Dynamic Modeling and Simulation of the Omnidirectional Locomotion of a Mobile Manipulator Robot with Four Swedish Wheels and an Independent Suspension System

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EXTENDED ABSTRACT

1 Introduction

A mobile manipulator robot, named CHARMIE (Fig. 1a), has been developed to assist patients with mobility limitations by performing domestic chores, consequently increasing their autonomy and quality of life [1]. The system's forward kinematics and inverse dynamics have been successfully accomplished using an in-house code [2], which was evaluated based on several simplifications regarding the robot's navigation. Thus, the present study overcomes those limitations by expanding and completing CHARMIE's computational analysis with an accurate representation of its locomotion system.

The studied locomotive system, shown in Figure 1b, uses four Swedish omni wheels [3] with two sets of bearing rollers. Each wheel axle is directly driven by a DC motor. The wheel and motor assemblies can move vertically, with a prismatic degree of freedom, which corresponds to the deflection of the two parallel compression springs of an independent suspension system.

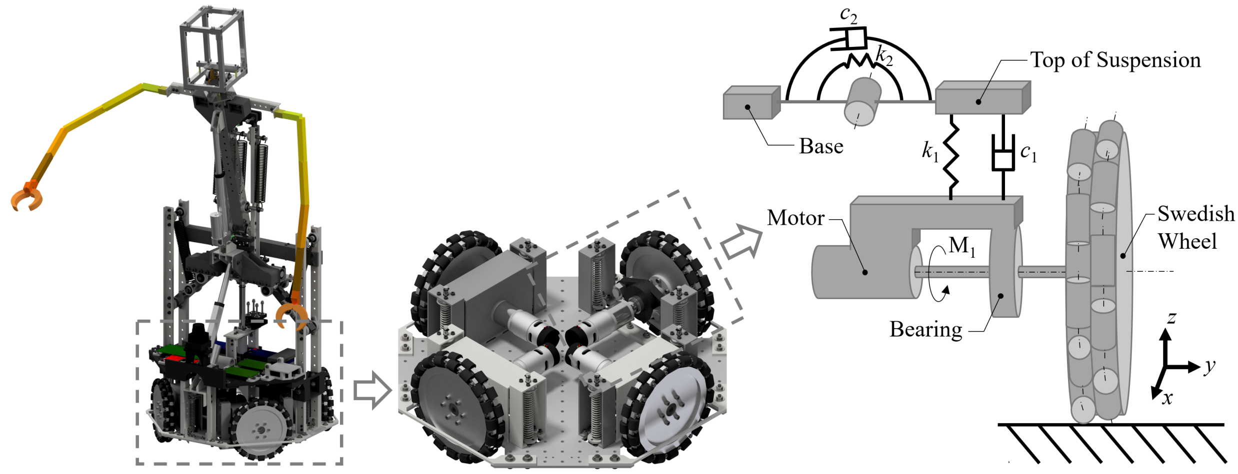

Figure 1: (a) CAD model of the developed CHARMIE robot; (b) highlight of CHARMIE's locomotion and suspension systems, with one of the bearing and motor supports hidden to allow better interior visibility; (c) schematic representation of the studied wheel and suspension assembly.

The majority of the studies on omnidirectional locomotion focus on modelling the system using kinematic approaches for navigation trajectory control, for example [3, 4]. Most dynamic-related works in this scientific area aim at achieving optimal model-based control solutions, such as trajectory optimizations using friction compensation [5], by taking into account different phenomena, namely the friction of the wheels [6], the effect of weight transfer and Coulomb friction in the maximum robot accelerations [7], the interactions between the manipulative and locomotive systems of a mobile manipulator [8], and the dynamics of each motor [8]. The possible number of wheels (usually three or four) and wheel types (Swedish wheel, mecanum wheel, etc.) cause significant changes in the dynamic behaviour of separate omnidirectional systems, which further highlights the need for more specific developments.

The goal of this work is to evaluate and compare the effects of different mechanical parameters (e.g. spring stiffness) on CHARMIE's locomotion response. The study is conducted entirely in a computational environment, where real-time results are not required, so a more complex model can be used that considers: wheel friction, DC motor dynamics, the suspension system's dynamics, and the effects the upper body movements cause on the locomotion. This tool will be utilized to optimize CHARMIE and to confirm its stability in various work environments (traversing wheelchair ramps or door thresholds). The main contributions of this study deal with the merging of distinct dynamic concepts into a single model, as well as the analysis of a realistic suspension system on a robot with omnidirectional locomotion.

2 Description of the multibody model

The inverse dynamics of CHARMIE's main body has been studied in [2] using a model that consists of 38 rigid bodies, interconnected by 33 revolute joints and eight prismatic joints, resulting in a total of 24 degrees-of-freedom (18 for the robot's articulation, and six for its global position and orientation). The effects caused by the configuration of the upper body on the locomotion are obtained as the total force and torque applied by the ground plane on the robot.

In the present work, the robot's locomotion and suspension systems are modeled following the representation of Figure 1c. Each independent suspension has two degrees-of-freedom, the main prismatic motion associated with the spring deflection (spring stiffness k_1 and damping coefficient c_1), and a limited revolute motion with a very high spring constant, which was observed in the physical prototype of CHARMIE, due to the material deformation and the joint tolerances of the mechanism (spring stiffness k_2 and damping coefficient c_2). These eight degrees-of-freedom (two for each wheel) define the overall vertical position, roll angle, and pitch angle of the robot, as well as the contact of each wheel with the ground.

Swedish wheels allow omnidirectional locomotion by incorporating two degrees-of-freedom. The first one corresponds to the active component of the wheel velocity, which is controlled by a DC motor (rotating around the y axis in the example of Figure 1c) and is responsible for the robot's propulsion. The second one is the passive component of the velocity that results from the unrestrained rotation of the wheel's rollers. The angle between the active and passive velocity vectors of CHARMIE's wheels is always $\pi/2$. The combination of these velocities for all four wheels defines the robot's translational motion along the x and y directions, as well as the yaw angle. The suspension and locomotion systems result in a combined total of 16 degrees-of-freedom, four of them directly controlled by DC motors.

3 Final Remarks

In this work, the developed multibody model of CHARMIE has been expanded by including a locomotion system with four Swedish wheels and an independent suspension system. The focus is to evaluate the performance of the locomotive system using a model with high levels of detail by considering several dynamic phenomena. The analysis computes the wheel friction, the weight transfer due to the upper body motion, and the dynamics of the DC motors. The results obtained from this study confirm CHARMIE's safety and stability, and also provide a valuable resource for the optimization of the robot.

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