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A roller-skating/walking mode-based amphibious robot

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ABSTRACT

An amphibious spherical robot capable of motion on land as well as underwater is developed to implement the complicated underwater operations in our previous research. In order to improve the speed performance of the spherical robot on a slope or comparatively smooth terrains, we propose a new roller-skating mode for the robot by equipping a passive wheel on each leg to implement the roller-skating motion in this paper. A braking mechanism is designed to transform the state of each passive wheel between free rolling and braking states by compressing and releasing the spring, which is controlled by the vertical servo motor on each leg. Besides, in order to improve the walking stability of the wheeled robot in longitudinal direction, a closed-loop control method is presented to control the stability of the direction of movement while walking. Therefore, we conduct the experiments on smooth terrains and down a slope to evaluate the performance of the roller-skating motion, including gait stability and velocity. Finally, plenty of walking experiments are conducted to evaluate the ability of directional control.

1. Introduction

As amphibians possessing strong abilities to adaptation in the various environments, a few studies have focused on the amphibious robots inspired by amphibians [1–5,22,23]. In our previous research, we designed and developed a novel amphibious spherical robot with transformable composite propulsion mechanisms, as shown in Fig. 1 [6]. The composite mechanism is designed to switch between water-jet propeller and leg. Using the leg mode, the amphibious robot is able to move from the water to the ground without manpower, and vice versa. However, there are some limitations on the movement speed and the gait stability on land.

As we know, walking robots on land including biped robots, quadruped robots and multi-legged robots, can select discrete foot placement with multi-articulated legs, which causes the robot to have a high efficiency and stability even on rugged terrains [7–9]. With the advantages of having the adaptive capacity to complicated terrains and higher energy efficiency on deformable terrains, researches of the walking robots have been focused on by researchers around the world and some robots edge closer to practical use. Locomotion, as one of the basic functions of a mobile robot, becomes an important indicator of performance evaluation of the robot, including the movement speed and the ability of directional control. For a walking robot, it can implement a holonomic and omnidirectional motion and can move on soft terrains. Besides, it can also be a stable and movable platform for a manipulator when it stops walking.

However, on the hard level terrain, wheeled locomotion shows a better performance than legged locomotion in terms of mobile velocity and energy efficiency, especially on a slope. When the wheeled robots stop providing the motive power, they are in passive motion with free rotation of the wheels, which can decrease the energy consumption. Consequently, many researches proposed the combination of the advantages of the locomotion of the legged robots and wheeled robots through leg-wheel hybrid vehicles.

In the previous researches, some of the hybrid vehicles are equipped with driven wheels, while others are outfitted with passive wheels. Compared to active wheel-legged robots, passive wheel-legged robots have the advantages of low energy consumption and low weight and compact structure, because driving the active wheels requires actuators, which are usually heavy and bulky. Since the robot in walking mode is already heavy enough, equipping driven wheels will cause in a serious defect during walking.

As the early leg-wheel hybrid mobile robots, the passive wheel-legged robot named Roller-Walker with two actuating modes is proposed [10–13]. The quadruped robot has one passive wheel on each leg, which can be transformed into sole mode by rotating the

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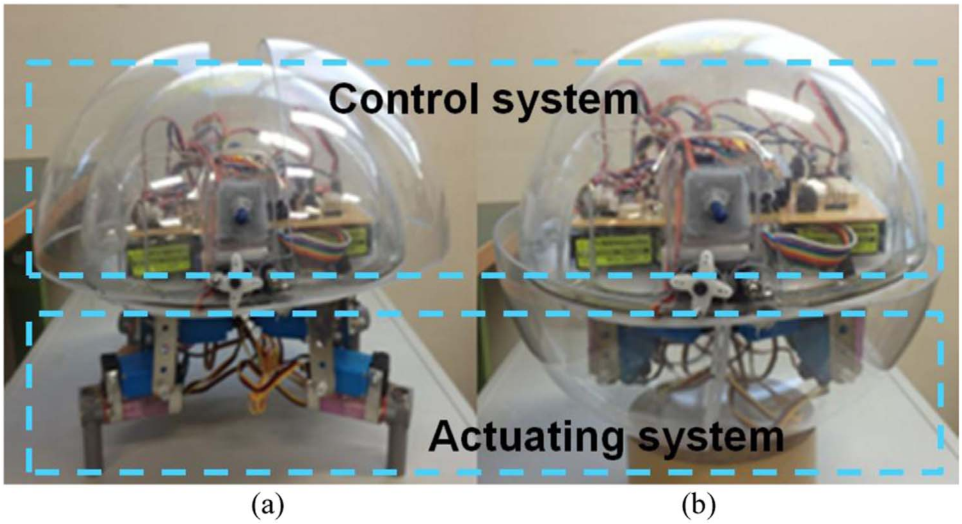

Fig. 1. The amphibious robot in (a) quadruped walking mode, and (b) water-jet propulsion mode.

ankle roll joint. With this transformation mechanism, the locomotion can be switched from quadruped walking to roller-skating on the flat ground. Each leg has three degrees of freedom, one of which is just used for the transformation of the actuation modes. Body extendable quadruped robot (BEQR) is a novel wheel-legged robot with extendable body [14]. Each leg is equipped with a passive wheel and has four degrees of freedom. These two kinds of robots are actuated by passive wheels while roller-skating. Another leg-wheel hybrid platform named Quattroped is designed, which has two separate mechanisms, wheels and legs [15]. With a leg-wheel switching mechanism, the robot can implement the locomotion switching from the wheel mode to the leg mode by shifting the hip point out of the center of the rim. And a leg-track-wheel articulation-based robotic platform, AZIMUT, possessing abilities of adaptation to three-dimensional environments, is developed [16]. However, these two kinds of active wheel-legged robots are heavy and bulky because active wheels need to be driven by additional motors. And all the robots should consider their ability of directional control during walking.

For our previous amphibious robot, the maximum walking velocity on the even terrains, especially on a slope, is not enough for the movement on land. Moreover, the robot can only walk down a slope with a maximum inclination angle of 8°. Additionally, the vibration in yaw direction is generated while walking due to the roughness of the ground. Because of the torus contact surface between the robot leg and ground, it is easy for the robot leg to stumble over the bulges on the ground, which causes the moving direction unstable.

Therefore, in order to improve the on-land performance of the robot, we proposed a new roller-skating mode to improve the on-land speed performance of the robot on the smooth flat surface as well as down a slope. Considering the compact structure of our robot, it was equipped with passive wheels. A braking mechanism was designed to implement the transformation of state of each passive wheel between free rolling state and braking state by controlling the vertical servo motor to compress and release the spring. Using a transformation mechanism, a modified walking gait was applied to the robot to implement the walking motion in the meantime. Besides, we developed a closed-loop control algorithm to realize the directional control of the robot during walking. Roller-skating experiments are conducted to evaluate the performance of sliding motion, and walking experiments of the robot in modified walking gait are also carried out. Finally, the walking experiments of the robot with the closed-loop control system are conducted to evaluate the performance of directional control.

The remainder of this paper is organized as follows. In Section 2, we describe the general design of the previous amphibious spherical quadruped robot. In Section 3, we introduce the new structure of the robot in roller-skating mode, actuating mechanism for movement, a novel roller-skating gait and the control system. The braking mechanism and transformation mechanism are described, and a modified walking gait is presented in Section 4. The development of a prototype in roller-skating/walking mode is described, and results of on-land experiments in these two modes are presented in Section 5. Section 6 introduces a closed-loop control method for directional control of the robot and plenty of closed-loop control experiments. Section 7 concludes the paper.

2. General design of our previous amphibious robot

In our previous research, we developed an amphibious spherical robot capable of motion on land and underwater to perform complicated operations [6]. The configuration and physical dimensions of the amphibious spherical robot are illustrated in Fig. 2. To obtain a better performance in terms of adaptation to various complex environments, on land and underwater, the spherical robot can change its actuating mode between water-jet propulsion mode [21] and quadruped walking mode with transformable composite propulsion mechanisms. The amphibious robot is able to move from the water to the ground without manpower, and vice versa.

The amphibious robot is composed of a sealed transparent upper hemispheroid, two openable transparent quarter spherical shells, a plastic circular plate and four actuating units, each of which consists of a water-jet propeller and two servo motors, as shown in Fig. 2. With the two mutually perpendicular servo motors fastened to the same actuating unit, each actuating unit can realize two degrees of freedom movement. The control circuits, batteries and sensors are carried on the sealed hemispheroid for being waterproof. The diameter of the upper and lower hemisphere is 234 mm and 250 mm respectively. The height of the actuating unit in standing state is 108 mm.

From the results of our pervious researches [17,18], the maximum walking velocity of the robot on the even terrains is 22.5 cm/s, which is not enough for the on-land movement especially moving down a slope. Besides, the robot cannot climb a ramp over an inclination angle of 8° as a result of its higher center