Space Point Target Ranging System Based on Laser Beam Triangulation

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Abstract. With the rapid development of ranging technology, people's requirements for ranging technology are more and more high. In some special occasions, such as live, high temperature, explosive and other inconvenient scenes, the importance of non-contact ranging technology is highlighted. As a non-contact measurement technology, laser ranging technology has faster measurement speed, higher measurement accuracy, longer measurement distance and stronger anti-interference ability compared with other measurement methods. However, at present, the measurement accuracy of laser ranging technology in China is not very high, and the design is relatively complex. Aiming at the above problems, this paper designs a spatial point target ranging system based on laser beam triangulation. The system uses the combination of laser ranging module and angle sensor module to measure the distance, uses the laser axis angle algorithm based on triangle method to calculate the distance, and uses the pyboard development platform to design the simultaneous acceptance and processing of multiple serial port data, and finally displays the measured data through the display. The experimental results show that the system can measure the distance between two points in space with relative error less than 1%, and it has the functions of circle and quadrilateral perimeter measurement, continuous measurement distance and data storage, which can meet the ranging requirements in various fields of engineering.

1. Introduction

With the development of measurement technology, spatial distance measurement has become an important research content in the field of ranging. The advantage of this technology is that the convenient, accurate and reliable measurement method is an important factor in the development of related industries. In order to ensure the safety and convenience of measurement work, non-contact measurement technology [1] has been widely used in various fields. At present, the most widely used non-contact measurement technologies are: laser ranging [2-3], CCD ranging [4], ultrasonic ranging [5], microwave radar ranging [6], infrared ranging [7] Wait. Compared with these technologies, laser ranging technology has the advantages of being free from electromagnetic interference, high measurement accuracy, and strong anti-interference ability, and the technology is simple in operation, convenient to use, and can work around the clock. At present, laser range finder is progressing toward
miniaturization, simplification of structure, and high precision with the continuous development of
digital processing technology. The development of laser ranging sensors has promoted the intelligent
advancement of various industries, such as unmanned driving, monitoring vehicles, anti-collision
alarms in intelligent transportation, detection in space space, and precision measurement of satellite
orbit [8].

The laser ranging technology is divided into non-time-of-flight measurement method and time-of-
flight method. The non-flight time measurement method includes trigonometry and interferometry.
The time-of-flight method mainly includes pulse method and phase method [9-10]. The accuracy of
triangulation ranging and interferometry is up to the micron level, and the measurement speed is very
fast, but the ranging range is only in the centimeter level, so it is mainly used for the measurement of
small distances, such as micro-displacement, diameter, gyroscope, etc. The field of precision
measurement [11-12]. The accuracy of the pulse method is determined by the accuracy of the
measurement time, and the accuracy of the ranging time is mainly determined by the clock oscillation
frequency. However, the excessively high clock frequency requires high hardware design and requires
a large cost, so it is mainly it is used in areas with long-distance measurement and low precision
requirements, such as ground-moon distance measurement and topographic survey [13-14]. The range
measurement range is related to the modulation signal frequency. The modulation frequency reduction
can improve the range of ranging, and the ranging circuit is easy to integrate, suitable for small range
finder [15-16]. In this paper, the laser ranging module uses the phase method to measure the distance,
uses the laser ranging module and the angle measurement module to collect the key data, applies the
laser axis angle algorithm based on the triangulation method to calculate the distance, and designs the
multi-serial data using the PyBoard platform. At the same time, the solution of the measured distance
is received, and finally the measurement data is displayed through the display, and a spatial point
target ranging system based on laser beam triangulation is realized.

2. Overall design of the system

This system uses PyBoard as the main controller of the system. This controller is the execution control
unit of the whole design system and is responsible for measuring the data processing and analysis of
the whole process. The overall framework of the system is shown in Figure 1. It consists of a
measurement module, a main controller module, a human-computer interaction module and peripheral
modules. The measuring personnel operate the human-computer interaction panel, and the
measurement module is controlled by the main controller to obtain the measurement data, and the
result is displayed on the electronic ink screen after being calculated by the main controller. The
system is debounced by the peripheral module, thereby reducing the influence of human factors on the
ranging system and reducing the accidental error of the ranging system.

![Figure 1. Overall system block diagram](image-url)
3. System hardware design

3.1. Design of the main controller module
In order to ensure the real-time performance of the system and the convenience of development, the main controller module selects the PyBoard development board based on STM32F405RG microcontroller. The core is 168MHz cortex M4CPU (with hardware floating-point computing capability) with 1024kib flash rom and 192kib Ram. The main controller module has a MicroUSB card slot to expand the space for data storage. The bus is powerful, with 5 UART serial ports and 2 SPI interfaces. Serial communication is simple to use and takes up less software and hardware resources. This design can meet system design requirements.

3.2. Design of the measurement module
The measuring module of the system consists of two laser ranging modules and an angle measuring module. For the purpose of non-contact measurement, the laser distance measuring sensor uses SK60 laser ranging sensor, its working voltage is DC3.3V, the working temperature is between 0-40℃, and the maximum working current is 300mA when measuring. The laser ranging sensor is connected to the development board through a UART (serial port) method, and the baud rate of the communication configuration is 19200 bps, and the laser range finder is controlled by transmitting a hexadecimal number corresponding to the ASCII code. The module returns a string containing the measured distance and the measured signal quality, eg "12.345m, 0079", indicating a measuring distance of 12.345m and a signal quality of 79. In order to ensure the accuracy of the measurement, we set the laser sensor to the automatic measurement mode. The automatic measurement will automatically select different measurement speeds according to the condition of the reflection surface and ensure the measurement accuracy. The laser ranging module mainly includes five parts: signal processor, signal generating circuit, laser transmitting circuit, laser receiving circuit and signal mixing circuit. The circuit block diagram is shown in Figure 2. The PyBoard main controller transmits the relevant measurement commands to the signal processor of the laser ranging module through the serial port, and then works through the signal generating circuit, the laser transmitting circuit, the laser receiving circuit and the signal mixing circuit, and then the A/D acquisition is performed. The mixing signal parameters are analyzed and processed to obtain corresponding distance measurements.

![Figure 2. SK60 laser ranging sensor circuit block diagram](#)

The angle sensor uses the LQ_ECM202004xx_ANG angle sensor, which operates at DC5V. The sensor uses non-contact detection technology, the sensor is not affected by dust or other debris, and has good anti-interference and small size. The serial communication mode is used to connect with the PyBoard main controller. The signal type is TTL and directly received by the UART port of the single-chip microcomputer. The serial port baud rate is set to 9600. The serial output format is in the form of Axxx.yy, where A is the initial identifier, xxx is the integer part from 0 to 359°, . is the
decimal point flag, and yy is the fractional part. For example, A015.25 indicates that the current angle is 15.25°.

3.3. Design of human-computer interaction module
The human-computer interaction module is mainly composed of a button panel and a display screen. The button panel uses two independent buttons to indicate the measurement button and the setting button, and performs data communication with the PyBoard main controller through the communication mode of the GPIO to realize the setting of the system function. The display uses a low-power Waveshare electronic ink screen. The advantage of the electronic ink screen is that it displays well under strong light, and it only consumes power when there is a display content change refresh. Its working voltage is 3.3V, it communicates with PyBoard main controller through SPI communication protocol, built-in driver IC, no need to provide additional driver, only a small number of peripheral devices can be used to control display through PyBoard main controller, saving resources.

3.4. Design of peripheral modules
The peripheral module is mainly composed of a fixed part and a fine adjustment part. The fixed part adopts the "laser distance measuring sensor + sight" method. The laser distance measuring module includes the sensor fixing foot 1 and the sight on it, the sensor fixing foot 2 and the sight on it, which are attached to the aiming device. Amplify the microscope, observe and aim at the point to be measured, ensure the accuracy of the laser irradiation point, and reduce the operation error caused by misoperation. The fine-tuning section includes a software debounce scheme and a hardware debounce scheme. The software debounce scheme electronically stabilizes according to the motion posture of the device, adjusts the compensation in real time, and eliminates the jitter of the laser point; the hardware debounce scheme adopts an anti-shake bracket, which is connected through the X, Y, Z three-axis, and the heading axis X can be rotated. 360°, the roll axis Y can be rotated by 325°, and the pitch axis Z can be rotated by 330°, which is fixed by clamping the distance measuring device. In addition, the shell design adopts a non-fixed measurement method, that is, it does not need to be installed on the ground, and is not limited by the terrain. The outer casing uses a corner reducer to define a minimum rotation angle, thereby avoiding angle drift and error.

4. System software design
4.1. Choice of development environment
MicroPython [17] is a very popular embedded Python VM and development environment. It has its own parser, compiler, virtual machine, and class library, and the syntax is basically the same as Python. The underlying software is refactored using ANSI C, which encapsulates most of the functions in the C language and can run in both microcontroller and resource-constrained environments. Currently it supports 32-bit based ARM processors, such as STM32F405RG, which can run the Python language directly on the ARM processor STM32F405RG, and use the Python language to control the microcontroller. PyBoard complies with the MIT protocol and is a MicroPython development board produced by TurnipSmart. It is based on the STM32F405RG microcontroller and transmits data via the USB interface. With MicroPython, you can implement hardware underlying access and control through the Python scripting language.

4.2. Algorithm design
In this paper, the non-contact length measurement of the line segment EF is mainly carried out by using the plane geometry model shown in FIG. Since the axis of the angle sensor is not the actual triangular apex of the line segment EF, the data obtained by the laser ranging sensor and the angle sensor are directly used for calculation, and the measurement result must have an error (especially close distance ranging). In order to obtain more accurate measurement results, the measurement
algorithm needs to perform line segment compensation for the triangle side length, that is, correct the triangle vertices, thereby reducing the systematic error of the ranging system.

Figure 3. Principle of line segment measurement

As can be seen from the schematic diagram of the algorithm design, O is the axis of the angle sensor, and A_i, B_i, C_i (i = 1, 2) is the outer vertices of the measuring arm (the fourth vertex is the O point). \( OA_1 = OA_2 = a, OC_1 = OC_2 = b, O' \) is the intersection of two laser lines (actual triangle vertices), \( L_1, L_2 \) is the measured length of two laser sensors, \( L_0 \) is the length of the compensation line segment, and \( \theta \) is the angle sensor angle between the two laser sensors that are obtained is opened. Using the cosine theorem, we can get the formula of \( EF \) as follows:

\[
EF = \sqrt{O'E^2 + O'F^2 - 2O'E \cdot O'F \cos \theta}
\]  

(1)

As can be seen from the above formula, where \( O'E = L_0 + L_1, O'F = L_0 + L_2, L_0 = a + \varepsilon, \varepsilon \)
is the compensation factor, \( \varepsilon = \frac{b}{2} \cot \frac{\theta}{2} \), it can be obtained by combining the actual measurement data \( a = 0.108m, b = 0.04m \), and we can draw \( L_0 = 0.108 + 0.02 \cot \frac{\theta}{2} \).

With the above principle, it is only necessary to obtain the distance between the two laser sensors measured by the two laser sensors \( L_1, L_2 \) and the angle \( \theta \) between the two laser sensors obtained by the angle sensor, and the value of the length of one line segment at a distance can be calculated. According to this principle, the measurement is performed multiple times, and the distance of multiple line segments can be obtained, and the circumference of the polygonal object can be calculated.

4.3. Design of data communication

In this system, the communication between the laser range finder and the angle sensor and the main controller is UART serial communication. The serial communication uses only two wires, the connection is simple, no clock signal is needed, and the parity bit ensures the accuracy of the data. In order to ensure the accuracy of the measurement, it is necessary to ensure that the measurement data of the laser sensor and the data of the angle sensor are collected at the same time. For this reason, in this system, after each measurement data, a time stamp is added to facilitate the measurement of the data. Synchronize to improve the accuracy of the measurement.
4.4. Flow chart of the program

The design of the software part is mainly to configure the laser ranging module and the angle measuring module and the display module in the measuring module, to process the data collected by the sensor, and to display the data of the display and control the input and output. Boot into the aiming mode, continue to shoot the laser point for easy aiming, system, serial port and display initialization, press the measurement button to send measurement commands to the laser ranging sensor and angle sensor, if the laser ranging signal quality is good, then data synchronization. The data obtained by the sensor will be transmitted to the main controller module for data processing, and then the processed data will be displayed through the display through the SPI communication protocol; otherwise, the measurement command will be sent to the laser ranging sensor and the angle sensor until the laser ranging The signal quality satisfies the measurement requirements and then the data is processed after synchronization. The program flow chart is shown in Figure 4.

5. Experimental verification

In order to ensure the performance of the measurement system, this paper uses 50m tape measure and 1m ruler as the measurement standard, and compares the developed measurement system. First, calibrate two space points, measure with tape measure or ruler as the actual value, and then use the system. The calibration point pair is measured from a plurality of different positions, the measured value is obtained, and the relative error measured by the system is calculated according to the following formula.

\[
\text{Relative error} = \frac{|E_F_{\text{measurement}} - E_F_{\text{actual}}|}{E_F_{\text{actual}}} \times 100\% \quad (2)
\]
In this way, multiple sets of spatial points are measured to verify the performance of the system, and some system distance parameter measurement results are shown in the following table.

| Serial number | $L_1$ / cm | $L_2$ / cm | $\theta$ / ° | $EF_{\text{measurement}}$ / cm | $EF_{\text{actual}}$ / cm | Relative error / % |
|---------------|------------|------------|--------------|-------------------------------|--------------------------|-------------------|
| 1             | 101.7      | 106.0      | 28           | 60.9                          | 60.0                     | 0.83              |
| 2             | 22.4       | 34.4       | 92           | 59.7                          | 59.0                     | 0.5               |
| 3             | 178.5      | 91.6       | 34           | 120.8                         | 120.0                    | 0.67              |
| 4             | 71.6       | 54.1       | 106          | 120.5                         | 120.0                    | 0.42              |
| 5             | 173.8      | 312.5      | 49           | 248.7                         | 250.0                    | 0.52              |
| 6             | 178.4      | 76.5       | 124          | 250.7                         | 250.0                    | 0.28              |
| 7             | 387.0      | 288.4      | 52           | 321.6                         | 320.0                    | 0.50              |
| 8             | 173.8      | 224.7      | 118          | 318.5                         | 320.0                    | 0.46              |
| 9             | 480.0      | 391.0      | 64           | 482.3                         | 480.0                    | 0.48              |
| 10            | 202.5      | 292.2      | 136          | 481.4                         | 480.0                    | 0.29              |

The experimental verification results show that in the measurement of the length of the same calibration line segment at different positions, the larger the angle of the measurement arm opening is, the smaller the relative error is. Since the calculation of the compensation line segment is related to the length of the measurement hardware, and the measurement of the hardware length has an accidental error, the smaller the angle of the compensation line segment is, the smaller the relative error is, and the smaller the relative error is. The addition of the compensation factor reduces the systematic error of the ranging system and also improves the accuracy of the ranging system. The experiment verifies that the measurement system can measure the length of the line between any two points in the non-contact measurement space, and the relative error does not exceed 1%. Since the verification model in this paper is relatively simple, the relative error of the measured data is within an acceptable range, which also proves the effectiveness and usability of the system.

6. Conclusion

Based on the cosine theorem in plane geometry theory, the laser ranging module and angle measuring module are used as the measurement methods of key length and angle data. PyBoard is used as the main control chip, and the control unit is executed and responsible for measuring the whole process of data processing and analysis. The design implements a system for real-time measurement of non-contact line segments. The experimental results show that the system has the characteristics of high measurement accuracy, wide range, convenient operation and easy portability. The system can meet the ranging requirements of engineering construction.

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