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Experimental Validation of a Hybrid Mobile Robot Mechanism with Interchangeable Locomotion and Manipulation

Pinhas Ben-Tzvi, *Member, IEEE*

***Abstract*—**This video submission presents the experimental validation and testing of a novel Hybrid Mobile Robot (HMR) system design using a complete physical prototype. The HMR consists of a combination of parallel and serially connected links resulting in a hybrid mechanism that consists of a locomotion platform and a manipulator arm for manipulation, both interchangeable functionally. The new design has the ability to interchangeably provide locomotion and manipulation capability, both simultaneously. This was accomplished by integrating the locomotion mechanism and the manipulator arm mechanism as one entity rather than two separate and attached mechanisms. The manipulator arm can be used as part of the locomotion platform and vice versa. The video demonstrates how this paradigm significantly enhances mobile robot functionality for locomotion and manipulation tasks.

***Index Terms*—Mobile Robots, Locomotion, Robot Manipulation**

I. Description of the Robot Mechanism

The video demonstrates the experimental results related to the new mechanical design architecture of the Hybrid Mobile Robot (HMR) system. The proposed idea is two-fold and is briefly described as follows: (i) integrate the manipulator and the mobile platform as one entity resulting in a hybrid mechanism rather than two separate and attached mechanisms. Consequently, the same joints (motors) that provide the manipulator's dof's also provide the locomotion dof's; (ii) design the overall mobile robot platform in a symmetric manner (geometrically) in order to allow flip-over and invert-ability. Therefore, when a flip-over takes place, the robot can continue its destination from the current position, with no need of self-righting or added active means to return it.

A. Description of the Design Architecture

The design details of the HMR embodying the proposed idea are depicted in Fig. 1. If the platform is inverted, the fully *symmetric* design (Fig. 1(b)) allows the platform to continue to the destination from its new position with no need of active means for self-righting. Also it is able to deploy/stow the manipulator from either side of the platform.

Pinhas Ben-Tzvi is with the Department of Mechanical and Aerospace Engineering, The George Washington University, Washington, DC 20052 (phone: 202-994-6149; e-mail: bentzvi@gwu.edu).

The platform includes two identical and parallel base link 1 tracks (left & right), link 2, link 3, end-effector (EE) and passive wheels. To support the symmetric design, all the links are nested into one another. Link 2 is connected between the two base link tracks via joint 1 (Fig. 1(a)). Passive wheels are inserted between links 2 and 3 and connected via joint 2 and another passive wheel is inserted between link 3 and the EE via joint 3 (Fig. 1(a)). The passive wheels are used to support links 2 and 3 when used for various configuration modes of locomotion/traction. Link 2, link 3 and the EE are connected through revolute joints and are able to provide continuous 360^o rotation and can be deployed separately or together from either side of the platform. To prevent immobilization of the platform during a flip-over scenario, rounded and pliable covers are attached to the sides of the platform as shown in Fig. 1(b). The design also includes a built-in dual-operation track tension and suspension mechanism that accounts for the symmetric nature of the design and is also used to absorb some of the energy resulting from falling or flipping. Readers are referred to references [1] & [2] for details on the design development, analyses and relevant technical characteristics and features of the system (i.e., physical dimensions, weight, torques and comparisons to other mobile robot systems).

B. Configuration Modes of Operation

The video demonstrates how the links can be used in three modes: (a) Locomotion mode – all links used for locomotion to provide added level of maneuverability and traction; (b) Manipulation mode – all links are used for manipulation to provide added level of manipulability; (c) Hybrid mode – combination of modes (a) and (b). While some links are used for locomotion, the rest could be used for manipulation at the same time, thus the hybrid nature of the design.

II. Experimental Validation

The experimental results shown in the video demonstrate the robot's locomotion and m characteristics and some challenging tasks that the mobile robot accomplished.

The tests shown in the movie are described as follows:

1) Traversing Cylindrical Obstacles

The first part of the movie shows how the segmented nature of the robot's structure allows it to be able to surmount cylindrical obstacles such as pipes and tree logs up to 0.6 m in diameter.

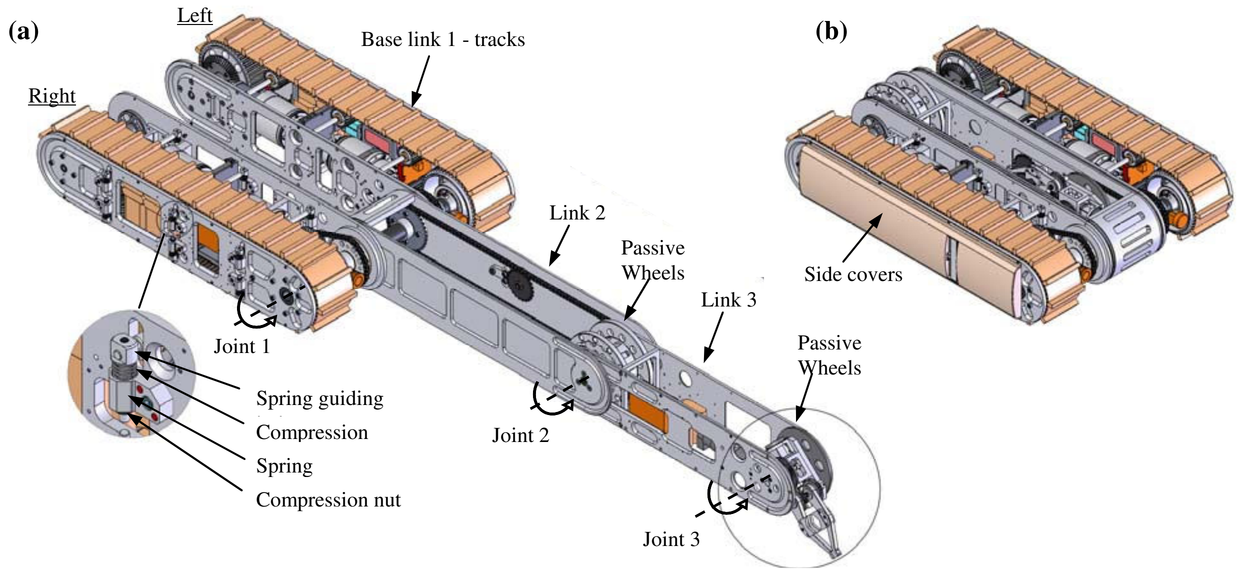

Fig. 1 (a) open configuration mode; (b) Stowed-links configuration mode (all other covers removed).

Some of the required links configuration steps to accomplish such tasks are as follows: the base link tracks are deployed until they touch the obstacle; at that point, the tracks start to propel the platform while at the same time they continue their rotation about joint 1. The combination of these simultaneous motions allows the robot to surmount such obstacles.

2) Step Obstacle Climbing with Tracks

This part of the video shows series of motions in order to climb up to 0.7 m step obstacles with the base link tracks. The steps are as follows: the base link tracks are first deployed on the step; link 2 continues to rotate until the base link tracks adjust with the profile of the step; the platform advances to accomplish the climbing process and link 2 closes. This climbing can also be accomplished with link 3 by interchanging the roles of links 2 and 3 (in this case, the back of the robot will be facing the step obstacle).

3) Descending Obstacle with Base link Tracks

If climbing was performed with the base link tracks than the back end of the robot will be facing the step edge. In this case the platform reconfigures itself such that descending is performed with the robot's front end in order to be able to deploy and use both links 2 and 3 in the descending process as shown in the movie. The reconfiguring in this case was done by the robot flipping over the table. This is allowed thanks to the ability of the interchangeable track tension/suspension mechanism to absorb some of the energy resulting from flipping over events.

4) Simultaneous Climbing and Manipulation

This part of the movie demonstrates one of the hybrid modes of the HMR. It shows the mobile robot's capability to pick up an object, and climb a step obstacle with the base link tracks while holding the object with the gripper mechanism. In this case, link 3 remains deployed in order to manipulate the object at the same time.

5) Manipulator Payload Capacity

This part of the experiment demonstrates the actuator strength capacity for manipulation purposes. It dramatically increases due to the hybrid nature of the mechanical structure. For example, The HMR can provide various configurations in the manipulation mode. The configuration shown in this part of the movie provided maximum payload capacity of **~59 Kg (~130 lbs)** due to its noticeably greater resistance to tip–over instability. In cases where it is required to remove objects or lift heavy objects from underneath, the compact and symmetric structure of the robot together with increased actuator strength due to the hybrid structure allows is to go under objects and lift as shown in the movie.

The experimental results demonstrate a mobile robot capable of demonstrating challenging locomotion and manipulation functions that are of great importance in applications, such as search & rescue, reconnaissance, military and police operations, planetary explorations, etc. The new functions shown are a direct consequence of the novel design paradigm – namely, the hybrid mechanism that provides both locomotion and manipulation and their ability to be interchangeable in their roles.

ACKNOWLEDGMENT

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