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A Differential Steering Control with Proportional Controller for An Autonomous Mobile Robot

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Abstract—**In this paper, differential steering control with proportional controller method are developed. In the steering control of mobile robot, the underlying dynamics of processes are often highly complex due to operating problems such as actuator constrains, time delay and disturbances. Because of these reasons, many control system of mobile robots require extensive retuning the control parameter and the worst cases may result in redesigning or change the control program and hardware. To solve the above mentioned problems, we use proportional control method. Based on the model proportional control method, we predict the path that the mobile robot will follow by using the current velocities of the right wheel and the left wheel which update the real-time current position of mobile robot. The model proportional method is to overcome time delay cause by slow response of the sensor and other dynamic processes. The outputs from the control are the velocity and angular velocity of mobile robot. From these velocity and angular velocity of mobile robot we determine the number of encoder pulses for the right wheel and left wheel. The number of encoder pulses for the right wheel and left wheel are input to the right DC motor and to the left DC motor of mobile robot to generate the velocity of each wheel. The proportional controller is used to produce the same speed of the right wheel and the left wheel in order to make the mobile robot move in a straight line. It also used to produce the desired speed of the right wheel and left wheel for steering control to make left or right turning.**

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Keywords—***mobile robot, differential steering control, straight line, PID.***

I. INTRODUCTION

In 1995 about 700,000 robots were operating in industries around the world. Over 500,000 were used in Japan, about 12,000 in Western Europe and about 60,000 in United States [1]. Many robot applications are for dangerous, difficult and unpleasant tasks for human beings. In industries areas, robots are used for repetitive, monotonous tasks in which human performance might deteriorate over time. Robot can perform these repetitive, high-precision operation 24 hours in a day. A major user of robots in the automobile industries such as welding, painting, machine loading, parts transfer, carrier and assembly.

The large difficulty in the design of robots for other areas application, such as domestic environments, is uncertainty. In an area where humans move about, positions of things are bound to change. The variety of objects and obstacles that the robot will encounter become very numerous. In such circumstances, both sensing and control become more complex; as Latombe said [2]: "when knowledge at planning time is too incomplete, it may become necessary to interweave planning and execute in order to collect appropriate information through sensing." The term of "interweaving planning and execute" in this context is feedback control.

The trajectory straight line tracking control and steering control is essential for autonomous mobile robots such as guide robots, security robots, and office robots. As the demand increase for mobile robot in the application for the hospitals, warehouses and nuclear waste facilities, the need for precise stable target trajectory straight line tracking and turning control of mobile robots is clearly understand; hence, a closed-loop sensor based controller is required. In this paper, we purposed differential steering control with proportional controller to get a straight line tracking and precision turning of mobile robot. In the field of mobile robot control, many control schemes for stabilization and trajectory tracking problem have been proposed [3]. At the moment, many different methods to find parameters for suitable controllers exist [4]. The methods difference in complexity and flexibility. Depending on the application, there is a need to have several types of tuning method [3]. There are simple and easy methods to use which require little information [5] as well as more sophisticated methods which require more information and more computations [3].

II. MOBILE ROBOT

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A. Structure of Mobile Robot

Your In this experiment, we have developed a Nonholonomic Mobile Robot is shown in Figure 1. The mobile robot well suited at the Autonomous and Machine Vision System Laboratory at University Malaysia Perlis.

The mobile robot has two driving wheels powered by two independent DC motors located along the central axis, thus providing both drive and steering. Each DC motor is controlled by a PWM digital DAQ NI-USB 6212. At the front, a passive castor was installed for support. The castor wheel is not considered in creating kinematics and dynamics models. It is assumed that the plane of each wheel is perpendicular to the ground and the contact between the wheels and the ground is pure rolling and non-slipping. The velocity of the center of the mass of the mobile robot is orthogonal to the wheel axis. It is further assumed that the masses and inertias of the wheels are negligible. The center mass of the mobile robot is located in the middle of the axis connecting the driving wheels.

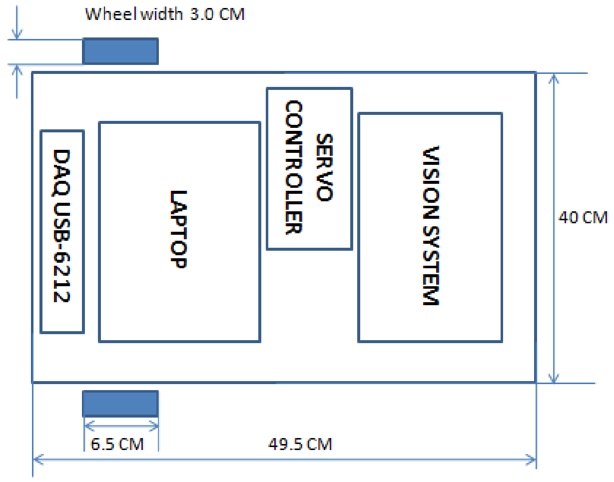

Fig. 1 Structure of Mobile Robot

The 5V Quadrate Hall Effect encoders as sensors are used to decode the position of the mobile robot and the speed of the wheels. The encoder provides 12 counts per revolution of the rear shaft. The encoder is mounted at the rear shaft 1:150 geared motor where the resolution is 1800 count per main shaft revolution. The mobile robot uses a 6.5 centimeter diameter wheel which means that each pulses of the encoder can counter the distance of 6.5x3.1415/1800=0.011344 centimeter per pulse.

TABLE I
MOBILE ROBOT SPECIFICATION

Specifications Mobile Robot	
Body	Width: 40cm Length: 49.5cm
Wheel	Radius of 2 driving wheel (r): 3.25cm Circumference of wheel ($2\pi r$): 20.4cm Distance between 2 wheel (2d): 13cm
DC motor	Rated Speed: 26RPM Rated Torque: 588mN.m
Body	Width: 40cm Length: 49.5cm
Laptop	CPU: Intel Core Duo 2.0 GHz RAM: 2.0 GB OS: Windows 7
Encoder	12 counts per rear shaft revolution

A 2 GHz Intel Core Duo Laptop running Windows 7 and a RAM consisting of 2.0 GB was used as the robot computer. It is powered either an adapter or rechargeable batteries. The Laptop is connected to optical quadrate encoder via interface counter DAQ NI-USB6212. Table 1 shows specification of mobile robot.

B. PWM DC Motor Wheel Operation

PWM DC motors control the wheel's motor speed by driving the motor with short pulse. These pulses vary in duration to change the speed of the motor. PWM works by switching the power supplied to the motor on and off very rapidly. The longer the pulses, the faster motor turns, and vice versa. The DC voltage is converted to a square-wave signal, alternating between fully on and zero, giving the motor a series of power. The DC motors are controlled by relays which switch the power on/off and change the polarity to give forward/reverse of wheel rotation.

PWM refers to the method of applying a square wave signal show in Figure 2 to DC motor that will vary its speed by changing the signal duty cycle.

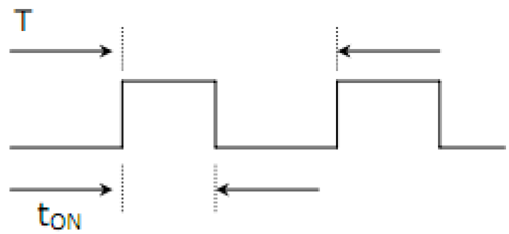

Fig. 2 Example of PWM Signal

T is the period in (s). F = 1/T is the frequency in (Hz). (tON / T) is the Duty Cycle in (%). The frequency is always constant, what a change is the duty cycle.

The speeds of the wheel rotation can estimated by take the difference between the current count and the previous count, as well as calculate the time that has elapsed and divide the change in position by the elapsed time to get velocity.

III. ROBOT MODELING

A. Kinematic Model

The mathematic model that will be used for developing mobile robot controller is a kinematic model. A kinematics deals with the relationship between control parameters and the behavior of a system in state space [6]. This type of model of mobile robot is shown below in Figure 3.

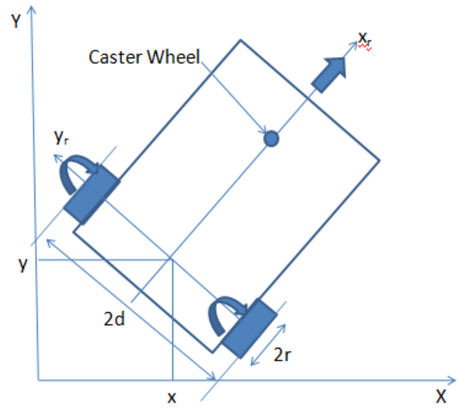

Fig. 3 Nonholonomic Mobile Robot

The V_L and V_R is the left and right wheel's velocity and V velocity of the robot center point. x and y is the robot's location in the world coordinate frame while θ is the robot's heading in the real world coordinate frame where counterclockwise is positive angles. Finally, l is the distance between the robot's two wheels. With the forward kinematics model shown above, we can now derive forward kinematics equations for differential drive robot.

$$V = \frac{V_L + V_R}{2} \tag{1}$$

$$\dot{\theta} = \frac{V_L - V_R}{l} \tag{2}$$

The equations (1) and (2) can then be used to fine the state-space kinematics model of a differential drive robot.

$$\begin{aligned} \dot{x} &= V\cos\theta \\ \dot{y} &= V\sin\theta \\ \dot{\theta} &= \frac{V_R}{l} - \frac{V_L}{l} \end{aligned} \tag{3}$$

We consider the velocity along the plane perpendicular to point of contact between wheel and the ground is zero.

B. Differential Steering System

In differential steering system, to avoid slippage and have only a pure rolling motion, the mobile robot must rotate around a point that lies on the common axis of the two driving wheels. The point is known as instantaneous center of curvature (ICC) or the instantaneous center of rotation (ICR). By changing the velocities of two driving wheels, the ICR will move and different trajectories will be followed.

If VR= VL , the mobile robot will move in a straight line, for different value of VR and VL, mobile robot does not move in a straight line but rather follows a position and orientation. If VR= -VL, then the mobile robot will rotates around the center point of mobile robot in place.

A differential steering system mobile robot is very sensitive to the relative velocities of two wheels. Small differences between the velocities provided to each wheel cause different trajectories. The castor is used for a balance differential steering mobile robot.

In the differential steering system, incremental 5V Quadrate Hall Effect encoders are mounted onto the two drive DC motors to count the wheel revolutions.

IV. PROPORTIONAL CONTROLLER

PID (proportional integral derivative) control is a control strategy that has been successfully used over many years [7-8]. This research focused on analyzing closed-loop properties of PID controllers and improving tuning on closed-loop stability to get desired speed. PID compares the measure output, the speed, to the desired value. Proportional control makes duty cycle is increased when the speed too low. Derivative control makes duty cycle decreased when the speed increases quickly. Integrating control make the duty cycle increased when speed has been consistently too low over a period of time. All this effects (PID) are combined into one resulting of the duty cycle.

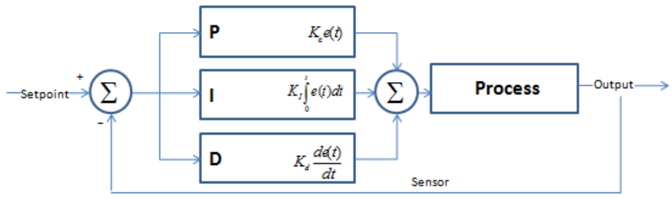

Fig. 4 PID Closed-Loop Control

PID controller compares the setpoint (SP) to the process variable (PV) to obtain the error *(e)*.

$$e = SP - PV \tag{4}$$

Then the PID controller calculates the controller action, *u(t)*, where K_c is controller gain.

$$u(t) = K_c\left(e + \frac{1}{T_i}\int_0^t e\,dt + T_d\frac{de}{dt}\right) \tag{5}$$

If the error and the controller output have the same range, -100% to 100%, controller gain is the reciprocal of proportional band, T_i is the integral time in minutes, also called the reset time, T_d is the derivative time in minutes, also called the rate time. The following equation represents the proportional action.

$$u_p = K_c e \tag{7}$$

The following equation represents the integral action.

$$u_D(t) = K_c T_d \frac{de}{dt} \tag{9}$$

Closed-loop tuning is very accurate, the process have to in steady-state oscillation and observe the PV on a graph. The following step is to perform the closed loop manual tuning.

- Set both the derivative time and the integral time on PID controller to 0
- Carefully increase the proportional gain (K_c) is small increments. Make a small change in SP to disturb the loop after each increment. As increased K_c, the value of PV should begin to oscillate. Keep making changes until the oscillation is sustained, neither growing nor decaying over time.
- Increase integral gain (K_I=Kc/T_i) until any offset is correct in sufficient time for the process. However, too much K_I will cause instability.
- Finally, increase derivative gain (K_d=K_cT_d) until the loop is acceptably quick to reach its reference after a load disturbance. However, too much K_d will cause excessive response and overshoot.\

In this paper, we focused on proportional control to achieve stability and trajectory of mobile robot.

V. RESULT

A. Experiment

In this experiment, the tuning of proportional control parameter K_{Cr} and K_{Cl} determine to simulate the control action and close-loop process respond. A series of experiments were done.

The experiments were conducted with the proportional control parameters K_{Cr} (right wheel) and K_{Cl} (left wheel) between the ranges of 0.1 to 1.0 without any disturbed like a floor. Based on the experiment observation if K_{Cr} and K_{Cl} are more than 1.0 mobile robot will make a high speed movement cause by the maximum percentage of duty cycle, thus mobile robot will not be stable.

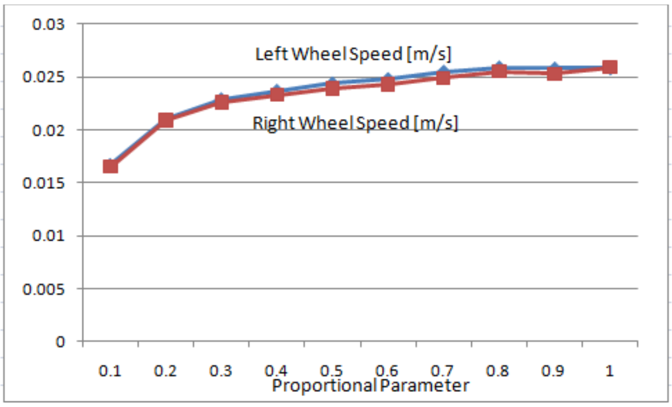

Fig.5 Experiments to Confirm the Proportional Control Parameter

Figure 5 shows the result in speed of the wheel rotations for the right wheel and the left wheel. From the experimental results (Figure 5), we found that the minimal right wheel speed and left wheel speed were within the range 0.1 for the proportional control parameters defined by K_{Cr} and K_{Cl} respectively. The results also show that the right and left wheel shows the smallest difference between of both wheel speeds. Base on these results, we are able to perform a fine tuning experiments. We conducted the fine tuning experiment with the proportional parameters K_{Cr} and K_{Cl} between 0.01 to 0.1. The fine tuning experimental results of the speed in wheel rotation for the right and left wheel are shown in Figure 6.

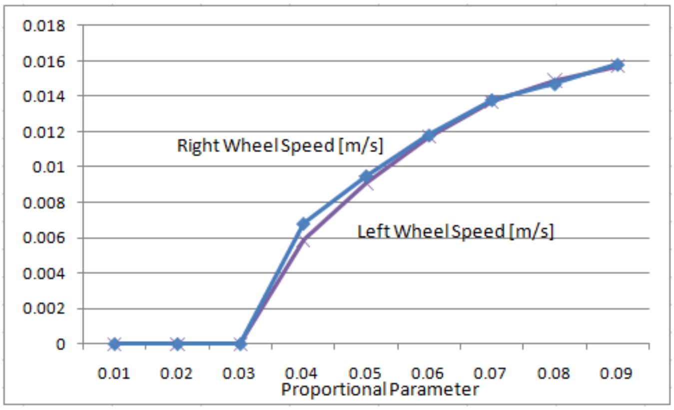

Fig.6 Experiments to Confirm the Proportional Control Parameter

As shown in Figure 6, the right and left wheel speed have less different speed at K_C 0.07 to 0.09. However the mobile robot can move at K_C 0.01 to 0.03.

In order to prove the effectiveness of the proposed control method in practical application, a laboratory experimental setup was used. The experimental conditions are stated as follows target straight running distance of 100 cm. Base on the previous experiment without any disturbance the best proportional parameter is 0.07, 0.08, 0.09 and 1.0. Figure 7, 8, 9 and 10 show the differential speed of right wheel and left wheel.

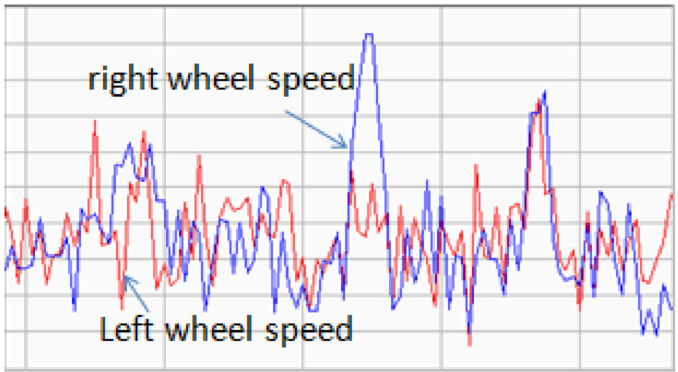

Fig.7 Proportional Parameter 0.07 for 100 cm distance

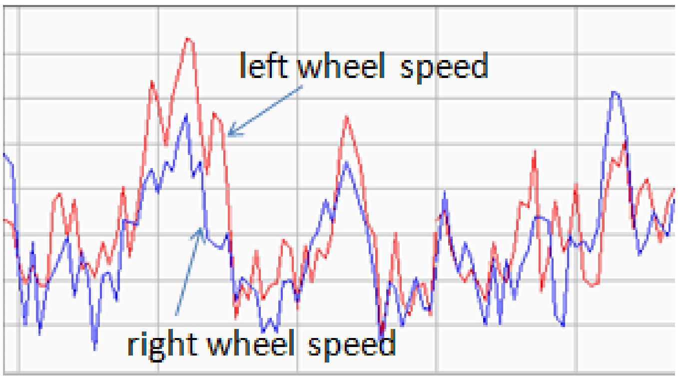

Fig.8 Proportional Parameter 0.08 for 100 cm distance

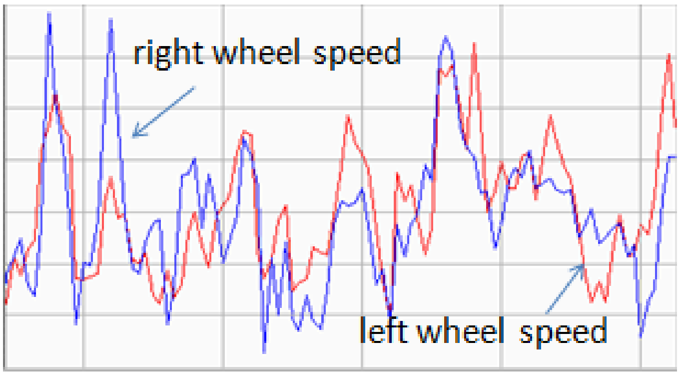

Fig.9 Proportional Parameter 0.09 for 100 cm distance

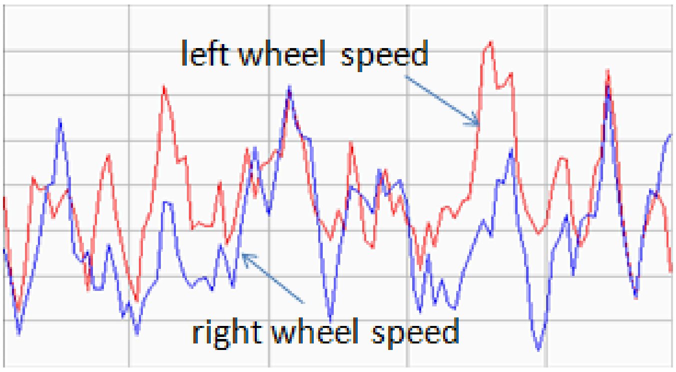

Fig.10 Proportional Parameter 1.0 for 100 cm distance

The differential speeds of propotional parameter 0.08 and 0.07 between right and left wheel in Figure 7 and 8 is less then others proportional parameters. The important thing that we have to consider when running this experiment is the sensitivity of the limitation of encoder resolution and sampling rate. The sensor is very important to give the accurate respond for proportional control to recalculate. We assume that the performance of this system can be improved by using another controller like PI, and PID. Another reasons the mobile robot has difficulty to move in a straight line are unequal wheel diameter, misalignment of wheels and wheel slippage.

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