AZIMUT, a Leg-Track-Wheel Robot

François Michaud[1], Dominic Létourneau[1], Martin Arsenault[1], Yann Bergeron[1], Richard Cadrin[1], Frédéric Gagnon[1], Marc-Antoine Legault[1], Mathieu Millette[1], Jean-Franois Paré[1], Marie-Christine Tremblay[1], Pierre Lepage[1], Yan Morin[1], Serge Caron[1]

[1] *Université de Sherbrooke, Sherbrooke (Québec Canada), laborius@gel.usherb.ca*

Abstract

AZIMUT is a mobile robotic platform that combines wheels, legs and tracks to move in three-dimensional environments. The robot is symmetrical and is made of four independent leg-track-wheel articulations. It can move with its articulations up, down or straight, or to move sideways without changing the robot's orientation. To validate the concept, the first prototype developed measures 70.5 cm × 70.5 cm with the articulations up. It has a body clearance of 8.4 cm to 40.6 cm depending on the position of the articulations. The design of the robot is highly modular, with distributed embedded systems to control the different components of the robot.

1 Introduction

The most common way to build a mobile robot is to use two-wheel drive with differential steering and a rear balancing caster. Controlling the two motors independently makes the robot holonomic in its motion. Such robots can work well indoors on flat surfaces and in environments adapted for wheelchairs. Many commercial platforms based on this locomotion mechanism exist. Using such platforms allows to focus on two important aspects regarding intelligent autonomous robots: perception and decision-making.

However in real-life settings it is necessary to deal with uneven terrains (outdoors and also indoors): stairs and obstacles that robots would need to go over or to pass across limit the use of conventional wheeled robots. Designing robots that can address the complexity of operating in three-dimensional worlds moves the focus on the locomotion capabilities of autonomous machines, which are as important if not more as perception and decision-making. In fact, the locomotion aspect of a robot plays a direct role in the perceptual and reasoning capabilities it requires to operate in these complex conditions.

Humanoid robots are surely one design solution to deal with 3-D environments. As humans, a robot with two legs would be able to go up and down stairs for instance. Since stairs are structures built by humans, making a robot similar to humans allows it to be compatible with human-structured environments. Nevertheless, this might not be the most appropriate solution. For instance, a legged robot requires active control algorithms for the dynamics of the robot, e.g., to keep its balance (which usually requires for higher energetic needs). A robot with legs cannot generally move as fast as a robot with wheels, or work well on soft surfaces (snow, mud, etc.). Other locomotion modalities might be more appropriate, like combining legs to wheels and tracks. This is kind of a natural solution since humans use various types of machines like cars, bicycles, snowmobiles, etc., to assist them in traveling more efficiently and compensate for the limitations of their legs. But unlike humans, it is possible for robots to combine the advantages of all by integrating multiple locomotion mechanisms to its structure.

This paper describes the design of a new robotic platform that we have named AZIMUT. AZIMUT is made of four independent leg-track-wheel articulations and can handle a wide variety of movements. This concept would allow the robot to be capable of holonomic and omnidirectional motion, climb or move over obstacles, go up and down stairs (even rotating ones). The design of such a sophisticated robot involves expertise in mechanical engineering, electrical engineering, computer engineering and industrial design. Modularity in all of these design areas is a key specification for such large-scale project, in order to benefit from the knowledge gained over the different prototypes made and to be made of the robot.

This paper is organized as follows. Section 2 describes the overall characteristics of the robot, outlining its locomotion capabilities. Section 3 presents its mechanical, hardward and software components. Section 4 addresses the capabilities of the first prototype built. Section 5 presents related work, followed by future work on the concept.

2 Characteristics of AZIMUT

The design objectives is to build a new robotic platform capable of performing a wide variety of movements in 3-D space like moving forward and backward, turning, rotating on itself, lifting itself up, moving over obstacles, going up and down stairs, and moving in all directions (omnidirectional). The design must also be modular, allowing to add and to change parts easily at the structural, hardware and software levels.

The design we came up with is shown in Figure 1. AZIMUT has four independent articulated parts attached to the corners of a square frame. Each articulated part combines a leg, a track and a wheel, and has three degrees of freedom. Overall, the robot uses 12 motors for its locomotion. The leg can rotate 360 degrees around the y axis and 180 degrees around the z axis. Once an articulation is placed at the right position, the system is designed to keep it in position without consuming electrical energy. When the articulations are stretched, the robot can move by making the tracks rotate around the legs. As the articulations move upward toward the orientation of the z axis, the point of contact of the leg with the ground moves from the track to the rubber strip fixed outbound of the attachment axle of the articulation (visible in figure 3). This rubber strip creates a very narrow wheel that allows the robot to change the direction of an articulation with minimum friction.

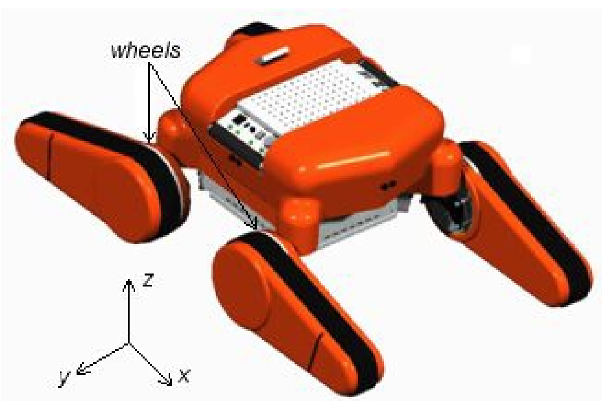

Figure 1: *AZIMUT.*

The robot also offers nice features such as: two retractable side-handles to lift the robot; an accessory-fixing plate on the top of the chassis; a PDA interface for debugging the onboard embedded systems of the robot; two control panels allowing easy interface with the onboard systems of the robot; a sliding compartment for the onboard PC/104 computer, making computer upgrade and maintenance easier; bodywork attached to the chassis using easily accessible fixtures.

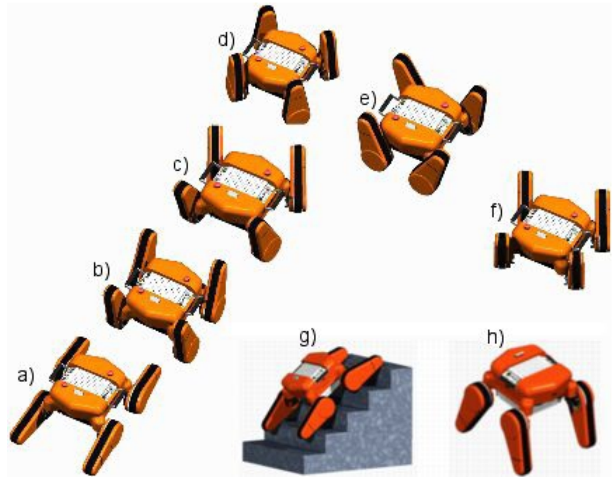

Figure 2: *Locomotion modes of AZIMUT.*

By placing the articulations in different positions, AZIMUT can adopt various locomotion modes like the ones shown in Figure 2. AZIMUT can move with its articulations parallel to the ground (a, g), on its wheels with the articulations up (b, c, d, e, f) or on the tracks with its articulations down (h). Differential steering can be used to make the robot turn in all of these modes, or the articulations can be placed in the desired direction of the robot. For instance, going from b) to f), the direction of the robot changes but not its orientation. The robot can turn on itself with minimum friction using mode d). In f), the robot can move using front or back two-wheel steering modes. The tracks are used in g) and h) to make the robot work on stairs, climb over obstacles or change its perceptual perspective of the world by raising itself up. Since each articulation is independent, the robot can create much more sophisticated modes. For instance, in can turn while climbing a staircase by changing the direction of the front and the back articulations. The robot can move with its front articulations stretched at 45 degrees in relation to the horizontal axis, which will allow the robot to climb over obstacles. The robot can cross its articulations and lift itself up when it gets stuck over an obstacle. Being omnidirectional, it would also be possible for a group of AZIMUT robots to change direction in a coordinated fashion while transporting together a common payload or large objects. Many other configurations can be imagined, and the 12 degrees of freedom on AZIMUT give the robot great flexibility and versatility in its motion capabilities.

3 AZIMUT's Design

Going from the concept to an actual prototype is a challenging endeavor. It requires the integration of sophisticated mechanical, electrical and computer components. Modularity at the structural, hardware and embedded software levels, all considered concurrently during the design process, reveals to be key in the design of such sophisticated mobile robotic platform.

3.1 Mechanical

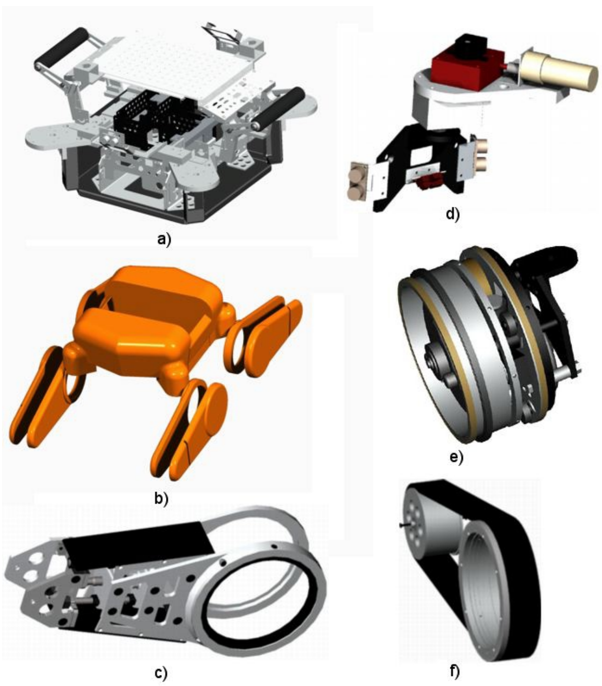

Figure 3: *AZIMUT'S mechanical subsystems.*

The mechanical components of AZIMUT are grouped into six subsystems, as shown in Figure 3. The four articulations are attached to the *Chassis* (a), which also holds the robot's hardware and its batteries. The batteries are placed at the bottom of the chassis to keep the center of gravity of the robot as close as possible to the ground. The retractable side-handles and the accessory-fixing plate are attached to the chassis. The *Bodywork* (b) is there to protect the internal components and for aesthetic reasons. The other subsystems are for each articulation. The *Direction* subsystem (d) allows to change the direction of an articulation and to lock it in position. The *Propulsion* subsystem (e) makes the combination of the track-wheel rotate, and allows the rotation of an articulation around the y axis. Once placed in position, the articulation is locked mechanically. An articulation is made of an assemblage of a track with two wheels (the *Track-Wheel* subsystem (f)) and the *Tensor* (c)) to extend the tracks and support the weight of the robot when it moves with its articulations down. Concerning the tracks, one particularity is that it is made of diamond profile conveyor belt (rubber) to ensure maximum adherence with stairs without damaging them. Figure 4 shows a closeup picture of a track-wheel.

Figure 4: *Diamond-shape track left to the rubber strip for the wheel.*

3.2 Hardware

AZIMUT's hardware is modular and is made of different subsystems that communicate with each other to exchange information and to coordinate their actions. Each subsystem has its own microcontroller, selected according to the processing requirements for the given subsystem. For AZIMUT, this approach is the most appropriate one because it allows to easily add functionality to the robot and to increase its robustness by distributing control over all its components.

Figure 5 represents the subsystems. Each articulation has its own *Local Control* subsystem (controlling its three motors using PID controllers) and *Local Perception* subsystem. The *Power* subsystem distributes energy coming from batteries or an external power source to all of the other subsystems. The *User Interface* subsystem is there to interface the PDA with the other subsystems of the robot. The *Inclinometer* subsystem measures the inclination of the body of the robot. The *Remote Control* subsystem allows to send commands to the robot using a wireless remote control. The *General Control* subsystem manages positioning of the articulations when modes are changed to avoid interference, and monitors the states of the subsystems to insure safety of the platform. The *Computing* subsystem consists of the onboard computer used for high-level decision making (e.g., vision processing for a camera that would be used by the robot). All of the subsystems exchange information using the *Coordination* bus. The *Synchronization* bus is also used to synchronize the control of the articulations (e.g., to make the robot go straight forward).

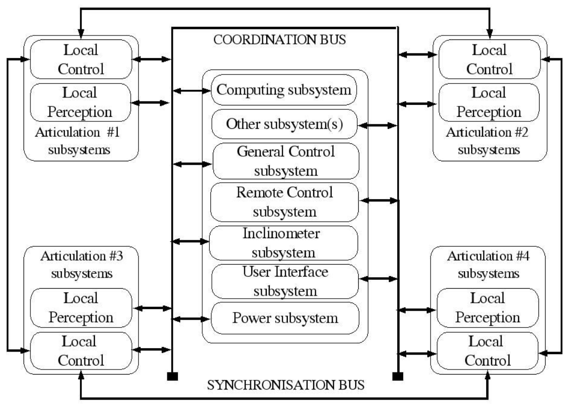

Figure 5: *AZIMUT'S Hardware Subsystems.*

The *Local Perception* subsystem of each articulation is made of one long-range ultrasonic sensor, two short-range ultrasonic sensors and five infrared range sensors, to detect objects and surfaces around the articulation. Figure 6 shows the perceptual zones using these sensors.

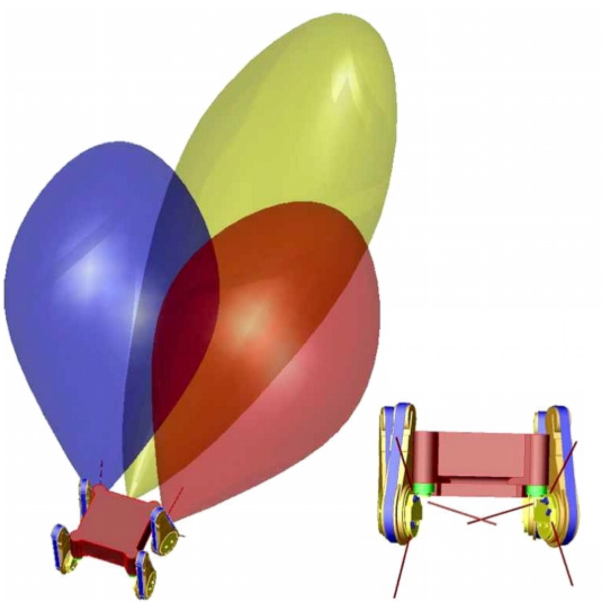

Figure 6: *AZIMUT'S Onboard Sensors.*

3.3 Software

There are two levels of software for AZIMUT: software for the subsystems and software designed for the overall control of the robot.

- At the subsystem level, each subsystem follows a general procedure that allows it to examine conditions and requests posted on the bus, to complete a self-diagnostic test, to process a command or a request addressed to it, to get the data from its sensors, to process them, to give commands to its actuators and to transmit back its status on the bus. Each subsystem is designed to be implicitly safe: when not activated, a subsystem is in a state that will not put the robot in a dangerous condition. The *General Control* subsystem has the responsibility of activating the appropriate subsystems.

- For the overall control of the robot, two types of software are used. The first is for testing and monitoring the states of the robot, using two different devices. One is implemented on a PDA. The PDA is a nice device for such purposes since it allows to use graphical representations of the status of the robot. A second interface is implemented on a remote computer connected to the *General Control* subsystem via a RS-232 serial link. This interface allows independent control of the motors and to monitor the states of motor encoders, the control loops and the data exchanged on the bus.

  The second type of software developed for the overall control of the robot is a simulator. The simulator makes it possible to imagine control scenarios without having to use the actual prototype. Such scenarios can be the transitions made by the articulations to move from one locomotion mode to another, the position of the articulations as the robot goes up or down stairs, the possible interference between the articulations, etc. The simulator allows to develop the algorithms for the *General Control* and the *Computing* subsystems.

4 First Prototype

Figure 7 shows pictures of the first prototype of AZIMUT, completed in December 2002. The robot is made of more than 2500 parts. The characteristics of this first prototype are summarized in Table 1. The nominal speed is measured on a flat surface and at 50% motor capacity. The motors used for propulsion are Ferrite ServoDisc motors. The direction and the rotation of the articulations use standard brush motors. The robot is equipped with two packs of 24V Ni-MH cells.

Concerning the embedded systems used for the onboard distributed subsystems, this prototype uses four nanoMODUL164 from Phytec, equipped with Infineon C164CI 20 MHz microcontrollers. These microcontrollers provide sufficient processing power

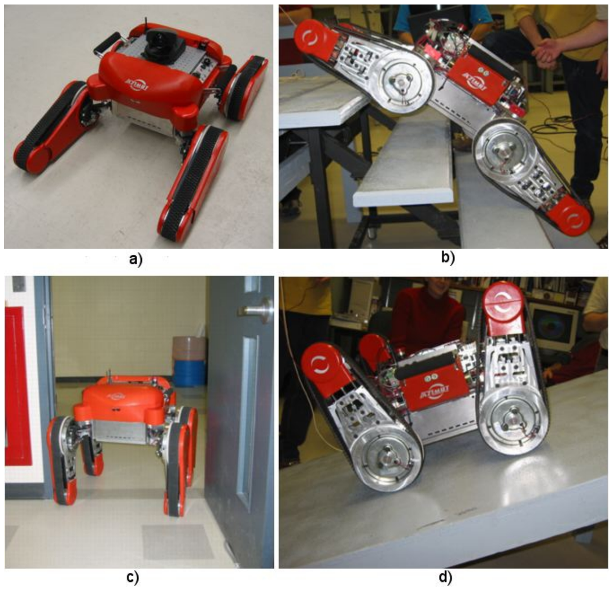

Figure 7: *AZIMUT a) with its articulations stretched; b) on stairs; c) going through a door; d) on an incline surface.*

to implement PID controllers for all of the three motors of an articulation. For subsystems other than the *General Control* subsystem, less processing capabilities are required. We designed a board that we named the PICoMODUL. It is made of a PIC 16F877, running at 20 MHz. Both the nanoMODUL and the PICoMODUL are designed to be stacked on other boards made for specific functions, like a 100 Amp motor drive for an articulation, a sensor board for the *Local Perception* subsystem, a board that monitors the energy consumption and recharges of the batteries, a board for the RF remote control, etc. CAN 2.0B 1 Mbps buses are used for communication between the subsystems.

The first prototype of AZIMUT demonstrates the capabilities of the robot in changing the orientation of its articulations for omnidirectional movements. The robot is also capable of moving with its articulations down and going through doors. Tests also confirms the ability of the robot in going up and down stairs and on incline surfaces. However, because of time and financial constraints, the chassis of the robot had to be made using aluminum and steel parts. This made the platform heavier than expected. So, this first prototype is not yet capable of lifting itself up. But the implementation allowed to pinpoint critical components that can be improved in a second prototype.

Table 1: *Specifications of the first prototype of AZIMUT*

Characteristics	Measures
Length	70.5 cm (articu. up/down) 119.4 cm (articu. stretched)
Width	70.5 cm
Heigth	38.9 cm (articu. stretched) 66 cm (articu. down)
Body clearance	8.4 cm (articu. stretched) 40.6 cm (articu. down)
Weight	63.5 kg
Nominal speed	1,2 m/s (4.3 km/h)
Direction speed	120°
Rotation speed	45°
Length articu.	48.9 cm

5 Related Work

Even though we came up with many solutions on our own, a lot of ideas from other robotic platforms exist in AZIMUT. For instance, AZIMUT is capable of changing the orientation of its articulations, like four-wheel steering vehicles [4]. Compared to other mobile robots, AZIMUT shares similarities with mostly three mobile robotic platforms: the Urban robot, the Workpartner and the HUR-Badger.

The Urban robot made by iRobot inc. is the most well known example of tracked mobile platform [3]. This robot has two side-tracks of 6 cm in length on each side, with two articulated tracks in the front that can do continuous 360 degree rotation and enable crossing curbs, climbing stairs and scrambling over rubble. For stairs, the robot deploys its side tracks, keeping good contact with the ground (making it more stable without requiring as much energy as to a humanoid robot). When the articulations are stretched out, the robot measures 88 cm in length. It is 40 cm wide and 18 cm high. It weighs 20 kg, with 3 kg of batteries. It can go as fast as 80 cm/s on flat surfaces. The newest version, named PackBot[1], is faster (2.2 m/s to 3.7 m/s). While AZIMUT might be heavier than the Urban robot (we evaluate that we can reduce the weight of AZIMUT by at least 20 kg), it provides a much diverse set of locomotion modes. The increase in weight might be compensated by the versatility of the locomotion modes. For instance, with its tracks deployed the Urban robot might have difficulty climbing a circular staircase for instance, while AZIMUT will more easily do so by reorienting its articulations.

WorkPartner [2, 5] is made from the Hybtor robotic platform. This design differs from AZIMUT by

[1] http://www.irobot.com

putting wheels at the end of four legs, but the robot also has 12 degrees of freedom. Using its wheels, the robot can reach a speed of 7 km/h (1.94 m/s). The robot has a hybrid power system, which consists of a 3 kW combustion engine and batteries, which means that it would be mainly used for outdoor applications. The platform is around 1.2 meters long, 1 meter high, weighs about 160 kg and the possible payload is 60 kg. Each leg has its own Siemens 167 microcontroller, which is similar to what we used, and the computer system is also distributed around a CAN bus protocol. The robots locomotion is made of three modes: the wheeled driving mode (with active balancing and active suspension), the walking mode (as for a four-legged robot) and a hybrid locomotion mode that allows the robot to walk by keeping the wheels on the ground. Workpartner is much more heavier than AZIMUT, and the legs on WorkPartner cannot change their orientations as in AZIMUT. AZIMUT would provide more flexibility in the locomotion modes.

The concept closest to AZIMUT is the High Utility Robotics (HUR) Badger [1]. The HUR-Badger concept is derived from an analysis of what kind of locomotion capabilities a mobile robotic platform would need to follow a human soldier in an urban combat scenario. The design they came up with is made of two tracked units connected to a common body using rotational joints. The tracked units are sized such that they can be rotated through each other. By simulating in Working Model[2] the operational modes of the robot, they were able to demonstrate how the platform could be used in various configurations that would be necessary in real operational conditions. For AZIMUT, the target was for indoor environments like homes and offices. But AZIMUT validates with a real prototype the concept of leg-track articulations. AZIMUT's articulations can be made to work in pair-units instead of independently, and placed on an unsymmetrical base, coming close to create a first implementation of the HUR-Badger concept. In that regard, the expertise gained while making AZIMUT could be mostly beneficial to making a real first prototype of the HUR-Badger.

6 Conclusion and Future Work

In this paper we presented AZIMUT, a mobile robotic platform with four independent leg-track-wheel articulations. The overall objective of the concept is to make a robot capable of versatile motions and to negociating difficult 3D obstacles such as stairs. The first prototype confirms AZIMUT's potential to reach these objectives, and opens up new research issues such as distributed control of the articulations and perception in 3D environment for navigation and for obstacle avoidance. We will continue working with this first prototype to explore further the various capabilities of the robot such as the four-wheel-steering control modes, active perception derived from sensors embedded on each articulation and the measurements returned by the inclinometer in the various locomotion modes of the robot. In the very near future we hope to be able to build a second prototype, correcting the limiting factors of the first and demonstrating the full capabilities of the concept.

[2] http://www.krev.com/

Acknowledgments

F. Michaud holds the Canada Research Chair (CRC) in Mobile Robotics and Autonomous Intelligent Systems. This research is supported financially by CRC, CFI and the Faculty of Engineering of the Université de Sherbrooke. The authors also want to thank other participants involved in the project: M. Deschambault and H. Rissmann from the Department of Industrial Design of the Université de Montréal; É. Desjardins, P. Faucher, M.-A. Fortin, H. Lavoie, F. Rivard, M.-A. Ruel, V. Bao Long Tran from the Department of Electrical Engineering and Computer Engineering of the Université de Sherbrooke. A patent is pending on AZIMUT.

References

[1] B. L. Digney and S. Penzes. Robotic concepts for urban operations. In *Proceedings SPIE*, 2002.

[2] A. Halme, I. Leppänen, and S. Salmi. Development of Workpartner-robot - Design of actuating and motion control system. In *Proceedings Second International Conference on Climbing and Walking Robots*, Portsmouth, England, 1999.

[3] L. Matthies, Y. Xiong, R. Hogg, D. Zhu, A. Rankin, B.Kennedy, M. Hebert, R. Maclachlan, C. Won, T. Frost, G. Sukhatme, M. McHenry, and S. Goldberg. A portable, autonomous, urban reconnaissance robot. In *Proceedings Sixth International Conference on Intelligent Autonomous Systems*, 2000.

[4] D. Wang and F. Qi. Trajectory planning for a four-wheel-steering vehicle. In *Proceedings International Conference on Robotics and Automation*, 2001.

[5] S. J. Ylönen and A. J. Halme. Workpartner - Centaur like service robot. In *Proceedings IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2002.