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The Design of Precise Positioning System for Three-Axis Stepping Motor Based on TMC429

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Abstract

This article mainly describes the physical design of a high-precision positioning system composed of three parts including stepper motor as an actuator, encoder and grating ruler as a measurement feedback element, and STC15W as a MCU. By using the TMC429 three-axis motor control chip, the MCU's on-chip resources are greatly released. At the same time, it has a good positioning accuracy and the ability to make the motor run with less noise. After the PC sends the position command through the serial communication, the MCU parses the data to the TMC429 through the SPI port. The system completes the execution of the motor movement, and then feedbacks and corrects the number of steps of the motor operation through the encoder to ensure that the motor does not lose step or overshoot, and Finally, the grating ruler is used to perform a position feedback on the target position to form a double closed-loop structure with the pan-Boolean PID control algorithm to make the motor accurately reach the command position.

Keywords

TMC429; Hybrid Stepper Motor; Pan-Boolean; PID Algorithm; STC15W Mcu.

1. Introduction

At present, stepper motors are widely used in the industrial field. The main applications include servo positioning and constant speed control. Most of the early device is still in open-loop control mode. In the open loop operation mode, the position and speed signals of the rotor have no real-time feedback to the system, so it is only suitable for use in areas with low precision requirements, and it is often difficult to meet the increasing demands in practical applications. Although there are many advanced control algorithms in stepper motors, such as vector control and fuzzy control, most of them are implemented in Matlab/Simulink simulation, which is not easy to complete on the hardware circuit and does not have practical value [7]. To a certain extent, the application of the two-phase hybrid stepping motor control system in the industry is restricted. Therefore, it is necessary to study the design of a two-phase hybrid stepping motor closed-loop control system based on the easy-to-implement pan-Boolean pid control strategy.

2. Stepper Motor

Stepper motor is a device that converts pulse signals into proportional angular displacement. As an actuator, it is widely used in digital control systems, servo systems and industrial robots. Within the load capacity of stepper motors the step angle and speed are not affected by voltage fluctuations and load changes, nor are they affected by environmental conditions such as temperature, air pressure, shock, and vibration. The step angle θ_s of the two-phase hybrid stepping motor has the following (1) relationship with the number of phases m and the number of rotor teeth Z_r [8].

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$$\theta_s = \frac{360°}{2mZ_r} \tag{1}$$

The driver tb6600 in the system design in this article is a subdivision driver, and the subdivision is the microstep angle θ_{ms} and the relationship between the step angle θ_s is as follows (2)

$$\theta_{ms} = \frac{\theta_s}{k} \tag{2}$$

The relationship between the speed n of the stepper motor and the pulse frequency f of energization is as follows (3)

$$n = \frac{60f\theta_{ms}}{360°} \tag{3}$$

This will provide a critical theoretical basis for the selection of parameters in the chip TMC429 in the subsequent part.

3. TMC429 Chip Overview

TMC429 is a small stepping motor controller with feature set. In order to achieve the best stepping accuracy of the two-phase stepping motor. According to the target position and speed which can be changed at any time, it can automatically perform all real-time critical tasks. In the article, STC15w56S4 microcontroller provides TMC429 with its main clock frequency f_{sys} through the system clock output port. After it starts, according to the SPI communication protocol, after SCK_C goes low, SDO_C becomes valid at least four CLK clock cycles later, and the SPI interface moves serial data into SDI_C at each rising edge of the clock signal SCK_C. Then, at the rising edge of the selection signal nSCS_C, the contents of the 32-bit shift register are copied to the buffer register. The serial interface of TMC429 immediately sends back the data read from the register or from the internal RAM through the signal port SDO_C. The MCU can sample the signal SDO_C on the rising edge of SCK_C. Send 4 data frames from LBS to MSB, a total of 32bit data, to configure the Ramp_mode, as shown in Figure 3.1.

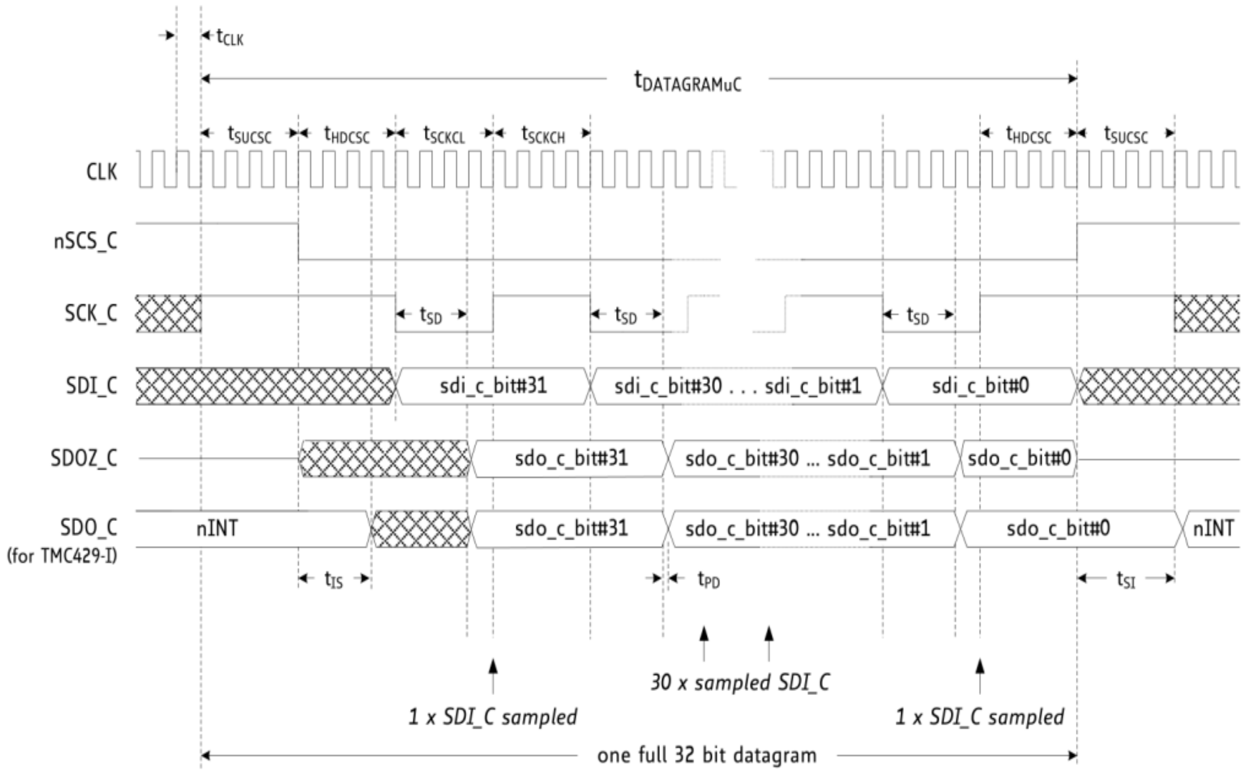

Figure 1. Timing diagram of the serial μC interface

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This system actually uses TMC429 as the stepper motor controller instead of MCU, so the actual output control Step Pulse Rate R and the motor speed n, the differential relationship of the motor speed involves the following (4) (5), where $PLUSE\_div$ is the pulse frequency division coefficient of TMC429, $ramp\_div$ is the pulse frequency division coefficient of TMC429, A_MAX is the pulse acceleration coefficient of TMC429, $velocity$ represents the mapping of the internal motor speed n of TMC429, and the stepper motor can only work normally when the value is appropriate.

$$\mathrm{R} = \frac{f_{sys} * velocity}{2^{PLUSE\_div} * 2048 * 32} \tag{4}$$

$$\Delta\mathrm{R} = \frac{\mathrm{A\_MAX} * f_{sys}^{2}}{2^{PLUSE_{div} + ramp_{div} + 29}} \tag{5}$$

In addition, TMC429 also has a variety of topological structure connection methods to meet different types of drivers and complex application scenarios. In this paper, the TMC429 chip adopts the DIR/STEP connection mode to directly connect to the three stepper motor drivers, as shown in Figure 2.

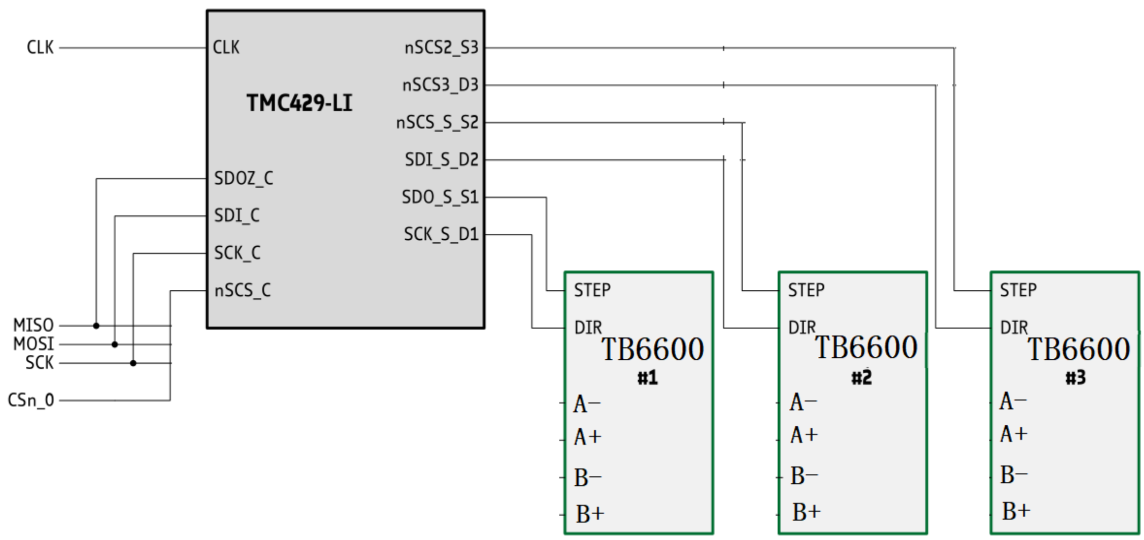

Figure 2. TMC429 / TB6600 outline for configuration via SPI and STEP/DIR for motion

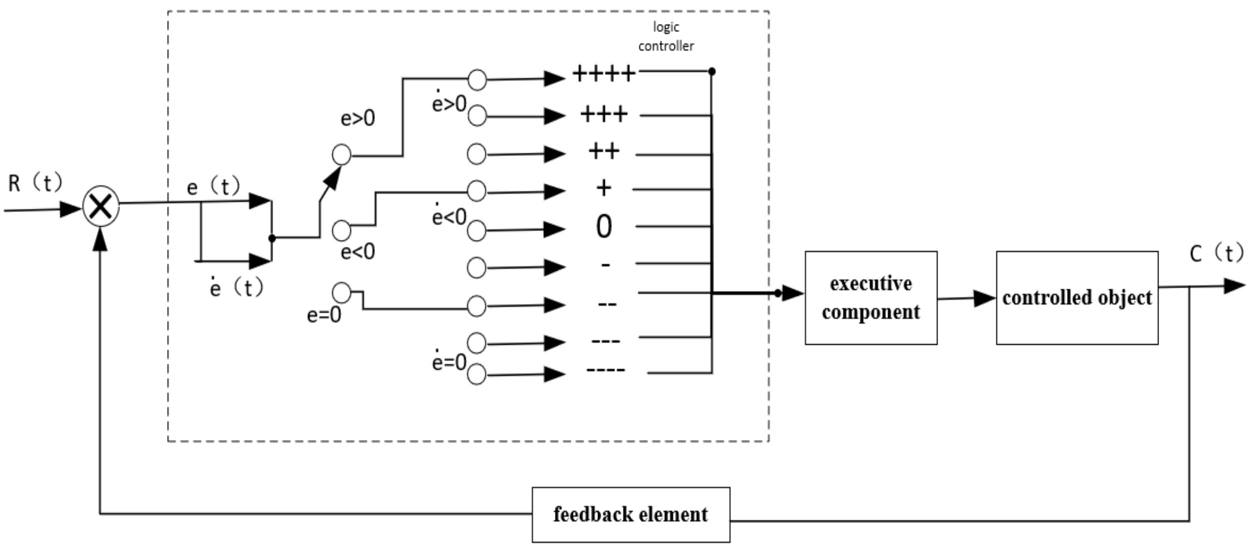

Figure 3. Pan-Boolean PID control system block diagram

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4. Pan Boolean Pid Controller

As we all know, the method of controlling according to the deviation proportional, integral and differential linear combination is the well-known PID control. It occupies an unshakable position in the classic control theory. However, in the face of some systems that cannot be abstracted out of specific mathematical models, it has certain limitations. In digital systems, the number of Boolean algebras, namely 0 and 1, are mostly used. Pan-Boolean PID control is based on a logic control model, using the theoretical basis of Pan-Boolean algebra, and better adaptability is its advantage [2] [3]. The composition of the Pan-Boolean PID control system is shown in Figure 3, and the construction of the Pan-Boolean PID controller in the simulink simulation in matlab is shown in Figure 4.

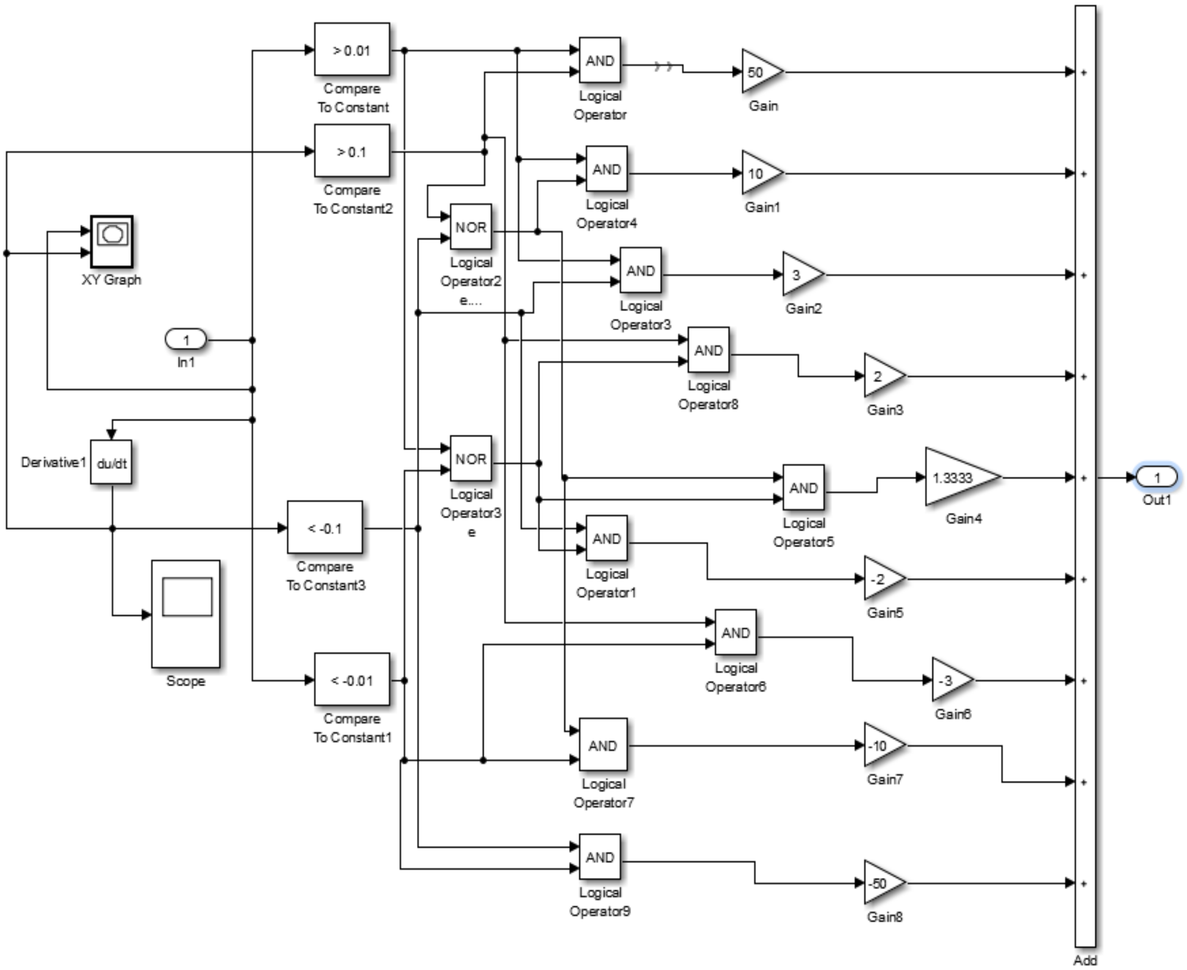

Figure 4. Pan-Boolean PID controller

5. System Design

5.1 Hardware System Design

The hardware system adopts modular design and is divided into STC15W56S4 microcomputer, TMC429 stepper motor controller, TB6600 stepper motor driver, stepper motor, TLP291-4 optocoupler isolation, absolute encoder and raster rule, etc., as shown in Figure 5. The microprocessor sends instructions to TMC429 to output control stepping pulses, and provides drive signals to the stepping motors through the subdivision driver. The feedback signals are monitored by the encoder in real time to monitor the rotation angle of the motor rotor and enter through the microprocessor PCA port to form a closed loop as a whole structure.

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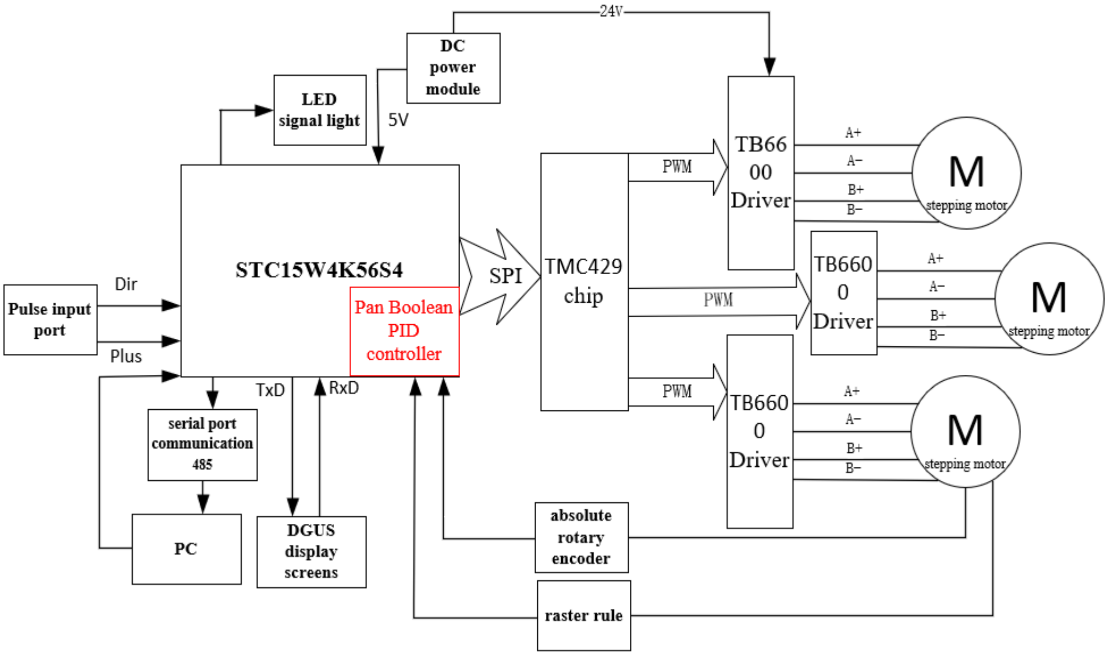

Figure 5. System hardware circuit

5.2 Software Design

The software design of the whole system includes: motor control program, serial communication program, main program and interrupt service program, etc. [1]. The main program and stepper motor control program flow are shown in Figure 6. Due to limited space, the following part of the code of TMC429 parameter design is shown

```
    void CalcPMulPDiv(int a_max,int ramp_div,int pulse_div,float p_reduction,
    int *p_mul, int *p_div)
  {
   Int a_max_lower_limit, pdiv, pmul, pm, pd ,a_max_upper_limit;
   double p_ideal, p, p_reduced;   //, p_best
   a_max_upper_limit = ((int)pow(2,(12+(ramp_div-pulse_div)))) -1;
    a_max_lower_limit = (int)pow(2,(ramp_div-pulse_div-1));
   if(a_max>a_max_upper_limit)
   {
   *(Init_429_reg_1+17)=a_max=a_max_lower_limit+1;
   }
   else if (a_max<a_max_upper_limit)
   {
   *(Init_429_reg_1+17)=a_max=a_max_lower_limit+1;;
   }
   pm= -1;
   pd= -1; // -1 indicates : no valid pair found
   p_ideal     = a_max /   (pow(2, ramp_div-pulse_div)*128.0);
   p           = a_max /   (128.0*pow(2, ramp_div-pulse_div));
```

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```
    p_reduced = p* ( 1.0- p_reduction );
    for (pdiv=0; pdiv<=13; pdiv++)
    {
        pmul = (int)(p_reduced*8.0*pow(2, pdiv)) -128;

        if ( (0 <= pmul) && (pmul <= 127) )
        {
            pm = pmul + 128;
            pd = pdiv;
        }
    }
}
```

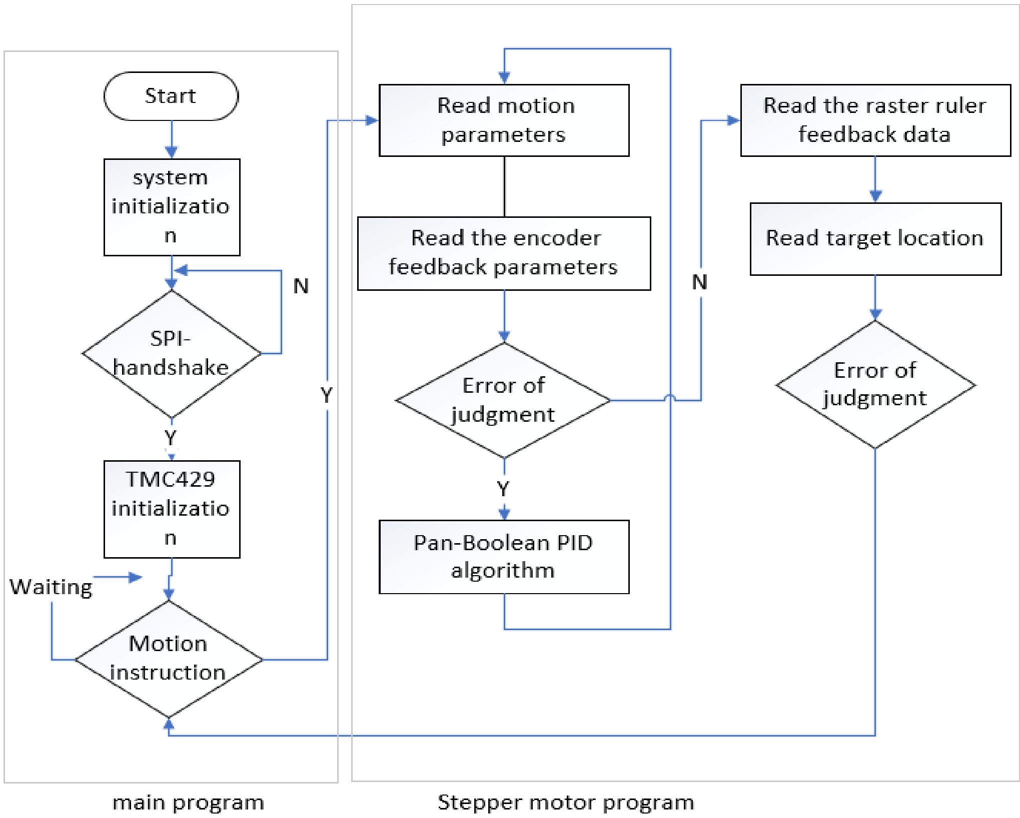

Figure 6. Main program and stepper motor program design flow chart

6. Conclusion

The TMC429-based precision positioning system of stepper motor designed in this paper uses a chip with subdivision drive function to design the drive circuit so that the stepper motor can rotate at a smaller step angle, the running process is more stable, and the noise is further reduced. As the dual feedback mechanism of Pan-Boolean PID control, the stepper motor can get more accurate results in servo positioning applications, and it is easier to implement in the actual application layer.

Together with a microcontroller the TMC429 forms a complete motion control system. High integration and small form factor allow for miniaturized designs for cost-effective and highly competitive solutions.

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