AN HYBRID LOCOMOTION SERVICE ROBOT FOR INDOOR SCENARIOS [1]

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Abstract
This paper describes the project of a hybrid locomotion robot for basic indoors service missions or to act as an indoors companion robot.
Two crawlers allow the robot to move through medium rough flat surfaces and ramps. Wheeled-legs are used to overcome common obstacles such as stair steps. This alternative way of locomotion empowers the robot to overcome obstacles by lifting up its main body above them.
Preliminary experimental results demonstrate the effectiveness of this form of hybrid locomotion in a typical indoor scenario.

Keywords: Hybrid robot, Indoor scenario, Companion robot, Service robot

1. INTRODUCTION

Along the years robotics has been setting some simple kinematics structures as a sort of locomotion standards. This is the case of the unicycle robot, legged (biped, tripod, hexapod) robots and more recently omni-directional robots. These are examples of robots able to move on smooth surfaces. However, the real world is often clutered with obstacles that force the robots to use complex navigation algorithms.

This paper presents a robot designed to operate in a specific environment, that is, the kinematic structure is drawn from the observation of the environment yielding a hybrid wheeled-legged robot.

Hybrid locomotion, with crawlers and wheeled-legs, offers a new solution to navigate through typical indoor scenarios. These are often formed by a set of flat surfaces superimposed on each other according to some particular structure. Figure 1 illustrates common examples of such scenarios.

Figure 1. Typical indoor scenario with ramps, stairs and flat surfaces

A robot able to move freely in a human environment, with stairs, ramps and similar obstacles,

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would certainly be useful for many applications, such as active surveillance and robotic services like transporting light materials in a hospital. The study of autonomous agents with these capabilities is far from being concluded. Robots using hybrid locomotion systems, such as the "Octal Wheel", (Takita *et al.*, 2004) and the "Chariot III",(Nakajima *et al.*, 2004), are able to navigate through multiple indoor scenarios. Both examples have complex mechanisms of locomotion, with a large number of actuators and sensors that requires a complex control architecture. However, typical indoor scenarios may present difficulties to these robots For instance, the "Octal Wheel" can only climb steps with very restricted dimensions.

The robot described in this paper (see Figure 2) is specially fit to move over stair steps. Its dimensions allow the operation over most types of stair steps and maneuver in most of the spaces inhabited by humans. Therefore, it represents an interesting platform to develop more ambitious projects (of social relevance) such as the development of a companion robot that is able to perform basic domestic services.

Figure 2. The hybrid robot THOR

The hybrid locomotion of the robot results from the merging of crawlers with wheeled-legs. The crawlers are used due to their traction capability and easy maneuvering that allow the robot to change orientation rotating over its central axis, and passing over small obstacles or gaps without major problems. The wheeled-legs are used to lift the robot over higher obstacles. Once there, the wheeled-legs are retracted and the crawlers are used to support him and advance. This combination of locomotion modes enables the robot to successfully pass over a large variety of obstacles.

The experimental prototype was developed using Lego MindStorms bricks to profit from the incomparable prototyping flexibility of the Lego system. Despite the limited power of the motors, gear backlashes and low precision sensors, the experimental results show the effectiveness of the robot.

The paper is organized as follows. Section 2 describes the structure of the robot. Section 3 details the locomotion strategies the robot can use. Section 4 presents the results of a set of experiments. Section 5 presents the conclusions of the paper and points future work.

2. ROBOT STRUCTURE

This project aims at developing a robot that could easily climb stair steps and navigate through fairly hard terrains, with gaps, small obstacles and inclined surfaces such as those often encountered in indoors scenarios. In order to achieve the desired locomotion characteristics the robot was equipped with rubber crawlers that yield the locomotion over smooth and medium rough surfaces and with wheeled-legs to sustain the robot while climbing/descending the stairs.

The robot is composed by three main parts shown in Figures 3, 4 and 5. The actual structure with legs, RCX and 6 batteries, is 31,5 cm height, 12,5 cm long and 18,5 cm large. The overall weight is about 1,0 kg.

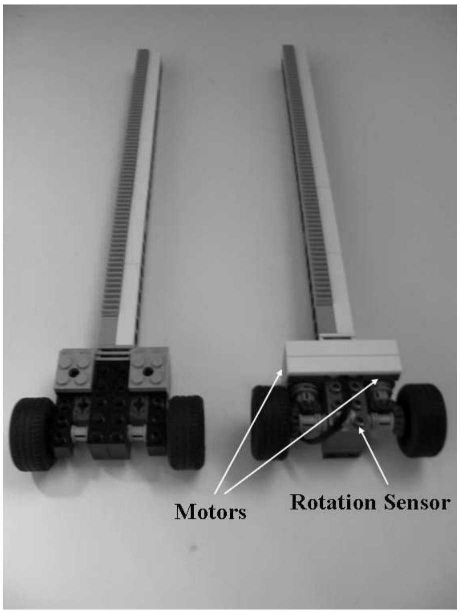

Figure 3. Wheeled legs

Figure 3 illustrates the two wheeled-legs which are capable of elevating and propelling the robot forward. The front one (leftmost in the picture) will be equipped with a light sensor that will be used to detect terrain gaps arising when descending steps. The wheels in this leg are not actuated, only being used in supporting and rolling. The rear wheeled-leg (rightmost in the picture) also helps in support, but its primary function is to move the robot when lifted. It is therefore equipped with two small motors and a rotation sensor. Both legs measure 29,5 cm and allow the robot to climb steps up to 18,5 cm.

The design of the wheeled legs is the result of the need to build a compact and robust lifting mechanism. Alternative kinematic structures, e.g., using serial kinematic chains, can easily be used to replace these legs, eventually with somewhat additional flexibility. Still, the structure considered in the paper adequately illustrates the potential of hybrid locomotion.

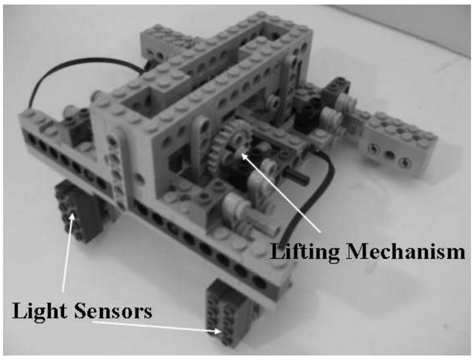

Figure 4. Main body

Figure 4 shows the main body of the robot that links the two crawler structures and supports the wheeled-legs and lifting mechanism. The torques needed to lift the robot are obtained through a set of micro-motors with reduction gears including worm screws. In addition to the high reduction factor, worm gears set the force transmission as unidirectional, meaning that a force applied to the wheeled-leg does not submit the motor to the corresponding opposite force, while a force imposed by the motor generates the wheel-leg movement. This is extremely useful when the robot is fully lifted, supported only by the wheeled-legs, as the motors do not need to be in permanent effort to uphold the elevation.

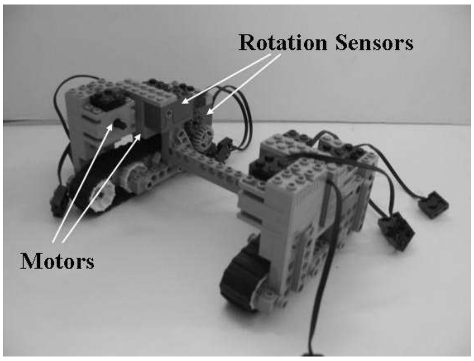

Figure 5. Crawler structures

Figure 5 displays both right and left crawler structures. The torque transmission from the motor to the caterpillar is identical to the used in the lifting mechanism. This strategy allows forceful, but slow, motion (approximately 1,33 cm/s) and prevents the crawlers from applying opposite forces to the motor, saving power and avoiding extended usage. Each of the crawlers is actuated by a single motor.

3. LOCOMOTION STRATEGIES

The robot, named THOR, is able to operate in most indoor scenarios. This type of environment usually presents some structure, often being composed by objects in three main classes: smooth surfaces (Figure 6), stairs (Figure 7) and ramps (Figure 8).

Figure 6. Flat surface in an indoor scenario

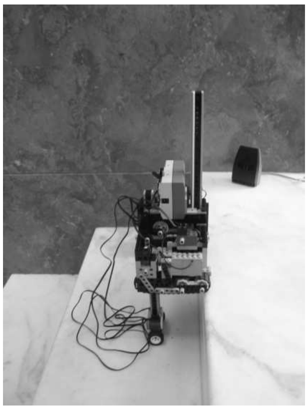

Figure 7. Stairs in an indoor scenario

Figure 8. A ramp in an indoor scenario

Excluding stairs and very inclined surfaces, where wheeled-legs are likely to be more effective, the robot can successfully navigate in most scenarios using only its primary mean of locomotion, i.e., the crawlers. In specially inclined surfaces the robot only needs to compensate with one of the wheeled-legs, leaving stair steps as the most challenging indoors obstacle.

In order to test THOR's ability to surmount stair steps, a simpler version of THOR was developed. The finite state automaton that controls the surmounting of stair steps has the following states (see Figure 9) :

(1) Move forward until a stair step is detected,
(2) Lift until the height of the obstacle is reached,
(3) Advance until the front of the caterpillars are over the stair step,
(4) Retract the frontal leg,
(5) Advance until the rear leg touches the obstacle,
(6) Retract the rear leg.

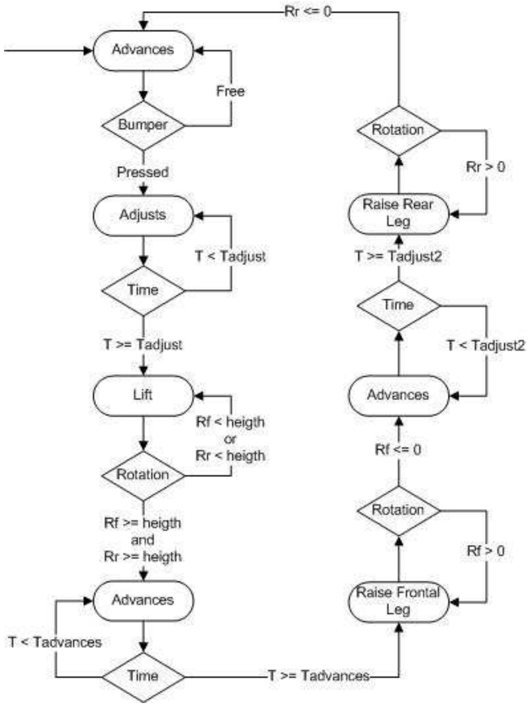

Figure 9. A FSM for surmounting stair steps

The usual state machine semantics is used, with circles containing the operation that is being performed and diamonds showing the variable that is being evaluated. Table 1 describes the action in each state. Sensor information from the rotation sensors in the lifting mechanism of each wheeled-leg and a frontal bumper are used.

The algorithm in Figure 9 uses only one environment variable, the step height, and hence the adjustment of the locomotion to a large variety of stairs, is a fairly easy task.

Advance forward	The robot moving forward
Adjust	The robot is moving to gain some distance from the step, avoiding friction while moving up
Lift	Both legs are lifting the robot until the height of the step is reached
Raise Front Leg	the robot is retracting the frontal leg
Raise Rear Leg	The robot is retracting the rear leg
Rf	The robot is rotating of the front wheeled-leg
Rr	The robot is rotating of the rear wheeled-leg

Table 1. Actions in the stair climbing FSM

Similar FSMs can be provided for the other classes of indoor scenarios considered in Section 3, smooth surfaces, ramps and stair steps.

4. EXPERIMENTAL RESULTS

The THOR version presented in the paper is a reduced version of the full robot currently under development. This version uses the Lego RCX 1.0 microcomputer and hence it is limited to three actuators and three sensors. Such small number of available sensors and actuators allowed by the RCX brick impose severe restrictions on the motion capabilities of this test robot.

Climbing steps requires independent control of the lifting mechanism of each wheeled-leg, leaving only one actuator channel for both crawlers and wheels. This limits the robots movement to forward and backwards, constraining wheels and crawlers to move at the same time.

In order to accomplish a stable elevation, both lifting mechanisms need a rotation sensor to control the height of each wheeled-leg. The third sensor considered is connected to a bumper for sensing stair steps.

The speed of the wheels and crawlers is set to a constant value. This is not an issue in what concerns step climbing as the crawlers are not required to run over large distances and hence the small differences between their speeds are likely not to originate a significant undesired turning effect.

The first demonstration setup for THOR was developed implementing the low level motor controllers in the RCX and the FSA in Figure 9 in MatLab.

Communication between the computer running the Matlab and the RCX brick was made using the Lego infrared tower with a simple bidirectional communication protocol. The following figures illustrate the main stages of a step climbing phase.

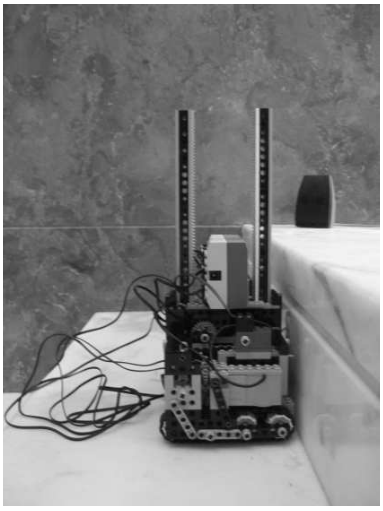

Figure 10. Approaching stair steps

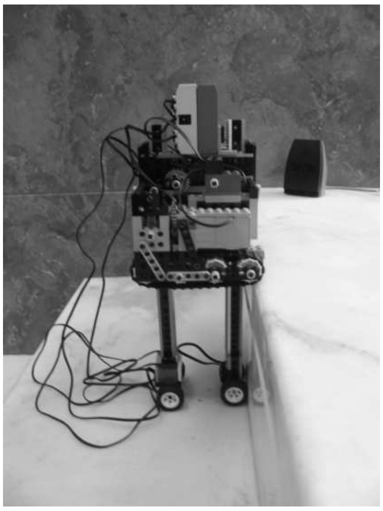

Figure 11. Elevating to even the step's height

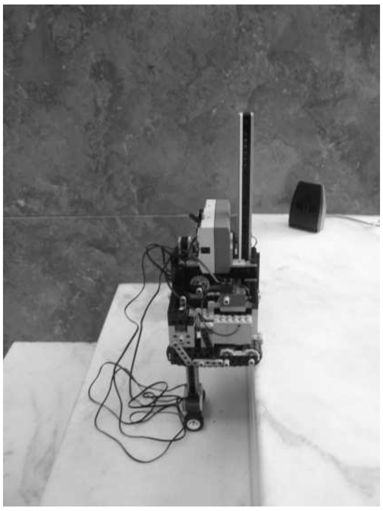

Figure 12. Retracting frontal wheeled-leg

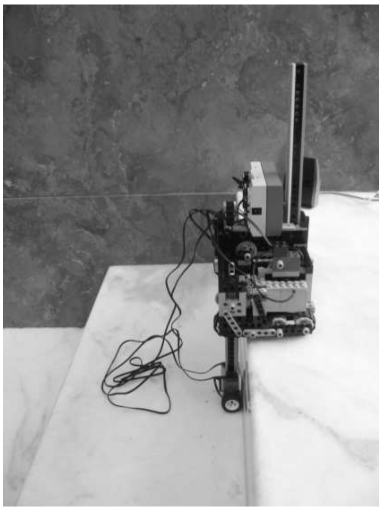

Figure 13. Advancing over the step

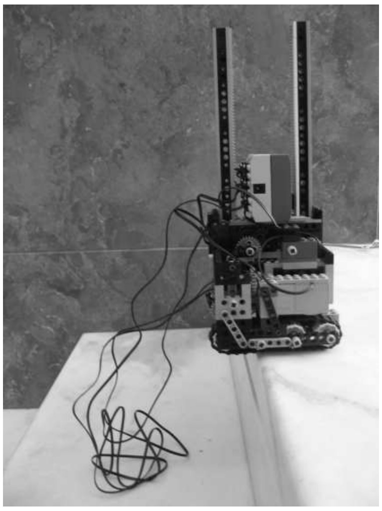

Figure 14. Retracting the rear wheeled-leg

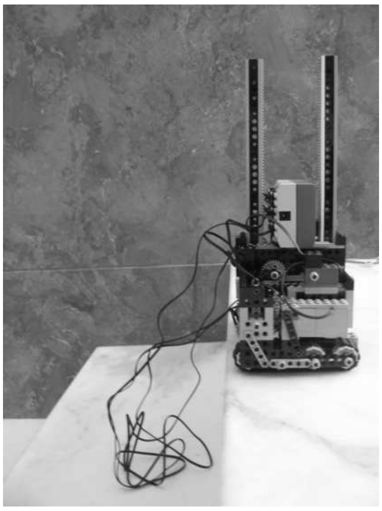

Figure 15. Proceeding towards the next stair step

5. CONCLUSIONS

The experimental results demonstrate the effectiveness of the hybrid locomotion structure proposed in step climbing. The robot is able to maintain the equilibrium even at full elevation (around 18,5 cm above the ground). Additional lifting capabilities are likely to require the use of active control techniques and even small design improvements. However, the prototype presented is already able to move over the important classes of scenarios that are usually found indoors.

The robot structure has already been defined (up to minor adjustments). The development of dedicated hardware to communications and control, able to account for more sensors and actuators is likely to improve the performance of THOR. For instance, the use of an inclinometer and additional rotation sensors in the crawlers will extend the motion capabilities of the legs.

The final stage of this project regards the development of high level navigation algorithms, which will enable the robot to navigate in most indoor scenarios. The robot may work in cooperation with external sensing devices and/or other robots in the environment such as video cameras that may provide data used to locate the robot in the environment.

6. ACKNOWLEDGEMENTS

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