Precise Control of Screw Stepping Motor Based on MSP430 Single Chip Microcomputer

Hu Bei¹*, Zheng Liping² and Yu Yang³

¹ Department of artillery engineering, Shijiazhuang campus, Army Engineering University, Shijiazhuang, Hebei, 050003, China
² Department of artillery engineering, Shijiazhuang campus, Army Engineering University, Shijiazhuang, Hebei, 050003, China
³ Department of artillery engineering, Shijiazhuang campus, Army Engineering University, Shijiazhuang, Hebei, 050003, China

*Corresponding author’s e-mail: 1140192488@qq.com

Abstract. Screw stepping motors are widely used in many high-precision fields including manufacturing, precision calibration, and precision positional movement. Hence, research on the precise control of the screw stepping motor has important value in engineering application. In this paper, an ultra-low-power 16-bit MSP430F437 single chip microcomputer is used as the processor, combined with the subdivision drive system technology; the host computer is programmed with C#, and the communication between the host computer and the single chip microcomputer is established through Bluetooth, and a human-computer interaction interface is well established; the host computer sends a command to the single chip microcomputer to drive the screw stepping motor so as to control the speed and displacement of the load motion driven by the screw stepping motor.

1. Introduction

The screw stepping motor uses a stepping motor as a rotary power source, and converts rotary motion into linear rotation through screw-type drive. The screw stepping motor features simple structure, low cost, high precision and high efficiency, which makes it popular in the era of increasing automation, and it is widely applied to the fields requiring precise positioning, fast motion and long service life. Typical applications include X-Y work benches, medical equipment, semiconductor processing, communication devices, modulation valves, printing equipment, environmentally friendly equipment, automatic robots, 3D printing technology, and so on. The application of screw stepping motors in the high-precision fields makes their precise control particularly important. Under the condition that the step angle of the screw stepping motor can not meet the requirements for use, the subdivided drive can be used to drive the stepping motor. The principle of the subdivided drive is to change the angle of the resultant magnetic field by changing the magnitude of the adjacent two phase current to determine the size of the step angle. The subdivided driving method can not only change the size of the step angle, but also increase the effective electromagnetic torque of the stepping motor and reduce the torque fluctuation amplitude, improving the operating efficiency and stability of the stepping motor[1]. The screw stepping motor can be driven with single chip microcomputer or PLC. In this paper, the MSP430F437 single chip microcomputer is used as the processor to drive the screw stepping motor. The single chip microcomputer of MSP430 series is a 16-bit mixed signal processor with ultra-low power consumption.
and reduced instruction set produced by Texas Instruments (TI) in America[2]. The biggest feature of this single chip microcomputer is low power consumption. The power supply voltage of MSP430 single chip microcomputer is 1.8-3.6V, the minimum current of the chip is about 65uA, and the minimum power consumption in RAM hold mode is only 0.1uA. In this paper, combined with the subdivided driving method, the single chip microcomputer is used as the processor so as to realize the high-precision control of the screw stepping motor to precisely control the speed and displacement of the load motion driven by the screw stepping motor.

2. Working principle of screw stepping motor
The rotor of the screw stepping motor is a permanent magnet. When the current flows through the stator winding, the stator winding will generate a vector magnetic field. Under the action of such magnetic field, the rotor is rotated by a certain angle so that the direction of a pair of magnetic fields of the rotor coincide with that of the magnetic field of the stator[3]. The rotor and the lead screw are connected by a coupling. Thus, each time an electrical pulse is input, the motor rotates by a certain angle which corresponds to a certain amount of displacement of the lead screw. The screw stepping motor controls the angular displacement by controlling the number of input pulses to achieve accurate positioning; the screw stepping motor controls the rotation speed by controlling the frequency of inputting pulses, thereby achieving speed regulation.

3. Hardware design and realization

3.1. Overall design scheme
With the MSP430F437 single chip microcomputer as the controller and the stepping motor drive with subdivision function as the driving module, as well as combining the host computer and the Bluetooth communication technology, the whole control system realizes precise intelligent control of the screw stepping motor. Figure 1 is a diagram of the overall hardware structure.

The screw stepping motor in Figure 1 is the sliding table module whose schematic diagram is shown in Figure 2.

The stepping motor in Figure 2 is a two-phase four-wire stepping motor with screw specification of T6/2, that is, the diameter of the screw is 6mm and the lead of the screw is 2mm; when the stepping motor rotates one turn, the displacement of the lead screw is 2mm, that is, the slider moves 2mm. The horizontal load of the sliding table is 0-2.5KG, the vertical load is 0-1KG, and the step angle is 1.8°.

It can be seen from Figure 1 that after the control work starts, the basic settings such as baud rate and data bit set by the host computer software in a laptop will be matched and connected with the single chip microcomputer through Bluetooth. Then, the number of pulses and the pulse frequency of the stepping motor are set in the host computer software interface to control the speed and displacement of the screw stepping motor. After the relevant data is transmitted to the single chip microcomputer, the single chip microcomputer transmits the relevant signal to the stepping motor drive with the subdivision function to drive the screw stepping motor to drive the slider movement.
3.2. MSP430F437 single chip microcomputer
MSP430F437 is a 16-bit ultra-low-power single chip microcomputer. It not only consumes low power, but also integrates abundant on-chip resources. The working mode of the single chip microcomputer is divided into 1 active mode and 5 low-power modes. The minimum power consumption in low-power mode can reach 0.1uA. When it is necessary to control the screw stepping motor, it is in the active mode, and it is in the low-power mode to enter the dormant state in the rest of the time, and it needs to be reawakened to enter the active mode when CPU is required to work[4]. The P2.0 and P2.1 ports of the single chip microcomputer are used as ordinary IO ports to generate direction signals and pulse signals. Its P2.4 and P2.5 are used as the sender and the receiver respectively to connect with the Bluetooth module, and it communicates with the host computer software in the laptop through Bluetooth.

3.3. Screw stepping motor drive
The drive of the screw stepping motor used in the control system is a drive with a subdivision function, and its circuit diagram is as shown in Figure 3. As seen in Figure 3, the screw motor drive of the system adopts the common-cathode connection method, and the direction signal line and the pulse signal line of the drive are respectively connected with the P2.0 and P2.1 ports of the single chip microcomputer; A-, A+, B-, B+ are connected to the motor winding wires of the two-phase screw stepping motor. The subdivision drive is provided with a dial switch used for setting the subdivision, and the subdivision relationship is as shown in Table 1. For example, the stepper drive is set as 4 subdivisions, and assuming that the original step angle is 1.8°, then such angle turns to be 0.45° after 4 subdivisions.
Figure 3. Circuit diagram of screw stepping motor drive.

Table 1. Subdivision relationship.

| subdivide | S1  | S2  | S3  |
|-----------|-----|-----|-----|
| 1         | ON  | ON  | ON  |
| 2         | OFF | ON  | ON  |
| 4         | ON  | OFF | ON  |
| 8         | OFF | OFF | ON  |
| 16        | ON  | ON  | OFF |
| 32        | OFF | ON  | OFF |
| 32        | OFF | OFF | OFF |

4. Software design

The step angle of the screw stepping motor of the control system is 1.8°, the screw stepping motor rotates 360° (one turn) corresponding to a lead of 2mm of the lead screw, so that the slider on the lead screw moves 2mm[5]; thus, it is calculated that when one pulse is input to the screw stepping motor, the slider moves 0.01mm correspondingly; at the same time, if 2 subdivisions are set for the screw stepping motor drive, then when the single chip microcomputer outputs a pulse signal, the slider moves 0.005mm correspondingly.

By setting the P2.0 port to a high level, the single chip microcomputer makes the screw stepping motor rotate forward, causing the slider on the lead screw to move to the right along the straight line rail, and the low level moves to the left; continuous setting of the P2.1 port to the high and low level causes the P2.1 port to output a series of pulse signals; the direction signal and the pulse signal are implemented as shown in Figure 4. In Figure 4, T refers to the period of the pulse output by the single chip microcomputer, and 1/T means the frequency of output pulse. That is, the larger T is, the faster the screw stepping motor drives the slider to move, and vice versa. The T of the system is controlled by software delay in the single chip microcomputer, which facilitates the host computer to send the command to control speed. The host computer software of the system is programmed with C# language. The host computer can specify the number, direction and value of T of output pulses to realize the intelligent control of the screw stepping motor.
Figure 4. Diagram of direction signal and pulse signal.

5. Experiments and data analysis

Hardware connection and power supply are provided for the entire control system, and the speed and displacement of the movement of the slider on the screw stepping motor are controlled by setting different parameters on a host computer. Multiple experiments are performed and the experimental data is recorded as shown in Table 2 and Figure 5. The ordinate $T_1$ of Figure 5 indicates the time required for the slider to move 50 mm.

According to Table 2, the relative error of the control system is 0.03% or less in the range of the slider displacement amount of 50 mm. As the number of pulses output by the single chip microcomputer increases gradually, the displacement amount of the slider also increases linearly; as the displacement amount increases, the relative error becomes larger, which is in line with the actual situation. It shows that the control system has relatively high-precision control of the displacement amount of the slider on the screw stepping motor, with good error control. It can be seen from Figure 5 that increasing the period value of pulses output by the single chip microcomputer is to reduce the frequency of the pulses, and accordingly the time required for the slider to move 50 mm is gradually increased; the linear relationship between the two is good, which proves the moving speed of the slider is in proportion to the frequency of the pulses, and the system precisely controls the movement speed of the slider.

Figure 5. Experimental data on displacement control.

Table 2. Experimental data on speed control.

| Pulse number | Theoretical displacement | Actual displacement | Error | Relative error |
|--------------|--------------------------|---------------------|-------|----------------|
| 2000         | 10mm                     | 10.02mm             | 0.02mm| 0.20%          |
| 4000         | 20mm                     | 20.04mm             | 0.04mm| 0.20%          |
| 6000         | 30mm                     | 30.06mm             | 0.06mm| 0.20%          |
| 8000         | 40mm                     | 40.10mm             | 0.10mm| 0.25%          |
| 10000        | 50mm                     | 50.14mm             | 0.14mm| 0.28%          |

6. Conclusion

Nowadays, the precision of the factory-produced screw stepping motor is getting higher and higher. It can realize the high-precision movement of the load in two-dimensional and three-dimensional way through the assembly of multiple sliding tables, and it has vast potential for future development in the
automation industry such as CNC machining and 3D printing. In this paper, the ultra-low-power MSP430 single chip microcomputer is designed as the core controller, and the subdivision drive technology, programming technology and communication technology are adopted to precisely control the displacement amount and speed of the screw stepping motor. The experimental results show that the control system has good control effect and can achieve precise control of the screw stepping motor. The control system has a simple structure and is easy to be implemented, and provides an effective method and reference for how to realize high-precision control of the screw stepping motor in its application in the industrial fields.

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