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Ultrasonic Automatic Tracking System

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Abstract

Ultrasonic ranging system has many characteristics, such as well-directionality, small volume, and low price, but fails to realize a long distance measured. In order to realize exactly locating motion objects, multiple ultrasonic sensors are adopted to measure their motion orientation so that their 2D coordinates should be located and positioned, which results in calculations complicated and meanwhile measurement subject to errors. This study addresses a measurement method to realize automatically tracking motion objects. It has a reasonable distribution structure of the ultrasonic sensors adopted, critical tracking calculation method, which makes it possible to solve complex problems of equations. As it has simple control instruction sequence, it is able to precisely control timing period and effectively solve measure error caused by irregular delay from commands. These programs and methods are well deployed in the parameters collection and status control system for a moving object.

***Keywords**: ultrasonic, ranger finding, tracking, assembler instruction*

1. Introduction

In moving objects monitoring system, a great number of data are usually required for dynamically tracking, such as location, distance, and trajectory. Usual technologies used in racking system include ZigBee technology, ultrasonic directional range finding technology, and microwave distance measuring technology. Among them, Zigbee technology has a great advantage in network communications.

Distance can be calculated by analyzing RSSI parameters. However, the actual measure error is large enough to reach approximately one meter. This technology also requires three or more ZigBee modules in combo when locating the object's position. Furthermore, the tested object may also be required to have a ZigBee module.

Ultrasonic modules are generally used to measure distance. It has well-directionality, high precision. Unfortunately, it fails to measure long distance. It can reach a high precision of millimeter when the target is within a range of several meters.

In a microwave ranging system, the distance and orientation can be realized by means of frequency spectrum analysis and calculating the phase difference between a transmitted electromagnetic wave and the wave reflected by and received from the object. It has a high precision and is able to realize a long distance measurement. In particular, it is the optimal choice to detect moving things, especially those metal objects. For a general motion object, there are two common requirements for detecting a moving subject in a project, i.e. measuring its trajectory and collecting its status data in real-time. Compared with other distance measuring techniques, the ultrasonic range-finding method has so many advantages, e.g. 1) Non-sensitive for external light and electromagnetic fields with the result that it can be used in the dark, dusty, smoke, electromagnetic interference, toxic and other harsh circumstances; 2) Simple structure, small volume, low cost, less technical difficulty, simple and reliable in processing information, easy to be miniaturized and integrated [1]. This article mainly discusses how to use ultrasonic sensors to overcome long distance measuring problems and to solve measurement errors caused by the program.

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2. System Structure

Tracking system is mainly consisted of two components, i.e. hardware and software, discussed as follows, respectively.Its hardware mainly includes: sensor, turntable and its drive module, motor and its drive module, MCU, interface drive module, display module, power supply and so on. Figure 1 describes the structure of its sensor and turntable.

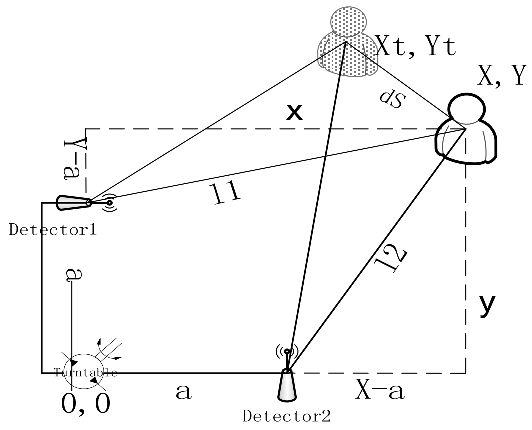

Figure 1. System Structure Diagram

The moving object discussed in this study is located at the coordinate of (x, y). The distances measured by detector 1 and 2 are named separately as L1 and L2. The distances between the turntable and detector 1 and 2 are both defied as a. The schematic circuit for its control core and interface drive module is shown in Figure 2.

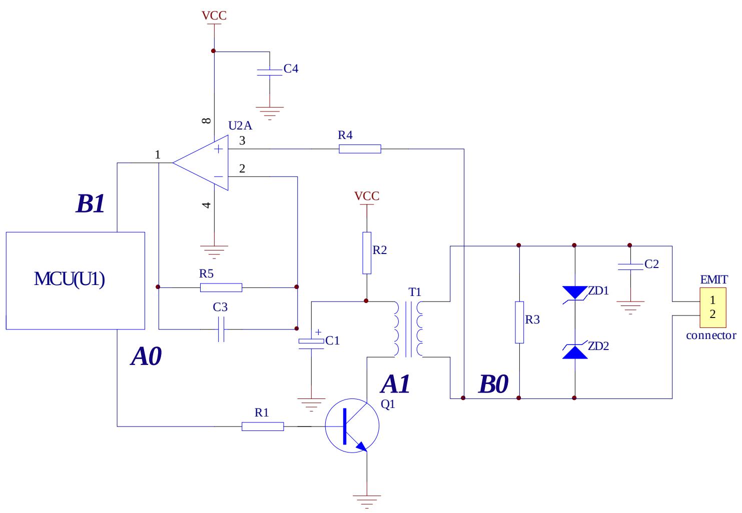

Figure 2. Sensor Signal Transceiver Schematic Diagram

In order to conveniently locate the object’s 2D coordinates, this system adopts two ultrasonic sensors, i.e. detector 1 and 2 in Figure 1. For accurately locating a moving object, multiple ultrasonic sensor modules are typical measurement devices in the system [2]. This system tries to adopt ultrasonic sensor modules to convert the detecting signals of moving object from multiple directions to the corresponding distances, and then employ algorithms of calculation of points to determine the 2-D coordinates of a moving object, and meanwhile determine the behavior of a moving object in real time. The two ultrasonic sensors are assembled in a vertical angle direction, shown Figure 1. We think about the feature that ultrasonic sensors are able to receive wave from a direction to detect moving objects, then based on the position data of them, turntable adjusts its direction in order to keep them in detectable corner in a certain distance for tracking.

The Transmit-Receive signals of ultrasonic are provided by MCU and an isolator T1, shown in Figure 2. A0, a coded digital signal, is supposed to be transmitted by MCU and then A1 is achieved by the amplifier Q1. Subsequently, the signal A1 goes through the isolator T1, and transmits the amplified coded signal A0 to transducer connected with wireless interface. B0 is the signal coming from the wireless interface and is put into MCU after running through the operational amplifier B1. The distance of object can be calculated depending upon the input/output signal delay time.

This system's software program mainly aims at generating the coded signals in specific time and receiving the wireless signals, then judging whether it is the measured signal or not. If the answer is yes, the delay time between the output and input signals should be figured out, and may be multiplied by the microwave transmission speed. Then, the expected distance and its projection on the coordinate axis of system can be achieved. Based on the previous projection data and the principle of inertia, the object's inertia flow will represents its track [3]. By using a locating algorithm, its position at the next moment can be estimated. Therefore, the turntable will be now turned to the location mentioned above in order to achieve the object tracking [4]. The moving object status can also be sampled in real time by the other transmission devices and sensors in the system. If such moving object needs to be controlled, the corresponding signal may be transmitted by those communication devices in system.

3. Realization Method

Among the function designing progress of tracking system, there may be many factors having effect on its tracking performance. Therefore, the most important problems in this study are focused on selecting one perfect automatic-tracking method and greatly reducing the error generated by the program. These two problems will be discussed below in detail.

3.1. Automatic Tracking Method

In Figure 1 mentioned above, the angle is 90°, the distances from the coordinates center (0,0) to these two detectors are both a. We define the distances between such two detectors and the detected object as l1 and l2. Based on the Pythagorean Theorem, we will get:

$$\begin{cases} y^2 + (x-a)^2 = l_2^2 \\ (y-a)^2 + x^2 = l_1^2 \end{cases} . \tag{1}$$

From (1), we may calculate the values of x and y, i.e. the projection values on the coordinate axis of system. Obviously, the solution of this formula is quite complex. However, if l1 and l 2 can be measured in advance, the system turntable is now rotated to some extent so that we'll get $l_1 = l_2$. Based on the principle of congruent triangles, the object is located on the coordinate axis of system at this moment, i.e. the projections of the object on both the axis x and y are equivalent. We may calculate x and y by:

$$\begin{cases} y^2 + (y-a)^2 = l_2^2 = l^2 \\ or \\ (x-a)^2 + x^2 = l_1^2 = l^2 \end{cases} . \tag{2}$$

The solution of (2) is expressed as:

$$\begin{cases} x = \dfrac{a \pm \sqrt{2l^2 - a^2}}{2} \\ y = \dfrac{a \pm \sqrt{2l^2 - a^2}}{2} \end{cases} \tag{3}$$

When l has two solutions, their locations are respectively on the two points which are the intersection points on the circles and line $y = x$. Such circle is defined by centers of (a, 0) or (0, a), radius of l. The minimum sum of distances between the object and the two detectors shall be vertical lines from two detection points to line $y = x$. According to right triangle characteristics, those vertical lines shall be the connection line between detector 1 and detector 2, shown in Figure 3.

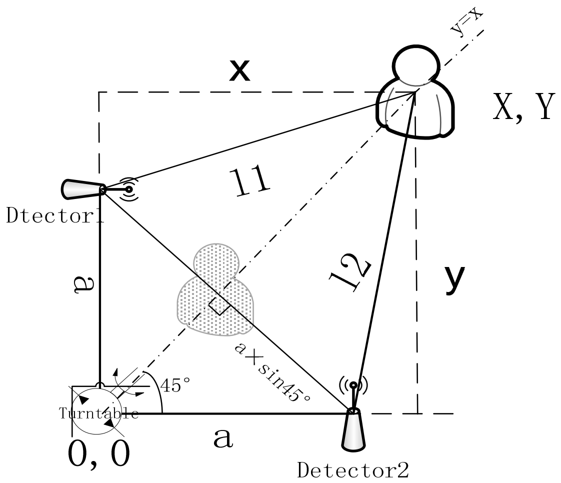

Figure 3. The Shortest Distance among the Tracking Process

The minimum length of l is $\frac{\sqrt{2}}{2}a$, i.e. $\sin 45° \times a$. We' also get $l \geq \frac{a}{\sqrt{2}}$, i.e. x and y cannot have imaginary solutions. Which solution is more suitable between such two solutions? Generally, it is required to analyze its status of the previous second in order to select a suitable solution based on the previous track [4]. For the purpose of this system running fast and meeting the function of real-time tracking moving object, the tracking steps are designed as follows: the turntable rotation is controlled by means of measuring l_1 and l_2 so that the tracked object is located on the perpendicular bisector of connection line between the two detectors' points, i.e. l_1=l_2. Controlled by the mechanical drive system, the system moves forward and backward in order to continuously keep the shortest distance from the object, which meets:

$$l_1 = l_2 = l = \frac{a}{\sqrt{2}}. \quad (4)$$

During the period of system moving, the angle of turntable rotation and moving status are recorded and taken on as estimation position value for the next test. Then, let the system keeps tracking and the values of l_1 and l_2 may be arrived at time t. The system's motion can be adjusted by the steps listed above.

Considering of the limitation of ultrasonic detection distance, we do select the tracking method of keeping shortest distance. The detectable range of ultrasonic sensor mainly depends on its wavelength and frequency. As the wavelength becomes longer, its frequency correspondingly becomes smaller, and its detectable range becomes larger. For example, the detectable range of a compact sensor's with millimeter-scale is about 300~500mm, and the one of the sensor with wavelengths greater than 5mm may be up to 8m [5]. When the selected ultrasonic's frequency is up to 40KHz, its wavelength is about 8.5mm (i.e. the velocity of ultrasonic (34000m/s) is divided by frequency (40000Hz)). Theoretically, its measuring distance should be less than 5m. According to (4), when we define the value of a as 1m, the system may keep the shortest distance $I = \frac{1}{\sqrt{2}}$, less than 1m. According to the maximum detectable distance of 4m, it can be measured when the objects move forward or backward with a speed less than 3m/s.

3.2. Errors Generated by the Program

Generally, ultrasonic sensors are known as transceivers when they both send and receive. These sensors launch a series of ultrasonic beam at a certain time, and the corresponding receiver will start as soon as the sending operation ends. Such sending and receiving operations are completed under control of the microcomputer program. Therefore, the program optimized may affect the measurement accuracy.

Because language C may produce quite long codes, it is not recommended when test code are designed. Instead of C language, assembly language is adopted. It may directly operate on pins, such as clr Px.x and setb Px.x. The time they spend is up to only one machine cycle, i.e. 12 times of the crystal oscillator cycle, which can be precisely calculated.

In the design of receiving program, jnb Px.x commands are also recommended. It takes precise time-two machine cycles. Interrupt method is not selected just because the interrupt response time remains uncertain. The interruption response time is uncertain. The reason of this is due to sampling operation performed every machine cycle and then such interruption sampled queried in the next machine cycle. If there exists an interrupt flag, the system will produce a long call instruction (LCALL double cycles), which may control CPU to run the corresponding interrupt service program. However, this call may be blocked by one of three cases listed below: an equivalent or higher priority program is being progressed; the current (query) cycle is not the latest one in which the current instruction is executed; the current instruction is the exact return (RETI) command or is to read and write instructions on IE and IP registers (Executing another instruction is necessary). If the blocking condition has been cancelled and the interrupt flag still exists, then the interrupt service program will be activated. In interruption process, it takes about 3-8 machine cycles from starting the signal to executing the first instruction, which will bring uncorrectable errors [6]. Here, we take an example for ranging program,shown in Figure 4.

```
unsigned int distance()
{ ... ..            // timer initialization
#pragma asm         // insert assemble program
clr P1.0            // microcomputer pin operation, send ultrasonic detecting pulse signal
nop
setb P1.0
Nop
… ..                // sending the required ultrasonic coded signal
clr P1.0            // the ultrasonic detecting signal ends
setb TR0            // activating the timer to start work
jnb P1.1,$          // determine whether the ultrasonic response signal is received or not
clr TR0             // freezing the timer
mov R0,TH0          // dealing with the timing value
mov R1,TL0
#pragam endasm // end of the assembler
......              // calculate the distance
return l;           // return to the detected value
}
```

Figure 4. The Shortest Distance among the Tracking Process

3.3. Ultrasonic Wave Sensor Controller

Ultrasonic is referred to a mechanical wave with a frequency greater than the human hearing range, i.e. approximately 20kHz. The common ultrasonic frequencies are from dozens of kHz to MHz. The control part is mainly used to determine those things sent from the transmitter, such as pulse chain frequency, duty ratio, sparse modulation, counting and distance detection. In order to achieve a better precision in a wide range, we may adopt two ultrasonic pulses with different frequencies sent altogether, in which the one with a greater frequency is used to measure the near target, while the one with a less frequency is used for the far one [4].

In this tracking system, we adopt two ultrasonic wave sensors with 50kHz and 80KHz frequencies, between which the one acts as the transmitter and the other as the receiver. In actual process, we select the ultrasonic module integrated control with detecting function, well compatible with the microcomputer. The microcomputer provides two series (3-5) pulses trigger signal whose width is 10us (high and low level are both 10us) and another width is 6us (both high and low level are 6us), i.e. the frequencies are $\frac{1}{10\times 2\times 10^{-6}}$ (about 50KHz) and $\frac{1}{6\times 2\times 10^{-6}}$ (About 80KHz). After each series pulse has been sent, the corresponding timer should be immediately activated (setb TR0). Once the response signal is detected (jnb P1.1,$), then the timer is frozen. By measuring the difference in time between the pulse being transmitted from the particular direction and the corresponding echo being received, it is possible to calculate the expected distance by:

$$v = 331.5 + 0.607T \tag{5}$$

Where,

v represents the velocity of ultrasonic wave in the air;

T represents the environment temperature. Its value can be measured during the initialization or spare time.

Therefore, the expected distance l can be calculated by:

$$l = v \times \frac{t1 - t0}{2} \tag{6}$$

Where,

l represents detected distance;

t1 represents ultrasonic response received time(provided by timer), and

t0 represents ultrasonic pulse transmission time (set this value as 0).

Using MCU capture feature, we can easily read the timer value --t1, based on equations above, a software program can be designed and the distance l can be calculated.

4. Conclusion

The method proposed in this system is suitable for tracking the objects slowly moving on the surface. When tracked objects moving faster, Doppler signal problems should be took into consideration. When it is used to realize a stereo tracking, the calculation will become more complex, and the result is not good enough. There is a problem during tracking progress: when a new object inserted between the system and the original tracked objects, the system will turn to track the object inserted. Lack of image collection and analysis equipment, how to lock the objects tracked exactly has became a challenge. We have attempted to acquire features of the objects, or to use inertia principle to analyze the track of detected objects, and then to filter out methods for tracking objects. Such methods have some of effects, but fail to solve it completely. In the further research, we'll seek for the sensors, which can acquire the characteristics information, in order to improve performance of tracking system and achieve reliable feature to track specific moving objects.

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