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Research paper

Design and analysis of a multi-mode mobile robot based on a parallel mechanism with branch variation

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ABSTRACT

In this paper we propose the design idea of branch variation of a mobile parallel mechanism so that it can execute different locomotion modes. A novel robot is presented based on this idea, which can be reconfigured to be different equivalent mobile robots in topological structure.

The robot is a four-limbed parallel mechanism in which each limb contains eight revolute joints. Based on the branch variation with topological reconfiguration of the parallel mechanism, the robot has 3 locomotion modes with 7 gaits to reply to different situations by analyzing its topological structure via adjacency matrixes and transformation equations.

Tracked locomotion mode is realized by the motion of platforms as a 3-dof (degree of freedom) planar 6R closed-loop mechanism which can operate obstacles. Legged mode is realized by the deforming of four limbs to carry out trot-walking gait with 1-dof mechanism units. Wheeled mode is realized by the relative motion between each limb and platforms as a 4-dof mechanism to carry out fast moving and direction switching in this mode.

To verify the locomotion modes and functionality of the robot, we present the results of a series of experiments, performed on a simulation system and a manufactured prototype.

1. Introduction

Territorial mobile robots mainly include wheeled robots, tracked robots, legged robots, snake robots, and spherical robots. Among these, wheeled robots and spherical robots are usually used on regular roads, while the others are usually used on bumpy roads. Each moving mode has its own merits and demerits in different environments. For example, a legged robot can achieve walking, crawling, and jumping by alternatively changing the supporting legs on the ground, which enables the mobile platform to explore different environments flexibly. However, the lower walking efficiency and the complicated controlling system are consequent shortages [1–3]. Therefore, hybrid robots, which are constructed by the superposition of several different mobile mechanisms together (especially, legged, wheeled and tracked) [4–7], are put forward to enhance the moving capability of the robot in different working environments instead of using only one single locomotion mode. But the increase of weight and volume of these designs reduces the robot agility [2].

Modular mobile robots, which are different from hybrid robots, can realize different locomotion modes with modules which have the same shape and functions. Modular mobile robots can deform in various topology structures, e.g., rolling, walking and crawling, by switching among the locomotion modes [8–10]. The docking methods to divide and re-connect to change between locomotion modes lead to mechanisms with large DoFs that are difficult to control.

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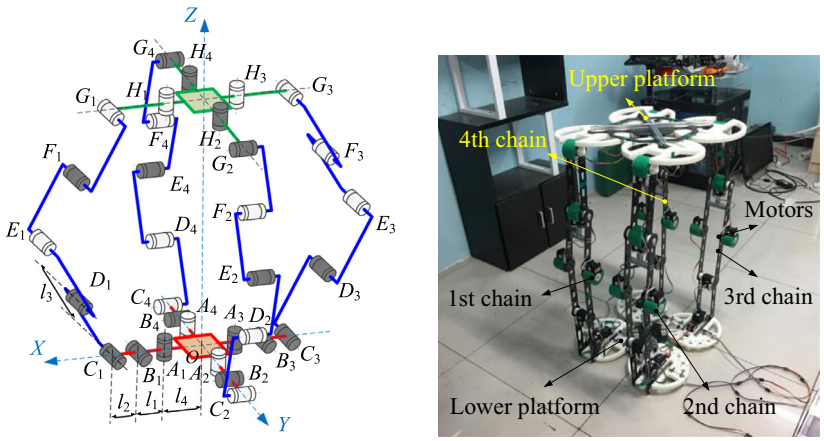

Fig. 1. (a) The schematic of the mobile parallel robot, (b) the prototype of the mechanism.

Except for modules method, robots can also be reconfigured to switch between different locomotion modes by restructure the mechanism of moving devices. Chen et al. [11] proposed a robot with four legs which can be transformed into wheels; Phipps et al. [12,13] proposed a kind of rolling robot which can switch locomotion modes between a circle or spherical robot and a legged robot.

In addition, existing research works related to parallel mechanisms working as mobile robots are very rare. Ota et al. [14–16] put forward a parallel mobile mechanism with three limbs which can climb stairs and slopes with adding three legs on each platform. Sugahara et al. [17,18] proposed a manned mobile robot with two legs structured by the Stewart parallel mechanism, such that the robot can walk on the ground or climb the stairs with someone taking on it. There are also quadruped reconfigurable walking robot with parallel leg mechanisms with each being a 3-UPU or 6-SPU parallel mechanism [19]. Moreover, in our previous works, we proposed several walking robots [20,21] and rolling robots [22–25] by using parallel mechanisms. Nevertheless, the locomotion modes of these robots are fixed and the working spaces of legs are limited, that reduces the moving ability of these robots in different working environments.

In this paper, we propose a reconfigurable robot with multiple locomotion modes based on a four-limbed parallel mechanism with branch variation [26–28], which can be viewed as an extension of our earlier works. Using the topology analysis based on adjacency matrixes and transformation equations of limbs, platforms and whole mechanism, the corresponding mechanisms in each mode can be obtained. Thus, the robot can realize tracked locomotion mode, legged locomotion mode and wheeled locomotion mode, which are achieved by the motion of platforms, the deforming of each limb, and the relative motion between each limb and platforms respectively. And three different locomotion modes can carry out seven kinds of gaits to reply to different situations. In addition, this robot can be folded and expanded which may be useful for storage or hiding itself in some missions.

The rest of the paper is organized as follows: in Section 2, the mechanism design of the robot is presented; Section 3 explains the tracked locomotion mode of the robot; in Section 4, the legged locomotion mode of the robot is demonstrated; in Section 5, we present the wheeled mode of our robot; Section 6 shows the results of the locomotion tests and folding functions on a physical prototype; and a conclusion of the paper can be found in Section 7.

2. Mechanism design

In this section, the structure design of the mobile parallel mechanism with branch variation is introduced firstly. Then, based on the topological structure, the mobility of the parallel mechanism in general state is analyzed and the three locomotion modes (tracked rolling locomotion, legged walking locomotion, wheeled locomotion) is put forward. By using these modes, the robot can be viewed as the equivalent mobile mechanisms to realize some special movements and surmount obstacles.

2.1. Mechanism design

The mobile parallel robot is illustrated in Fig. 1. As shown in Fig. 1(a), the structure of the proposed robot is a parallel mechanism with two equal platforms (lower platform $A_1A_2A_3A_4$ and upper platform $H_1H_2H_3H_4$) and four equal limbs on the symmetric arrangement, where A_i and H_i are the end joints of each limb. For the lower platform and the upper platform, $||OA_i|| = ||OH_i||$, and $A_1A_3 \perp A_2A_4$, $H_1H_3 \perp H_2H_4$. Each limb consists of eight R joints at A_i, B_i, C_i, D_i, E_i, F_i, G_i and H_i (for $i = 1$, 2, 3, 4). The positions of R joints and dimension relations of links on each limb are as follows: