Research and Design of Infrared Remote Control and Self-balancing Car Based on STM32

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Abstract. This paper introduced a design of infrared remote and self-balancing car.STM32 is master control chip on this system. Infrared remote control devices serve as the control devices. Firstly, the MPU6050 sensor acquire data of the car’s attitude. Then, using Kalman filter algorithm and Data fusion technology process the data. After fusion processing, using the PID algorithm calculate the duty cycle of PWM to control the current electromotor. Finally，the car can self-balance, move forward, move back, turn left and turn right.

Introduction

Self-balancing two-wheel car is a special kind of wheeled mobile robot, extreme instability, which is a kind of multivariable, nonlinear and strong coupling system. It is a typical device to verify various theory of control. Self-balancing two-wheel robot is a collection of a variety of functions in a body's comprehensive and complex system, the key is to complete the balance of control tasks at the same time also to be able to apply all kinds of environment. The advantage of Self-balancing two-wheel car is small volume, flexible movement, zero turning radius, which can move into the complex, narrow and dangerous space to perform high challenge task. It has a high developing potential in dangerous rescue, topographic reconnaissance, unmanned transportation, ride instead of walk. Some commercial organizations produce Self-balancing two-wheel car, put it on the market, and get consumer’s attention. It will become the battlefield robots or “baby-sitter” robots, which has a bright application prospect in the field of military and civilian.

System design

A. System Chart

STM32 is master control chip on this system. The MPU6050 sensor acquires data of the car’s attitude. Using Kalman filter algorithm and Data fusion technology process the data. After fusion processing, using the PID algorithm calculate the duty cycle of PWM to control the swerve and speed of the current electromotor. Through the infrared remote control, the car can move forward, move back, turn left and turn right, based on the self-balancing. System chart is shown in Fig. 1.

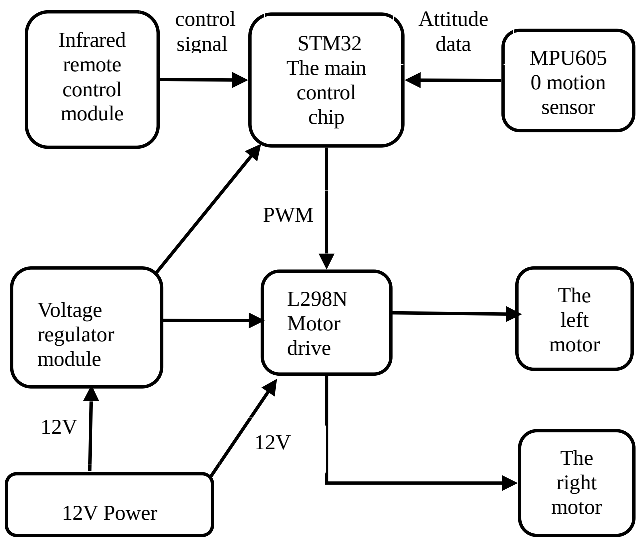

Fig. 1 System chart

Control chip: STM32F103C8T6 serves as the master control chip on this system. The core of STM32F103C8T6 is the high-performance ARM Cortex-M3 32-bit RISC core operating at a 72 MHz frequency, which can acquire real time data from MPU6050, and improve stability of the system. The devices offer three general purpose 16-bit plus one PWM timer, standard and advanced communication interfaces: two I2Cs, three USARTs.

MPU6050 motion sensor: MPU6050 motion sensor can measure the angle and acceleration. The MPU6050 is integrated 6-axis Motion Tracking device which combines a 3-axis gyroscope, 3-axis accelerometer. The MPU6050 features three 16-bits ADCs for digitizing outputs, which is advantageous to the processing, storage and transmission.

Infrared remote control module: We should use the timer to achieve the decoding communication between the infrared remote control device and STM32. The IRCP for these infrared remote control devices have the standard protocols, for example, NEC protocol and RC-5 protocol and so on. This system uses the NEC protocol. The NEC protocol uses pulse distance encoding of the bits. Each pulse is a 560µs long 38kHz carrier burst (about 21 cycles). A logical "1" takes 2.25ms to transmit, while a logical "0" is only half of that, being 1.125ms. The recommended carrier duty-cycle is 1/4 or 1/3. With this protocol the LSB is transmitted first. A message is started by a 9ms AGC burst, which was used to set the gain of the earlier IR receivers. This AGC burst is then followed by a 4.5ms space, which is then followed by the Address and Command. Address and Command are transmitted twice. The second time all bits are inverted and can be used for verification of the received message. The total transmission time is constant because every bit is repeated with its inverted length.

L298N motor driving module: L298N is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors, which has Two enable input, through four PWM to control two current electromotor.

Voltage regulator module: The voltage of battery is 12V, using LV7805CV and AMS1117 to get 3.3 V for STM32.

Electromotor: use JBG37-371 current electromotor, 143RPM.Rated voltage is 12V.

The implementation of system

B. Balancing algorithm chart

using the original data from gyroscope and accelerometer subtract the zero bias value respectively to process the data, we can get the original Angle and angular velocity ,using the Kalman filter algorithm to process the original data about angle and angular speed, we can get the optimal angle at that moment. The reference angle (set to 0 DEG) minus the current angle is dip angle, dip angle times Kp(from PID) is the value to control the PWM, depends on the PWM to control the speed of electromotor, and through the integral of speed to get the displacement of the car. The speed and the displacement times Kd and Ki respectively is the value to control the PWM. Finally, it become a closed-loop control system, it will be more stable. Balancing algorithm chart is shown in Fig. 2.

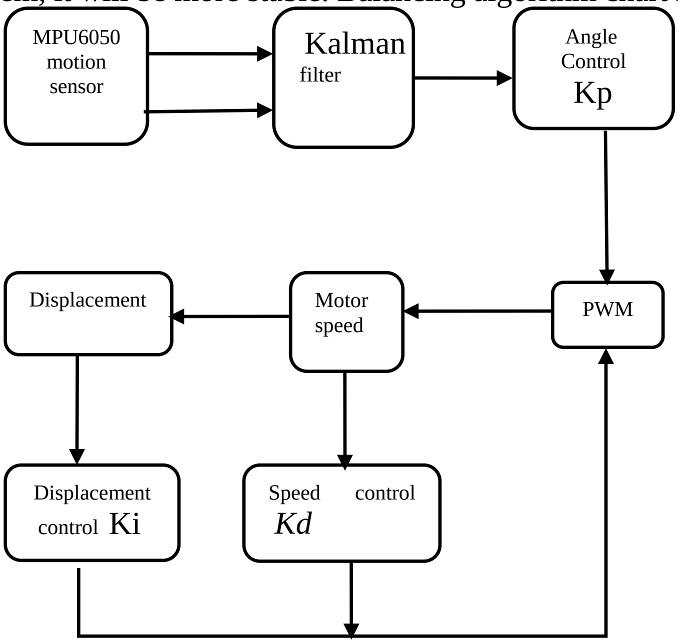

Fig. 2 Balancing algorithm chart

MPU6050 sensor calibration: system error exists in MPU6050. To reduce systemic error and improve the performance of the system, we should adjust MPU6050. Methods of calibration are as follows:

1) Keep still of MPU6050, record the data of 3-axis gyroscope, and write it into the program, to correct the zero bias value.
2) Place the sensor horizontally, let the X-axis perpendicular to the horizontal plane. This direction is positive direction. Record the maximum value of X-axis, and flip the sensor 180 degrees, place the sensor horizontal, let the X-axis perpendicular to the horizontal plane, This direction is negative direction. Record the minimum value of X-axis, add the maximum value and minimum value get the sum. we can get the compensation value through the sum divided by 2 . The method of Y-axis and Z-axis calibration is same like X-axis. Finally, we can use these values to correct the zero bias value.

Kalman filter algorithm: Kalman filtering is a kind of optimal estimation algorithm for the system state, which uses the linear system of equations of state and observes data by system input and system output to cut down the noise and interference among the data acquired at utmost. Taking the minimum mean-squared error for the best estimation standard, using the former estimated value and current acquisition value calculate the current state estimations. Algorithm is based on the system equation and observation equation to make estimation satisfying the minimum mean-squared error for the needed processing data. For this system, the controlled quantity of estimated value is the angular speed of the gyroscope output, and the measured value is the current speed of the accelerometer output. Then, making the optimal estimation for current angle, and the formula is as follow:

1) $X(k|k-1) = A*X(k-1|k-1) + B*U(k)$
2) $P(k|k-1) = A*P(k-1|k-1)*A'+Q$
3) $Kg(k) = P(k|k-1)*H'/(H*P(k|k-1)*H'+R)$
4) $\mathrm{X(k|k)} = X(k|k-1) + Kg(k)*(Z(k) - H*X(k|k-1))$
5) $P(k|k) = (I - Kg(k)*H)*P(k|k-1)$

On the formula, 1), 2) are prediction equation.3), 4), 5) are correction equation. $U(k)$ is control variable on system on K time. A and B are system parameter, H is a parameter on measurement system, Q is noise of system, R is the covariance of observation noise. $X(k-1|k-1)$ is the optimal estimate on last state. $X(k|k-1)$ is the last state's prediction value. $Kg(k)$ is Kalman gain.

$X(k|k)$ is the optimal estimate on K state. $P(k|k)$ is $X(k|k)$'s covariance. I is matrix of 1, for single module and single measurement I=1. $P(k|k-1)$'s initial value is unit matrix. In order to speed up the convergence, we can use test to make sure the value of $P(k|k-1)$, R depends on the variance of the angular speed and the variance of dip angle. The picture processed by Kalman filter algorithm is on the Fig. 3.

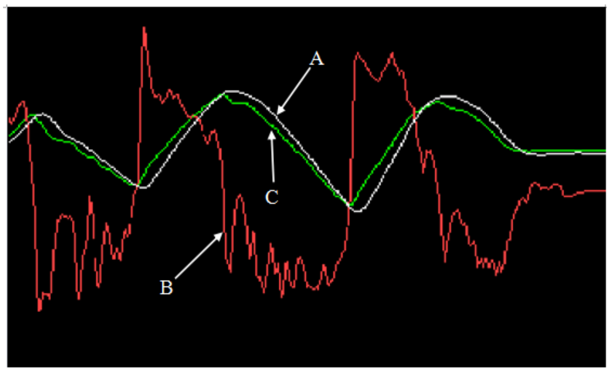

Fig. 3 Kalman filter algorithm processing picture

PID algorithm: Proportion, Integral and Differential are integrated by the linear combination, which become Controllable variables. We can control the controlled object though the variable. PID algorithm is the most widely algorithm in industrial control process at present. In this system, in order to improve the system's stability, the input of PID algorithm is the output of Kalman filtering which are deviation angle, speed of electromotor and displacement. Kp, Kd and Ki .The output is PWM. formula is as follow:

$$U(k) = Kp * e(k) + Ki * \sum_{s=0}^{k} e(s) + Kd * e(s) + Uo$$

Because the integral is displacement of speed, so we can write it as follow:

$$U(k) = Kp * e(k) + Ki * e(d) + Kd * e(s) + Uo$$

Kp is differential coefficient, $e(k)$ is deviation angle of input on simple time. Ki is integral coefficient. $e(d)$ is displacement. Kd is differential coefficient. $e(s)$ is speed, Uo is initial input value of system.

PID's parameters setting is debugging the value of Kp, Ki, Kd and the value of simple period. The essence of adjustment is to improve the dynamic and static indexes of the system, to get the high performance of control. On the system, First of all, we use the critical ratio method. Then, we use gather method to get the best value.

In this system, $Kp = 60$, $Ki = 0.02$, $Kd = 1$, $Uo = 87$ and the simple period is 0.01s. The change of car when it keep balancing is shown in form. 1.

form. 1 Parameter debugging data

Kp	Ki	Kd	Uo	System change
40	0.02	1	87	The speed of system response is getting slow, respinse of angle is getting huge.
80	0.02	1	87	System is overstrike,the car shake obviously.
60	0.01	1	87	System adjustment precision is getting reducing, the time of system response is getting slow.
60	0.03	1	87	Integral of System become saturation, shocking with limits.
60	0.02	0.5	87	The time of system response is getting slow, controllable angle is getting small.
60	0.02	0.5	87	The system starts to shake,the time to adjust is longer,reduce the anti-interference ability.
60	0.02	1	67	System need more time to response.

In our system, the programming language is as follows:

$speed\_motor = Kp * angle\_error + Ki * position + Kd * speed;$ In this system, no matter the inputs are displacement or speed, the essence is controlling the angle. Through the control of displacement, we can keep the car basically at the origin position, the error is within 3cm , When no infrared remote control signal. Through the control of speed, we can prevent the car go to the reference site, if the speed is too fast. This system improves the stability of the car.

Conclusions

This paper's research object is based on single-axis of two wheeled self balancing car, it is discussing about the design and the implementation of the algorithm. This system includes the hardware system (voltage regulator module, the drive module.etc) and balancing algorithm (Kalman filter algorithm, PID algorithm.etc).

The experimental results show that the system has good stability and flexibility, and the displacement doesn't exceed 3cm. The self-balancing two-wheel car can stably complete forward, backward, turning left and turning right when which receive the infrared remote control signal. This system adopts STM32, which is powerful and has fast processing speed. Kalman filter algorithm and PID algorithm can be quickly finished, because the STM32 improve the validity of data, and improve the system stability and anti-interference ability.

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