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Elastic Locomotion of a Four Steered Mobile Robot

Michel Lauria, *Member*, *IEEE*, François Michaud, *Member*, *IEEE*, Marc-Antoine Legault, Dominic Létourneau, Philippe Rétornaz, Isabelle Nadeau, Pierre Lepage, Yan Morin, Frédéric Gagnon, Patrick Giguère, Julien Frémy, Lionel Clavien

Extended Abstract

THE most common ground locomotion method to make a mobile robot move is to use two-wheel drive with differential steering and a rear balancing caster. Controlling the two motors independently makes the robot non-holonomic in its motion. Such robots can work well indoor on flat surfaces and in environments adapted for wheelchairs. But the benefit of providing mobility to a robot directly relies on its locomotion capability, for handling different types of terrains (indoors or outdoors) and situations such as moving slowly or rapidly, with or without the presence of moving objects (living or not), climbing over objects and potentially having to deal with hazardous conditions. It is with this objective in mind that we designed AZIMUT. AZIMUT is a legged tracked wheeled robot capable of changing the orientation of its four articulations [1]. Each articulation has three degrees of freedom (DOF): it can rotate 360° around its point of attachment to the chassis, can change its orientation over 180°, and rotate to propulse the robot.

AZIMUT's first prototype was built in 2002 using stiff transmission mechanisms, with motors and gearboxes placed directly at the attachment points (for directing and for rising) of the articulations (which were wheel-leg-tracks). These design choices made the platform vulnerable to shocks when moving over rough terrain. To deal with the variety of conditions of the real world, mobile robotic platforms need to be more "elastic", "compliant" or "interactive" [2], as opposed to rigid as most of the current platforms are. Adding compliance to the platform's actuators and being able to sense the forces from the environment are important requirements for making safe and efficient robots operating in real life settings.

In 2004, we initiated the design of AZIMUT's second prototype, increasing stability and compliance by adding a vertical suspension (shown bottom right of Fig. 1) and using Series Elastic Actuators (SEA) for the motorized direction (upper left of Fig. 1) of AZIMUT's articulations. An elastic element (e.g., a spring) is placed in series with the actuation mechanism, and a sensor is used to measure its deformation, allowing to sense and control the torque at the actuator's end [4,5,6]. The second prototype is smaller (60,3 cm × 51,9 cm × 29,3 cm) than the first, lighter (33.7 kg vs 63.5 kg) and faster (directional speed of 180°/sec vs 120°/sec, no load; maximum velocity of 1.4 m/s vs 1.2 m/s). The video shows the different capabilities of this prototype. The vertical suspension allows all four wheels to stay on the ground when moving across obstacles. Elasticity in the direction can be seen from the small oscillations when the robot changes direction, and is necessary to protect the gearboxes when moving on rough terrain.

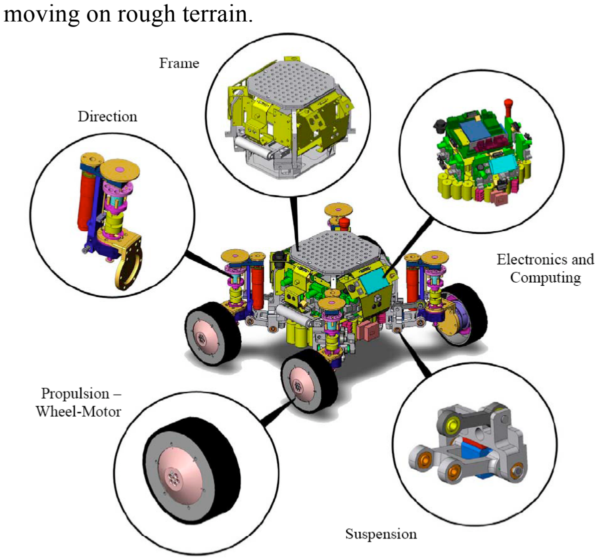

Fig. 1 – Illustration of AZIMUT's second prototype

One limitation found with SEA is their size, and making compact elastic actuators is a requirement when designing a robot that has to be small enough to go through doors. The use of SEA at the attachment point of tracked articulations (circled on Fig. 2) would make the robot too large. This led us to design a new and compact high-force low-impedance rotary actuator named Differential Elastic Actuator (DEA)

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F. Michaud holds the Canada Research Chair (CRC) in Mobile Robotics and Autonomous Intelligent Systems. He is with the Department of Electrical Engineering and Computer Engineering, Université de Sherbrooke, Québec, Canada, (e-mail: Francois.Michaud@USherbrooke.ca).

M. Lauria is with the Department of Electrical Engineering and Computer Engineering, Université de Sherbrooke, Québec, Canada, (819 821-8000 x 62867, e-mail: Michel.Lauria@USherbrooke.ca).

M.-A. Legault, D. Létourneau, P. Lepage, Y. Morin, F. Gagnon, P. Giguère, J. Frémy and L. Clavien are with the Department of Electrical Engineering and Computer Engineering, Université de Sherbrooke, Québec, Canada.

P. Rétornaz is with the Department of Microtechnics, École Polytechnique Fédérale de Lausanne, Switzerland.

[3,7]. DEA uses a differential coupling instead of a serial coupling between a high impedance mechanical speed source and a low impedance mechanical spring. This results in a more compact and simpler solution, with similar performances.

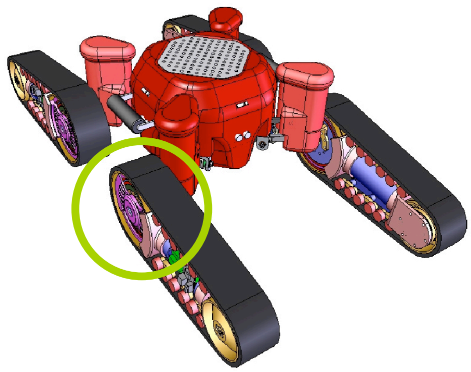

Fig. 2 – Track version of AZIMUT

In Dec. 2007, we completed the first integration of AZIMUT's third prototype, using DEA for the direction of the wheels. In [7], we demonstrate that AZIMUT has a degree of maneuvrability of 3 (i.e., a degree of steerability of 2 plus a degree of mobility of 1) and that it can be controlled from its Instantaneous Centre of Rotation (ICR). The video shows three teleoperation modes, illustrated in Fig. 3.

a) Because of the symmetrical shape of the robot, there are four possibilities in this mode. The ICR is constrained to move along two portions of a straight line perpendicular to the previously defined forward direction and its position can be shifted using the «left-right» degree-of-freedom (DOF) of a joystick. The «forward-backward» DOF is used to define a desired acceleration or deceleration.
b) The ICR is constrained to move along a quarter portion of an infinite radius circle, i.e., the four wheels are constrained to remain parallel to some direction, comprised within a 90° range, which can be shifted using the «left-right» DOF of the joystick. The «forward-backward» DOF is used to define a desired acceleration or deceleration. This mode is similar to the locomotion of *synchro-drive* robots because the chassis of the robot keeps always the same orientation.
c) This mode can be used to steer the robot with a very tight turning radius. In this mode, both DOF of the joystick are used to shift the ICR position within a central squared area. Right and left buttons of the joystick are used to control the turning direction.

It is important to note that for each of these three modes, ICR position can be changed without having to stop the robot. This is possible because there is some natural compliance due to the presence of the torsion spring in the four steering axis and of some artificial compliance, implemented by a low gain proportional speed controller, in the four propulsion axis.

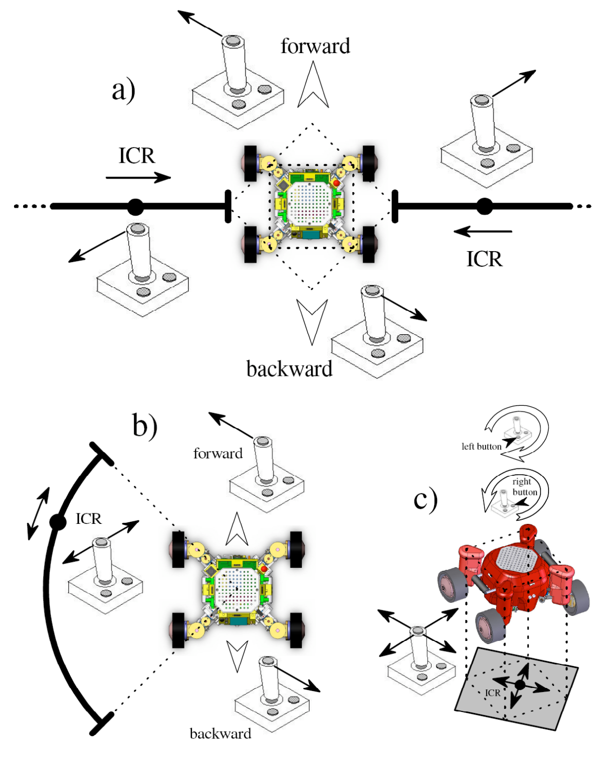

Fig. 3 – AZIMUT's teleopreation modes

Being omnidirectional and elastic, AZIMUT shows great potential for autonomous or semi-autonomous usages for search and rescue, service robotics, rehabilitation robotics (playing the role of an assistive walker) and in group transportation of common payloads or large objects (changing direction in a coordinated fashion without requiring a rotative fixture for the object to carry).

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