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PID application in mobile robot control

Tran Thi Thanh Hai
[1]*Thai Nguyen University ofTechnology, Thai Nguyen, Viet Nam*
Corresponding Author: Tran Thi Thanh Hai

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ABSTRACT: There has been increased research interest in systems composed of multiple mobile robots exhibiting collective behavior. Groups of mobile robots are constructed, with an aim to studying such issues as group architecture, resource conflict, origin of cooperation, learning, and geometric problems. The mobile robot is a robot integrating multi- sensor navigation and positioning, intelligent decision making and control technology. This paper presents the control system architecture of the mobile robot, called “the autonomous vehicle”, and the path tracking and stability of motion to effectively navigate in unknown environments is discussed. In this approach, a two degree- of- freedom dynamic model is developed to formulate the path- tracking problem in state space format. For controlling the instantaneous path error, traditional controllers have difficulty in guaranteeing performance and stability over a wide range of parameter changes and disturbances. Therefore, a newly developed adaptive- PID controller will be used. By using this approach the flexibility of the vehicle control system will be increased and achieving great advantages.

KEYWORDS: Multiple mobile robots, Mobile robot, Autonomous vehicle, vehicle control, PID control.

I. INTRODUCTION

There has been much recent activity toward achieving systems of multiple mobile robots engaged in collective behavior. A mobile robot is a combination of various physical (hardware) and computational (software) components. In terms of hardware components, a mobile robot can be considered as a collection of subsystems for: Locomotion, how the robot moves through its environment; Sensing, how the robot measures properties of itself and its environment; Reasoning, how the robot maps the measurements into actions; Communication, how the robot communicates with an outside operator. In terms of software components, a set of subsystems are responsible for: Planning in its various aspects.

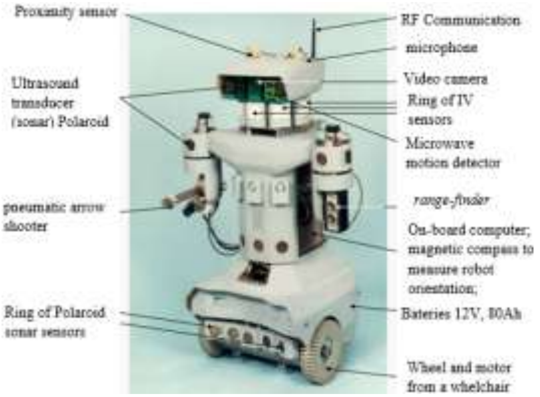

Figure 1. Components of a Mobile Robot

The study of multiple robots naturally extends research on single-robot systems, but is also a discipline unto itself: multiple-robot systems can accomplish tasks that no single robot can accomplish, since ultimately a single robot, no matter how capable, is spatially limited. Multiple-robot systems are also different from other distributed systems because of their implicit “real-world” environment, which is presumably more difficult to model and reason about than traditional components of distributed system environments (i.e., computers, databases, networks). The term collective behavior generically denotes any behavior of agents in a system having more than one agent. Cooperative behavior, which is the subject of the present survey, is a subclass of collective behavior that is characterized by cooperation. Explicit definitions of cooperation in the robotics literature, while surprisingly sparse, include: (a) “joint collaborative behavior that is directed toward some goal in which there is a common interest or reward”; (b) “a form of interaction, usually based on communication”; and (c) “[joining] together for doing something that creates a progressive result such as increasing performance or saving time”.

As a significant platform to show the level of artificial intelligence technology and the future of the vehicle industry, research into mobile robot has become a focus of the field of robotics worldwide. An autonomous vehicle is an intelligent mobile robot which covers a set of frontier research fields including environment perception, pattern recognition, navigation and positioning, intelligent decision and control and computer science. The purpose of the research is to realize autonomous driving by the vehicle instead of human drivers and to improve traffic safety and transport efficiency.

The path- tracking control of an autonomous vehicle is one of the most difficult automation challenges because of constraints on mobility, speed of motion, high- speed operation, complex interaction with the environment and typically a lack of prior information. The vehicle control can be separated into lateral and longitudinal controls. Here we focus on the lateral control to follow a given trajectory with a minimum of track error. In the previous studies, various theories and methods have been investigated. These include the PID control method[3], the predictive control method [5], the fuzzy control method [4], the model reference adaptive method [1], the neural- network control method [9], the SVR (support vector regression) method, the fractional- order control method, etc. Recently much attention has been attracted by the use of the PID control method. PID control has such advantages as a simple structure, good control effect and robust and easy implementation.

In this paper we describe the intelligent control system designed for mobile robot in this challenge. We first introduce briefly the system architecture used by autonomous vehicle, then describe the control algorithm used to generate every move of the vehicle based on the vehicle's lateral dynamics and PID control. Then we discuss the performance of the control strategy in the simulative environment and provide results from autonomous vehicle. Finally, the discussion and future work are presented.

II. MATHEMATIC MODEL ANALYSIS OF THE MOBILE ROBOT CONTROL SYSTEM

Figure2. describes the model of the driver- vehicle- road closed loop system, where the vehicle is the controlled object, the road and the environment are constraints of its motions, and the driver is in charge of environment cognition, planning decisions and vehicle operation and control. The purpose of this paper is to design a controller, which will realize the vehicle's autonomous driving instead of a human driver.

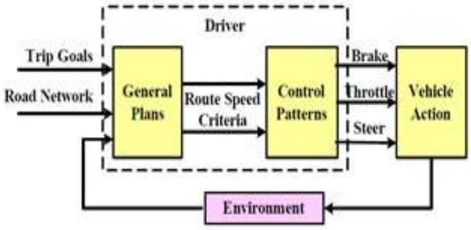

Figure 2. Model of the driver-vehicle-road closed loop system

The external forces and torques acting on the vehicle are two main types: tyre contact forces and aerodynamic forces [7]. But the vehicle motion dealt with in this paper is mainly generated by the tyre forces produced by the vehicle motion itself. Three forces act upon the tyre, namely longitudinal force, lateral force and vertical force.

The effect of longitudinal force will cause vehicle traction and braking. Driver controls the magnitude of the vehicle's driving force by the acceleration pedal and shift gear, and controls the magnitude of braking force by the braking system. The effect of lateral force is to make the vehicle turn. The driver makes the tyres generate a steering angle using the steering system to control the lateral force of the tyres. The effect of vertical force is good adhesion of the vehicle to the road. For a general vehicle travelling on a city road, the effect of aerodynamics is little, therefore, we can ignore aerodynamic force in this problem of designing the vehicle's controller as mentioned below. Several different models have been used to simulate the dynamics of the vehicle. One common approach is to treat a four- wheeled vehicle as a two- wheeled system, also called the "bicycle model", which makes the analysis of vehicle motion simpler [2].

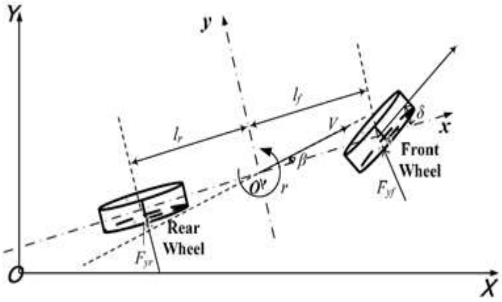

Figure3. Equivalent two- wheeled system (bicycle model).

Under the following assumption, we can build a two degree- of- freedom dynamic model for describing the motion of the vehicle.

1) Supposing that the vehicle travels on a flat and level road, and that there is no input of vertical angle caused by road unevenness, we can ignore the vertical force and its coupling effects related with vehicle dynamics.
2) The structure of the vehicle is rigid including the suspension system.
3) Putting the input on the tyre directly ignoring the steering system; or supposing the steering system is rigid, which puts the input imposed on the turning tyres through the steering wheel with a fixed transmission ratio.
4) Ignoring aerodynamic force.
5) The vehicle is disturbed merely by the small perturbation in the equilibrium point, this means the input angle of the front wheel is small enough to ensure the linearity of equations of the vehicle motion.

As the left and right tyre side- slip angles are equal, the steer angle is small and there is negligible roll motion. This is suitable for the left and right tyres of the front and rear wheels to be concentrated at the intersecting point of the vehicle x- axis with the front and rear axles as shown in Figure3. In this model, we set up a vehicle- centred coordinate system, O′- xyz. The rigid body vehicle has a velocity component of u in the longitudinal, x direction, and v in the lateral, y direction. The vehicle also has an angular velocity of r around the centre of gravity. The net force components in x and y direction are ΣF_x and ΣF_y, and the external torque around z axis is ΣM_z. The lateral motion of the vehicle is described below:

$$m(\dot{u}-vr)=\sum F_x \qquad (1)$$

$$m(\dot{v}+ur)=\sum F_y \qquad (2)$$

$$I\dot{r}=\sum \mathrm{M}_z \qquad (3)$$

here, m is the vehicle inertia mass. I is vehicle yaw moment inertia.

The state space system described as below:

$$\dot{\mathrm{X}}=\mathrm{AX}+\mathrm{BU} \qquad (4)$$

Where:

$$\mathrm{A}=\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}=\begin{bmatrix} -\frac{C_f+C_r}{mu_c} & -\frac{aC_f-bC_r}{mu_c}-u_c \\ -\frac{aC_f+bC_r}{Iu_c} & -\frac{a^2C_f-b^2C_r}{Iu_c} \end{bmatrix}$$

$$\mathrm{B}=\begin{bmatrix} b_{11} \\ b_{21} \end{bmatrix}=\begin{bmatrix} \frac{C_f}{m} \\ \frac{aC_f}{I} \end{bmatrix}$$

$$\mathrm{X}=\begin{bmatrix} v \\ r \end{bmatrix}; \qquad \mathrm{U}=\delta_f(t)$$

Vehicle Parameter	Value
vehicle mass/kg	2325
vehicle yaw moment inertia I/kg.m^2	4132
wheelbase/m	3.025
longitudinal position of front wheel from vehicle centre of gravity a/m	1.430
height of vehicle centre of gravity h_g/m	0.5
cornering stiffness of front tyre C_f/N.rad^{-1}	80000
cornering stiffness of rear tyre C_r/N.rad^{-1}	96000

Table 1. Pertinent vehicle parameters of a mobile robot

Assume that the vehicle is driving at a constant velocity with 20m/s (u_c = 20m/s) and referring to the table of pertinent vehicle parameters given in Table 1, substituting these into Equation 4, we have:

$$\begin{bmatrix} \dot{v} \\ \dot{r} \end{bmatrix}=\begin{bmatrix} -3.785 & -19.167 \\ 0.469 & 0.976 \end{bmatrix}\begin{bmatrix} v \\ r \end{bmatrix}+\begin{bmatrix} 34.409 \\ 27.686 \end{bmatrix}\delta_f(t) \qquad (5)$$

In the dynamic equation above, the two state variables are yaw rate and lateral velocity. In this paper a lateral controller is designed to reduce lateral error E of trajectory tracking. The lateral path error E is a function of the lateral velocity V, the heading θ, and the longitudinal velocity V.

This relation is shown in Equations 6 and 7.

$$\dot{E}=v+u_c\theta \qquad (6)$$

$$\dot{\theta}=r \qquad (7)$$

The augmented state space model is shown in Equation:

$$\begin{bmatrix} \dot{v} \\ \dot{r} \\ \dot{\theta} \\ \dot{E} \end{bmatrix}=\begin{bmatrix} -3.785 & -19.167 & 0 & 0 \\ 0.469 & 0.976 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 20 & 0 \end{bmatrix}\begin{bmatrix} v \\ r \\ \theta \\ E \end{bmatrix}+\begin{bmatrix} 34.409 \\ 27.686 \\ 0 \\ 0 \end{bmatrix}\delta_f(t)$$

It is assumed that the lateral path error E is the measurable output of the system. Consequently, the equation can be described as:

$$\mathrm{Y}=\mathrm{CX}+\mathrm{DU} \qquad (8)$$

Here the C matrix is described as:

$$\mathrm{C}=\begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}; \qquad \mathrm{D}=0$$

The lateral path error E is also the quantity which must be controlled. This system's open- loop control transfer function of interest is thus the transfer function from steering angle input to path error output. This may be determined using Equation 9.

$$G(s) = C(s-A)^{-1}B + D$$
$$= \frac{34.41s^2 - 10.52s + 2419}{s^4 + 2.809s^3 + 5.295s^2} \qquad (9)$$

The numerator is Hurwitz, the denominator has a double root at the origin and the sign of the high frequency gain is known (positive). Now that the structure of the plant is known, the next section describes the design of a model reference adaptive controller for controlling the lateral path error.

III. PID CONTROLLER DESIGN

In the design of the controller, the study is based on the performance index of these [8]:

(1) Settling time less than 2s, within 1% of final value;

(2) Overshot of step responsive less than 10%;

(3) Steady- state error of step responsive is 0.

Equation 9 can be written as below:

$$G(s) = \frac{34.41s^2 - 10.52s + 2419}{s^4 + 2.809s^3 + 5.295s^2}$$
$$= \frac{1}{s^2}.\frac{34.41s^2 - 10.52s + 2419}{s^2 + 2.809s + 5.295} = \frac{1}{s^2}.C(s) \qquad (10)$$

Because 0 is the double pole of the system, the system will be unstable. We must use velocity feedback, see as Figure 4.

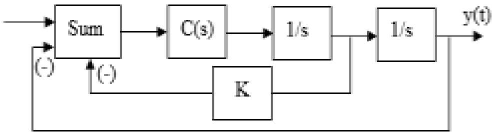

Figure 4. Closed- loop control strategy.

Figure 5 shows the structure of the control strategy used. It is simulated using MATLAB.

The coefficient is chosen at K=10 to make the additional zero point nearby the origin, therefore, H(s) = (1+10s). The system's open- loop transfer function becomes:

$$\frac{1}{s^2}.C(s)H(s) = \qquad (11)$$
$$\frac{1}{s^2}.\frac{(1+10s)(34.41s^2 - 10.52s + 2419)}{s^2 + 2.809s + 5.295}$$

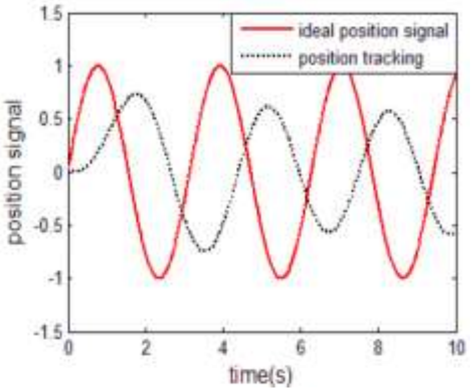

Figure 5. Performance without PID control.

In the optimal response of step response the overshot is 30.9% and the settling time is 1.63s. The performance of sinusoid response is shown in Figure 7. This shows that we have to further design a PID controller to improve the performance. The PID control law is given by:

$$G_C(s) = K_P + \frac{K_I}{s} + K_D s \qquad (12)$$

The block diagram of closed- loop PID control is shown in Figure 6. The result of the system simulation using MATLAB with sinusoid response shows that the system has better performance, as shown in Figure 5.

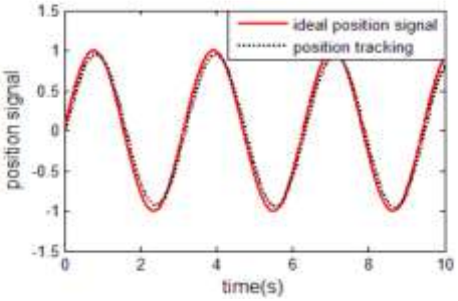

Figure 6. Performance of PID control.

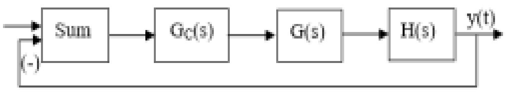

Figure 7. Block diagram of PID control.

The above analysis is just a preliminary approach under ideal dynamics models, but this paper has ignored many factors which make automatic lateral control of vehicles difficult. These include changing vehicle parameters with time, changing road conditions, as well as disturbances caused by GPS signal attenuation and other factors. Traditional controllers have difficulty in guaranteeing performance and stability over a wide range of parameter changes. In order to solve these problems and make the system automatically adapt to changes of the environment and parameters, the later studies can design an adaptive PID controller. The requirement of the adaptive PID control is control of the system's internal parameters independent of a precise mathematic model and that the parameters can adjust automatically online by real- time performance requirements. The adaptive PID control combines with the advantages of adaptive control and conventional PID control. Using an adaptive PID controller, the PID parameters can be changed with the state of control object to obtain better control performance.

IV. CONCLUSION

In this paper a simplified model of a mobile robot was use d to model the vehicle's lateral dynamics. Based on the vehicle parameters for mobile robot, a suitable reference model was developed. In addition, the adaptive PID control system described in this paper used for mobile robot proved good adaptability and stability. The approach presented here features some innovations which were well grounded in past research on autonomous driving and mobile robotics. These innovations include: a controller that is capable of both following the rules of the road and intersections, and a controller based on adaptive PID which can change the parameters automatically when faced with changing environments. Although simplicity was central to our control system development, approximate control algorithms could work well in most cases, and it made the interfacing between processes simpler, thus it simplified the system's software and hardware. Combining the vehicle model with an efficient on- road controller we could safely handle the high- speed driving involved which was also central to the vehicle's control performance.

However, the mobile robot control algorithms that have been studied recently mainly refer to positioning, moving trajectory to the target, small working space, communication delay time. is constant, the degree of cooperation in task performance, obstacle avoidance and communication between robots is limited.

Therefore, it can be said that the system of mobile robots is currently an important research area in robotics engineering and artificial intelligence. This system is applied in many different fields such as: operating space robots from the ground, commanding unmanned underwater vehicles, handling hazardous materials in nuclear plants, in operations. surgery, to maneuvering mobile robots to avoid obstacles, to rescue people, to applications in the fields of mining and manufacturing...

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