Dynamic Analysis and Control Synthesis of a Spherical Wheeled Robot (Ballbot)

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***Abstract*— Ballbot is a mobile robot consists of a body mounting on a spherical wheel. The spherical wheel can make the robot move in any directions. This robot is an unstable underactuated system with nonholonomic velocity constraints. In this paper, first, a 3D dynamic model of the robot is derived while taking the nonholonomic constraints into considerations. Since Ballbot is an underactuated system, finding a normal form for the equations could be helpful in the control point of view. Therefore, the equations of motion are examined to find whether there is a simple normal form or not. To enforce the robot to track any given trajectory on the ground, an online fuzzy logic trajectory planning is suggested. A computed torque method and a sliding mode controller are used along the fuzzy trajectory planning to perform the tracking goal. To consider uncertainties and disturbances, some simulations are performed. The results show that the sliding mode controller demonstrate much better performance compared to the computed torque controller. When there is no uncertainty, the computed torque method is candidate showing less tracking error than the sliding controller.**

***Index Terms*— Ballbot, Moving mobile, Wheeled inverted pendulum, Nonholonomic systems**

I. INTRODUCTION

Stabilization problem of cart-pendulum system has been investigated both theoretically and practically extensively [1-3]. Ballbot introduced in [4] is actually an inverted pendulum mounted on a spherical wheel (Fig. 1). As shown in Fig. 2, the wheel receives its motion from the drive motors which are installed in the cylindrical body. The capability of moving in different directions without turning around, in addition to some other features like compact size, light weight and convenient in moving through narrow ways, has attracted some researchers to study this spherical wheeled robot recently. The balance control of Ballbot using LQR [4] and fuzzy controller [5] has been investigated, assuming planar motion for the system. Since uncertainties do exist in real situation, the fuzzy controller has resulted in better performance in practical. Besides balancing problem, an offline trajectory planning is also proposed in [6] to move the ballbot between two static situations. In order to keep the robot upright in static situations, system with hydraulic legs has been designed in [7].

It should be noted that in all the previous, Ballbot has been modeled as a 2D dynamic system. Although the planar model of the ballbot is valuable, but the spatial analysis is more reliable in practical situations. Besides, in study of the controlled system, linear controllers have been used. These controllers show appropriate performance if the body of the robot deviates slightly from the upright position. This is not the condition when the robot affected by large external disturbances or robot is under a fast maneuver. Therefore, designing a nonlinear controller for the system seems to be inevitable.

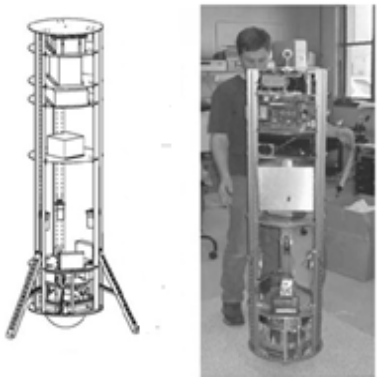

Fig. 1. Ballbot [4]