DESIGN AND LOCOMOTION MODES OF A SMALL WHEEL-LEGGED ROBOT

IOAN DOROFTEI
Robotics Laboratory, Mechanical Engineering, Mechatronics and Robotics Department, "Gheorghe Asachi" Technical University of Iasi, B-dul D. Mangeron, 61-63 700050-Iasi, Romania

ION ION
Manipulators and Robots Laboratory, Technology of Manufacturing Department, POLITEHNICA University of Bucharest, Splaiul Independentei, 313, 060042-Bucharest, Romania

Legged robots have superior terrain adaptability comparing to traditional wheeled vehicles. They also offer attractive capabilities in terms of agility and obstacle avoidance. On the other hand, traditional wheeled platforms provide sufficient robustness, mechanical simplicity and energetic performance. They are fast, powerful in terms of load to weight ratio, stable, and easy to control. Hybrid locomotion systems were developed to exploit the terrain adaptability of legs in rough terrain and simpler control as well as high speed associated with wheels. In this paper the design and the locomotion modes of a small wheel-legged robot are presented.

1. Introduction

Walking vehicles have superior terrain adaptability, comparing to other mobile robots. They also offer attractive capabilities in terms of agility and obstacle avoidance. Their use is convenient on soft ground or in unstructured environments, where the performance of wheels and tracks are considerable reduced. On the other hand, wheeled robots provide sufficient robustness, mechanical simplicity and energetic performance. They are fast, powerful in terms of load to weight ratio, stable, and easy to control. Later on, hybrid locomotion systems were developed to exploit the terrain adaptability of legs in rough terrain and simpler control as well as high speed associated with wheels.

Many hybrid locomotion systems with different architectures have been developed since today. In Japan [1] has been developed a vehicle with five locomotion devices, each device consisting of a wheel and a leg. Another hybrid robot, called SAPPHYR, with two free rear wheels and two traction legs in the front, was designed in France [2]. WHEELEG [3], developed in Italy, was a
robot with two pneumatically actuated front legs, each one with three degrees of freedom (d.o.f.), and two independently actuated rear wheels. A hybrid wheelchair with two d.o.f. planar legs, and four wheels, has been developed at University of Pennsylvania [4], destined for use on uneven terrain. In Finland, Halme et al. [5] designed a hybrid locomotion robot, called WorkPartner, using four legs equipped with wheels. Each wheel was used to serve as a foot during walking mode and as a wheel in wheeled mode. Roller-Walker, a hybrid mobile robot with a special foot mechanism in each leg was developed in Japan [6]. In Finland, has been developed a hybrid system, called Hybtor [7]. This robot has four wheeled legs, each consisting of a three d.o.f. mammal-type leg and a rubber wheel as a foot. The rolling mode of locomotion has been introduced. The advantages of this locomotion mode, comparing to normal walking, are better speed and stability. At Tohoku University, in Japan, has been developed a robot with four legs (two in the front and two rear legs) and two wheels in the middle, to develop a leg-wheel type robot for the exploration [8], [9]. In 2004, in Thailand, a leg-wheel hybrid robot, with two active two d.o.f. legs in the front and two passive rear wheels, has been developed [10, 11].

In this paper the design of a small wheel-legged robot and its locomotion modes will be presented. This report is the result of a research conducted at the Robotics Laboratory, Mechanical Engineering, Mechatronics and Robotics, “Gh. Asachi” Technical University of Iasi, Romania.

2. Robot Architecture

The robot developed by our laboratory [12] consists of a chassis, two legs with two d.o.f. each and two passive wheels as feet, in the front, and two rear actuated/passive wheels, respectively. The rear wheels can be passive or actuated, thanks to the two electromagnetic clutches that connect these wheels and the shafts of their driving motors.

The robots using the same architecture (two legs and two wheels), developed before [3, 10, 11], are able to move using only hybrid locomotion mode. Our hybrid locomotion robot (see Figure 1) can move using three locomotion modes: wheeled locomotion mode, using the rear actuated wheels and the two passive wheels in the feet; the first hybrid locomotion mode, using the active front legs and the passive rear wheels; the second hybrid locomotion mode, using the legs and active rear wheels.

Another advantage of this configuration (see Figure 2.b), comparing to other previous designs kinematics (Figure 2.a) [10, 11], is an improved stability, when only one leg is in support phase.
Figure 1. Hybrid locomotion robot: a) CAD model; b) real prototype

Figure 2. Robot stability area and kinematics: a) other solutions; b) our robot – top view; c) our robot – front view

The prototype developed by us is a small scale hybrid locomotion platform,
with 230 x 186 x 125 [mm] as overall dimensions \((H \times l \times h)\). At a real scale, it may be a robotized chair for people with locomotion disabilities.

3. **Locomotion Modes**

Three locomotion modes can be implemented on this robot: wheeled locomotion mode, using the big actuated wheels (acting in the front, for this locomotion mode) and the two passive wheels in the feet; the first hybrid locomotion mode, using the active front legs and passive rear wheels; the second hybrid locomotion mode, using the legs and active rear wheels.

3.1. **Wheeled Locomotion Mode**

The two actuated wheels (big ones) act in the front of the robot and the small wheels, as feet of the passive legs, are passive.

One of the small passive wheels, or both of them (depending on the instantaneously trajectory of the robot), will be in contact with the ground, only to keep the stability of the robot. We will have two small passive wheels on the ground when the robot is moving forward/backward on a straight or curved trajectory (see Figure 3), and a single passive wheel in contact with the ground for turning on the spot (see Figure 4).

![Figure 3. Wheeled locomotion mode on a straight trajectory: a) robot configuration; b) diagram of motors parameters (angular position of the two legs servos; angular velocities of rear wheels)](image)

As we may see in Figure 3.b, in this sequence, the two legs are orientated in the front of the robot, with the feet (small passive wheels) on the ground. Rear wheels are active and will usually rotate as well as the robot will move backward. Is preferred this direction because the robot could climb obstacles,
thanks to the big diameters of the actuated wheels. If the robot moves forward, the small passive wheels will not be able to climb. Anyway, the robot can move forward on a flat terrain or for some maneuvers.

This sequence is using to change the robot trajectory direction. In this case, one leg is touching the ground (both the legs are in the neutral position, according to the vertical axes) and the rear wheels have opposite rotating directions.

3.2. Hybrid Locomotion Modes

There are two hybrid locomotion modes that could be implemented on this mall platform

- **First hybrid locomotion mode:** the two legs are actuated and the rear wheels are free (decoupled from their motors shafts);
- **Second hybrid locomotion mode:** the legs and the rear wheels are simultaneously actuated (in order to increase the power of the robot).

The single difference between these two hybrid locomotion modes consists in the actuation (or not) of the rear wheels. The second solution has the advantage of improving the traction force of the vehicle, when it moves in an unstructured terrain. Some intermediary sequences of the robot configuration during one cycle of the hybrid locomotion mode are shown in Figure 5.

Because the trajectories of the legs are crossing in the support phases, few precise rules should be established for the case when the robot is using hybrid locomotion mode:
- The legs could not be simultaneous in transfer phase (in that case the robot will fall down);
- The legs could not be simultaneously in support phase otherwise they will cross each other and they can be destroyed;
- When a leg is in support phase the other one should be in transfer phase, moving in opposite direction.

Figure 5. Hybrid locomotion mode: a) locomotion sequences; b) diagram of motors parameters (angular position of the two legs servos; angular velocities of rear wheels)
In Figure 5.a, six sequences of the hybrid locomotion modes are demonstrated, starting from the first robot configuration (noted with 1) till the last configuration (noted with 6) of a locomotion cycle (two steps).

Even if the diagram shown in Figure 5.b is identical for both hybrid locomotion modes, in the first hybrid locomotion mode, when the rear wheels are passive, their angular velocities, $\omega_l$ and $\omega_r$, are generated by the displacement of the support leg.

In order to avoid legs/wheels slippage, for the second hybrid locomotion mode next relation should be respected:

$$\omega_{med} \cdot R = \omega_{leg} \cdot l_3$$

where

$$\omega_{med} = \frac{\omega_l + \omega_r}{2}$$

$l_3$ is the horizontal projection of the leg length, $\omega_l$ and $\omega_r$ are the angular speeds of the left and right rear wheels, $\omega_{leg}$ is the angular speed of the support leg, $R$ is the radius of rear wheels (see Figure 2.a). In order to simplify the control algorithm, the robot has been designed as well as $l_3 = R$.

4. Conclusion

The testing gave a qualitative view of the system’s mobility performance. All the locomotion modes have been tested, using: forward, backward, turning right on the spot and turning left on the spot sequences, curved trajectory. All the tests have been done in the laboratory. We should also test the robot on a soft ground. The accuracy of direction and movement of the mobile robot is improved thanks to the small passive wheels used as feet. These wheels avoid the legs slippage. An open loop control was enough to test the mobility of the vehicle and no sensors have been used till now. A closed loop control should be implemented in the future, using encoders for the wheels and legs, touch sensors for the feet and range sensors for the robot.

References


