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A Two-Degree-of-Freedom Pendulum-Driven Spherical Robot Platform

Po-Yu Chang*, Chih-Hao Chou*, Tai-Jie Wang*, Yao-Peng Chang* and Pei-Chun Lin**
Department of Mechanical Engineering, National Taiwan University

Abstract—**This study focuses on the design of a spherical robot platform driven by a two-degree-of-freedom (2-DOF) pendulum. We investigate how to utilize the 2-DOF pendulum to actuate internal mechanisms within the spherical shell, enabling the robot to move along arbitrary trajectories on a plane. From a kinematic perspective, we analyze the motion characteristics of the pendulum and its influence on the spherical body. From a dynamic perspective, we further explore the robot's behavior during movement, providing insights into potential challenges that may arise during future control implementations.**

I. Introduction

This work presents a spherical robot platform driven by a two-degree-of-freedom (2-DOF) pendulum. While most existing designs, such as Sphero, enclose all drive and control components inside the shell, this internal architecture limits functional scalability due to spatial constraints. To address this, we propose an alternative design that relocates the drive and control mechanisms to the exterior, making the shell part of the robot's active structure. This approach preserves key advantages like omnidirectional rolling and core protection while enhancing modularity. It also enables the integration of additional components—such as robotic arms or legs—on the shell, expanding the robot's adaptability for various applications.

II. Method and Results

The core of this spherical robot is a two-degree-of-freedom (2-DOF) pendulum mechanism, enabling movement by shifting its center of mass via two perpendicular rotational axes. Two stepper motors, connected through a gear and differential system (Fig. 1), drive the pendulum to achieve omnidirectional motion. Slot-based mounts (Fig. 2a), allow for easy removal and replacement of modularized components like motors and batteries (Fig. 2b), facilitating maintenance and system upgrades.

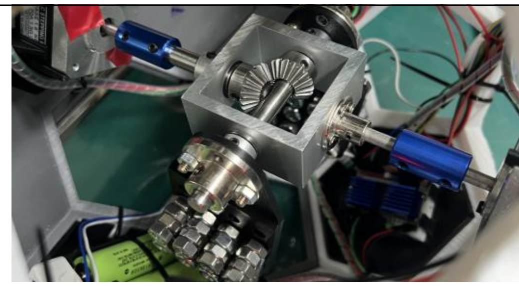

Fig 1. Gear differential system for omnidirectional motion

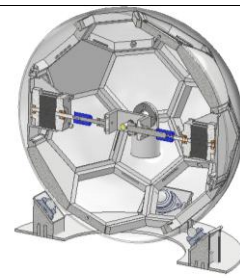

Fig 2a. Slot-Based Mount Frame

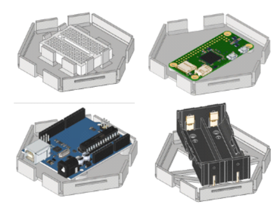

Fig 2b. Modular Components

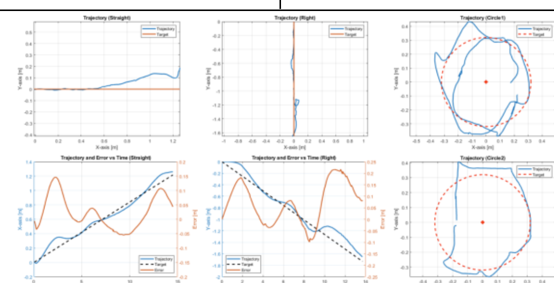

Fig 3. Experiment Data

This study evaluates the robot's motion behavior and stability during forward straight-line, lateral straight-line, and circular movements. Trajectory data was analyzed to assess how effectively the 2-DOF pendulum controls motion and maintains stability (Fig. 3). In straight-line motion, the robot initially maintains a consistent direction, but internal imbalances gradually lead to deviation over time. In circular motion, terrain friction and frame imbalance affect the path's accuracy. When the pendulum is preset to a 45° angle, the robot can follow a relatively stable circular trajectory; however, deviations from this configuration may result in control inaccuracies.

Conclusions

This study successfully designs a spherical robot with great modularization to improve its extensibility. There are two future directions for this research. First, we will further improve the stability of motion through feedback control. Second, we will further increase the capability of getting over obstacles using the momentum of the pendulum.

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*These authors contribute equally to this work
**The authors are with Department of Mechanical Engineering National Taiwan University (NTU), No.1 Roosevelt Rd. Sec.4, Taipei 106, Taiwan. (Corresponding email: peichunlin@ntu.edu.tw)

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