Applied Mechanics and Materials Vols. 385-386 (2013) pp 867-871 *Online: 2013-08-30*
© (2013) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.385-386.867

Motor control application based on STM32 and PID control theory

ZHAO Zhetuo

HKUST Clear Water Bay Kowloon Hong Kong

zzhaoaa@stu.ust.hk

Keywords: motor controller, PID control, three-loop feedback control.

Abstract. This paper introduces a motor control application. In terms of hardware, we design and build the motor control board based on STM32 microcontroller (MCU). In software part, the code loaded in the MCU is designed to apply a feedback control on the motor based on proportional-integral- derivative (PID) control theory and the three loops control of motor. We have achieved the angular displacement and speed control of the DC brushed motor in this application. Thanks to the current loop control of the motor, the controlling performance less sensitive to the external disturbance and the robustness is better compared with the motor controller in current market like LM629. Besides, the maximum current passing through the motor can be set by user in the program, which makes this motor control board more stable and durable.

Introduction

Motor is one of the most widely used actuators in the robotics field and the accurate and robust control of the speed and angular displacement of motors are basic requirements when people try to control the behavior or movement of robots. Hence the motor controller is needed in many applications involving robotics, which acts as an intermediate device between main control system and motors, in order to keep at a speed set by user or to turn to desired angle or rounds.

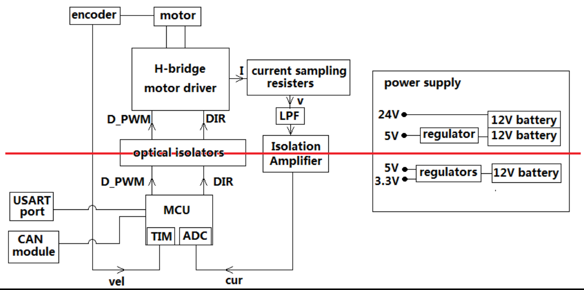
There are many ICs in the market operating motor controlling function which can receive the commands sent by a microcontroller and calculate the duty cycle of PWM(pulse-width modulation). One of the disadvantages is that the signal generated by the IC cannot drive the motor directly. A extra motor driver is need to connect the motor controlling ICs and motors, which increases the complexity of the whole control system and reduce the stability in the same time.

The motor controller built in this application uses the STM32 MCU to perform motor controlling IC's function and combine it with the motor drive. In this way the motor controller can work as a integral and independent unit in the whole controlling system of the robot, which simplifies the structure of the whole system. Controlling motor in software method (using MCU to replace motor controlling IC) is more stable and easier for users to debug. In this application the motor controller has following functions: control the speed of the motor, make motors to turn to the given angle or rounds, brake the motor, detect current overload and short-circuit.

This paper will first introduce hardware design of the motor controller, including H-bridge motor driver, current sensing and signal isolation. The second section is a introduction of the three-level motor control method used in this application. After that, the experiment results will be shown.

Hardware design

The motor control board is designed to achieve a closed loop control of motor. As it is shown in Fig. 1, the MCU takes the current feedback signal from isolation amplifier and motor velocity feedback signal from the encoder and then applies PID algorithm to calculate the duty cycle of PWM. The D_PWM and DIR signals will be sent to H-bridge motor driver and control the DC brushed motor. The USART port and CAN (controller area network) module support different protocols in the communication with the computer or the main control system of the robot.



D_PWM	Duty cycle of the PWM calculated by the MCU
DIR	Direction of the motor running calculated by the MCU
TIM	Timer in the STM32 MCU
ADC	Analog and Digital Convertor in the STM32 MCU
LPF	Low-pass filter
MCU	Microcontroller
I	Current passing through the motor
V	Voltage across the current sampling resisters
vel	Velocity feedback signal detected by the encoder
cur	Current feedback signal detected by the isolation amplifier

Figure 1. Block diagram of the motor controller with signs specification

Current sensing. Because of the current PID control loop, the current going through the motor is needed to be detected in the algorithm as the feedback signal. In this application, the isolation amplifier IC A788J is used to collect current samples and send them to MCU. Two 0.01 Ω current sensing resisters (*R1*,*R2* in Fig. 2) transfer the current signal to electrical potential signal, which can be sensed by the IC.

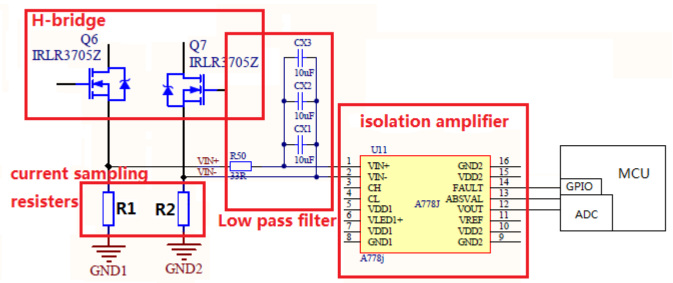


Figure 2. Current sampling circuit

Note: The pin arrangement is not shown completely;
VIN+ and *VIN-* represent the electrical potential on the upper terminal of *R1* and *R2* correspondingly.

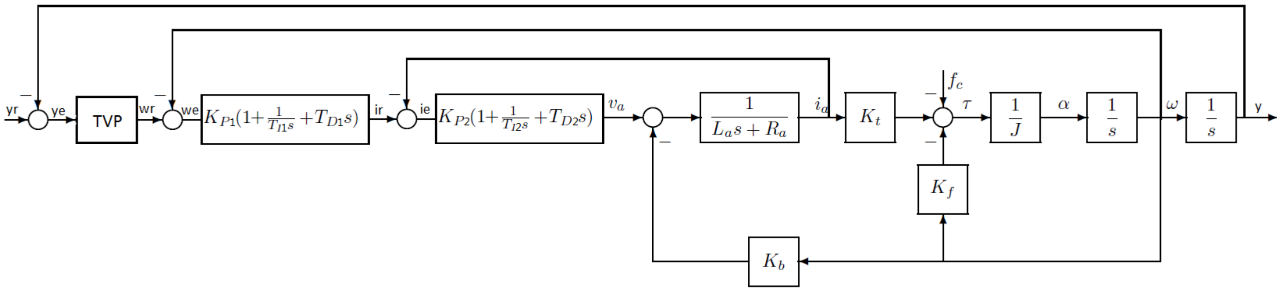
When the square wave of PWM signal goes to logic 1 and direction is set to logic 0, *stream 1* is cut off. With no current passing through *R1*, *VIN+* is effectively connected to ground. With current passing through stream 2, *VIN-* reveals the current value through motor according to Ohm's Law. When both PWM signal and *DIR* are logic 1, *VIN-* is effectively connected to ground and *VIN-* reveals the current value through motor. In this way, both the magnitude and the direction of the current can be detected by single IC A788J.

The signals at the terminals of resisters are square waves since PWM is used to control the DC motor. A low-pass filter is built between the current sensing resisters and IC, in order to get the effective value of the square wave, which can be used directly in the algorithm.

Signal isolation. As it is shown in Fig. 1, the motor control board is divided into 2 parts. One is the high voltage motor driver field with 24 V power supply and the other is the STM32 MCU field with 3.3 V power supply. The two parts are completely isolated and the output signals from MCU are transported through optical isolators to the motor driver. In that way, the MCU is relatively safe and less influenced by the rapid voltage changes in high-voltage field. The MCU will not be damaged even if the motor drive is burnt due to high current.

Three-level motor control

For a DC motor system, we need to design a controller to make the system having swift response and good robustness. In this application, 3-level motor control is applied (shown in Fig. 3), which includes position control loop , velocity control loop, and current control loop[3].



yr	Angular displacement reference, the expected rounds or angle that the motor turn, set by user.
ye	Angular displacement error
TVP	Trapezoidal velocity profile alogorithm
wr	Angular velocity reference, the expected Angular velocity that the motor turn, set by user or calculated as the output of TVP.
we	Angular velocity error
ir	Current reference, the expected current that go through the motor, calculated as the output of the PID in velocity control level.
ie	The current error
V_a	The duty cycle of PWM signal, calculated as the output of the PID in current control level.
L_a	Motor coil inductance
R_a	motor coil DC resistance
i_a	The current passing through motor, detected by isolation amplifier, received by the ADC of MCU.
K_t	motor torque constant
f_c	External disturbance
τ	Torque of the motor
J	system inertia
α	Angular acceleration
ω	Angular velocity, detected by the encoder.
y	Angular displacement, detected by the encoder.
K_f	Viscous friction constant
K_b	motor back *emf* (Electromotive force) constant

Figure 3. Block diagram of 3-level motor control system and signs specification.

Position control loop. The position control loop is the most external loop in motor control, where user set a desired Angular displacement *yr* as input and then the desired velocity is calculated to form a standard trapezoidal velocity trajectory according to the parameters set by users, including limiting velocity, destination position, constant acceleration and deceleration[2].

Velocity control loop. The velocity control loop is the middle level, where the output of the position loop or the expected speed set by users is taken as the input and PID algorithm is applied to calculate the expected current[4]. (Pseudocode of velocity control loop is shown in Fig. 4)

Velocity control loop (incremental PID algorithm is used)

```
we=wr-w
P_term=(we-prev_error)*KP1
I_term=we*KI1
D_term=(we+prev2_error-2*prev_error)*KD1
prev2_error=prev_error
prev_error=we
ir+=P_term+I_term+D_term
if (ir>max_current)
       ir=max_current
if (ir<-max_current)
       ir=-max_current
```

Note:
1. max_current is set to be 75 percent of the maximum current that isolation amplifier can detect, which is 20A in this application.
2. *we*, *wr*, *w*, *ir* refer to Fig. 3.
3. KP1=K_{p1} ; KI1= $\frac{K_{p1}}{T_{I1}}$; KD1= $K_{P1}\bullet T_{D1}$ (refer to Fig. 3).

Figure 4. Pseudocode of velocity control loop

Current control loop (incremental PID algorithm is used)

```
ie=ir-ia
P_term=(ie-prev_error)*KP2
I_term=ie*KI2
D_term=(ie+prev2_error-2*prev_error)*KD2
prev2_error=prev_error
prev_error=ie
D_PWM +=P_term+I_term+D_term
if (D_PWM>100%)    D_PWM=100%
if (D_PWM<-100%)    D_PWM=-100%
```

Note:
1. *ia* = VOUT signal read from ADC - ADC offset (ADC offset is gotten by the calibration process before PID algorithm runs)
2. *ie, ir, ia* refer to Fig. 3, D_PWM refers to Fig. 1.
3. KP2=K_{p2} ; KI2= $\frac{K_{p2}}{T_{I2}}$; KD2= $K_{P2}\bullet T_{D2}$ (refer to Fig. 3).

Figure 5. Pseudocode of current control loop

Current control loop. The current control loop is the inner level, where the expected current calculated in velocity control loop is used as the input and PID algorithm is applied to gain the duty cycle of PWM and direction to drive the motor. (Pseudocode of current control loop is shown in Fig. 5)

In this application, the frequency of STM32 timer is 72MHz. The frequency of PWM is 40KHz and the resolution of the duty circle of PWM can reach 1800. The main program runs at 8KHz, including current control loop and velocity control loop. The position control loop runs every ten times that velocity control loop runs.

Application

We have done the PID parameter tuning to optimize the performance of the system. To assess the response speed of the system, we apply step reference input to *ir*, *wr* and observe the setting time, steady state error, error band of the *ia*, *wr* correspondingly. To assess the robustness of the system, we apply step reference input to f_c and observe the setting time and steady state error of *wr*. (the curves of *wr* under different PID parameters is shown in Fig. 6)

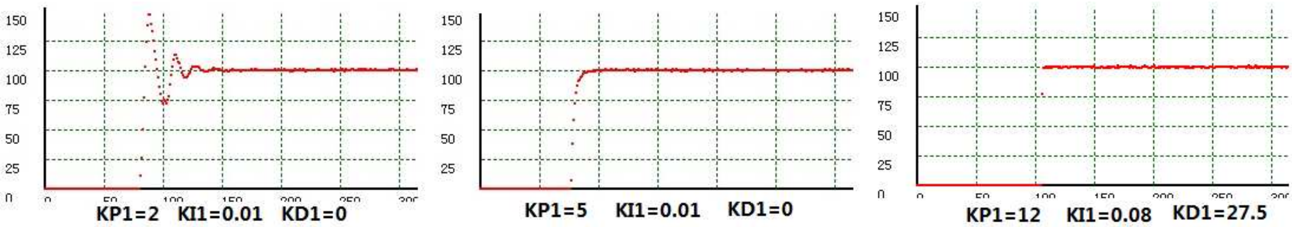


Figure 6. The curve of the angular velocity ω, obtain from step reference input: $wr(t)=100\sigma(t)$,with KP2=3, KI2=0.2, KD2=0, f_C=0. The horizontal axis is time(ms) and the vertical axis is angular speed(rpm). It is obvious that the response speed of the system when KP1=12, KI1=0.08, KD1=27.5, is faster than the other two PID parameter pairs.

As a result, the application achieve to build a DC motor feedback system with zero steady state error, less than 0.02s setting time and -0.007 round/sec to +0.007 round/sec error band for step reference input of *wr*; less 0.01s setting time and zero steady state error for step reference input of f_c.

Conclusion

This application build a DC motor feedback control system with fast response speed and great robustness. It can be used in robotic field, which can receive the commands from main board of the robot and control the motor to run at certain speed, brake or reach a certain angular displacement. The application can work properly with load not exceeding 50kg and 850 rpm maximum speed. The current is constrained in 15A in operation and the short-circuit can be detectded, which make the hardware safer and more stable.

Reference

[1] Gupta, V., "*Working and analysis of the H - bridge motor driver circuit designed for wheeled mobile robots,*" Advanced Computer Control (ICACC), 2010 2nd International Conference on , vol.3, no., pp.441,444, 27-29 March 2010

[2] Thirachai, S.; Komeswarakul, P.; Supakchukul, U.; Suwatthikul, J., "*Trapezoidal velocity trajectory generator with speed override capability,*" Control Automation and Systems (ICCAS), 2010 International Conference on , vol., no., pp.1468,1472, 27-30 Oct. 2010

[3] Sathyan, A.; Krishnamurthy, M.; Milivojevic, N.; Emadi, A., "*A low-cost digital control scheme for Brushless DC motor drives in domestic applications,*" Electric Machines and Drives Conference, 2009. IEMDC '09. IEEE International , vol., no., pp.76,82, 3-6 May 2009

[4] Basilio, J.C.; Matos, S. R., "*Design of PI and PID controllers with transient performance specification,*" Education, IEEE Transactions on , vol.45, no.4, pp.364,370, Nov 2002

Applied Scientific Research and Engineering Developments for Industry
10.4028/www.scientific.net/AMM.385-386

Motor Control Application Based on STM32 and PID Control Theory
10.4028/www.scientific.net/AMM.385-386.867