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The Design of Sound Source Location and Tracking System Based on TDOA

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ABSTRACT

In this scheme, STM32F407 is used to process the information, and a system is designed to detect and track the short-range acoustic signal source continuously. After a detailed analysis of the hardware circuit, a complete system circuit design and software flow chart are presented. In this design through the single-chip drive passive buzzer sound, silicon-wheat audio signal sampling, silicon-wheat data collected by the single-chip computer data processing, based on the principle Of Time Difference of Arrival (TDOA), the distance and angle between the sound source and silicon malt are determined. The step motor is driven to rotate the laser pen to emit light spot to precisely locate the sound source and continuously track it. The system integrates computer hardware, software and sensors to enable intelligent instruments to locate and track sounds similar to the human auditory system, and to integrate with other systems, let mankind enter a new era of interconnectedness as soon as possible.

KEYWORDS

Time Difference of Arrival; Sound Source Location and Tracking; STM32F407 Single-Chip Microcomputer; Non-synchronous sampling; Stepper Motor

1. INTRODUCTION

Sound source location and tracking technology refers to the sound signal to determine the location and movement of the sound source technology. As early as the 19th century, people began to use sound to locate objects, the technology called sonar technology. In the early 20th century, people began to use acoustic sensors to record the sound of musical instruments, which gave birth to sound-based signal processing technology. In the late 20th century, the invention and popularization of silicon microphone array initiated the era of sound source localization and tracking technology based on silicon microphone. In 1970, the research of sound source localization technology was first carried out, and the wide application of medical, video conference and vehicle-mounted system also promoted the development of this localization technology [1]. Microsoft uses the microphone array architecture on all versions of its operating systems to enable the computer to accurately locate sound sources, thus enhancing the human-computer interaction experience [2].

A silicon-malt array is a system consisting of multiple silicon-malt units. The sound signal obtained by the array unit can be analyzed by the single chip microcomputer in the time-frequency domain and the spatial direction information of the signal. Compared with traditional silicon-malt arrays, the advantages of distributed silicon-malt arrays lie in the following aspects. In traditional silicon-wheat arrays, a central control node is usually needed to gather and process signals, while distributed silicon-wheat arrays are deployed in a distributed manner, no central control node is required to avoid single point of failure and signal transmission bottlenecks.

The signal quality of distributed silicon-wheat array is more stable. Because distributed silicon-wheat array uses multiple silicon-wheat for signal acquisition and processing, it can make the signal quality more stable and reliable by signal fusion and noise reduction algorithm.

TDOA-based silicon-wheat array sound source location and tracking technology can be widely used in safety detection system, intelligent robot, acoustic camera, video conference, robust speech recognition, seismology, sonar and other fields. With the advent of "Voice-controlled era", the construction of sound source location and tracking system has become the focus of acoustic research, which integrates computer hardware, software and all kinds of sensors [3]. The application of this system will make the intelligent instrument and the human hearing system have the same ability of locating and tracking the sound; by integrating with other systems, human beings will enter the age of interconnectedness of all things early. Through the research of sound source localization and tracking technology, silicon-wheat array can be applied to a wider range of scenarios, such as improving the quality of directional audio signal, achieving speech enhancement, accurate speech recognition; Due to the influence of lighting, distortion and so on, the tracking effect will be worse, and the sound propagation is not affected by these factors, so the sound source tracking can be used to compensate for the shortcomings of video tracking, and guide the camera to track in real time, improve the performance of the tracking system. Therefore, the research of sound source location and tracking based on TDOA is helpful for the development of man-machine interaction system, the improvement of computer intelligence and the development of driverless vehicles, it is a milestone to promote the upgrade and value transformation of artificial intelligence [4].

2. THEORETICAL ANALYSIS AND CALCULATION

2.1. Theoretical Analysis of Difference Time Arrival Ranging (TDOA)

The TDOA principle uses a small number of microphones, requires a small amount of calculation, and is easy to implement. The ranging method based on TDOA is to collect the time difference between the sound signal emitted by the sound source and each silicon microphone, Calculate the coordinates of the unknown point based on the time difference. As shown in Figure 1, there is a point sound source S (r, θ) and three silicon microphones A, B and C with spacing d in the plane, and the silicon microphone B is used as the reference array element. Then $r = r_2$ and θ is the angle between r_2 and the x-axis. Let the time delays of the signals received by the silicon microphones B and A and the silicon microphones B and C be τ_{21} and τ_{23} [5].

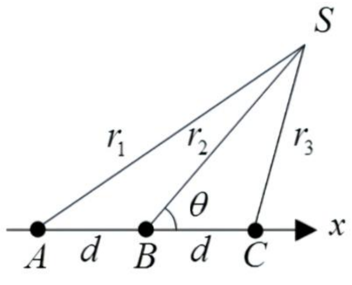

Figure 1. TDOA Location Method

The time delay of the signals received by the two silicon microphones is the distance between the reference array element and the sound source minus the distance between the silicon microphones on both sides and the sound source divided by the sound speed. Where, C is the speed of sound, because the speed of sound is affected by air pressure, temperature and other factors, to reduce the measurement error, it is recommended to measure according to the actual situation [6]:

$$\tau_{21} = \frac{r-r_1}{c}, \tau_{23} = \frac{r-r_3}{c} \tag{1}$$

The cosine theorem is used in triangle SAB and triangle SBC, and the estimation formula of the sound source position is obtained as follows.

$$\theta = arccos\left[\frac{c^3\tau_{21}\tau_{23}(\tau_{21}-\tau_{23})+d^2c(\tau_{21}-\tau_{23})}{dc^2(\tau_{21}^2+\tau_{23}^2)-2d^3}\right] \quad (2)$$

$$r = \frac{c^2(\tau_{21}^2+\tau_{23}^2)-2d^2}{2c(\tau_{21}+\tau_{23})} \quad (3)$$

By calculation, the angle θ and the distance R can be obtained.

2.2. Stepper Motor Control Principle of Tracking Module

Stepping motor driver is an important part of controlling the rotation of stepping motor. The BioPhase 1.8 Degrees stepping motor driver is a PWM pulse signal transmitted by a single chip microcomputer, The rotation of the motor is controlled by forward and reverse energization according to the time sequence. When the forward and reverse signals are received at the same time, the motor will lock the position. When a single forward or reverse PWM pulse signal is received, the motor rotates one step in this direction, with each step being 1.8 degrees. The whole process has high control precision and can realize accurate rotation and positioning [7].

A pulse signal is an electrical signal that conveys information with a change in voltage between ON and OFF States. It consists of a series of timed voltage pulses. In stepper motor control, each pulse signal turns the motor output shaft 1.8 degrees. In the pulse signal, "H" is generally used to represent the high level and "L" is used to represent the low level.

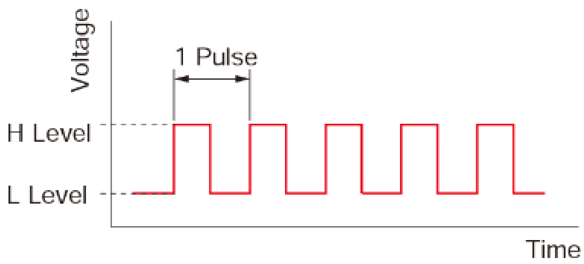

Figure 2. Relationship between High and Low-Level Change and Pulse Signal

The angle of each rotation of the stepper motor is fixed, which is called the basic step angle. In this design, a 1.8-degree two-phase stepper motor is used. The rotation distance of the stepping motor is calculated by controlling the number of pulse signals received by the driver; by dividing the number of pulses by the number of steps in one revolution of the motor (360 degrees/basic step angle), the actual rotation angle of the motor can be calculated. For example, for a 1.8 degree 2-phase stepper motor, the angle corresponding to each pulse signal is 360 degrees/200 = 1.8 degrees [8]. The relationship between the rotation distance of the stepping motor and the number of pulses is as follows:

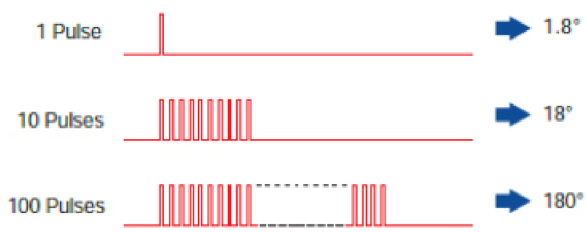

Figure 3. Proportional relationship between rotation distance and pulse number

There is a linear relationship between the speed of the stepping motor and the frequency of the pulse signal received by the driver. In the case of operating in step mode, the rotation angle of each step of the stepper motor is fixed, the speed of the motor can be controlled by changing the frequency of the pulse signal. The increase of pulse frequency will increase the speed of the motor, and the decrease of pulse frequency will reduce the speed of the motor [9]. The relationship between the stepper motor speed and the pulse frequency is as follows:

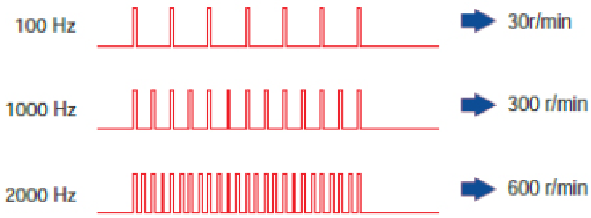

Figure 4. Proportional relationship between rotating speed and pulse frequency

3. HARDWARE DESIGN

3.1. Sound Signal Acquisition Circuit

The circuit collects the audio signal generated by the buzzer and provides it to the MCU.

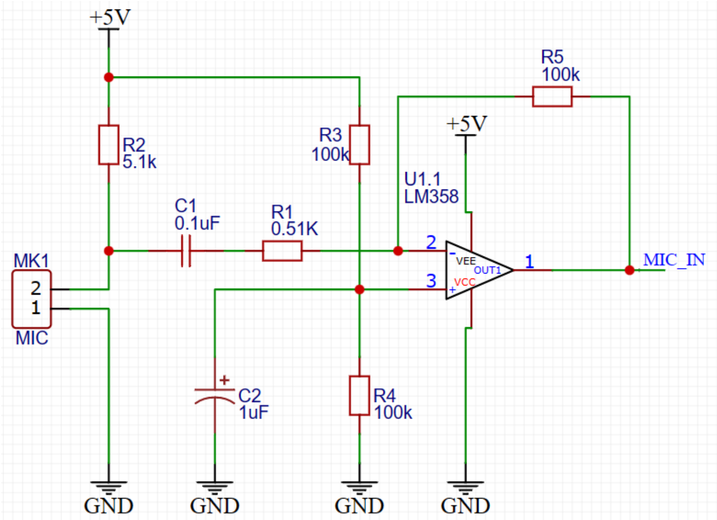

Figure 5. Sound signal acquisition circuit

MEMS microphone (integrated MEMS microphone) usually consists of two parts: the sensor of MEMS and the interface circuit. The MEMS sensor is responsible for receiving the sound signal. When the sound wave acts on the silicon diaphragm, it will vibrate, forming a change in capacity. This change can be measured by a micro-capacitance sensor. The micro integrated circuit then amplifies the electrical signal to output an audio signal for subsequent processing. At the same time, the RF anti-noise circuit will filter the signal to remove noise interference and match the front-end circuit as much as possible as to realize high-quality sound collection, and thus the conversion of the sound signal is completed. Through the sound signal acquisition circuit in Figure 5, the subtraction circuit composed of LM358 completes the reading of electrical signals as to realize the recognition of the sound.

3.2. Stepping Motor Control Circuit

An encoder within the stepper motor may calculate the speed of the stepper motor, Its main principle is that the encoder can obtain the speed of the motor according to the number of pulses of the motor rotation.

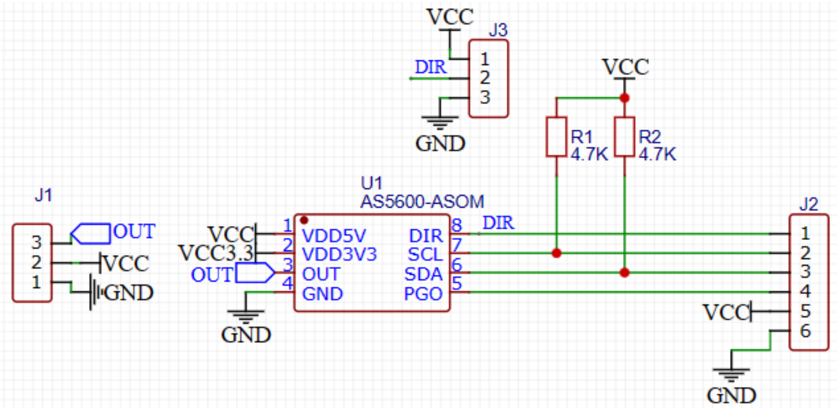

Figure 6. Stepper Motor Control Circuit

The AS5600 magnetic encoder is an element commonly used to measure the angular displacement of a motor. The element is a position signal sensor with high precision and high performance, which is mainly used to measure the position and speed of the rotating shaft. It uses magnetic encoder technology to provide position data with up to 13-bit resolution and multiple output formats. The AS5600 magnetic encoder can measure the angular displacement of the motor with high precision and realize precise positioning and motion control.

3.3. Comparator Circuit

The 200 Hz signal generated by the buzzer may be distorted due to the influence of the surrounding environment. To ensure that the detected sound signal quality is good, Filtering or comparison can be used for preprocessing. Filtering can filter the non-200Hz frequency part of the input signal and retain the effective signal as to judge whether the input signal conforms to the range and output a corresponding high or low-level signal. This can avoid the influence of interference and noise and ensure the accuracy and stability of the measured signal.

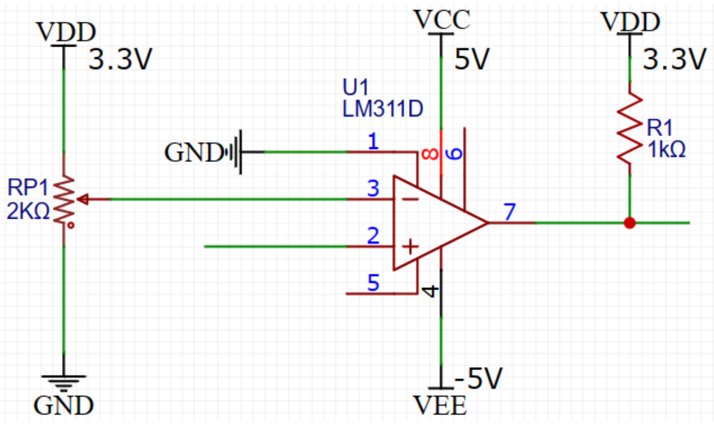

Figure 7. Comparator Circuit

The in-phase input end of the LM311 relates to the sound signal acquisition circuit, and when the silicon microphone receives a sound signal, a larger amplitude U + is generated, Set the noise amplitude U-. When U- is greater than U +, the output is 0. When U + is greater than U-, the output is 1.

4. SIGNAL TRACKING FUNCTION TEST

The test process of the signal tracking function includes a signal receiving stage, a time delay estimation stage, and a display positioning stage. In the time delay estimation stage, the positioning principle of TDOA is used to calculate the theoretical distance between the sound source and the silicon microphone. The distance, angle, reaction time and light spot deviation were tested every 50 cm, which were recorded as group A, B, C, D, E and F respectively. The actual distance and the actual angle are theoretical values calculated according to a formula, The measured distance and measured angle are the data after the sound source is located and tracked according to the designed system. The measured data are shown in the following table.

Table 1. Signal tracking function test

Location	A(0cm)	B(60cm)	C(120cm)	D(150cm)	E(270cm)	F(300cm)
Actual distance (m)	2.90m	2.65m	2.47m	2.49m	2.82m	2.96m
Measured distance (m)	2.92m	2.66m	2.52m	2.50m	2.78m	2.92m
Distance error (m)	0.02m	0.01m	0.05m	0.01m	0.04m	0.04m
Actual Angle (°)	30	20	7	0	25	30
Measured angle (°)	31.964°	18.799°	5.843°	0.529°	26.641°	32.438°
Angle error (°)	1.964	1.201	1.157	0.529	1.641	2.438
Reaction time(s)	3s	4s	3s	3s	5s	3s
Light spot deviation(cm)	2cm	1cm	3cm	1cm	2cm	2cm

As shown by the test results in Table 1, the average error is used as the criterion for judging the accuracy of the experiment. According to the error of distance and angle in the above table, it can be concluded that the error of distance is less than or equal to 5cm; The error of the angle is less than 3, and the error of the distance and angle is within 5%, which meets the requirements of the system design. When locating the indicating sound source, the response time of the stepping motor shall not exceed 10 s, and the average response time in the above table is 3.5 s. The pre-designed target can be achieved within the allowable error range. The light spot deviation is the distance from the light spot of the laser pointer to the buzzer, and the average deviation is calculated to be 1.83 cm according to the above table. The deviation is within the range of system design error and can be ignored, which meets the system design requirements. To sum up, this design can meet the pre-design requirements and expectations.

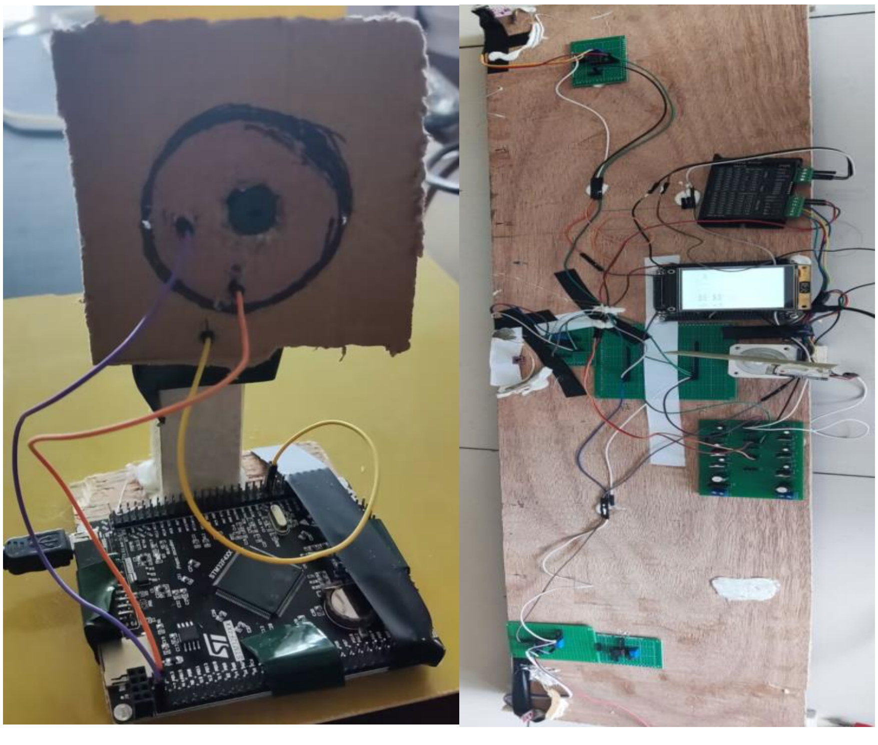

Figure 8. Picture of Design Object

Through the test of sound signal detection and signal tracking function of the system, the expected design goal is achieved. According to the test data, the location of the near-field sound source in the area can be displayed in real time on the single chip microcomputer. Displaying the straight-line distance R and the included angle theta between the audio signal generating module and the sound sampling and positioning module, the distance and angle of the test results are within the error range of 5%. In this design, the sound source is received by the silicon microphone (MEMS), and the passive buzzer is driven by the MCU. The stepper motor precisely locates the sound source by rotating the laser pointer to emit the light spot and keeps tracking. The positioning technology based on time difference can realize real-time positioning, which has the advantages of less calculation and high accuracy.

5. CONCLUSION

In this scheme, STM32F407 is used for information processing, and a close-range sounding signal source is designed. And continuously position and track the system. The system consists of audio signal generation module, sound signal acquisition and positioning module, and stepper motor control module. MCU1 acquires the sound via the sound signal acquisition module and converts it into the distance and angle by the principle of the TDOA algorithm for display on the LCD screen. Additionally, it outputs PWM pulse signals to control the stepping motor and drive the laser pointer to track the sound source. MCU 2 is accountable for inputting PWM waves and outputting periodic signal audio to the buzzer module. After testing, all the data are within the error range, and all the performance indicators meet the design requirements. The TDOA-based sound source localization and tracking technology of silicon microphone array can be widely used in security detection systems, intelligent robots, acoustic cameras, video cameras, Frequency conferencing, robust speech recognition, seismology, sonar and other fields.

Sound source localization is a key technology in many application fields, such as communication and speech recognition, smart home, security and so on [10]. However, there are still many problems to be solved in practical applications. For example, the rotation angle error of the stepping motor is large; Environmental noise will affect the positioning accuracy. The error of the rotation angle of the stepping motor can be measured by recording the data of the sound source moving to the starting point, the midpoint and the end point respectively for a plurality of times, ensure that the MCU collects valid data to solve the problem. The impact of environmental noise on the system can increase the sound of the buzzer by controlling the input voltage through a sliding resistor. To reduce ambient noise interference and select a quiet area for testing.

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