Decoupled Dynamic Control for Pitch and Roll Axes of the Unicycle Robot

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***Abstract*—This paper proposes a decoupled control algorithm for a single-wheel (unicycle) balanced robot. A unicycle robot is controlled by two independent control laws: the method involving mobile inverted pendulum control for the pitch axis and the method involving reaction-wheel pendulum control for the roll axis. We assume that both roll dynamics and pitch dynamics are decoupled from each other. As a result, the roll and pitch dynamics are obtained independently and all interactions between them are considered disturbances. Each control law is implemented by an individual controller, i.e., fuzzy-sliding mode control for roll and linear quadratic regulator control for pitch. Fuzzy logic is utilized to compensate for the interactions between the pitch and roll dynamics in real time. The unicycle robot has two dc motors: one to drive the disk for roll and the other to drive the wheel for pitch. Since there is no force to change the yaw direction, the dynamics of the yaw direction is not changed in this paper. Algorithms for the decoupled dynamics were implemented in a real unicycle robot, which was made to follow a desired trajectory along a straight line. Angle data was obtained by fusion of the gyro sensor and accelerometer. The results of experiments conducted confirmed the effectiveness of our proposed control system.**

***Index Terms*—Decoupled dynamics, fuzzy logic, fuzzy-sliding mode control, linear quadratic regulator (LQR) control, unicycle robot.**

I. Introduction

RESEARCH ON the single-wheel (unicycle) robot has been ongoing since the 1980s in the U.S., Europe, and Japan. A. Schoonwinkel of Stanford University proposed a linear dynamic model of the robot and presented its optimal motion control in his Ph.D. thesis in 1987 [1]. Prof. Yamafujii of Tokyo University also proposed a dynamic model of the robot as an upper turntable and a lower rotating wheel. He also implemented PI motion control for it in 1997 [2]. In 2005, M.-Q. Dao and K.-Z. Liu of Chiba University maintained the roll balance using two gyroscopes and an actuator, and the pitch balance using a rotating wheel. The rotational torque in the direction yaw was canceled out in opposite rotations. They obtained the dynamics based upon the Lagrangian of the system and implemented the gain-scheduling algorithm for robustness [3]. The roll axis control of the unicycle robot has recently been altered and studied by using two flying pans at both sides of the robot, where the PD and PID controllers have been adopted [4]. However, while there has been a lot of research focusing on the roll axis control of the robot, no research results have been reported for its velocity tracking control.

Over the last four years, several unicycle robots have been implemented in the Intelligent Robot Laboratory at Pusan National University. However, a dynamic model of the robot has proven too complex to be implemented in real time [5]–[7]. Intelligent algorithms that did not incorporate dynamic information also proved unsuccessful in the control of the trajectory of the robot. To overcome these difficulties, in this approach, the dynamics of the unicycle robot has been decoupled into two parts: roll axis and pitch axis dynamics. The coupling effects between the two axes are not considered in the dynamic models [8], [9]. However, in the roll control, the coupling effects are compensated by using a fuzzy sliding mode algorithm. The pitch axis is modeled as an inverted pendulum, while the roll axis is modeled as a reaction-wheel pendulum. The dynamics that were not modeled, such as disturbances, frictions, some coupling terms, and system uncertainties, were compensated for by using an equivalent control input to the sliding mode controller, which was obtained from fuzzy control logic. To minimize the chattering phenomenon of the sliding mode controller, the fuzzy-tuning scheme was adopted in the signum function, which is used as a switching function.

Because the pitch axis is modeled as an inverted pendulum, it is relatively robust against disturbances. As a result, a linear controller based upon the linear quadratic regulator (LQR) scheme was adopted in this research [10].

The unicycle robot consists of two dc motors: one for controlling the pitch axis and the other for controlling the roll axis. The motor's angle is measured by an encoder attached to the motor axis, and the robot angles (pitch, roll, and yaw) are measured by using a two-axis gyroscope and three-axis accelerometer. The decoupling control of the robot, gyroscopes, and accelerometers were utilized to measure the angle information of the robot.

In this paper, we discuss posture and motion controls of the unicycle robot. The paper consists of five sections including this introduction. In Section II, we discuss how the dynamics of the robot was derived based upon the Lagrangian method [11]. Section III introduces the design of the controllers, and Section IV illustrates the experimental environments. Section V demonstrates the experimental results for the posture and

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