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AN ULTRA-HIGH RESOLUTION MICRO STEP DRIVER

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Abstract. *Stepping motors are popularly installed in the auto system to provide position control due to its low cost, and easy control. However, the resolution of a standard stepping motor is only 200 or 300 steps per turn, and the micro stepping motor drives only achieved about 800 or 1600 steps per turn, due to open loop scheme. A close loop system, ultra-high resolution micro step driver is proposed in this paper. A magnetic rotary encoder is installed in the system to feedback high resolution angular information to adjust the angle of the rotating magnetic field created by SVPWM. The experimental results verify that the proposed driver could support the ultra-high resolution, 10,000 steps per turn.*
Keywords: Stepping motor, Micro step driver, Ultra-high resolution

1. **Introduction.** Stepping motors are popularly installed in the auto system, due to its low cost, and easy control. So, it is also a low cost solution to provide position control in a system. The resolution of a standard stepping motor system is 200 steps per turn, meaning 1.8 degree per step. However, the resolution requirement of position control is more and more accurate in these years, and micro stepping motor controllers are developed to provide more high resolution position control. Normally, these controllers achieved about 800, 1600 steps per turn, but with apparent error, due to open-loop and the structure. However, as the portable 3C products are more and more compact, the accuracy requirement for modern manufacturing systems, such as x-y planes, is more than 5000 steps per turn. Moreover, only few of the current stepping motor controls could support the resolution.

There are some papers which cover stepping motor control to improve the torque and speed response. [1] extended the direct torque control (DTC) to control stepping motors, and reduced the torque and speed ripple in low speed. Due to open loop, the best control parameters of acceleration and deceleration were analyzed and calculated in advance, and then a second order controller was designed. The simulation and experimental results indicated the high performance, but the control calculation is complex. [2] used the vector control and space vector pulse width modulation (SVPWM), to perform maximum torque control for two phase stepping motor. It installed a current close loop in its structure and developed an algorithm to estimate the average torque and the optimized control current. The chopping current is synthesized and the best control angle was used to keep smoothing running and higher acceleration [3] proposed a current tracking controller proximate in-phase current estimator (PIpCE), and the experimental results validated it reduced the torque ripple caused by the phase lag. However, the cost of the two previous papers is current feedback circuit. [4] proposes the stepping motor closed-loop control system, which is based on active disturbance rejection control technology, ADRC. Load torque is defined as external disturbance, and it and other internal disturbances are combined into total disturbance. A second order ADRC is designed, and the simulation results show faster transition time than normal PID control. This paper focuses on resistance the disturbance but not ultra-high resolution. Due to stepping structure, there is resonance and unstable current when stepping motor runs in low speed, and many literatures focus on the solution. [5] proposed novel modeling technique for hybrid stepper motors to simplify the high-order model with complexity measurements. Then 3-phase space vector control is the base of its proposed resonance reduction algorithm, and the first-, second-, and third-orders resonance are eliminated. [4] analyzed the increasing current ripple when transient, and then the vibration was identified and compensated in advance. The speed and position are estimated from the compensation algorithm. [7] measured the current damping of hybrid stepper motors online to identify the resonance, and designed an estimator for accurate position estimation and control. A new modulation technology, smart mixed-mode PWM (SMM-PWM), is proposed in [8], and the new modulation technology included the current feedback. This technology could reduce the current ripple and power switching to improve the efficiency. These studies may discuss about micro stepping control; however, never about the ultra-high resolution.

An ultra-high resolution micro step driver is proposed in this paper, and the resolution of 10,000 steps per turn, is achieved with the proposed magnetic rotary encoder feedback structure and the space vector pulse width modulation, SVPWM driver. This resolution is much better than the current micro stepping drivers. The structure will be described in next section; then, the control method is discussed in the third section; and finally, we will show the experimental results and discuss the conclusion.

2. **Micro Step Driver.** Stepping motors are brushless DC motors, and effectively have multiple "toothed" electromagnets. Normally, the number of the electromagnetic coils that may be in a stepping motor is two, three or five, in a two-, three- or five-phase stepping motor, and the step angle is 1.8°, 1.2° or 0.27°. The step angle, θ_{step}, is derived from (1); here, P indicates phase number, and N_r, normally 50, is the tooth number of the rotor. And the resolution of a step angle sometimes cannot meet the requirements of applications.

$$\theta_{\text{step}} = 180°/(P * N_r) \tag{1}$$

The micro step driver is a common technology, and the step resolution can be increased with sinusoidal waveform winding current. The driver skill is similar to the permanent magnet synchronous motors, PMSM control, and SVPWM technology is implemented in most micro step drivers. Ideally, if one can precisely control the angle of the rotating magnetic field, the stepping motor could be controlled in micro step. However, due to open loop scheme, the mechanical stiction, backlash and nonlinear error are between the rotor and stator, and the resolution increase is limited and is only about 32 times.

To improve the resolution, a magnetic rotary encoder is introduced into the proposed ultra-high resolution micro step driver. The magnetic rotary encoder could provide the high resolution angular information, and the device installed in the proposed system is a 15-bit resolution encoder, which means a count for 360/32768° as (2). The specification of the proposed system indicates 10,000 steps per turn within 1/2 steps error, and the resolution of the selected sensor may meet system requirement. This feedback angle information will be used to adjust precisely the angle of the rotating magnetic field to control the stepping motor approaching the command.

$$\text{A count} = 360/2^{15} = 360/32768 \tag{2}$$

3. **Hardware Structure.** The proposed ultra-high resolution micro step driver is shown in Figure 1, and it is used to drive a three-phase stepping motor. The system includes three blocks: power driver, controller and feedback circuit. First, the power driver block includes three legs which are used to provide the V_{DC} or ground connection for every

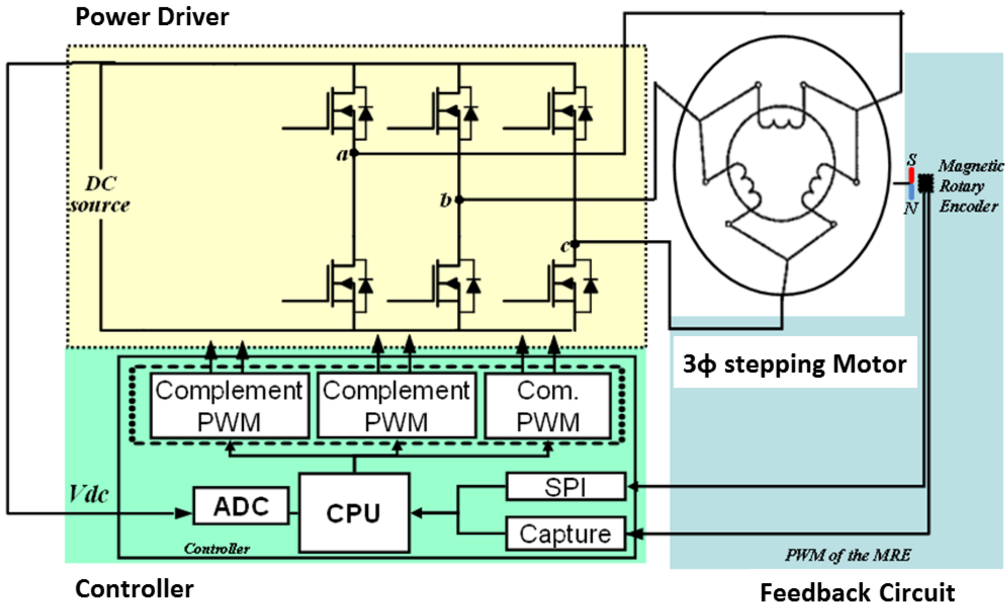

FIGURE 1. The proposed ultra-high resolution micro step driver

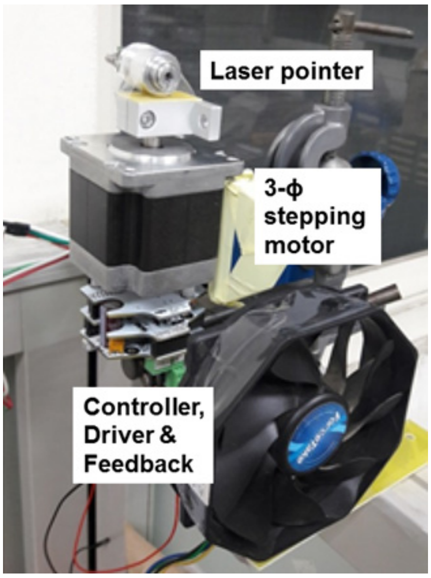

FIGURE 2. The experimental system

phase of the motor. So, each leg contains two power switches. Next, a micro control unit, MCU, is used to perform the controller, build-in timer peripherals are used to create pule width modulation, PWM waveform to control the power switches in power driver, analog to digital converter, ADC is used to monitor the voltage of the DC bus in power driver, and serial port communication and capture peripherals are used to sample the rotation angle feedback which comes from feedback circuit. Finally, as mentioned in last section, a magnetic rotary encoder in feedback circuit is used to provide the high resolution rotation angle information. This magnetic rotary encoder is the key to achieving ultra-high resolution.

4. **Experimental Result.** An experimental system is installed to verify the performance of the proposed driver. As shown in Figure 2, a laser pointer is fixed in the stepping motor, and the laser pointer will project on a screen which is located on 7 meters outside and printed scale rulers. The distances between lines are derived from (3) as presented in

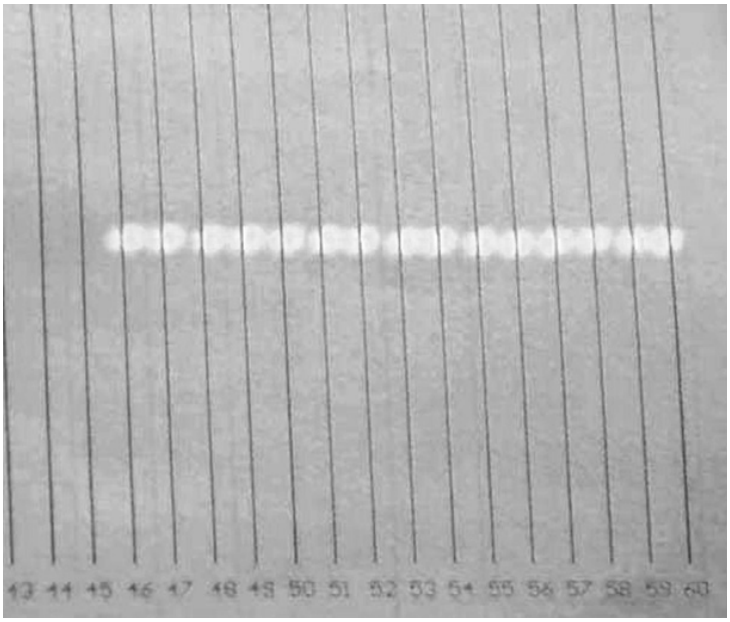

Figure 3. The position control experimental results

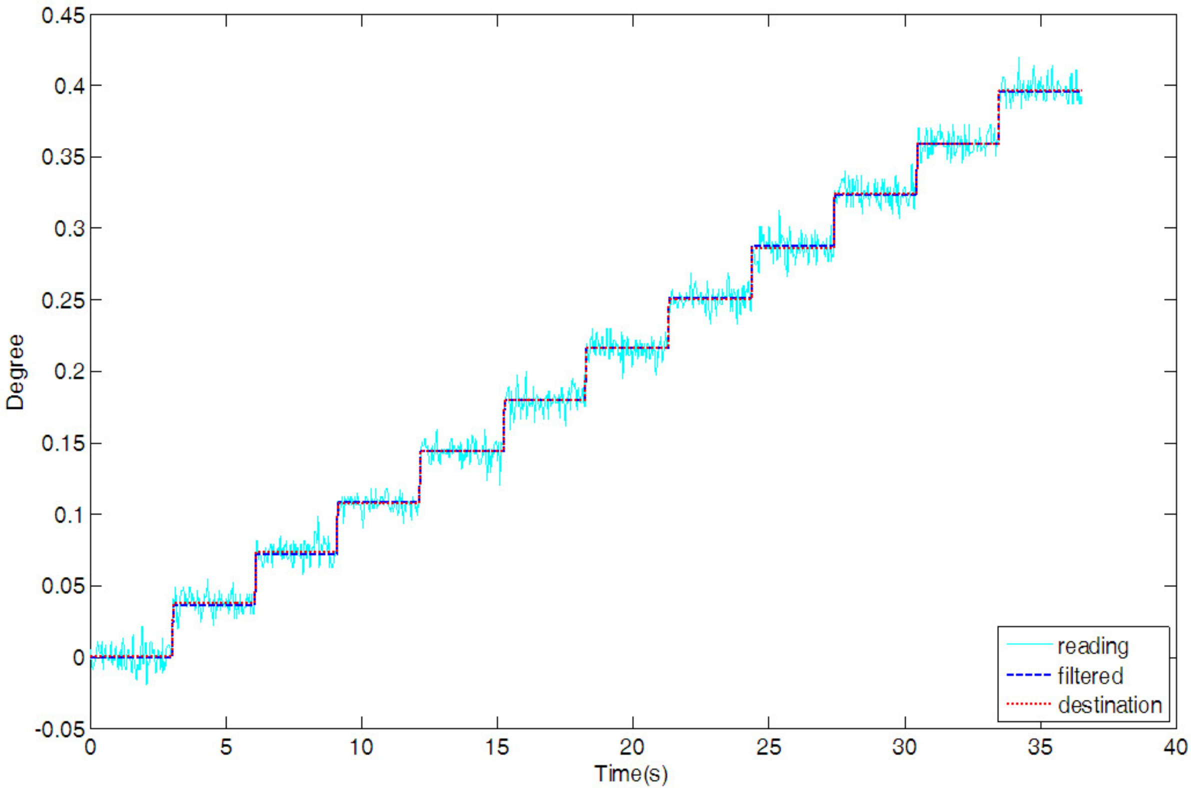

Figure 4. The details of the position control experimental results

Figure 3. The experimental result is also indicated in Figure 3, and the laser precisely points on the lines. The feedback numbers include noise, and a moving average filter is used to eliminate noise. The parameters of the filter are shown in (4). The details of experimental results are plotted in Figure 4, the dot line presents the commands, solid line shows the feedback readings and dash line indicates the filtered output. Next, the error ratios to one micro step are present in Figure 5, the solid line shows the feedback reading error and dash line indicates the filtered output error, again. Figures 4 and 5 indicate the resolution of the proposed system has achieved 10,000 steps per turn, meaning 0.036°

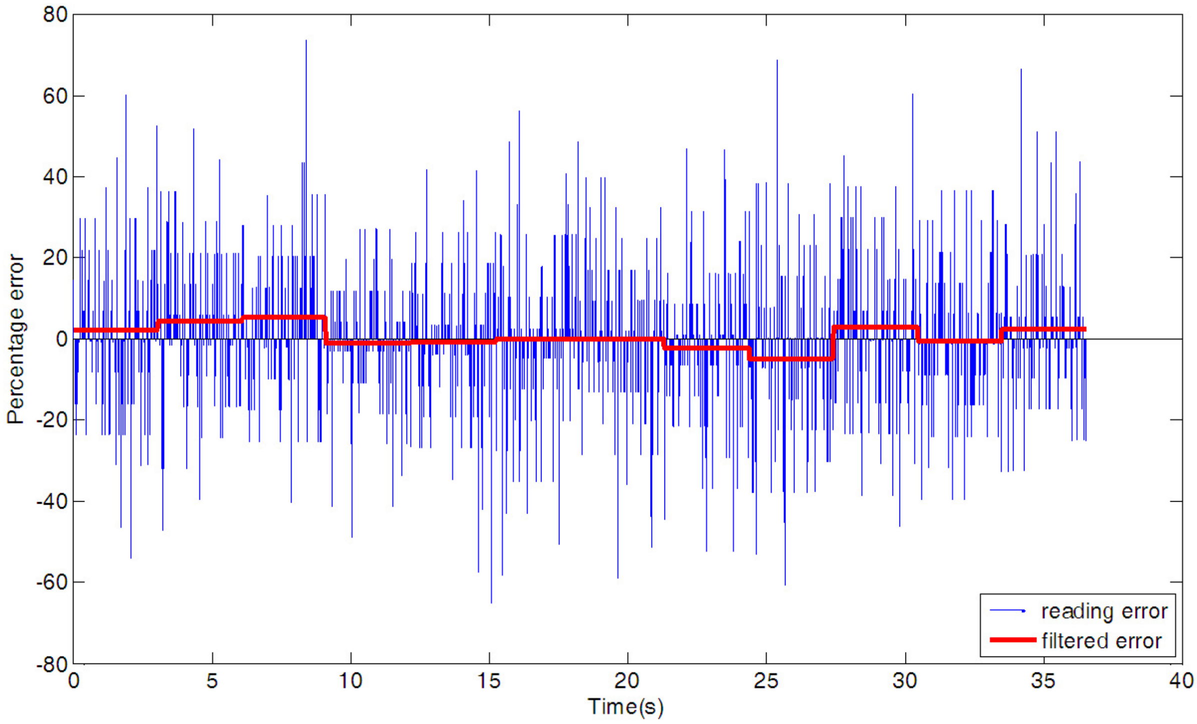

Figure 5. The error ratio of the position control experimental results

and the error is less than 10%. Note, some errors are difficult to be canceled, due to the fact that the proposed resolution 0.036° is not divisible by a count of the magnetic rotary encoder in system.

$$\text{Distances between lines} = 700 * \tan\left(\frac{360^\circ}{10000}\right) \text{ cm} \tag{3}$$

$$H(z) = 1/4 + 1/4z^{-1} + 1/4z^{-2} + 1/4z^{-3} \tag{4}$$

5. **Conclusion.** An ultra-high resolution micro step driver has proposed in this paper, and a magnetic rotary encoder has been installed in the system to provide precise angle feedback. This ultra-precise angle information has been used to adjust accurately the angle of the rotating magnetic field which is created by SVPWM. The experimental results show the resolution of the proposed driver is 10,000 steps per turn, meaning 0.036°, and the error is less than 1/2 step, and about ±10%. The resolution is much better than the most current open-loop solution, and the proposed system could be installed in the auto system. Due to a lack of suitable calibration instrument, in the future, the proposed driver that could be used in screw which is calibrated by laser rangefinder is considered. Moreover, after powerful feedback signal filter, the resolution should be improved to 32,768 steps per turn.

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REFERENCES

[1] H. Li and M. Jin, Vector control and SVPWM strategy of two-phase hybrid stepping motor, *Proc. of International Conference on Electrical and Control Engineering*, pp.467-470, 2011.

[2] T.-W. Chun, J.-R. Ahn, H.-H. Lee, H.-G. Kim and E.-C. Nho, Development of servo motor drive systems for embroidery machines, *Proc. of the 8th Russian-Korean International Symposium on Science and Technology*, pp.310-314, 2004.

[3] Y. Lee, D. Shin, W. Kim and C. C. Chung, Proximate in-phase current estimator to reduce torque ripple in permanent-magnet stepping motor, *IEEE Trans. Industrial Electronics*, vol.63, no.3, pp.1707-1716, 2016.

[4] Z. Xu and P. Kou, Stepping motor closed-loop control system based on active disturbance rejection control, *Proc. of the 35th Chinese Control Conference*, Chengdu, China, pp.5998-6002, 2016.

[5] K. W. H. Tsui, N. C. Cheung and K. C. W. Yuen, Novel modeling and damping technique for hybrid stepper motor, *IEEE Trans. Industrial Electronics*, vol.56, no.1, pp.202-211, 2009.

[6] K. Balakrishnan, B. Umamaheswari and K. Latha, Identification of resonance in hybrid stepper motor through measured current dynamics in online for accurate position estimation and control, *IEEE Trans. Industrial Informatics*, vol.9, no.2, pp.1056-1063, 2013.

[7] S.-M. Yang and P.-D. Su, Active damping control of hybrid stepping motor, *Proc. of the 4th IEEE International Conference on Power Electronics and Drive Systems*, pp.749-754, 2001.

[8] A. Bellini, C. Concari, G. Franceschini and A. Toscani, Mixed-mode PWM for high-performance stepping motors, *IEEE Trans. Industrial Electronics*, vol.54, no.6, pp.3167-3177, 2007.