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Motion control for a two-wheeled vehicle using a self-tuning PID controller

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Abstract

This paper presents the motion control and stability analysis of a two-wheeled vehicle (TWV). The TWV is driven using two independent wheel motors, upon which a vehicle body is mounted. A mathematical model of the TWV is obtained using dynamic analysis. The TWV is inherently unstable and its motion is controlled through the actions of the wheel motors. Vehicle action depends on both the desired wheel response and the tilt angle. A self-tuning proportional-integral-derivative (PID) control strategy, based on a deduced model, is proposed for implementing a motion control system that stabilizes the TWV and follows the desired motion commands. The controller parameters are tuned automatically, on-line, to overcome the disturbances and parameter variations. Experimental results are presented to demonstrate the reliability and effectiveness of the proposed control scheme.

Keywords: Two-wheeled vehicle; Self-tuning PID; Motion control; Stability; Neural

1. Introduction

Research involving mobile vehicles or robots, has been largely devoted to establishing and analyzing the model dynamics and developing an effective control device, such as the modular wheeled mobile robot (Mutambara & Durrant-Whyte, 2000), the walking machine ALDURO (Muller, Schneider, & Hiller, 2000), a mobile manipulator with external force (Inoue, Murakami, & Ohnishi, 2001), a mobile platform (Egerstedt, Hu, & Stotsky, 2001), the chaotic mobile robot (Nakamura & Sekiguchi, 2001), JOE (Grasser, D'Arrigo, Colombi, & Ruffer, 2002), underwater vehicle-manipulator system (Antonelli & Chiaverini, 2003), and the vision-based remotely operated vehicle (Caccia, 2007). These machines can be used in exploration, rescue, transport, war, as a carrier, etc. Among these mechanical systems, the styles are diversified using distinct leg and wheel combinations.

The TWV is driven using two independent wheel motors sharing a common axis. Its motion is inherently unstable and is controlled by the actions of the wheel motors. The vehicle motion depends on both the desired wheel response and the position of the vehicle body. The system configuration means that its highly coupled situations are due to the high nonlinear kinematics and dynamic behavior of the mechanical system (Muller et al., 2000).

Many practical control issues are characterized by variable and unpredictable input, noise propagation along a series of unit processes, unknown parameters and changes in motor/load dynamics. Under these conditions, a conventional linear controller is not sufficient to provide all the design requirements (Jeon & Tomizuka, 2007; Kim & Han, 2006). Therefore, the development of high-performance motor drives is very important in industrial applications. Generally, a high-performance motor drive system must have good dynamic speed and load regulating response. This performance should also be insensitive to system parameter variations and external load disturbances. An intelligent nonlinear control technology, fuzzy logic theory and neural network (NN) techniques, were developed to provide a systematic method that incorporated self-tuning capability to implement nonlinear algorithms. They are characterized by a series of linguistic or

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weight statements into the controller (Antonelli & Chiaverini, 2003; Su & Khorasani, 2001).

The motion control of a TWV is more complex than the balance control. There are some reciprocal relations between the TWV velocity and the tilt angle that are difficult to modify. To control the TWV motion and reduce the NN complexity, a NN-like PID control method was developed. The proposed control scheme consists of a self-tuning PID decoupling controller and two self-tuning PID controllers. As the TWV motions are relative to the tilt angle magnitude, it is necessary to make the tilt angle follow a designed trajectory. The TWV designed tilt angle depends on the velocity response. In this paper, a self-tuning PID velocity controller and a self-tuning PID tilt angle controller are presented. The self-tuning PID controllers guarantee that the TWV is stable, traces the tilt angle command and follows the forward desired velocity. The TWV rotation motion is dependent upon the velocity difference between the two wheels. The self-tuning PID decoupling controller is an electrical differential mechanism that distributes the wheel velocity and torque. The decoupling controller appropriately assigns the current command to two DC motors to drive the TWV. The results of the experiment demonstrate the feasibility and reliability of the proposed control scheme, along with the stability issues.

Fig. 1. Photograph of the two-wheeled vehicle.

2. Dynamics model of the two-wheeled vehicle

In this section, the dynamic equation for the TWV is derived from TWV analysis and controller design. The TWV shown in Fig. 1 consists of a vehicle body, two independent wheel motors, motor driver, TMS320F2407 digital signal processor (DSP), rotation angle sensor and tilt angle sensor. Fig. 2 shows the diagram of force acting on the TWV where the variables are defined as follows (McGill & King, 1995; Ren, Chen, Tsai, & Yao, 2004):

- T_L, T_R torque acting on the left and right wheels, occurring from the motors on the TWV
- θ_L, θ_R rotation angle of the left and right wheels
- H_L, H_R friction force
- F_L, F_R force interacting between the left and right wheels and the chassis
- f_{dL}, f_{dR} outside disturbances acting on the left and right wheels
- f_p outside disturbances acting on the vehicle body
- θ tilt angle of the vehicle body
- Θ TWV angle of rotation
- m the mass of the inverted pendulum body on the vehicle
- R radius of the wheels
- D distance between the two wheels along the axle center
- l distance between the body center of gravity and the wheel axis

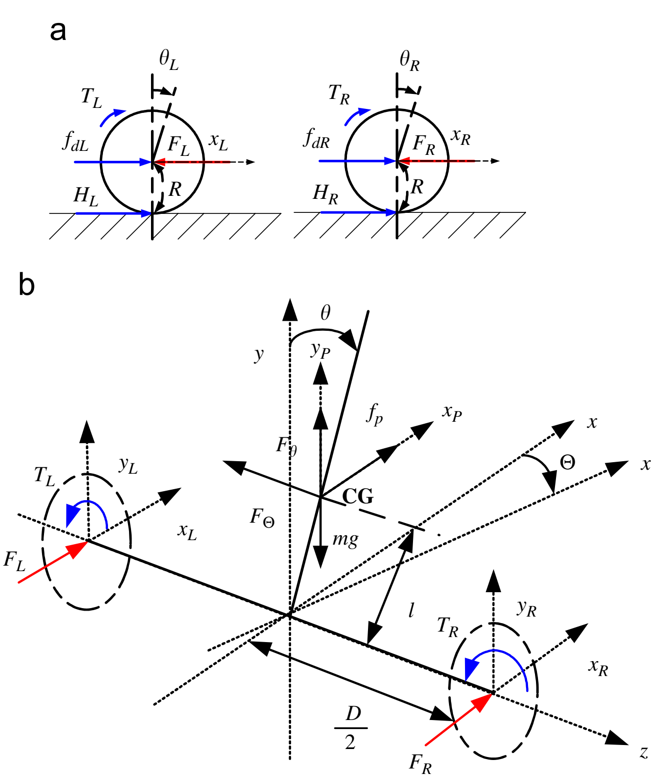

Fig. 2. Diagram of the forces acting on the TWV: (a) two wheels; (b) TWV body with two wheels.