Design of an Omni-directional Spherical Robot: Using Fuzzy Control

Ya-Fu Peng, Chih-Hui Chiu, Wen-Ru Tsai, and Ming-Hung Chou

Abstract-**In this study, an omni-directional spherical mobile robot is implemented. The key feature of this robot is it can move directly in any direction with no constraint. In order to control such a spherical robot, a fuzzy controller is proposed. The major advantage of the proposed fuzzy controller is it can deal with the unknown nonlinearities and external disturbances. Finally, the experimental results demonstrate the good performance of the whole control system.**

***Index Terms*— Omni-directional spherical mobile robot, fuzzy control**

I. Introduction

In the past years, mobile robot system control has received many attention and lots of significant developments have been proposed. The robot system is high nonlinearity that is usually unknown and time varying, and it also has many uncertainty terms in its dynamic, such as friction, payload variation, and disturbance. It is difficult to establish an exact mathematical model for the design of a model-based control system. To dealing with such an unknown nonlinearities and external disturbances, many control strategies have been proposed, including sliding-model control, adaptive control, and intelligent control.

Recently, the balance control of one-wheeled and two-wheeled platforms have been developed in robotic locomotion. Its features include compact size, light and portable, lower power consumption and convenient and suitable for traversing narrow spaces. The two-wheeled robot [1] and one-wheeled robot [2] have been demonstrated already. Such a wheeled robot balances in the forward and backward directions by moving the wheels.

There are many similar researches in the filed of wheeled mobile robot such as JOE [3], Segway [4], the Personal riding-type wheeled Mobile Platform (PMP) [5] and RMP [6]…etc. Segway is a transporter consists only of two wheels and a steering handle. The motion control of Segway likes a wheeled inverted pendulum by moving the wheels in the forward and backward directions. RMP is developed based on Segway. In 2005, PMP-2 was proposed in Japan [7] and it has only two wheels and standing platform without steering handle on it. Such a vehicle has two advantages: a reduction in total weight through its simple structure and a space-saving design that does not use a steering unit. Although the wheeled mobile robot has many advantages, the wheeled robot cannot immediately turn in a given direction without re-direct the drive wheels. In order to overcome this drawback, an omni-directional vehicle (B.B. Rider) is proposed by Tokyo University in Japan [8]. The B.B. Rider moves by rolling a basketball and balancing on it. In [9], a similar research of an omni-directional spherical mobile robot system (Ballbot) is proposed at Carnegie Mellon University in America.

Because the wheel-based robot has some constraint in mechanism, they can not move around well. In this paper, we design and implement of an omni-directional spherical mobile robot control system. The mobile mechanism of spherical robot is different from the wheel-based one. The major advantage of this spherical robot is that can move for omni-directional with no constraint. It is obviously such a robot system is high nonlinearity and is always unknown. It is difficult to establish an exact mathematical model for the design of a model-based control system. To dealing with such an unknown nonlinearities and external disturbances, the technique of fuzzy logic control is introduced. The fuzzy logic control is a complete difference approach that does not require a precise mathematical model of the system. This control method is based on human experience to understand the behavior of the system. Thus, control design is simple than traditional one. Recent years, there have been many researches about the intelligent control for complex nonlinear system [10]-[19].

In this paper, we will propose a fuzzy logic self-dynamic controller for an omni-directional spherical mobile robot system. The fuzzy rules in fuzzy controller can be adjusted by user experience. So for the omni-directional spherical mobile robot, it is easily implementation by using fuzzy control technique. This system is designed around personal computer, and comprises some hardware components. Experimental results show that the present fuzzy self-dynamic controller with simple and intuitively understandable structure can control the whole system very well.

II. Spherical robot system

In this paper, the spherical mobile robot is composed

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of a metal platform carrying a 24V dc motor coupled to a gearbox for each axis, an I/O board used to connect the robot and personal computer, two driver circuits for the motors, several necessary sensors and filter circuit to measure the robot's states. The total weight of the robot is about 20Kg.

The mobile robot structure is shown in Fig.2.1 and Fig.2.2. In Fig. 2.1, we can see the body is supported by a drive ball.

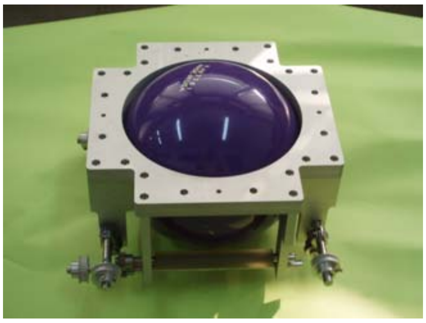


Fig.2.1 Mobile mechanism

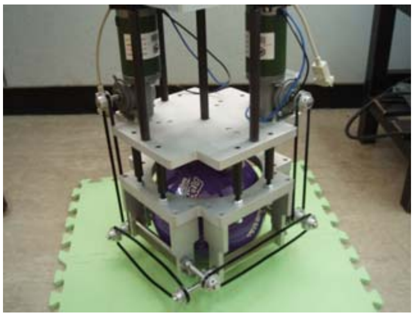
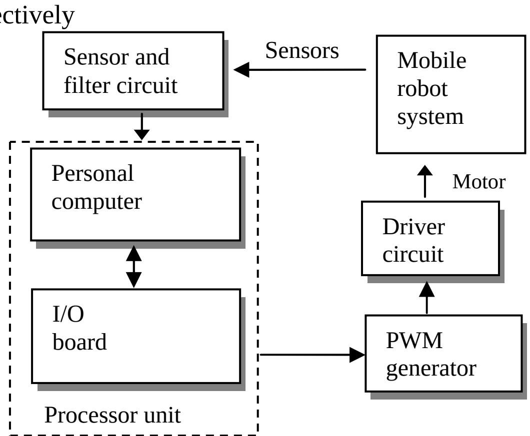
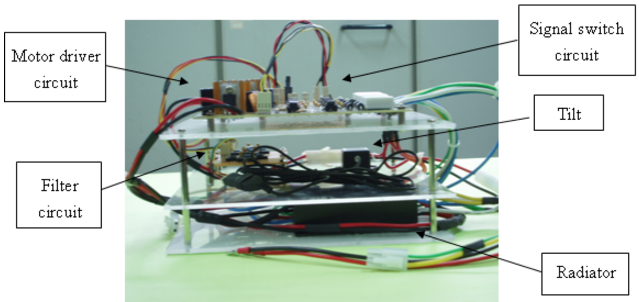


Fig.2.2 Body structure of robot system

Figure 2.3(a) is the hardware block diagram of the robot system. Control algorithms are executed in processor unit. A personal computer is the control center of the robot for signal processing and control algorithms. I/O board is the channel of the feedback signals from sensors and the command signals from computer. Sensors and filter circuit is used to catch the signals from inclinometer, gyro and two incremental encoders. H-bridge circuits are included in the driver circuit. The PWM (Pulse Width Modulation) signals from PWM generator are sent to driver circuit to deliver PWM power driving the motors. The hardware diagram and circuits shows in Fig.2.3(a) and Fig.2.3(b), respectively



(a)



(b)

Fig.2.3 The hardware diagram and key plan of circuits

III. Motion Control Strategy

This section introduces the motion control of spherical robot system. In this paper, the motion control of the x-axis and y-axis are controlled separately [12,13]. The swing range of body is $-90^{\circ} \sim +90^{\circ}$.

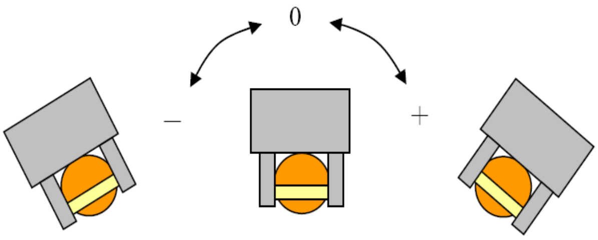


Fig.3.1 The diagrams of leaning back, standstill and leaning forward.

Here, we simply consider the whole system as an inverted pendulum on a ball (Fig. 3.1). By moving the ball back and forth, the body of the spherical mobile robot will keep balance. Then, the stable principle of the robot will be simply described. There are three cases needed to consider in the two-wheeled robot control system. First, if the body of the robot topples forward, move the wheels forward to balance the robot. Second, if the body topples backward, move the wheels back to keep robot balance. When the body of the robot is at the upright position, the robot is stable.

IV. Design of Fuzzy Controller

In this section, the stabilization fuzzy controller of the spherical mobile robot is described. Here, four state variables must be handled in order to cover the angular control and the position control. These four state variables are the error of position, error of angle, change rate of position error, and change rate of angle error. The output of this controller is the PWM (Pulse Width Modulation) command transmitted to DC motor. If we give five fuzzy sets for each input variable then there are 625 fuzzy rules in this fuzzy controller. It not only consumes a large amount of time to compute the fuzzy implication but also we are hard to derive a set of rules and membership functions for this big fuzzy rule base. It is also difficult to implement by a single chip.

In order to simplify the fuzzy control rule base, we separate the stabilization fuzzy controller into two

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sub-controllers, one is for position control and the other is for angle control. Then the four-input variable system becomes two two-input variable systems. We call it as a double loop structure. The control scheme is shown below.

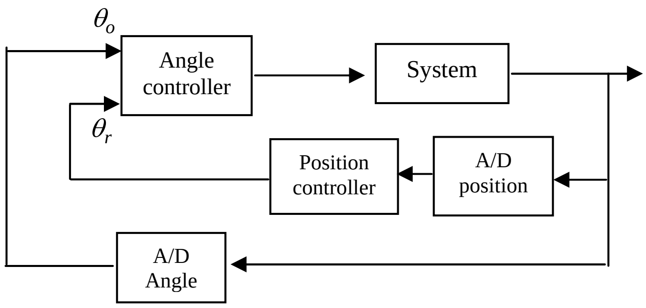

Fig.4.1 The control scheme of the stabilization controller

Now, we will explain this control system as follow. Let us consider this problem that we try to make the robot stand upright and set the position at set-point. First, we should move the robot away form the set-point in order to get a virtual angle on the direction to the set-point. Second, we must move the transporter to catch the virtual angle. Through such a moving process, we can make the robot stand upright and move it to the set-point gradually. So, we first generate a virtual angle from the position controller. We employ two premises and one consequence and overall 25 rules. The structure is shown below.

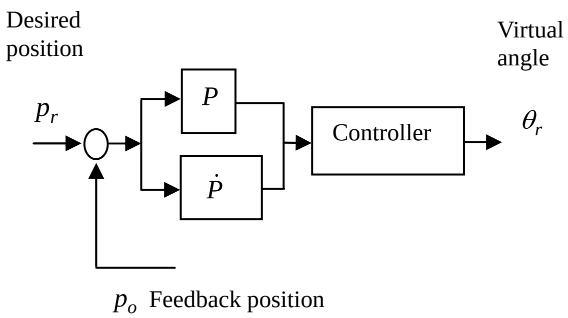

Fig. 4.2 The position controller

Table 1. The rule table of position controller

change rate of the position error $\dot{P}$ (columns); position error p (rows)

θ_r	NB	NS	ZO	PS	PB
NB	NVB	NB	PM	NS	ZO
NS	NB	NM	NS	ZO	PS
ZO	NM	NS	ZO	PS	PM
PS	NS	ZO	NS	NM	NB
PB	ZO	PS	PM	PB	PVB

When receiving the virtual angle, the angle controller should move the transporter to catch up the virtual angle in finite iterative loops. The angle controller has also 2 inputs and 1 output.

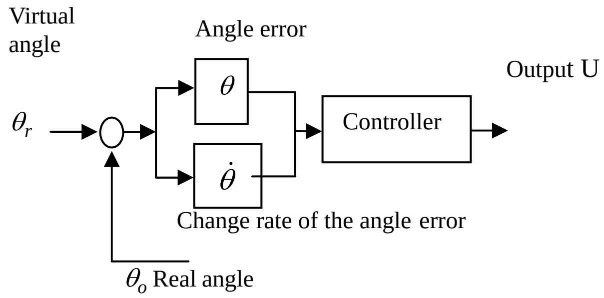

Fig. 4.3 The angle controller

Table 2. The rule table of angle controller

change rate of the angle error $\dot{\theta}$ (columns); angle error θ (rows)

U	NB	NS	ZO	PS	PB
NB	PVB	PB	PM	ZO	ZO
NS	PB	PM	PS	ZO	ZO
ZO	PM	PS	ZO	NS	NM
PS	ZO	ZO	NS	NM	NB
PB	ZO	ZO	NM	NB	NVB

Then, by simple fuzzy control theory, the desired result can obtain.

V. Experimental results

In the section, we will implement the spherical mobile using the effective proposed control scheme by several experiment results.

Balance control

First, we will keep the spherical robot standing upright at the original position.

Fig.5.1 shows the performance of spherical robot on the X-Y plane. Fig.5.2 shows the position trajectories of X and Y axes. Fig.5.3 shows the angle of body on the X-Y plane. The body angles of X and Y axes are shown in Fig.5.4.

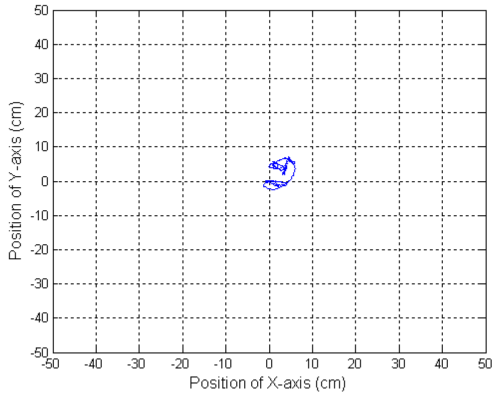

Fig. 5.1 The performance of the robot on the X-Y plane.

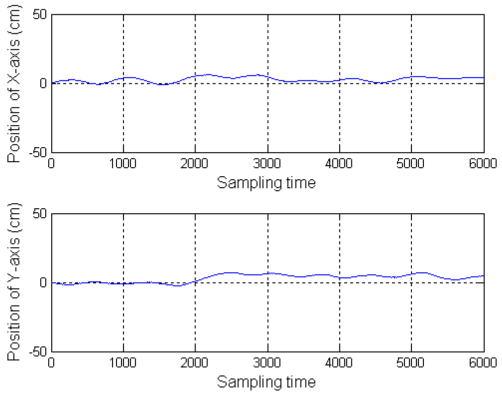

Fig.5.2 The position trajectories of X and Y axes.

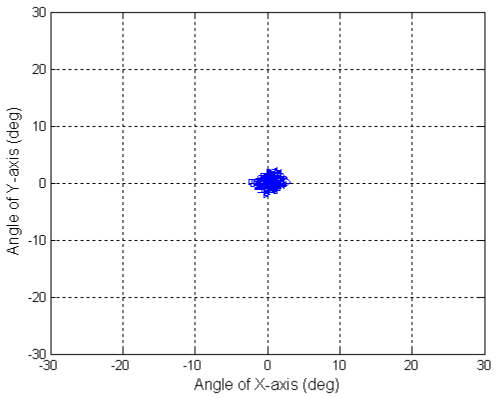

Fig. 5.3 Angle of the body on an X-Y plane.

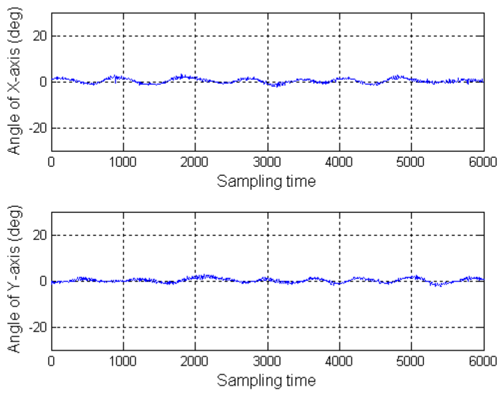

Fig.5.4 The angle trajectories of X and Y axes.

Give an external disturbance

In this case, the spherical robot is initially at the origin. Then, an external disturbance is added to the system.

Fig.5.5 shows the performance of spherical robot on the X-Y plane. Fig.5.6 shows the position trajectories of X and Y axes. Fig.5.7 shows the angle of body on the X-Y plane. Figure 5.8 shows the body angles of X and Y axes.

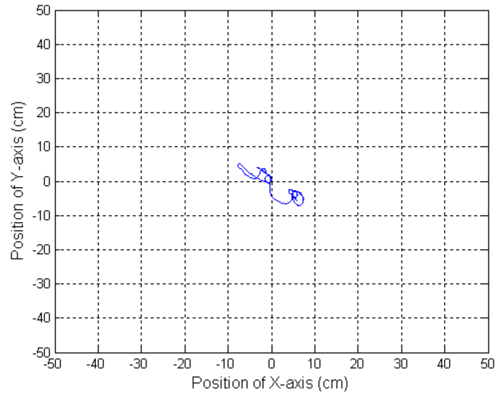

Fig. 5.5 The performance of the robot on an X-Y plane.

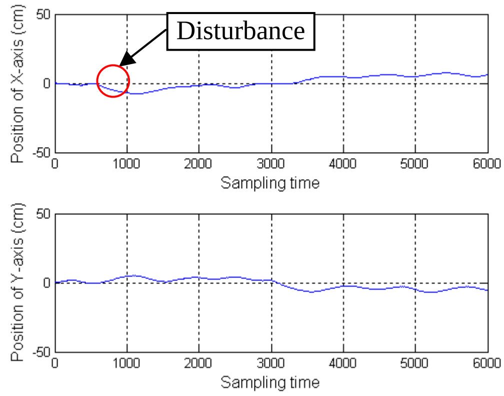

Fig. 5.6 The position trajectories of X and Y axes.

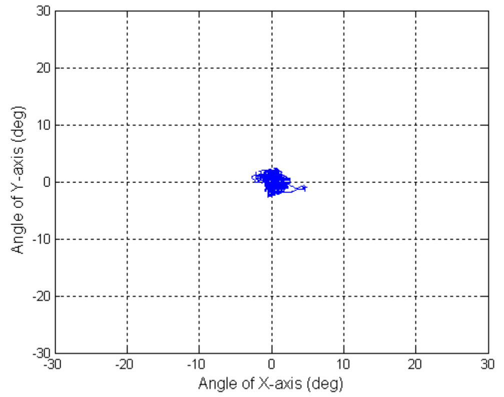

Fig. 5.7 Angle of the body on X-Y plane.

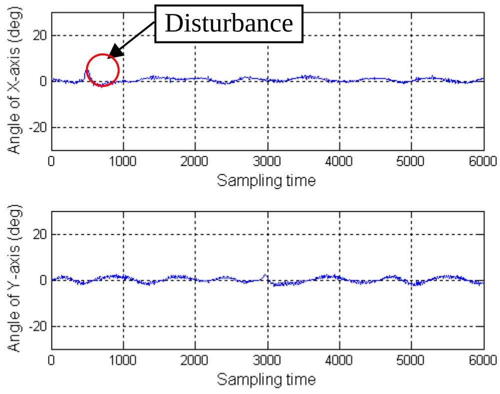

Fig. 5.8 The angle trajectories of X and Y axes.

Orientation

In this case, we will move the spherical robot from origin to the goal position. We chose the goal position is $(x, y) = (-30, 0)$ in this case.

Fig.5.7 shows the performance of spherical robot on the X-Y plane. Fig. 5.8 shows the position trajectories of X and Y axes. Fig. 5.9 shows the angle of body on the X-Y plane. The body angles of X and Y axes are shown in Fig. 5.10.

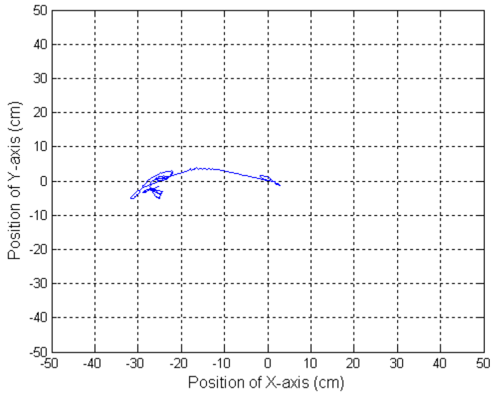

Fig. 5.7 The performance of the robot on an X-Y plane.

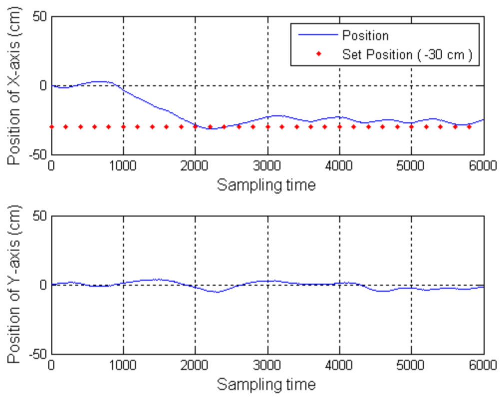

Fig. 5.8 The position trajectories of X and Y axes.

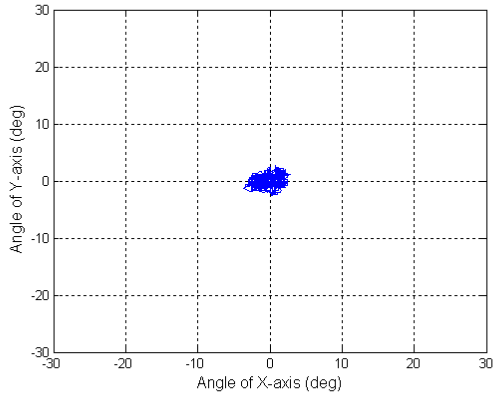

Fig. 5.9 The angle of the body on X-Y plane.

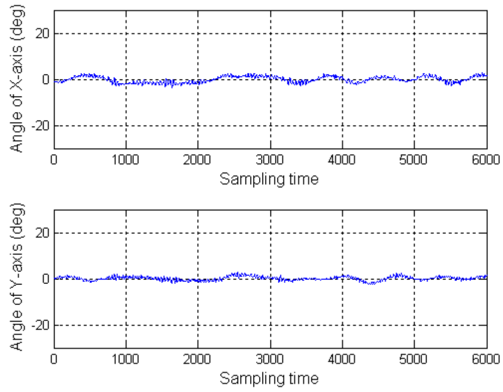

Fig. 5.10 The angle trajectories of X and Y axes.

VI. Conclusion

This study implemented successfully the omni-direction spherical mobile robot based on fuzzy control. The system is stabilized and controlled by a fuzzy controller at each axis. Finally, the experimental results show that the proposed control scheme can control the whole system well.

VII. Reference

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