Experiences on a Hybrid Locomotion Approach to Overcome Obstacles with Cassino Hexapod III

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Abstract. This paper describes the Cassino Hexapod III, a hybrid omniwheeled-legged hexapod robot, which has been designed and built at LARM in Cassino. Hybrid locomotion of the robot is simulated in a MATLAB environment. Namely, four different paths are simulated as a strategy for overcoming small obstacles. The implementation of the proposed path planning is achieved by using an Arduino script in combination with a specifically developed Android interface. Experimental tests are carried out to demonstrate the engineering feasibility and effectiveness of the proposed paths for overcoming obstacles with Cassino Hexapod III.

Keywords: Hexapod walking robots · Experimental robotics
Hybrid locomotion · Tests

1 Introduction

Design of intelligent walking machines that can move in uneven terrains and areas which are inaccessible to humans has been a challenge in robotics for a very long time [1–3]. Recently, requirements of industrial and service robotics have stimulated the development of novel mobile robots designed as walking robots (WR) with wheels, legs, or both. This can provide useful features for navigating in rough and uneven terrain or for obstacle overcoming as needed in various applications, such as inspection, preservation of cultural heritage, welding, or high-pressure cleaning tasks [4–8]. These robots can adapt to complex environments by adjusting their gait patterns, footfall trajectory or footholds [9, 10]. The Cassino Hexapod Robot III, is a six-legged light-weight hybrid hexapod robot that has a mecanum omniwheel at the end of each leg. This solution allows to achieve translations in any direction through proper operation of wheels. The hybrid configuration of this robot lets it overcome small obstacles by using legs and to patrol flat surfaces along complex paths by using the wheels. This paper, analyses four different ways to overcome small obstacles by using a hybrid locomotion combining wheeled locomotion and legged locomotion. In particular a human-like forward gait, a human-like backward gait, a horse-like gait, and a bird-like gait paths of

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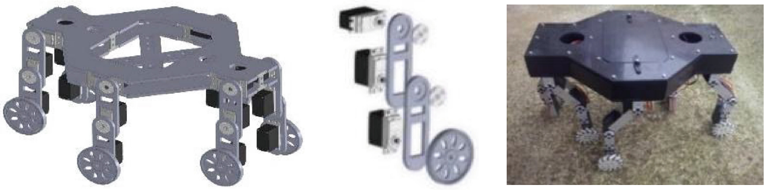
each leg are considered. The implementation of the proposed path planning is achieved by using an Arduino script in combination with a specifically developed Android interface. This paper, specifically focuses at experimental tests, which have been carried out to demonstrate the engineering feasibility and effectiveness of the proposed paths for overcoming obstacles with Cassino Hexapod III.

2 Cassino Hexapod III

Legged Hexapod Robots or Hexapod Walking Robots (HWR) are programmable robots with six legs attached to a frame, which is the robot body. The legs are controlled to perform intended motion tasks [11, 12]. The Cassino Hexapod Robot III, the newest version of the Cassino Hexapod family at LARM laboratory, has a rectangular configuration robot body with six hybrid legs in frontal orientation, Fig. 1(a). Each leg is hybrid, since it includes a Mecanum wheel at its extremity, with a length of 237 mm. This allows the robot to have a omni-directional displacements over a flat surface. The hybrid legs have been designed to avoid large obstacles by using the Mecanum wheels and to overpass small obstacles by using leg operation. Each hybrid leg has two servo motors for actuating the leg joints, and one continuous rotation servo motor for actuating a Mecanum wheel, as shown in Fig. 1(b). Figure 1(c) shows a built hexapod at LARM. The control hardware of Cassino Hexapod Robot III is fully onboard the hexapod, and it consists of an Arduino MEGA ADK as servo controller, a Mega Servo Shield to connect 18 servo motors, and a voltage regulator (REG15B) to reduce the voltage from the battery (Full Power 4S) to 5 V. This robot uses 12 RDS3115 metal gear servo motors (180°) and 6 AS3103 continuous rotation servo motors.



a) b) c)

Fig. 1. Cassino Hexapod III: (a) CAD design, (b) hybrid leg, (c) robot built.

3 Motion and Operation Planning

Path planning algorithms generate a geometric path, from initial to a final point, passing through predefined via-points, either in the joint space or in the operating space of the robot, while trajectory planning algorithms take a given geometric path and endow it with the time information [13, 14]. Motion planning of wheeled vehicles has attracted the interest of the scientific community along the last two decades [11, 15].

As a first step for achieving proper path planning, it is necessary to establish a proper mathematical model for the robot kinematics. Inverse kinematics allows to calculate the angular position of each joint of one leg by introducing the coordinates of the end effector, this is used to find the angular positions of each joint to follow a path. By applying the geometric method and using the cosine theorem, as presented in [16], it is obtained the mathematical solution for a up elbow configuration. These equations are used to simulate the hybrid locomotion with a human forward gait, a human backward gait, a horse gait and a bird gait for overcoming small obstacles by lifting the right leg of Cassino Hexapod III during a roll. The simulation was done on MATLAB. These paths are implemented in the robot for testing a hybrid locomotion of the robot. Direct and inverse kinematics are embedded in an Arduino script with the overcoming paths to be reproduced by an Android interface.

The interface has two buttons for connecting to the robot via Bluetooth, connection and disconnection buttons. Also, it has three checkboxes to select the operation mode of the robot: rolling, walking and overcoming. The rolling mode allows the robot to have a forward or backward displacement by using the mecanum wheels by just pressing the green arrows also this mode allows to turn with the omniwheels by pressing the back curved arrows. The walking mode allows to displace in a forward or backward direction with the legs, by using also the green arrows; the robot can turn with the mecanum wheels by using the black curved arrows. The overcoming mode lets the robot to overpass small obstacles by lifting the right leg during a rolling displacement. This mode has one button for each overcoming path. These buttons are: human forward, for a human-like forward gait; human backward, for a human-like backward gait; horse, for a horse-like gait; and bird, for a bird-like gait.

4 Experimental Setup and Paths Test

Several operation modes have been experimentally tested. In particular, forward and backward wheeled locomotion. Omniwheeled locomotion for circular motions, wheeled- legged hybrid operation with human-like forward gait, human-like back-ward gait, horse-like and bird-like gaits. The measured values of these tests are the robot Euler's angles, their accelerations, the power consumption, linear velocity and angular positions. To obtain the experimental measures a GY-87 IMU sensor is used together with a HC-SR04 ultrasonic sensor and a ACS712 current sensor.

4.1 Wheeled Locomotion

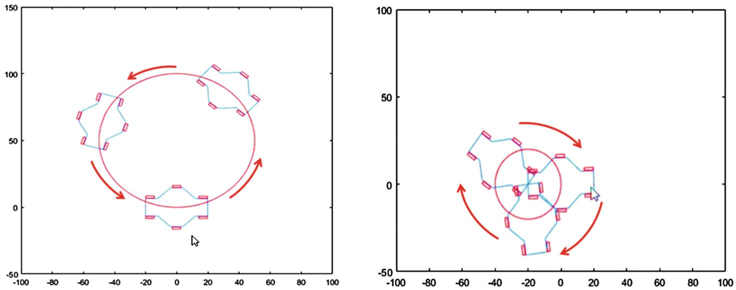
The wheeled locomotion of the robot is tested in two main modes: a four mecanum wheels mode and a six mecanum wheels mode, by using the angular velocities on Table 1. By this way is simple to know the performance parameters of the robot for a rolling mode with four and six wheels, thus is easier to select the best mode to roll. Angular velocities of mecanum wheels have been adjusted to each leg parameters to keep into account friction, which produces little lateral displacements during the rolling.

Table 1. Angular velocities for wheeled locomotion.

Wheel	ω [rad/s] (four wheels mode)	ω [rad/s] (six wheels mode)
Left forward wheel (ω_1)	3.0751	3.3244
Left wheel (ω_2)	0	3.3244
Left backward wheel (ω_3)	3.0751	3.3244
Right forward wheel (ω_4)	2.8258	2.8258
Right wheel (ω_5)	0	2.8258
Right backward wheel (ω_6)	2.8258	2.8258

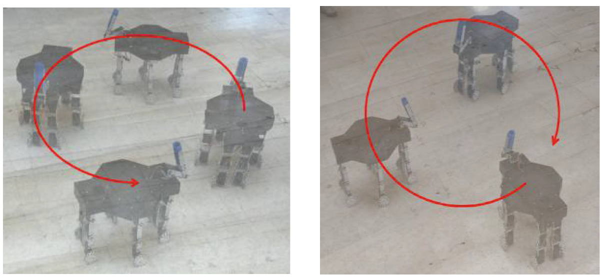
4.2 Omniwheeled Locomotion

The omniwheeled locomotion is tested by applying the equations of the mecanum wheels for a six-wheeled robot with odometry parameters, it is simulated the following of a circumference of one meter of diameter by changing it local coordinates in "x" and "y" axis, Fig. 2. The simulation uses the real lengths of the robot. With the simulation it is obtained the angular velocities of each wheel. In Fig. 3 it is shown a snapshot of the tested omniwheeled locomotion.



a) b)

Fig. 2. Simulation of an omniwheeled locomotion: (a) changing it local coordinates in "x" axis, (b) changing it local coordinates in "y" axis.



a) b)

Fig. 3. Snapshot of the omniwheeled locomotion: (a) changing it local coordinates in "x" axis, (b) changing it local coordinates in "y" axis.

4.3 Wheeled-Legged Hybrid Operation

The wheeled-legged hybrid operation is developed and tested to overcome small obstacles during a rolling mode. This overcoming mode has been implemented with four different obstacle avoidance paths, defined as human-like forward gait, human-like backward gait, horse-like and bird-like gaits. Each overcoming path let to over-pass obstacles of 50 mm of height and 100 mm of length. An obstacle overcoming test is implemented with each step path to overpass an eraser and a 3D printed cube. These step paths are implemented with the middle right leg (lifting leg) of the robot as shown in the snap-shot sequence in Fig. 4.

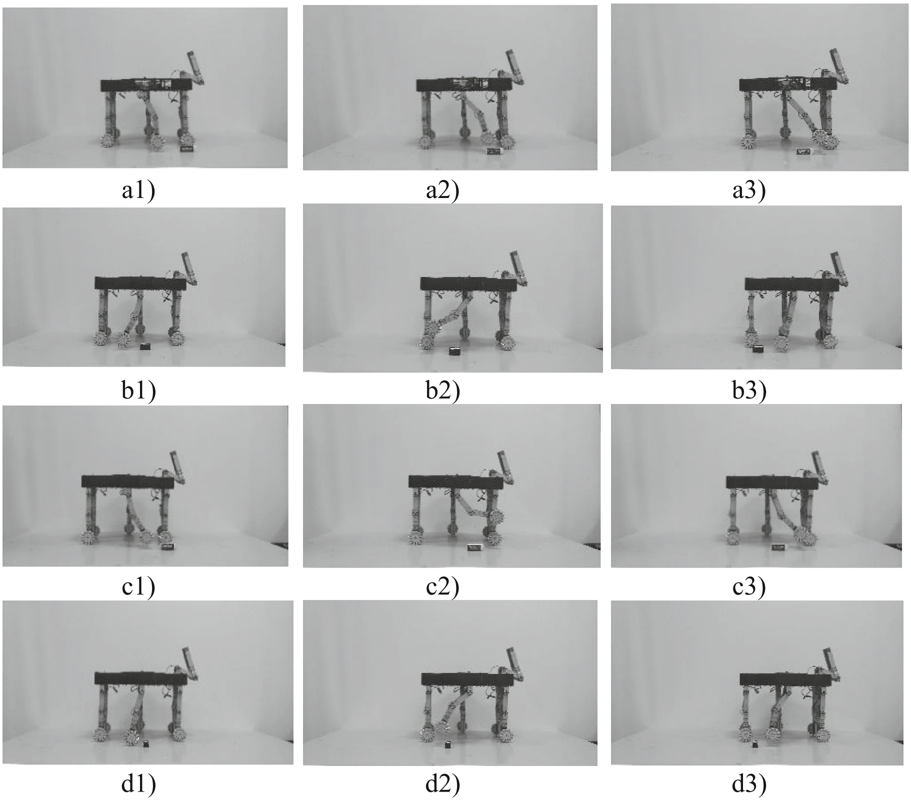


Fig. 4. Photo sequence of obstacle overpassing with human-like forward gait (a), human-like backward gait (b), horse-like (c) and bird-like (d) gaits: (a1) t = 0 s; (a2) t = 5 s; (a3) t = 10 s; (b1) t = 0 s; (b2) t = 5 s; (b3) t = 10 s; (c1) t = 0 s; (c2) t = 5 s; (c3) t = 10 s; (d1) t = 0 s; (d2) t = 5 s; (d3) t = 10 s.

5 Test Results

This section describes the experimental results, which have been obtained for the operation modes described in the last section. Data acquisition has been achieved by using a LABVIEW environment and a National Instrument NI-DAQ 6009 data acquisition board. An ultrasonic sensor is used to measure the linear velocity of the robot. A current sensor is used to obtain the current consumption by the robot during tests. An IMU sensor is used to calculate angular displacements as Euler's angles of the robot (Roll, Pitch and Yaw), also it let to know the linear accelerations along the above axes.

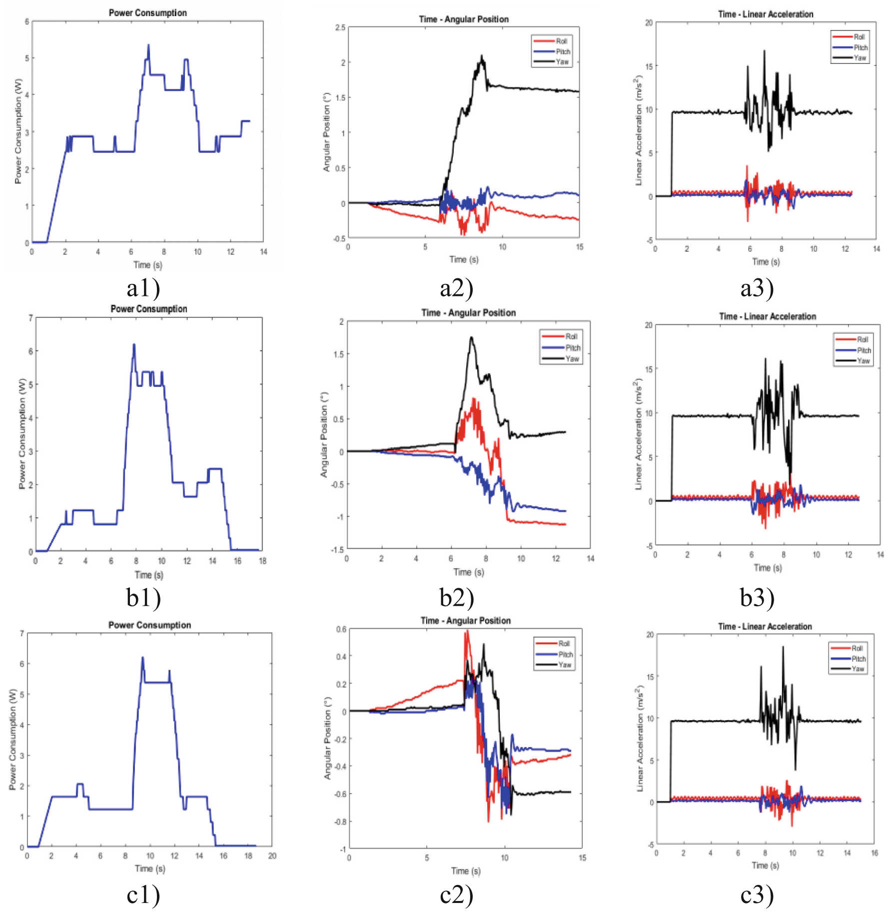


Fig. 5. Graphics of the acquired data of the wheeled locomotion test with four wheels (a) and six wheels (b), and overcoming obstacles test (c): (a1) power consumption; (a2) angular displacement; (a3) linear accelerations; (b1) power consumption; (b2) angular displacement; (b3) linear accelerations; (c1) power consumption; (c2) angular displacement; (c3) linear accelerations.

The behavior of the robot during the wheeled and wheeled-legged hybrid locomotion tests is presented in Fig. 5. One can note that power consumption is over 6 W for the six wheels mode, Fig. 5(b1). Moreover, it is possible to observe that the robot has a small angular displacement during the roll, in Yaw with maximum 2.1° with four wheels mode, Fig. 5(a2). Moreover, there is some vibrations, which is also reflected in the power consumption graphic, as shown in Figs. 5(a1) and (b1). The measured vibrations are mostly due to joint clearances and friction. The average values of the obtained results of all the tests are summarized in Table 2.

Table 2. Average measured values of the different tests with Cassino Hexapod III.

Test mode	Linear velocity [cm/s]	Max. angular displacement [°]	Max. linear acceleration (Roll) [m/s^2]	Power consumption [W]
Rolling: four wheels	13.46	2.1	3.51	3.35
Rolling: six wheels	15.23	1.73	2.21	6.85
Ominiwheeled	11.55	–	1.21	6.45
Overcoming	14.17	0.51	2.62	6.2

6 Conclusions

This paper presents successful laboratory experiences with the Cassino Hexapod III hybrid wheeled-legged robot. A simple interface has been implemented within an Android App to achieve various operations modes as rolling mode, walking mode and overcoming mode. Results of experimental tests with the rolling mode show the difference of the performance parameters between rolling with four and six wheels. Also, the experimental results of the omniwheeled and wheeled-legged hybrid locomotion demonstrate the motion capabilities of Cassino Hexapod III especially as referring to the use of mecanum wheels with legs motion for a hybrid locomotion to overcome obstacles successfully and to follow circular paths by using different configurations.

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