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Design and Implementation of Mobile Laser Engraving Machine

Daixuan Liu*, Bingxia Shen

School of Information and Communication Engineering, Beijing Information Science & Technology University, Beijing 100101, China
goldnevershines@outlook.com, shenbingxia@bistu.edu.cn

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Abstract. Laser engraving, as a high-tech product combining machine, light, electricity, and computer, has great demand in the market, and its application is quite extensive. This article focuses on the problem that the engraving area of the traditional engraving machine is limited by the frame, designs and implements a mobile laser engraving machine. The structure of the body adopts a three-axis omnidirectional wheel design, and the embedded system is used to control the movement of the body and the process of laser engraving by analyzing Gcode instructions. And use the triangle positioning technology to feedback the position information of the body, and observe the engraving effect. Through the design of this article, large-format engraving was realized, which solved the limitation of the engraving area of the traditional engraving machine, and brought better development to the engraving process.

Keywords: laser engraving, omni-directional wheel, triangulation

1 Introduction

With the development of science and technology, the first laser was produced in 1960. The emergence of laser is a major invention in the 20th century, and the laser has developed rapidly as soon as it came out. Because the laser has the characteristics of good monochromaticity, high coherence and high brightness, which makes the laser more conducive to operation and application in the industry [1], especially in the field of processing. The application of laser processing technology mainly includes laser engraving, cutting, welding, marking, surface treatment, etc. Laser engraving is an advanced equipment that uses a laser to engrave materials. The laser engraving machine can not only improve the efficiency of engraving, but also make the surface of the engraved part smoother and mellow, and has the characteristics of non-contact, low noise and fast speed [2]. Doran and Garnier [3] first invented a laser engraving device that can adjust the output laser beam in multiple directions. The device can communicate with an independent controller and is suitable for engraving any graphics. Later, Martinov and Lyubimov, etc. [4] used standardized real-time data exchange protocol in laser engraving machines to arrange different process tasks to control the execution device and input/output module in real-time, keeping the original processing details, Improve the performance of the entire device. Wang and Xu [5] proposed to control the interpolation operation and stepper motor movement in the process of laser engraving based on the STM32 main control chip by analyzing Gcode commands, which reduces the cost while improving accuracy.

However, the research on laser engraving mainly has progressed in control, and there is no change in the engraving area and engraving machine frame. At the same time, most engraving machines on the market are mainly desktop, with fixed engraving area and high-precision system control. But for the change of engraving requirements, the selection of the corresponding engraving machine also changes. The larger the engraving area, the larger the volume of the engraving machine to be selected, which generally use industrial-grade engraving machine. However, facing the choice of ordinary users, there is no large-scale engraving machine for ordinary users on the market. The choice of industrial-grade engraving machine is neither portable nor practical. Therefore, according to the engraving area is limited

* Corresponding Author

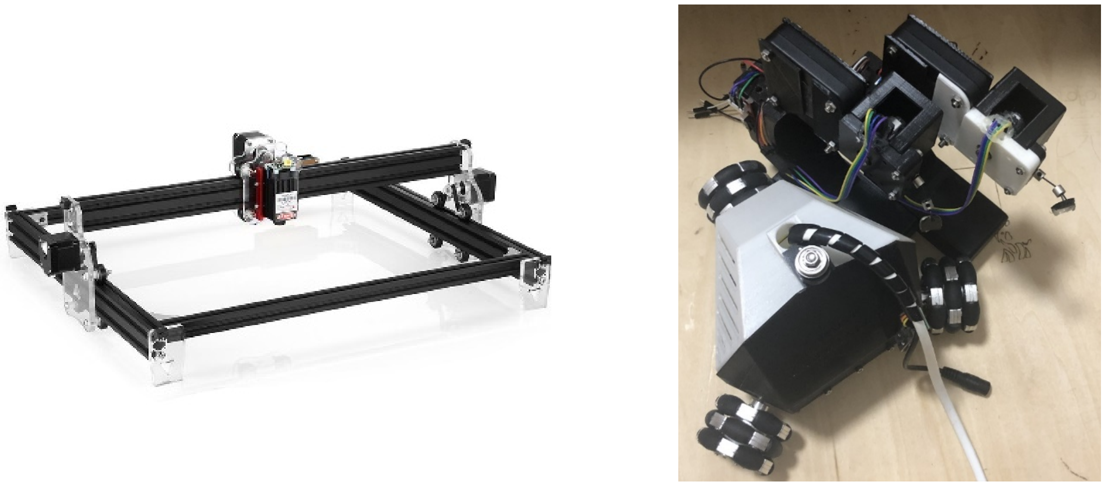
by the size of the engraving machine itself, and the desktop engraving machine is not easy to carry, etc., this paper studied the mobile laser engraving machine, using the omnidirectional mobile design to solve the problem of the limited engraving area.

This article uses the design of omnidirectional wheels to achieve the omnidirectional movement of the engraving machine, and the body is small and easy to carry. Users can choose any graphics for processing, transmission, and engraving, which is no longer affected by the limitations of the engraving area, to realize large format engraving of graphics. At the same time, a new type of pull line distance measurement positioning sensor is used to draw the carving track to observe the carving effect. And because of its portability, users can engrave anytime and anywhere.

2 Theory Fundamental

2.1 Three-axis Movement

Since most of the current engraving machines on the market are desktop-based, and the structure is XY axis distribution, the design of the square frame limits the engraving area, as shown in Fig. 1(a). But to achieve the omnidirectional movement of the engraving machine, this article uses a three-axis mobile chassis [6], as shown in Fig. 1(b). The design of the three-axis mobile chassis abandons the traditional frame restrictions and realizes a movable engraving design, as shown in Fig. 1. This solves the problem that the engraving area is limited by the frame.



(a) Traditional engraving machine (b) Mobile engraving machine

Fig. 1. Engraving machine frame

The three-axis omnidirectional moving chassis is widely used because of its good mobility and simple structure. The distribution of the three wheels at 120° intervals is shown in Fig. 2. The axis of each wheel forms a circle, and the body can move along the wheel axis or the oblique line of the wheel surface. After kinematic analysis [7], According to the two movements, cooperate to achieve arbitrary movement of the body in the plane.

According to Fig. 1, kinematics analysis is performed on the three-axis omnidirectional movement. To facilitate the kinematics analysis, the ideal situation is used as the basis. In the *XY* two-dimensional coordinate plane, point *O* is the center of the chassis, the three wheels are distributed at 120° according to point *O*. V_a, V_b, V_c are the speed of the three wheels, the arrow direction is the positive direction of wheel movement, and φ is the wheel The angle between the surface and the x-axis, $\varphi=\pi/6$, ω is the rotation angular velocity of the body.

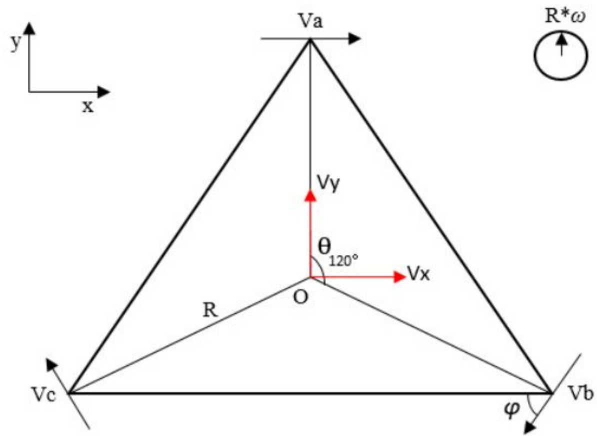


Fig. 2. Three-axis omnidirectional movement distribution

The movement of the body requires the cooperation of three wheels. According to the speed of the wheel and the angular speed of rotation, the following formula is obtained by kinematic analysis:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 0 & R \\ -\cos\varphi & -\sin\varphi & R \\ -\cos\varphi & \sin\varphi & R \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ \omega \end{bmatrix} \tag{1}$$

Transform:

$$\begin{cases} V_a = V_x + R\omega \\ V_b = -\frac{1}{2}V_x - \frac{\sqrt{3}}{2}V_y + R\omega \\ V_c = -\frac{1}{2}V_x + \frac{\sqrt{3}}{2}V_y + R\omega \end{cases} \tag{2}$$

According to the formula, programed to achieve omnidirectional wheel movement. For the driving of omnidirectional wheels, this article chooses a stepper motor, because a DC motor cannot reach the controllable angular displacement of the stepper motor. The stepper motor can use the pulse number and wheel diameter to calculate the displacement of a single wheel. After the motion synthesis, the moving speed and direction of the entire platform can be obtained.

2.2 Triangulation

In order to make an intuitive observation of the engraving process, this article uses triangle positioning to locate the engraving machine body and observe the engraving process through the returned engraving track. Before mentioning triangulation, we will introduce trilateral positioning [8]. In the positioning algorithm based on distance measurement, the trilateral positioning measurement method is a relatively simple algorithm. Therefore, according to the comparison of algorithm implementation results, the positioning method with high precision and high performance are selected. The three-sided positioning algorithm measures the distance to the unknown point through three known point positions and uses these three distances as radii to make three circles. The intersection of the three circles is the position of the unknown point, such as Fig. 3.

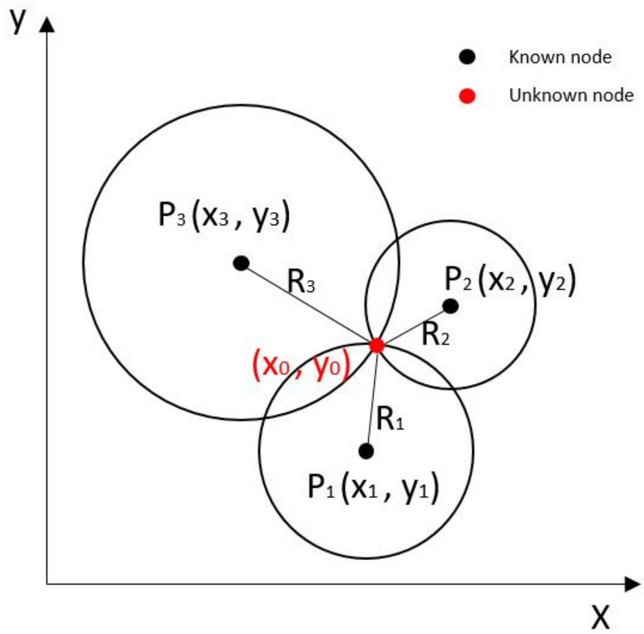


Fig. 3. Trilateral positioning

In the figure, P1, P2, and P3 are known nodes, R1, R2, and R3 are the distances to unknown nodes, and three circles are drawn with R1, R2, and R3 as radii, and the intersection points are unknown nodes. The following formula is obtained through analysis of mathematical formulas formula:

$$\begin{cases}(x_1-x_0)^2+(y_1-y_0)^2={R_1}^2\\(x_2-x_0)^2+(y_2-y_0)^2={R_2}^2\\(x_3-x_0)^2+(y_3-y_0)^2={R_3}^2\end{cases} \quad \textbf{(3)}$$

The position of the unknown node can be calculated according to the formula, but this method requires three known nodes as a reference, so it is not convenient when positioning the engraving machine body. Therefore, this paper proposes to use a triangular positioning algorithm. The triangular positioning algorithm is evolved from the Trilateral positioning algorithm. The unknown nodes are determined by the location of two special points, which reduces the number of known nodes and achieves the same positioning effect, as shown in Fig. 4.

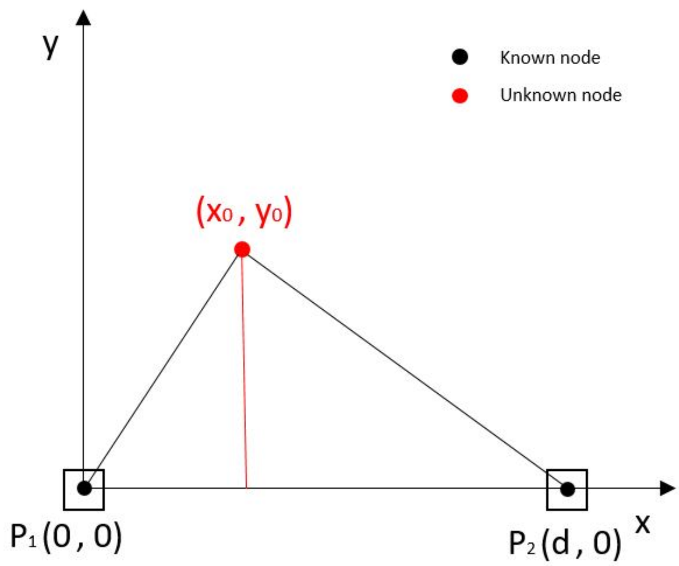


Fig. 4. Triangulation

2.3 Gcode Instructions

For CNC (Computerized Numerical Control) numerical control programming, Gcode is an instruction in the numerical control program, generally known as the G instruction. Using Gcode can realize operations such as fast positioning, circular interpolation, inverse circular interpolation, and intermediate point circular interpolation. For the laser engraving of this article, some G commands are needed:

(1) G00: Rapid positioning.
(2) G01: Linear interpolation.
(3) G90: Absolute size.
(4) Fxxx: Feed rate.

Example: G00 X10.0 Y20.0; realization function: fast positioning to (10,20) position.

Auxiliary function word M instructions are used to control the on-off quantity of the digital control machine tools, such as the forward and reverse rotation of the spindle, the opening and closing of the cutting fluid, the clamping and loosening of the workpiece, and the end of the program. This article uses the following two M codes for laser control:

(1) M03: Laser on.
(2) M05: Laser off.

2.4 Line Interpolation

In order to control the precise movement of the machine, the interpolation method is used to realize it. All interpolation methods can be linear interpolation [9]. The irregular curve is transformed into the smallest straight line segment by cutting, and the linear interpolation is realized under the minimum span supported by the system. Therefore, the arc curve should be split into multiple line segments to achieve linear interpolation, and the complex curve should be simplified.

Linear interpolation is executed from the starting point for the linear target that needs to be reached, as shown in Fig. 5. First，move one pulse to the x-axis to determine whether the moving point is above or below the actual straight line. If the moving point is below the actual straight line, move up a certain distance along the y-axis at this time, and continue to judge the position of the moving point. If it is still below the actual straight line, continue moving up a certain distance along the y-axis until the moving point is above the actual straight line. After that, the moving point moves a certain distance along the x-axis and continues in this loop until it reaches the actual linear target point.

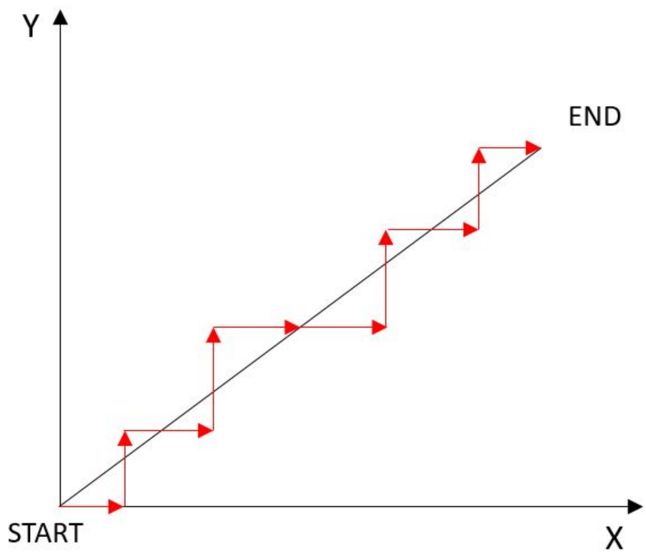


Fig. 5. Line Interpolation

2.5 Forward-looking Strategy

When performing linear interpolation for multiple line segments, in order to keep the axis moving continuity, it should be ensured that the movement of the axis cannot stop after executing a linear command and maintain a certain speed to execute the next linear interpolation operation. However, because there may be an angle between the two straight lines when moving to the junction point to turn, the axis movement speed cannot be too fast, otherwise, the position offset problem will occur. At the same time, the head-to-tail speed connection problem of the two straight lines must be considered. The solution to these problems is the speed forward-looking algorithm.

For the realization of the speed look-ahead algorithm, the information of each straight line segment is first stored in the circular queue. When a line segment information is parsed through Gcode, the line segment information is stored in the circular queue. Then the stored line segment information is combined with the previous line segment, and the forward-looking algorithm is used to modify the maximum running speed of the previous line segment to ensure that the speed after the end of the previous line segment is consistent with the initial speed of the current line segment. In this way, the linear interpolation operation can be improved, and the movement of the engraving machine is smoother.

3 System Design

3.1 Embedded Systems

This article uses the STM32 embedded system to control the engraving machine, transplant the GRBL source code applied to the Arduino’s AVR microcontroller to the STM32 for execution, and use the serial port to communicate with the host computer to realize the engraving process. Compared with the AVR microcontroller, STM32 has an enhanced peripheral interface and has two advantages of low voltage and energy saving. Because it has various peripheral interfaces, it is easier to operate and can handle analog and digital signals, so it is often used in control circuit design.

For the STM32 chip model in this article, select STM32F103C8T6 as the control, Select TMC2208 as the stepper motor drive. TMC2208 is an advanced single-axis stepper driver with stealthChop (low-speed silent mode), spreadCycle (high-speed anti-shake mode) and 256 subdivision high-precision control. The TMC2208 can replace the A4988 Pin to Pin. Although the basic principle is the same, the performance is different. In terms of performance, TMC2208 has low noise and high subdivision and can realize high-precision movement control for stepper motors. Although the TMC2208 obtains a 16-division pulse of the MCU (Microcontroller Unit), the drive can be compensated to 256-division by internal algorithm control. This method can reduce the burden on the MCU of the main control, but the corresponding increase The power consumption and heat of the chip are reduced. For laser control, select the MOS tube module with optocoupler isolation. High-level start, low-level stop, PWM speed can be used to control the motor start and stop, solenoid valve, and other tributary equipment. By enabling the signal to control the MOS tube module to control the laser opening and closing, it not only solves the problem of relay contact ignition but also solves the problem of loop isolation. The system flow diagram is shown in Fig. 6.

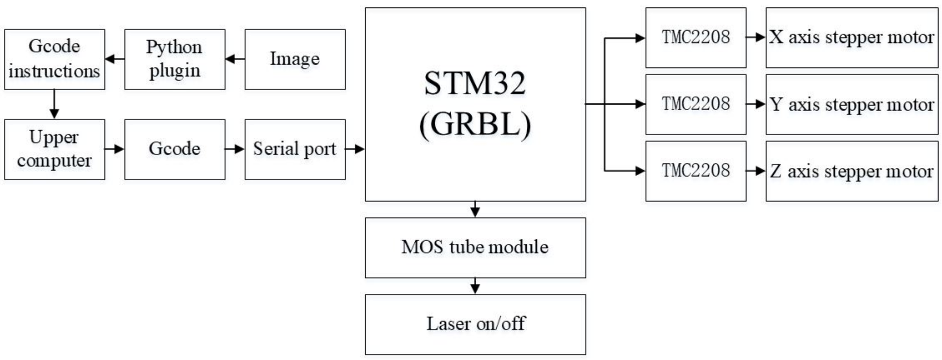


Fig. 6. Main control system

3.2 Design of Upper-computer Software

To realize the triangle positioning process of the engraving machine, the distance information measured by the sensor needs to be fed back to the host computer for processing. Use TCP connection for distance information transmission. Use Qt programming to establish the host server, used to receive the data sent by the two sensor clients. And preprocess the received data to solve the problem of TCP sticky packets. And use thread ideas to establish a thread processing program to receive preprocessed data. And used for complex calculations to prevent data loss and system crash caused by multiple data operations. The position information obtained after the processing is displayed on the host computer interface by Qt drawing. As shown in Fig. 7.

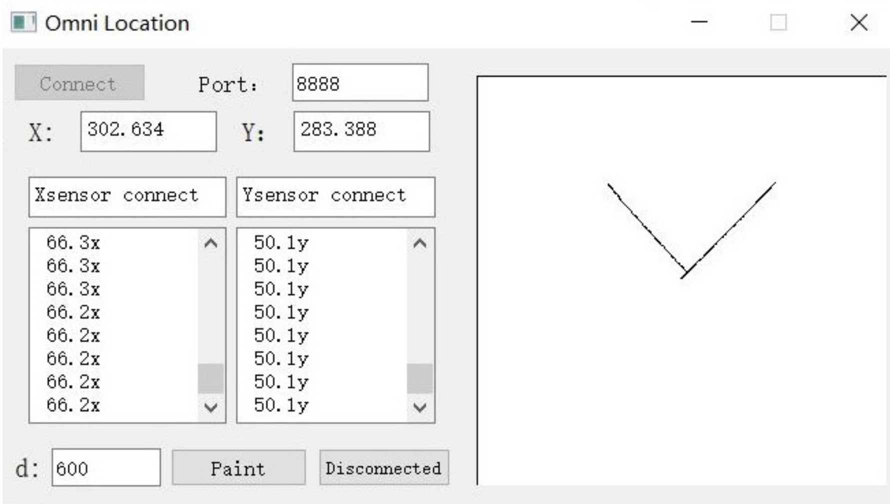


Fig. 7. UI interface drawing

4 Hardware Design

4.1 Engraving Machine Frame

According to the needs of this subject, choose an omnidirectional wheel with a 90° angle between the hub shaft and the roller rotation axis. The three omnidirectional wheels are distributed at an angle of 120° and driven by a stepper motor to build the frame shown in Fig. 8.

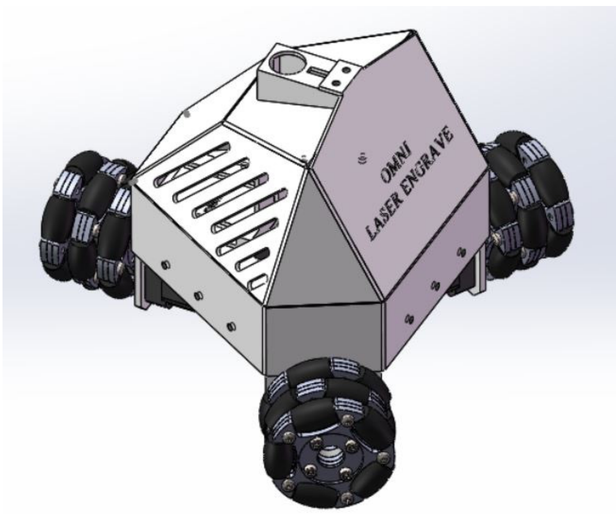


Fig. 8. Engraving machine frame

Stepper motor control uses TMC2208 driver, connects MS1 and MS2 driven by TMC2208 to 5V with jumper cap, so that 16 subdivision operation can be achieved, TMC2208 automatically compensates to 256 subdivision internally, improves accuracy and prevents movement deviation. Each omnidirectional wheel is composed of three single-layer omnidirectional wheels, which increases the contact area between the wheel and the engraving surface and improves the friction force, making the engraving machine more stable during the movement process.

For the control of the laser, the opening and closing of the laser are controlled by the enable signal. The preferred solution is relay control, usually an electromagnetic relay, which controls the on/off of the mechanical contact control circuit through the mechanical action control circuit and the electromagnetic effect. The essence is to use a small current loop to control a large current loop, and the two loops are isolated during the control process. However, since the enable signal voltage of the laser is 3.3V and the laser power supply is 12V when the relay is used to control the laser, contact ignition problems may occur and the laser head may be burned out. Afterward, a triode circuit is selected for control, and an NPN type low-power three laser tube is used to control the opening and closing of the laser. Although the triode controlled laser eliminates the ignition problem of the relay’s contacts, it fails to isolate the circuit, which easily breaks down the pins and causes chip damage. Finally, it was decided to choose a MOS tube module with optocoupler isolation, which not only solved the problem of relay contact ignition, but also solved the problem of loop isolation, and realized stable control of the laser. The control circuit system is shown in Fig. 9.

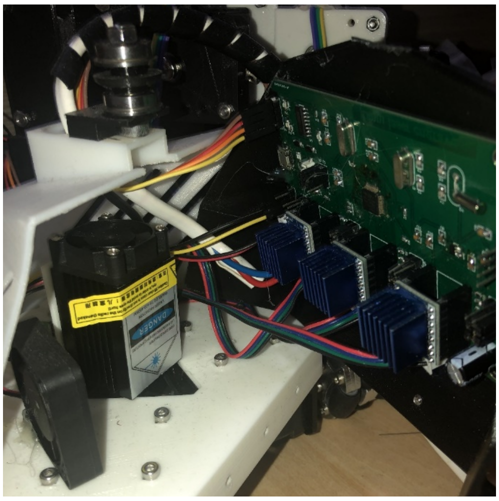


Fig. 9. Control circuit system

4.2 Positioning Sensor

For the triangulation algorithm in this paper, the distance from a known node to an unknown node needs to be measured, so the selection of sensors is particularly important, both to ensure accuracy and stability. Therefore, this article selects a grating encoder to make a new sensor device. The bearing and the code wheel are combined, and the bearing is driven to rotate by the pull box, and the code wheel is synchronously rotated, as shown in Fig. 10.

Common encoders include grating encoders and magnetostatic grid encoders [10]. The magnetostatic grid encoders are measured according to the Hall Effect. The grating encoder is composed of a photoelectric pair tube and a grating. The incremental grating encoder is the photoelectric signal directly converted to output three-phase square wave pulses A, B, and Z phases [11]. The phase difference between the two square wave pulses of A and B is 90°, as shown in Fig. 11. The Z-phase pulse represents the zero reference position. When a Z-phase pulse is an output, it indicates that the encoder rotates one revolution.

For the sensor design, when the grating encoder is in operation, the rotation of the grating code disk will cut off the optical transmission of the photoelectric pair tube, and the above waveform can be obtained at the receiving end. The phases of the A and B waveform pulses are 90° out of phase, so the direction of rotation of the code wheel is determined by detecting which phase of the waveform pulse

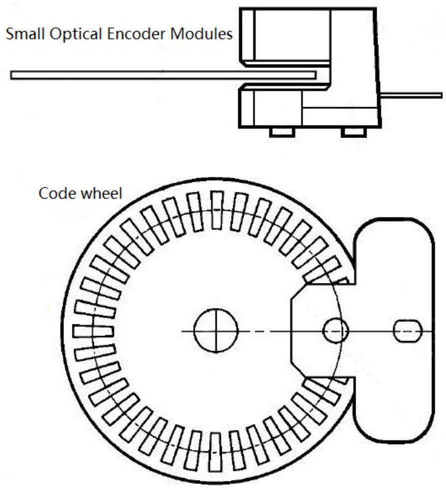


Fig. 10. Grating encoder

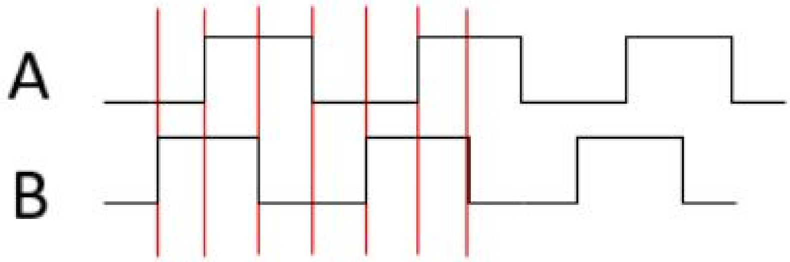


Fig. 11. A, B phase pulse waveform

was received first. The code wheel uses a 1000-line code wheel to achieve high-precision measurement. The 20-tooth synchronous belt wheel is combined with the code wheel and fixed on the sensor device. Use the pull box to wind the steel wire on the synchronous belt wheel. By pulling the synchronous belt wheel to drive the code wheel to rotate, the encoder outputs pulses. By calculating the circumference of the synchronous pulley/1000, the arc length of the synchronous pulley rotating under one pulse can be obtained, which is approximately equal to the tensile length of the wire. Then count the number of pulses, calculate the arc length after multiple pulses according to the arc length of one pulse, to get the stretched length of the wire, and measure the distance between the sensor and the engraving machine body by this method. The positioning sensor is shown in Fig. 12. In this paper, a pull box with resilience of 1.1N and a wire length of 6m is used for the production. The head of the wire rope of the pull box uses a magnet as a joint, which can be adsorbed on the fixed bearing on the engraving machine, and the engraving machine drives the cable to extend. As shown in Fig. 13.

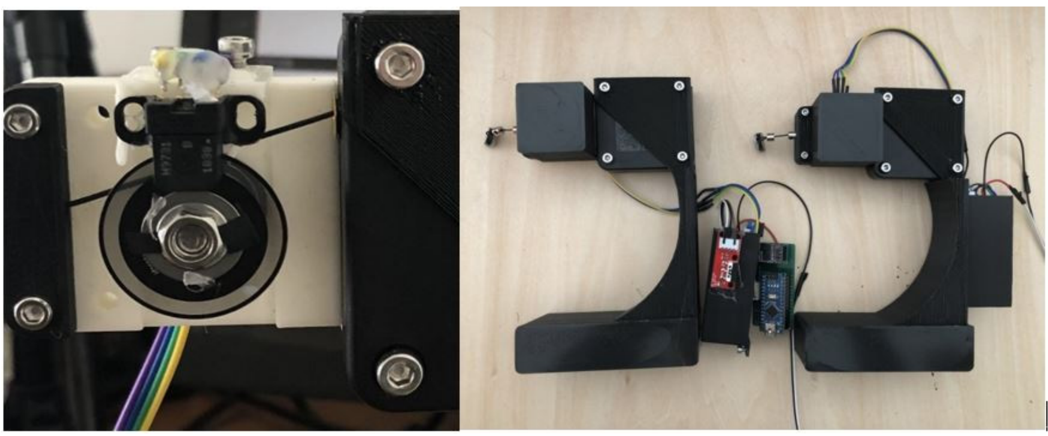


Fig. 12. Position sensor

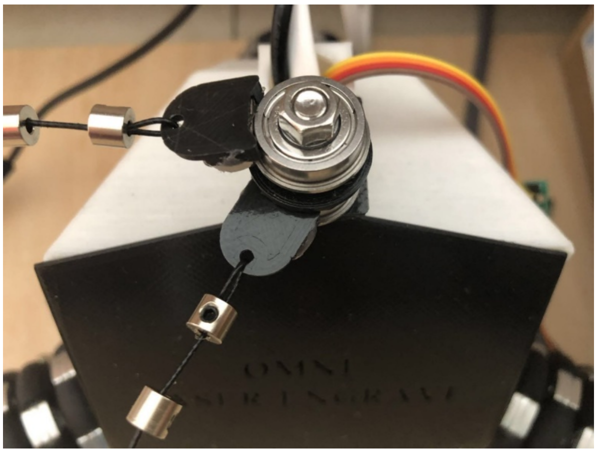


Fig. 13. Magnet connector

After obtaining the distance from the sensor to the unknown node, it needs to be transmitted to the upper computer for processing. In this paper, the Arduino pro mini is used to collect the A and B phase pulses of the grating encoder and calculate the measurement distance and direction. After the sensor collects data, it uses ESP8266 to establish a TCP connection with the upper computer server through the "three-way handshake". Transmit the collected data, process the data on the upper computer, and use the triangulation algorithm to calculate the position information of the machine body on the engraving surface. Since two sensors are used in the positioning process, it is necessary to consider that two ESP8266 clients establish multiple concurrent connections with the server. The flow chart of sensor collection and sending is shown in Fig. 14.

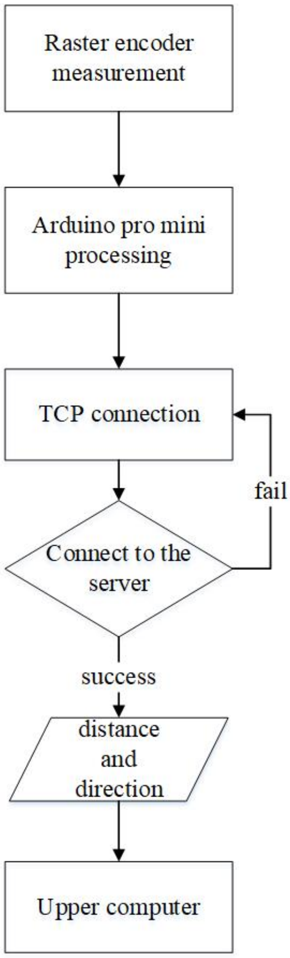
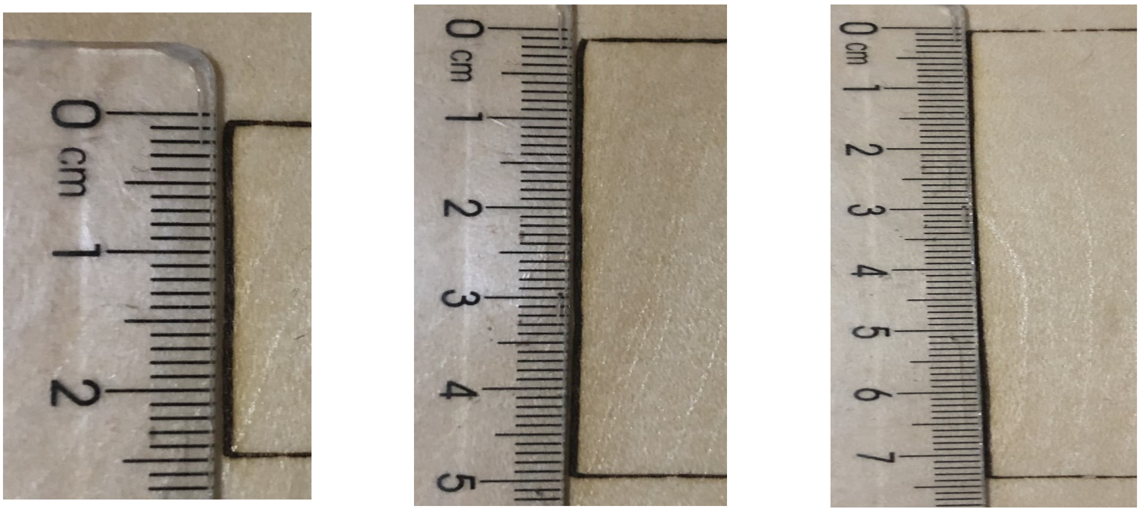


Fig. 14. Block diagram of sensor acquisition and transmission process

5 Test Analysis

5.1 Accuracy Test

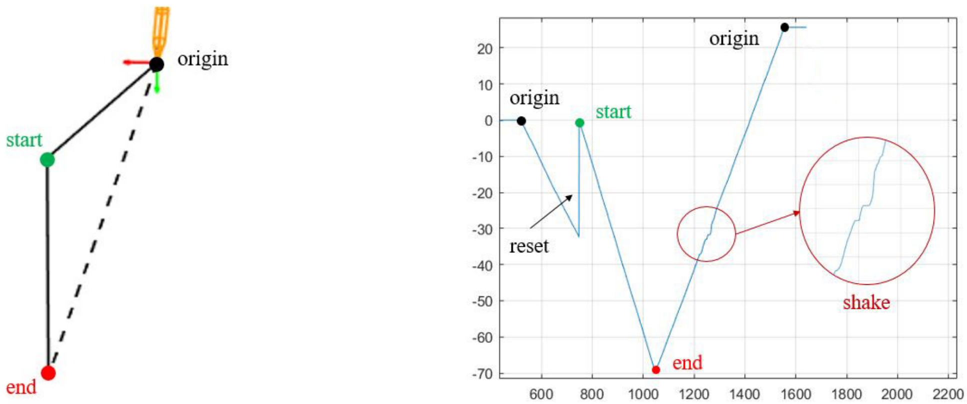
Carve three rectangles with side lengths of 25mm, 50mm, and 75mm, and judge the carving accuracy by measuring the actual length. As shown in Fig. 15, according to experimental analysis, the carving accuracy can be 1mm ± 0.5mm.



(a) 25mm rectangle (b) 50mm rectangle (c) 75mm rectangle

Fig. 15. Carved rectangle

Afterward, test the accuracy of a single pull-wire sensor, and test the accuracy of the sensor by engraving a straight-line track, as shown in Fig. 16(a). To ensure the accuracy of the test results, a reset operation is added to the hardware. The actual distance of the measured engraving line is 68mm, and the returned distance data measured by the sensor is 69.4mm. According to the comparison between the actual distance and the distance measured by the sensor, accuracy error is within an acceptable range. At the same time, there will be jitter in the process of pulling the sensor, as shown in Fig. 16(b). The main reason is that the pulling force of the sensor and the friction force of the wheels of the engraving machine act on the engraving machine, which causes the forward power of the engraving machine to be hindered, so a slight jitter phenomenon occurs. For the jitter phenomenon, the method of reducing the pull and increasing the contact area of the wheel is used to balance the influence of the force and reduce the influence on the actual engraving accuracy.

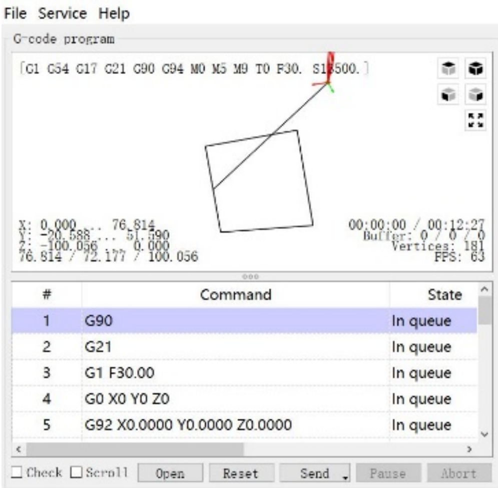


(a) Actual line carving (b) Sensor return data

Fig. 16. Sensor accuracy test

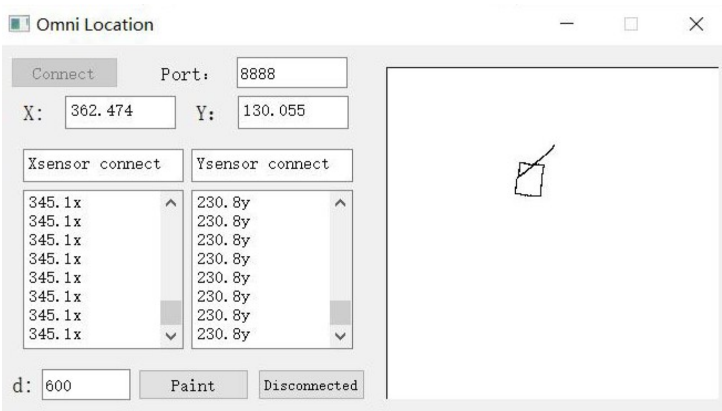
5.2 Positioning Test

Test the positioning effect, view the returned position information by engraving the rectangular path, and analyze the cause of the error by comparing it with the original path, as shown in Fig. 17.



(a) Gcode carving path

(b) Actual carving path



(c) Sensor return position trajectory

Fig. 17. Sensor test and analysis

According to the graphic analysis, the entire operation realizes the graphic engraving process of the engraving machine and the process of returning and drawing the positioning information and achieves the expected function. However, because the positioning sensor has a problem of shaking when collecting data, and the sensor uses the pull box to do the traction to measure the distance. Therefore, the engraving machine's power is blocked due to pulling the wire rope of the two sensors during the engraving process. This problem can be solved by replacing a more stable and torque motor, but at the same time, the cost will increase.

5.3 Engraving Test

The placement of the engraving machine and sensors is shown in Fig. 18. The GRBL control software candle is used to control the engraving process, as shown in Fig. 19. Import the generated Gcode instructions and transfer the Gcode instructions through serial communication to control the laser engraving process. The engraving results are shown in Fig. 20.

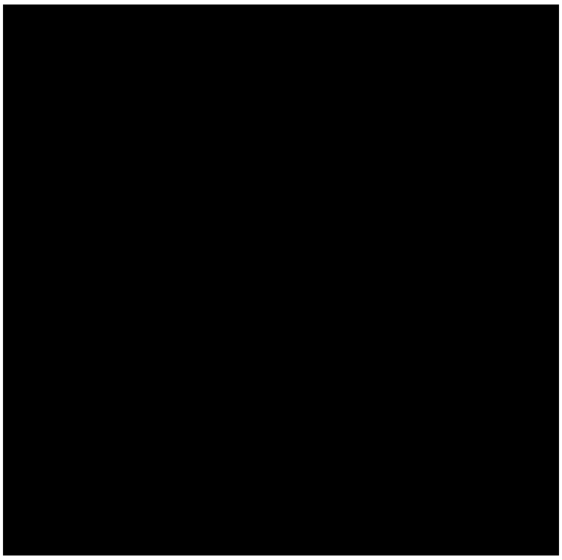


Fig. 18. Engraving machine and sensor

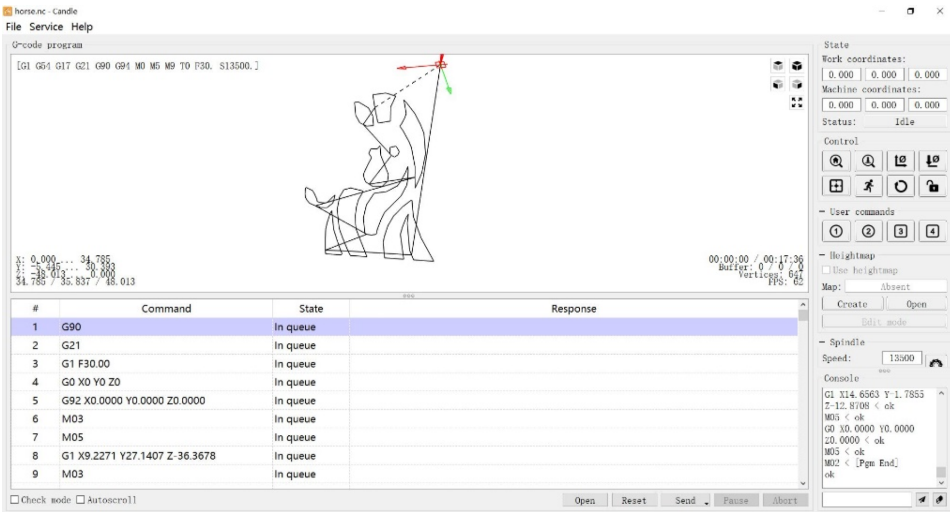


Fig. 19. Carving software candle

Fig. 20. Carving results

6 Conclusion

This paper designs and implements a mobile laser engraving machine for the limitation of the engraving area of the traditional engraving machine. In order to realize the omnidirectional movement of the engraving machine, the body structure adopts a three-axis omnidirectional wheel design. The lower computer is an embedded system, and the engraving process is controlled by analyzing Gcode commands. And use the incremental encoder to build a new sensor system, then use the host computer to process distance information and achieve triangle positioning and machine body position information feedback. Through the engraving trajectory drawing, intuitively reflect the engraving process.

In general, this article designs and implements a mobile laser engraving machine that breaks through the frame limitation of traditional engraving machines. The problem of the limitation of the engraving area of the traditional engraving machine is solved, and the engraving machine is small, light, and easy to carry, and can be engraved anytime and anywhere. And by improving the performance of the engraving machine, high-precision engraving operation can be realized, making this mobile laser engraving machine go to the market.

Acknowledgments

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