# Based on the research of self-balancing vehicle posture sensor system and design

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***Abstract: The main subject of this thesis is to study a single axis double, two-wheeled self-balancing vehicle system. The circuit part of this system is mainly composed of attitude sensors parts (including Gyroscope and Accelerometer), control circuit and the driver board. Firstly attitude sensors measure Car's tilt angle and the changing rate of Car's inclination, and then the controller calculates the appropriate data and instruction and finally drives the two DC motors forward or backward ,which produces forward or backward acceleration to make the model of cars remain dynamic balance.***

***Key words: Self- balance; Gyroscope; Acceleration; the PID***

Preface: In recent years, with the intensive study of human for robots, mobile robot applications become more extensive, but the working environment and tasks are more and more complicated, people have higher requirement for mobile robot, the robots often face some relatively narrow space, and there are a lot of big Angle of the working environment .Now It becomes a problem people concerned about that how robots work in this complex situation finishing task with high-efficient. Single axis double two-wheel self-balancing vehicle system concept is proposed in this case.

1. The mathematical modeling of the control system

To illustrate the control laws of balance models by single pendulum model, simple pendulum model as shown in figur1:

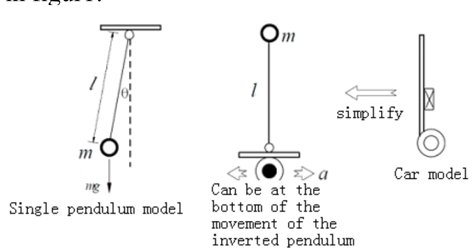


Figure 1: inverted pendulum model

The force analysis of ordinary inverted pendulum shows that when the object leaves equilibrium position due to force, restoring force will drove ordinary inverted pendulum back to the equilibrium position the size is: $F = -mg\sin\theta \approx -mg\theta$

Due to the tiny angular deflection, sine value equal to the Angle itself approximately, restoring force approximately is proportional to the size of offset Angle, but in the opposite direction.

Under the action of restoring force, the object do periodic simple pendulum, and objects are also influenced by air damping and air damping force is proportional to the speed of movement of the object, but the direction is in the opposite, the greater damping force, the greater long the pendulum stop in equilibrium position o, but if the damping force is too large, which will make objects being shaking.

The final summary pendulum can be stabilized in the vertical position with two factors: (1) by restoring force in the opposite direction of angle. (2) By the damping force in the opposite direction of speed

Assuming there is no damping force, objects will not stop and will always swinging. The final stable damping force will make the object in the vertical position. If damping force is too small the damping will make the pendulum swings back and forth near the equilibrium position, if the damping force is too large, damping can make simple pendulum to be balanced with longer time, so there is a critical damping coefficient, which makes the pendulum stop in the shortest time.

Comprehensive of the above analysis, self-balancing vehicle system is equivalent to a handstand pendulum, that is, inverted pendulum. and the self balancing system is not stable at the beginning when it deviates from the equilibrium position, because restoring force and displacement are in the same direction, thus restoring force will accelerate models of dumping.

In order to get restoring force in contrast to the direction of displacement, the models need to control two dc motors so as to make the whole car model done accelerating motion, then as a reference, the car model is equal to be influenced by the additional inertia force, this force, in contrast to the models of displacement, is equivalent to restoring force of inverted pendulum, size

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of: $F = mg\sin\theta - ma\cos\theta \approx mg\theta - mk_1\theta$

Because $\theta$ is very small in the practice, so it can be liberalized, if $k_1$ is greater than the gravitational acceleration, then the restoring force is in contrast to the models of displacement.

At the same time, in order to make models balanced in the vertical position as soon as possible, we also need to increase damping force for models, which is proportional to the speed of the deflection, and in the opposite direction, the so above formula can be turned into: $F = mg\theta - mk_1\theta - mk_2\theta'$

Therefore acceleration of models is as follows:

$a = k_1\theta + k_2\theta'$

In above formula, $\theta$ For models of the tilt Angle, $\theta'$ for the angular velocity, $k_1, k_2$ as the proportional coefficient. The control algorithm can guarantee $k_1 > g, k_2 > 0$ so as to guarantee upright models. In these parameters, $k_1$ decides that model is able to stabilize the equilibrium position, $k_2$ determines response time of stability at the equilibrium position, inclination angle and angular velocity models can be measured by attitude sensor.

## 2. The hardware design

Hardware of self-balancing vehicle system includes: attitude sensor module, a speed detection module and single-chip computer MC9S12XS128 module, voltage conversion module, motor drive module, the mechanical structure of the models. Elaborate the self-balancing vehicle system respectively from the following several modules in this paper.

### 2.1 The sensor

Attitude sensor is the main choice of acceleration sensor MMA7260 and produced by Honda ENC - 03 series of angular velocity sensor, position sensor output signal, after some processing the signal gets into A/D interface of the single chip microcomputer so as to do A/D conversion, eventually transformed into perspective.

### 2.2 The speed testing module

Speed detection module uses with the encoder.

### 2.3 The controller

The controller is MC9S12XS128 module, XS128 controller is rich in functional module, system use 4-way output PWM to control of dc motor, line 2 A/D conversion to collect data of module of acceleration sensor, gyroscope sensor, one USART to realize communication with MCU and PC, another USART just uses to communicate with MCU. In addition, we can use multiple I/O port for auxiliary debug module. For example, display module, buzzer module, keys module, dial the code switch module and so on

### 2.4 voltage regulator module

Voltage conversion module mainly uses TPS7350 as 5 V voltage chip, Input voltage range of TPS7350 is larger, at the same time has the protection of overheated, over-current and reverse connect voltage, when output current is 150 ma, the difference of voltage is very small just about 0.1 V. Therefore particularly select TPS7350 as system voltage chip, LM2940 chips as backup voltage chip for power system.

### 2.5 motor driver module.

MC33886 is whole bridge driver chip for motor the current top 5 a, calorific value is bigger. BTS7960 is half bridge driver chip, that is to say, it needs 2 chip to drive a motor with highest current 43 the whose internal resistance is small, so the heat dissipation is not very good, because determined by the parameter of group B dc motor, L298N or BTS7960 can be chose for motor driver chip.

## 3. The software design

Software module automatic balancing system is mainly composed of various functional initialization module data processing .module and the algorithm module. The following describes each module.

### 3.1 initialization module

Initialization module mainly includes A/D conversion, PWM, ECT, pulse trapping and PIT, common I/O module, etc.

### 3.2 data processing module

According to hardware output waveform in the sensors, we can see that the noise of output data of attitude sensors is more serious due to the defects of attitude sensor and system causes, so firstly we should do median value filtering to output signal of attitude sensors ,that is, remove to the maximum and minimum values, and then take the remaining value of average value .After median filtering, we also should fusion the gesture sensor data, then the data is stable, most noise be filtered out. After fusion data is the actual tilt Angle of models α, after PD operation it can be a signal upright, shown in the figure 2 diagram below, the specific procedures implementation of code as shown below:

Used in the scheme is a method of accelerometer and gyro sensor fusion through the angle to acquisition inclined angle and angular velocity of models, the two proportional coefficient control motor- driving voltage so that the model generates the corresponding acceleration and maintain models upright, in this scheme, it needs to ensure that the gravity acceleration sensor mounted perpendicular axis and the models of Z erect strictly maintain vertical, In actual if there is deviation control models which are not strictly vertical with the ground, but have a certain inclination angle, under the action of gravity

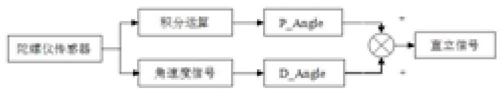


Figure 2 vertical signal controls

Models will speed along one direction, in order to keep the models static or uniform motion in a straight line, it need to eliminate the error of the installation, mechanical adjustment is needed in the actual process control and good parameters design for software, and it also need to speed control in the design of software so as to realize the speed stability. Compared with ordinary car model of speed control, self balancing car models of the speed control is relatively trouble, because the ordinary car speed control can be directly by controlling the duty ratio to get the desired result, but the balance of the car's speed control is based on the models under the premise of upright, the models of the speed control must always maintain models upright, so the self-balancing vehicle speed control system cannot be changed by direct motor speed to achieve, the first to analyze the factors of the change of the speed of car model.

First of all, we assume that the models have been able to keep balance under the Angle control, but due to installation error of the sensor measurement of Angle, it has some deviation of the Angle of the models so that no car model is vertical to the ground, due to the action of gravity models will speed up along the dip direction. It may draw a conclusion from this: as long as to control the tilt Angle of models can control the speed of the car model, the specific implementation need to address the following three questions: (1) how to measure the speed of the car model: models movement speed can be got by the encoder installed on the motor output shaft, which uses single chip microcomputer interface to external interrupt or dedicated pulse capture interface to capture the signal on the encoder, the speed of the pulse signal can reflect the actual speed of the machine in fixed time. (2) how to control models of the tilt Angle through erect models of signal: on the basis of the models of vertical Angle control, given models of vertical control set point, the car will automatically remain at an Angle, we can know models of the tilt Angle is to track the acceleration of gravity point of view by models of vertical control algorithm, (3) How to control models of the tilt Angle according to the control models of the velocity error: To control the tilt Angle of models is a difficult problem through the error of speed. Hypothesis models began to remain static, and then increase the given speed, therefore it need car model to lean forward certain Angle in order to get the acceleration. In models of vertical control in order to be able to have a forward tilt Angle, the wheels need to backward movement, so the speed of the wheel will decline. Negative feedback makes models forward Angle is bigger so that models will eventually fall in cycle. In order to get relatively stable control system, through a series of theoretical analysis and derivation of the mathematical model, finally itwill plan to do the following adjustment, first of all, for the above control scheme for the velocity error without integral control, the final differential static will not eliminate, the final speed is not strictly equal to the given value, in order to eliminate this error, the quantitative models of Angle Introduces direct integral compensation in the Angle control so as to eliminate control error. The second point, because joined the speed control, drift of gyroscope and accelerometer and errors can be compensated.

### 3.3 The PID algorithm module

PID controller mainly includes the proportion, integral and differential part: The following are the three parts of the regulating function.(1) Adjustment of the proportion (P)

System once appeared deviation, proportional part immediately adjust action to reduce the system deviation. In adjustment process, the greater the scale a parameter, the greater the system adjustment, so it responds more quickly so as to speed up the adjustment, proportional control action can reduce the system steady-state error but cannot eliminate the error. Excessive proportion coefficient will make the system being shaking, and even not stable, therefore parameters should be choose appropriately in PID control system. (2) The adjustment of integral part (I).

The integral element in the control system can eliminate the steady-state error of the system so as to improve the system of differential degrees, in the process of regulation, as long as there is system error, integral element will come into and doesn’t stop until the system error is zero. Then the integral output constant. (3)The adjustment of differential link (D)

Differential link reflect the rate of change of system deviation with advance and foresight to meet the change trend of deviation, so the differential regulation can produce adjustment in advance, before it did not produce deviation, differential link has been eliminated, thus it can improve the dynamic performance of system. In differential link parameters choosing the appropriate cases can reduce the system's overshoot volume, and reduce the adjusting time of the system.

Angle of PID parameter mainly includes the proportional and differential, proportion () parameter is equivalent to the restoring force of inverted pendulum, this parameter can only produce the desired effect when it is greater than the gravitational acceleration G, and models stay upright position in the end. In the process of adjustment, models appear to swing back and forth with the increase of scale parameter, and this kind of phenomenon is more and more big. Differential () parameters is equivalent to damping force of inverted pendulum, in the process of adjustment, it can eliminate the motion of the car model, when the differential parameters increase volatility may cause car model self shaking. This is mainly because the car itself is a non rigid body, and has a certain resonance frequency, as the differential effect when they make the models in the motor vehicle under the drive of resonance.

Speed control parameter mainly includes the proportion coefficient () and differential coefficient (), and these two parameters is for feedback speed of models. Proportional parameter determined that the ability of system restrains velocity error, but the speed control only with a proportional control models would have a double integral negative feedback control, the first integral is the integral error, the second is models of Angle control acceleration integral, such models can produce shock phenomenon, differential control aim at eliminating the phenomenon of the oscillation. In adjusting speed control parameter, The given value of speed control loop should set to zero , and adjust the proportion coefficient firstly and then differential coefficient in the adjustment process parameters, the only proportion coefficient link can make control models' movement back and forth at one point, and then combined with differential link, such models can still in the balance soon, gradually increasing the proportional and differential parameters can ensure that models have a certain anti-interference ability.

## 4. Programming and debugging environment

### 4.1 programming environment

CodeWarrior Development Studio (Studio) is used for programming applications in hardware which is a relatively complete integrated Development environment. It is a commercial software tools with independent research and Development of Free scale company for Free scale MCU and DSP embedded application, its function is very powerful due to using CodeWarrior IDE , developers can benefit from using a variety of processors and platforms (from Motorola to TI to Intel) between the general functionality. According to Gartner Dataquest' reports, CodeWarrior compiler and debugger in the commercial usage of the embedded software development tools are at ranking. And this is only two of popular CodeWarrior software development tools. CodeWarrior includes IDE, compiler, debugger, editor, linker, and assembler to build platforms and applications required for almost all the major tools. In addition, the developers can also add their favorite tools according to their habit in CodeWarrior IDE so as to work in their way freely.

### 4.2 program debugging

Downloader access to interface of BDM, and the corresponding interface should connected to the PC and single chip microcomputer, electric and refresh the program to MCU, of course, don't power off at this point, also don't disconnect BDM interface, click the run button, then debugging, debugging this system mainly includes the following modules: (1) Simple observation should be given to the sensor output signal of system. Posture sensor used in this system belongs to sensors with the micro mechanical structure, so it cannot afford the larger impact, in order to safe and reliable operation, before the system starts, it should do preliminary observation to output data of posture sensor, if the output data is right, we can started, system. (2) Variables of posture sensor data fusion: at the same time in the observed acceleration sensor and gyro output sensors, observing data output attitude sensor fusion, as it relates to the control part of angles. (3) The values of register controlling the duty ratio: control the duty ratio value from two aspects, one is vertical signal of Angle control, second, the speed control signal, the stack of both is the signal of control the duty ratio. (4) The value of a assist variable: sometimes we need to know systems' running state in the process of debugging, that is to say, where the program is running, it probably need to define some temporary variables to observe running status, because sometimes we don't know whether the program to run according to the way we imagine, now using temporary variables methods can have twice the result with half the effort.

## 5. Conclusion

Self-balancing vehicle system is based on MC9SXS128 series MCU embedded system design, encountering many problems in hardware circuit debugging process, we are mostly with a conclusion after theoretical analysis as the basis of debugging in the process of debugging so as to get a good effect.

The part of control algorithm in the system mainly uses the median value filtering data technology and complementary filter technology, vertical control and speed control of PID control.

In general, hardware is the foundation of the software: the software is the upgrade of hardware. I believe that this design experience for the future development will be a big help. Actual proof, self-balancing system behavior and rocket flight and self-balancing robot has a lot of similarity, therefore, the study of self balancing system is of great theoretical significance and practical significance.

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