Design and Implementation of a Multifunctional Self-balancing Mobile Platform

HAN Ying[1], GAO Yang[1], HUANG Lan[2], LUAN Yunbo[2]

1. Northeastern University, School of information engineering and science, Shenyang, 110004
E-mail: 512525750@qq.com

2. Northeastern University, School of Mechanical Engineering & Automation; Shenyang, 110004

E-mail: 306507690@qq.com

Abstract: A multifunctional self-balancing mobile platform is designed and implemented based on the inverted pendulum model and the theory of inertial navigation platform, which could carry both people and objects. Through the establishment and analysis of its motion equation, put forward the specific control scheme of the self-balancing mobile platform. Realize the platform angle, speed, direction control by feedback circuit. At the same time, the platform equipped with a comfortable human body mechanics saddle chair and a display screens which could output real-time motion parameters of the platform. By using WiFi remote control, realized the intelligent automation control. The platform is flexible, convenient, stable and reliable. It's also simple operational, environment-friendly. The platform can be used for daily short journeys, handling everyday objects, carry professional photographic equipment, realize the smooth track shoot. After adding intelligent sensor and processor, it can be used as the basic platform of two-wheels self-balancing service robot. Included nine axis of gyroscope, the platform can monitoring robot posture as an assistant controller of the robot.

Key Words: Intelligent Automation, Feedback Control, Self-balancing, Mobile Platform, Inverted Pendulum

1 INTRODUCTION

In recent years, with the deepening of wheeled mobile robot research and the increasing diversification of the way people traveling, two-wheeled self-balancing vehicle has gradually become a new means of transport which has been widely favored. However, the current two-wheeled self-balancing vehicle on the market mostly has single function and some other problems, such as can't run smooth enough, not easy enough to use and so on.

This paper presents a multifunctional self-balancing mobile platform, using WiFi remote control, so that users can control the distant mobile platform to reach the designated location. An ergonomic liftable saddle chairs which make users more comfortable is installed on the platform. Self-balancing platform using gravity to control its moving forward and backward. Platform also equipped with a real-time display to output motion state, so that drivers can know the battery charge and walking speed easily and directly. Platform can not only carry people and load goods as a vehicles, but also could equipped with pan-tilt and other professional photographic equipment as chassis. Meanwhile, the mobile platform is also the basis of two-wheeled self-balancing service robot, and then , it can be set to navigation robot after adding the intelligent sensor and processor. Above all, it has a wide range of applications[1].

Multifunctional self-balancing mobile platform designed in this paper has a light weight, small floor area, low energy consumption, flexible steering, free movement and other significant advantages, so it can be widely used in traffic travel, shopping malls laden, workshop transportation, tracking shooting and other related occasions[2].

2 STRUCTURE DESIGN

Structural design of the mobile platform in a flexible and lightweight criterion. On the basis of flexible move, easy to control and other basic requirements, we strive to simplify the structure, make its body lightweight and appearance attractive.

2.1 The Choice of Components and Parts

The structural design of the platform selected a number of cost-effective components to reduce costs.

In power plant, we chose 36V 350w DC motor which used for electric bicycle commonly. It has high reliability and can reach the required speed under certain bearing[3]. 36V 20Ah lithium battery was used which has large capacity, long life and strong endurance[4]. 16-inch wheels was chosen as driver on both sides to improve the appearance and obstacle crossing ability of the platform.

Aluminum square tube which is common on the market welded together the main body of platform, and platform around was welded or use bolt to fix high strength aluminum alloy plate. The main structure is more robust and reliable.

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2.2 Assembly Scheme

Ensuring simple and beautiful premise, how to assembly these larger components is the next problem to be solved.

As is shown in Figure 1, the two motors are installed on both sides of the platform symmetrically. They are fixed on the platform skeleton using flanges of the motors. The large size, heavy weight lithium batteries is set on the front of the platform, and it's balanced with the motors on the rear in weight. It's conducive to maintain self-balancing of the platform. For the 16-inch wheels, we installed it on the both ends of the axleuse using its own bearings, and the wheel can rotate around axis freely. In order to provide power for the platform, we replaced the disc brakes with spur gear whose thickness is 10mm, the number of teeth is 90, modulus of 1.5. There are three mounting holes on the spur gear, matching with disc brakes mounting hole on the wheel, and then tighten the countersunk screw to complete the installation.

Four mounting holes is uniformly distributed on the upper plane of connecting frame which used for installing the saddle chair, and each of the four corners distribute a mounting hole. There are eight mounting holes totally, so we can make it more firmly fixed; when installing three degrees of freedom adjustable pan-tilt, we need just the middle four mounting holes.

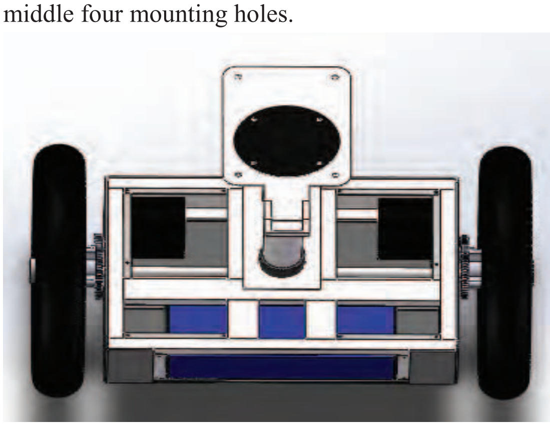

Fig 1. Assembling sketch. Assembly these larger components together ensuring simple and beautiful premise.

3 HARDWARE DESIGN

Hardware circuit diagram of the system is shown in Figure 2. The system is mainly composed of main control chip and sensors.

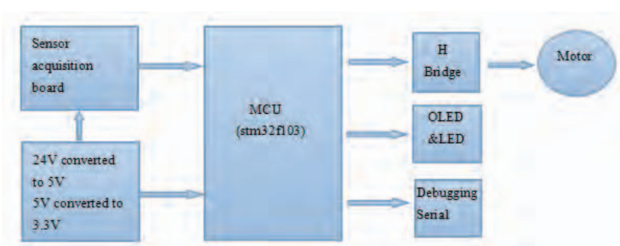

Fig 2. Hardware circuit diagram of the system. The system is mainly composed of main control chip and sensors.

3.1 Chip Module

Mobile platform realizes its function based on the closed loop control of motor and related sensors, we used the following modules to control the platform motion[5].

Table 1. Each module distribution

AD Conversion Interface	PWM Interface	Timer Interface	Communica -tion Interface	IO Interface
5 at least	4	2	standby	standby

3.1.1 AD Conversion Interface

- Electromagnetic detection: 2, using for two induction coil voltage measurements.
- Gyroscope: 2. One used for detecting tilt angular velocity, another for detecting rotation angular velocity.
- Accelerometers: 1, measuring acceleration in the Z-axis output voltage.
- Auxiliary for debugging (alternate): 1-3, using for setting and debugging.

3.1.2 PWM Interface

Control two electrodes run in both directions. As a result of unipolar PWM driving, you need four interfaces. If use bipolar PWM driving, you can use two-way.

3.1.3 Timer Interface

Measuring two motor speed, two timer pulse input port are needed.

3.1.4 Communication Interface

SCI(UART): 1, using for the program download and debug interface;

I2C(alternate): If you choose Freescale's digital accelerometer, you can read the acceleration directly through the I2C interface.

3.1.5 IO Interface

4-8, using for displaying running status, function settings. Among these interfaces, the sensors and gyroscopes measuring the gravitational acceleration and rotational speed can be omitted.

3.2 MCU Introduction

Main control chip uses ARM Cortex-M3 core stm32f103 chips manufactured by ST. Cortex-M3 is a 32-bit core, in the traditional areas of SCM, there are some applications different from the general-purpose 32-bit CPU. In the industrial field, the users require a faster interrupt, Cortex-M3 uses Tail-Chaining interrupt technology, a fully hardware-based interrupt handling, can reduce up to 12 clock cycles, in practical applications can reduce 70% interrupt.

Another feature is that debugging tool is cheap. For this feature, Cortex-M3 uses a new type of technology single-wire debug, a pin is used for debugging specifically, thus saving a lot of debugging tool costs. Meanwhile, Cortex-M3 also incorporates most of the memory controller, so that engineers can directly connect Flash outside the MCU, it reduces the design effort and application obstacles[6].

3.3 The Selection of Sensor

Taking stability of the application into account, we choose MPU-9250 9-axis sensor as a feedback regulator module. MPU-9250 is the second generation 9-axis sensor of InvenSense, which is the combination of 6-axis inertial measurement unit (gyroscope + accelerometer) and 3-axis magnetometer integrated 3 mm × 3 mm QFN package. The area is reduced by 45% compared to the previous generation.

Reducing of package size thanks to 3-axis gyroscope chip design, the InvenSense previous generation gyroscope's three sensing axis using three different structural design, and now uses a single structure gyroscope design. This new design allows the gyroscope size reduction of 40%. In addition, Nasiri process has changed: In the past, in order to ensure the MEMS structure movement, usually etched cavities in ASIC chip, but now do not need this step resulting in lower costs.

MPU-9250 integrated AKM magnetometer AK8963, compared with the previous generation, size reduction of 40%, the sensitivity increased, reaching 0.15μT / LSB.

4 WORKING PRINCIPLE

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4.1 Platform Balance Control

Platform balance control is achieved by negative feedback. Controlling wheel rotation and offsetting incline trend in one dimension can keep body balance[7]. The control process shown in Figure 3.

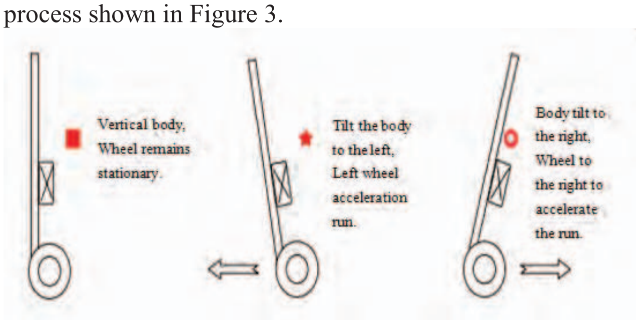

Fig 3. Platform balance control process. Controlling wheel rotation and offsetting incline trend in one dimension can keep body balance.

As is shown in Figure 4, assuming platform can be simplified into a pendulum, whose height is L, mass is m. It is placed on the driving wheels which can move around. Assuming the platform's angular acceleration caused by disturbance is x(t). Force analysis along the direction perpendicular to the chassis of platform, the motion equations among dip angle, driving wheel acceleration a(t) and the disturbance acceleration x(t) can be obtained.

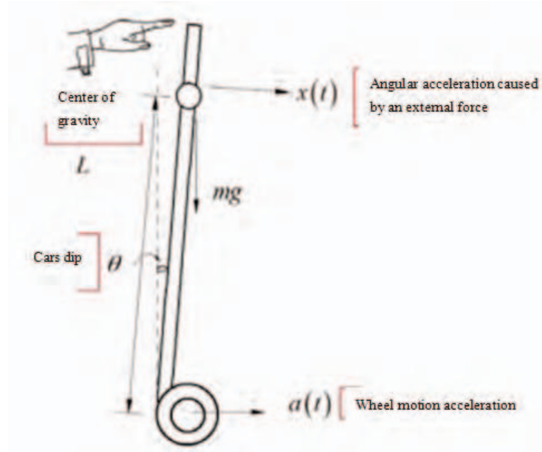

Fig 4. Platform can be simplified into a pendulum, whose height is L, mass is m.

motion equation:

$$L\frac{d^2\theta(t)}{dt^2} = g\sin[\theta(t)] - a(t)\cos[\theta(t)] + Lx(t) \quad (1)$$

when the angle θ is small, simplified motion equations:

$$L\frac{d^2\theta(t)}{dt^2} = g\theta(t) - a(t) + Lx(t) \quad (2)$$

when the platform is motionless:

$$a(t) = 0 \quad (3)$$

$$L\frac{d^2\theta(t)}{dt^2} = g\theta(t) + Lx(t) \quad (4)$$

In the angle feedback control, a control amount in proportion to the angle is called proportional control; a control amount in proportion to the angular velocity is called derivative control. Therefore, the above coefficients are known as proportional and derivative control parameters. Differential parameters is equivalent to the damping force which can restrain platform shocks effectively. The idea that control shocks through differential inhibitory also applies in the speed and direction control.

Summary the conditions that control platform upright and stable as follows:

(1)Measure the size of the dip angle and the angular velocity accurately;

(2) Control the driving wheel acceleration;

(3) Platform direction control can be realized by the motor differential speed control.

4.2 Platform Speed Control

Compared with the speed control of common platform, For controlling the phase velocity of the upright platform common platform for the speed control is more complex. Since the speed control process needs to always maintain balance of the platform, the platform and therefore the speed control can not directly be achieved by changing the motor speed. Details are as follows.

4.2.1 Measure Platform Speed

By installing the optical encoder on the motor output shaft, we can measure platform driving wheel speed. Measuring the number of velocity pulse signal during a fixed time interval the counter which control microcontroller, it can reflect the motor speed.

4.2.2 Through the platform of Vertical Control Realize the Change of Platform Angle

Given platform upright control set point, the platform will automatically maintained at an angle under the angle control adjusting. By upright control algorithm, we can know that the platform's dip angle eventually track the angle of Z-axis. Therefore, subtract the given the dip angle of the platform and the Z-axis angle, the final dip angle of the platform can be decided. Control flow is shown in Figure 5.

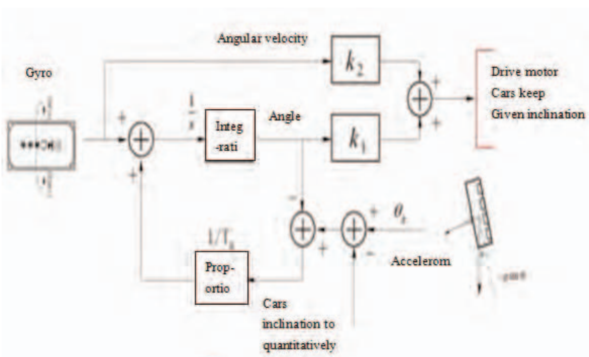

Fig 5. Control flow. Given platform upright control set point, the platform will automatically maintained at an angle under the angle control adjusting.

4.2.3 Control Platform Angle According to the Velocity Error

To simplify the analysis, we ignored the platform speed changes caused due to the dip angle control. The final speed of the platform is decided by the acceleration which dip angle generated, therefore the speed of platform can be obtained by integrating the dip angle.

4.3 Platform Direction Control

4.3.1 Motor's Differential Control

The use of magnet wire deviation detection signals and speed control signals addition and subtraction, forming left and right wheel differential control voltage. It makes the platform left and right wheel have different angular velocity, and then control the direction of the platform.

4.3.2 Direction Control Algorithm

Directional control algorithm forms motor differential control through testing electromagnetic induction voltage. The platform's turning is driven by the difference between the left and right motor speed, eliminating the deviation of platform distances from the center of the road. By adjusting the direction of the platform, coupled with the front-line motion, difference between the platform away from the centerline distance can be gradually eliminated. This process is an integral process, therefore the platform differential control usually require only a simple proportional control to control direction of the platform.

However, due to the platform itself is installed batteries and other relatively heavy objects with a great moment of inertia. There are always platform shift overshoot in the adjustment process, it will make the platform out of the way if unchecked. According to the previous experience of the angle and speed control, in order to eliminate the overshoot in the platform direction control, the differential control need to be added.

Differential control is correcting motor differential control amount according to the platform direction change rate, and therefore we need to add the rotational speed detecting sensor. Gyroscope sensor can be used.

4.4 The related software function

(1) Computing platform dip angle function. Computing platform angle and angular velocity based on the angle values collected by gyroscopes and gravitational acceleration sensor. If this part of the algorithm realized by an external operational amplifier, then the resulting collection is platform angle and angular velocity, and this part of the algorithm can be omitted. This function is called once every 10 milliseconds.

(2) Platform upright control functions. Calculate motor control amount based on the angle and the angular velocity of the platform. This function is called once every 10 milliseconds.

(3) Platform speed control function. Calculate the motor control amount according to the motor speed and the speed setting value which collected by platform. This function is called once every 100 milliseconds.

(4) Speed output smoothing function. As the speed is calculated once every 100 milliseconds, in order to make speed control more smoothly, the function allocate the change of speed output amount averagely to the 20 steps 5 ms control period.

(5) Direction control function. According to the numerical value platform collected about two electromagnetic sensors to calculate the amount of the angle control. This function is called once every 10 milliseconds.

(6) Direction control function output smooth function. Allocate the change of direction output amount averagely to the 2 steps 10 ms control period.

(7) Motor output collection function. According to the foregoing upright control, speed control and direction

control, the control amount obtained is superimposed, and then obtain output voltage control amount of the left and right two electrodes respectively. Saturate the superimposed output account. Function calling period is 10 milliseconds.

(8) PWM motor output calculation functions. According to the polarity of the left and right electrodes' output control amount, superposition of a small dead zone value to overcome the mechanical static friction force of platform. Function calling period is 10 milliseconds.

(9) PWM output function: Calculate value of the PWM control register according to the two motors' output. Set the value of the four PWM control register. Function calling period is 1 milliseconds.

5 PLATFORM'S APPLICATION

As mentioned earlier, multifunctional self-balancing mobile platform has the advantages of stable, reliable, flexible and convenient, simple manipulation, clean environmental protection, so it has a wide application prospect, mainly includes the following aspects[8].

(1) Walking: Mobile platform is flexible and convenient, it can enter the elevator and run on the small slope. It has less noise, so it's suitable for schools, parks, shopping malls, golf courses, aquarium, library, office buildings, amusement park and other places. Speed up to 20 km/h, it also can be used for short trips, going to work or school, supermarket shopping, outdoor filming and junketing.

Platform can be easily applied to work and entertainment, such as mobile shooting, product marketing, circus, reality games.

Fig 6. Platform walking. Mobile platform is flexible and convenient, it can enter the elevator and run on the small slope.

(2) Loading: Platform supports WiFi control remotely, users can operate its movement freely, so we can make it reach the designated position to complete the task. Platform can be used in the supermarket shopping, carrying books, documents, sorting boxes, etc.

(3) Professional photography: As is shown in Figure 7, the platform can carry three degrees of freedom adjustable pan-tilt. Professional photographic equipment fixed on it, which can realize remote control and tracking shoot[9].

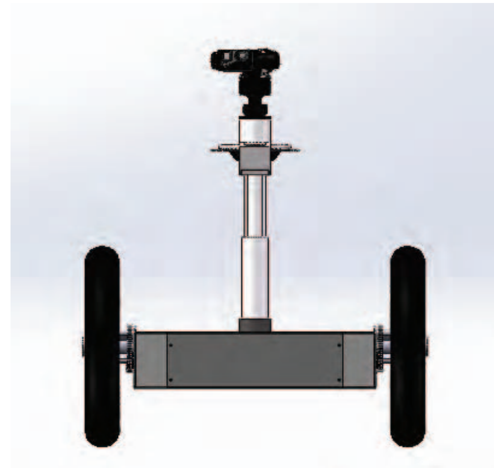

Fig 7. Platform carrying photographic equipment. Platform can carry three degrees of freedom adjustable pan-tilt.

(4) Robot chassis: For some robots which need to flexible movement, the platform can provide chassis. Its own nine axis of gyroscope can monitor the robot real-time posture to help control the robot.

6 CONCLUSIONS

In this paper, a multifunctional self-balancing mobile platform was introduced in terms of the platform assembly, hardware design, working principle, applications field. It has high practicability in passenger travel, loading transportation, professional photography, remote control and other occasions. In conclusion, it's a new type mutifunctional mobile platform of high availability.

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