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Decoupled Dynamic Control of Unicycle Robot Using Integral Linear Quadratic Regulator and Sliding Mode Controller

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Abstract

Unicycle robot is a non-holonomic, non-linear, static unbalance system that has the minimal number of point contact to the ground, therefore it is a perfect platform for researchers to study motion and balance control. This paper focuses on the dynamic modeling of unicycle robot. Two concepts used for modeling unicycle robot are: reaction wheel pendulum and inverted pendulum. The pitch axis is modeled as inverted pendulum and roll axis is modeled as reaction wheel pendulum. The unicycle yaw dynamics is not considered which makes derivation of dynamics relatively simple. For the roll controller, sliding-mode controller has been adopted and optimal methods are used to minimize switching-function chattering. For pitch controller, a Linear Quadratic Regulator controller has been implemented to drive the unicycle robot to follow the desired velocity trajectory.

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Keywords: Decoupled dynamics, Dynamic equation, unicycle robot, velocity and trajectory control, sliding mode control, linear quadratic regulator (LQR) control, lyapunov function;

1. Introduction

The interplay between robotics and control theory has a rich history extending back over half a century. Researches have been ongoing since the 1980s in the U.S, Europe and Japan. Various unicycle robots have been developed in number of studies and several control systems for these robots have been proposed. Dynamic model of Unicycle robot can be derived either by coupled [1] or decoupled modelling [2] methods. In coupled dynamic modelling method, the dynamic model of the robot has proven too complex to be implemented in real time. In this paper, a new unicycle robot is designed using decoupled dynamic modeling and a model based controller is designed to maintain balance and drives the unicycle robot to a desired location [2][6][10]. The dynamic characteristics of the roll and pitch axes are different, so two different controllers are designed for the roll axis balance

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and for the pitch axis control. Integral Linear quadratic regulator is designed for pitch axis control and Sliding mode control is applied to the roll axis [12] .

The paper is organized as follows. Section II introduces dynamic modeling of the unicycle robot. Section III describes about the control design and gives a detailed description on roll dynamics and pitch dynamics. Section IV includes the simulation results and discussion on results. Section V concludes the work.

Nomenclature

θ Roll angle

φ Pitch angle

θ_r Angle of wheel

θ_d Angle of Disc

S Sliding surface

H Hamiltonian

L Lagrangian

U Control input

2. System modeling

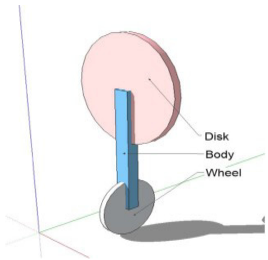

Fig.1.Free body diagram of Unicycle robot

2.1 Unicycle robot parameters

Dynamic parameters of the robot and Motor parameters are summarized in Table 1and Table 2. The inertia of the robot, J_d, J_b, J_φ and J_w have been taken from reference paper [2] and the motor parameters are provided by the manufactures.

Table.1. Unicycle robot parameters

Symbol	Parameter	Value
m_d	Mass of rotational disc	1.225 Kg
m_b	Mass of robot body	3.664 Kg
m_w	Mass of rotational Wheel	1.300 Kg
m_{bd}	$m_d + m_b$	4.889 Kg
m_{bw}	$m_b + m_w$	4.964 Kg
R_W	Radius of rotational wheel	0.110 m
R_d	Radius of rotational disc	0.200 m
L_2	Diameter to the centre of the rotational disc from the origin	0.570 m
L_{br}	$L_{br} = L_2/2$	0.258 m