment,such as micro-pressure,transient,strong external interference,etc.,requires that the selected sensor has the advantages of high sensitivity, high frequency response, wide working frequency bandwidth and strong overload ability[4].According to the above technical requirements, piezoelectric sensor QSY8116 is selected as the receiving end of shock wave signal.

3.2.2 Amplifier Selection

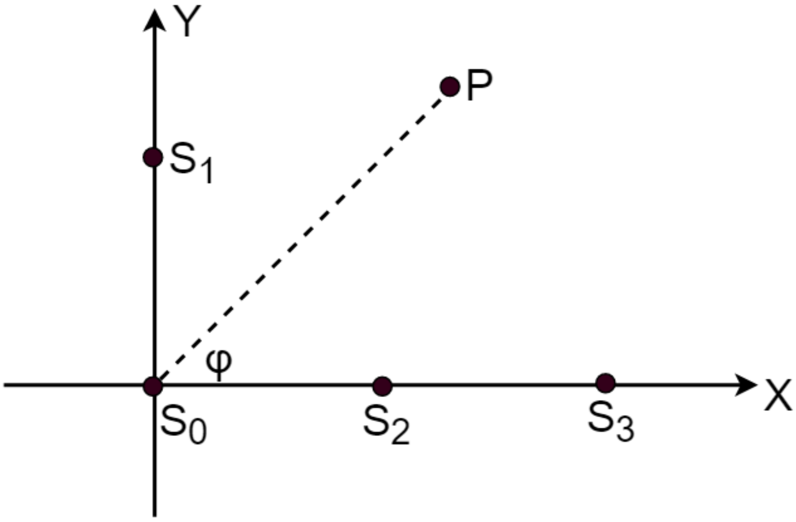

Fig. 2 Quaternary L-type sensor array model

See Fig. 2. ,the model consists of linear arrays S0,S2 and S3 on coordinate axis X and linear arrays S1 on coordinate axis Y, which are orthogonal to each other. The element spacing of the four-element L-shaped array is D,and the rectangular coordinates of the four sensors are S0(0,0), S1(0,D), S2(D,0)and S3(2D,0),respectively. In the Cartesian coordinate system shown in the figure, the spherical coordinate of the impact point is P(r,φ),so that the distance from the sound source to the sensors S1,S2,S3 to the sensor S0 is equal. Assuming that the distance between the source P and the element S1 is the same, since the source signal propagates in the form of spherical wave, the four sensors are located on four spheres with the source P as the center and the radius r,r+d10,r+d20 and r+d30 as the radius respectively. The equations can be obtained:

$$\begin{cases} x^2+y^2=r^2 \\ x^2+(y-D)^2=(r+d_{10})^2 \\ (x-D)^2+y^2=(r+d_{20})^2 \\ (x-2D)^2+y^2=(r+d_{30})^2 \end{cases} \tag{1}$$

In rectangular coordinate system, the coordinate of the impact point P in spherical coordinate system is P(r,φ).

$$\begin{cases} x=r\cos\varphi \\ y=r\sin\varphi \end{cases}, \ 0°\le\varphi\le 360° \tag{2}$$

The formula for calculating the impact point P(r,φ)of a quaternion L-type array can be deduced.

$$\begin{cases} r=\dfrac{d_{30}^2-2d_{20}^2-2D^2}{4d_{20}-2d_{30}} \\ \tan\varphi=\dfrac{D^2-2rd_{10}-d_{10}^2}{D^2-2rd_{20}-d_{20}^2} \end{cases} \tag{3}$$

In this way,the accurate formulas for calculating the distance and azimuth of the impact point of a four-element L-shaped projectile in spherical coordinate system are obtained. The position information of projectile impact point P can be calculated by estimating the delay_10,_20 and_30 by the method of time delay estimation.

The mathematical model describes the position relationship of the projectile's impact point, which provides a theoretical basis for the design of the solution method[5].

3.2.3 Selection of Sensor Array

Because the shock wave signal collected by the ultrasonic sensor is relatively weak, it needs to be amplified:an amplifier with high input impedance is connected at the output end of the sensor, and the input impedance of the amplifier is much larger than the output impedance of the sensor.OPA4340 integrated operational amplifier is chosen here. The operating voltage of OPA4340 is 3.3V,and the input voltage should not exceed 3.3V.It has simple power supply and can be used. Improve the reliability of power module.

The system has four sensor signals to be processed. Each signal is processed by two OPA4340 chips , that is, four amplifiers to collect signals,including impedance conversion,charge conversion voltage, filtering,amplification and so on.In the circuit,the connection scheme of OPA4340 is that the signal collected by the sensor is first transformed and amplified by impedance transformation and charge conversion, then the negative voltage signal is converted into positive voltage signal and amplified, and the amplified positive voltage signal is output[6].During this period,band-pass filter circuit,i.e. high-pass filter and low-pass filter circuit,is added to limit the pass-band frequency of the signal to a certain range,to attenuate or even filter the clutter in a large extent,and finally to amplify it twice through the second OPA4340 operational amplifier, which is the basic function of the analog circuit module.

Because of the need for subsequent digital signal processing, it is necessary to convert the analog signals from the front end into electrical signals that can be recognized by digital circuits. Voltage comparators are usually used as shaping chips to convert analog signals into digital square wave signals for subsequent time difference data extraction.The comparator chip selected in this project is LM393.

3.2.4 Selection of Single Chip Microcomputer

This part of the circuit is to control and organize the circuit. It mainly completes the timing control and data packing function of wireless module. This system is mostly used for field training support. When choosing the chip, besides meeting the functional requirements, it also needs to consider the power consumption of the system and the level matching of the upper circuit.MSP430F149 is a 16-bit ultra-low power monolithic computer of TI company. It adopts 16-bit RISC system and has a command cycle of 125 ns under the driving of 8 MHz crystal oscillator. There are one active mode and five low power modes in the system, and it has abundant on-chip peripheral modules.In addition, the chip belongs to Flash type in MSP430 series monolithic computers. It has JTAG debugging interface and Flash in the chip. Memory, in the development process, only need a PC and a JTAG debugger to download the program to Flash, can run.As the main control unit of the system, MCU receives the feedback signal, sends the clock pulse at a set frequency, and reads the corresponding output data. After receiving the data completely, it writes the data to the wireless module according to the time sequence of the wireless module and controls its transmission. When receiving the feedback signal of the wireless module,it stops working[7].

4. Programming

4.1 Programming of Lower Computer

The main function of the lower computer is to extract the time difference data of each channel by discriminating the digital pulse signals generated by each channel, output the time difference byte data of corresponding channels through sorting and digital conversion, and complete self-checking and data transmission[8].The program part mainly includes MCU program control, counter module, data storage module, channel sorting module and data conversion and transmission module design. When the MCU receives the interrupt signal, it sends out the reading clock signal, and reads the time difference byte data of each channel in turn.Finally, the data is sent to the host computer through the UART port of the MCU.

4.2 Upper Computer Programming

The upper computer program is written in LabVIEW environment. The upper computer can realize the function of remote self-check and reset of the system. Its wireless communication is mainly realized through the VISA port in LabVIEW. For practical testing, it can acquire the time difference data received by wireless devices through serial port, and transform the corresponding time difference data into decimal time difference data[9]which can be used for calculation through data processing. In the upper computer program, MATLAB script node is used to call the MATLAB equation file, and the coordinate value can be finally calculated by using the known solution model and substituting the measured time difference data of each channel.

5. Conclusion

In this paper, based on the traditional design principle of acoustic automatic target reporting system and according to the actual daily use needs of the army, an automatic target reporting system based on high frequency shock signal acquisition of projectiles is designed. The piezoelectric ultrasonic sensor with wider frequency band and faster response is selected as the receiving signal end. The signal conditioning circuit and the program with MSP430F149 as the main control chip are designed. The upper computer program is compiled to display the current coordinate position of the impact point in real time. Finally, the firing test of live ammunition is designed to verify the performance of the whole target-reporting system.

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