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Force-Controlled Motion of a Mobile Platform

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I. INTRODUCTION

Robots are usually built using stiff actuators that can provide impressive motion performances. However, they struggle to control the force, they do not handle collisions graciously and are generally bad at interacting significantly with partially unknown or kinematically constrained environments. One solution is to add a force sensor in the closed-loop control of backdrivable actuators [1], but this is limited in terms of stability, safety and robustness [2][3]. One of the foremost initiatives using this method was undertaken by the German Aerospace Center (DLR) and resulted in three generations of extensively optimized lightweight robotic arms [4] that can physically interact with people. Performances are impressive but robustness is still an issue [5].

Another solution consists of placing a compliant element between the actuator and the output to enhance force resolution, control stability and impact tolerance. For instance, Series Elastic Actuator (SEA) [6] put a low impedance element (i.e., a mechanical spring) in series with the actuator's gearbox. This provides a backdrivable actuator with intrinsic compliance [6]. SEA have been used in walking and running robots, motorized prosthesis-orthesis, rehabilitation devices and a few interactive manipulators such as Domo [7].

For wheeled or tracked robots, lack of compliance in locomotion is compensated by limiting their velocity and by avoiding contact with the environment using proximity sensors. A two-wheel balancing platform has built-in compliance as long as it has the required space to keep its equilibrium once contact is made with the environment. Another solution is implemented on AZIMUT-3, an omnidirectional nonholonomic platform with four steerable wheels. By having off-centered steerable wheels, an applied torque can be measured for each wheel. Since the offset acts as a lever, any force applied at the contact point of the wheel can be measured as a torque on the steering axis by applying the moment arm formula. This is impossible with a centered wheel, with which only forces applied anywhere but the contact point (and its antipode) would be measurable at the steering axis. It is still impossible, however, to measure any forces parallel to the propulsion axis with these off-centered orientable wheels. Measuring forces provoked at the contact point implies that it is not only possible to measure those provoked by collisions with the wheels, but also ones applied to the chassis as well.

Differential Elastic Actuators (DEA) [8] are used to steer AZIMUT-3's wheels, and provide compliance, safety and torque control capabilities. Compared to SEA, DEA uses a differential coupling instead of a serial coupling between a high impedance mechanical speed motor (K064-050 from Bayside) and a low impedance mechanical spring. This results in a more compact and simpler solution, with similar performances. The force is sensed using a MLP-300 load cell from Transducer Techniques on the output of the DEA, and the orientation of the wheel is provided by a RM44 absolute encoder from RLS. This makes DEA act as an elastic steering actuator that can inherently absorb shocks, perceive the forces coming from the environment and control its apparent mechanical stiffness and viscosity, in accordance with the admittance control scheme as expressed by (1), where F is the force sensed at the output of the DEA (provided by the MLP-300 load cell), D and K are the damping and stiffness, and X is the measured steer angle of the wheel (provided by a RM44 wheel encoder from RLS). As illustrated in Fig. 1, measured torque on each AZIMUT-3's DEA is used to calculate the direction and the amplitude of the forces applied on the chassis [9].

$$\frac{X(s)}{F(s)} = \frac{1}{Ds+K} \tag{1}$$

II. FORCE-CONTROLLED MOTION OF AZIMUT-3

This presentation demonstrates how the capabilities provided by DEA for motorization of steerable wheels can make a mobile platform respond to forces and torques from a human physically guiding the robot. Based on the forces and torques perceived at the chassis, direction of the steerable wheels and

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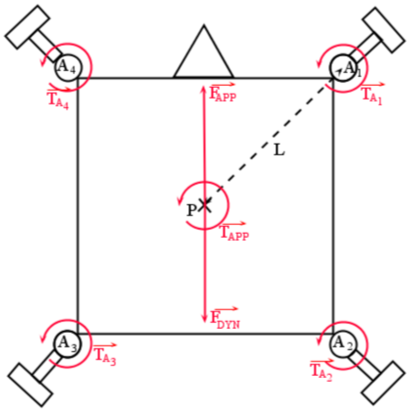

Fig. 1. Torque Sensing Through Differential Elastic Actuators

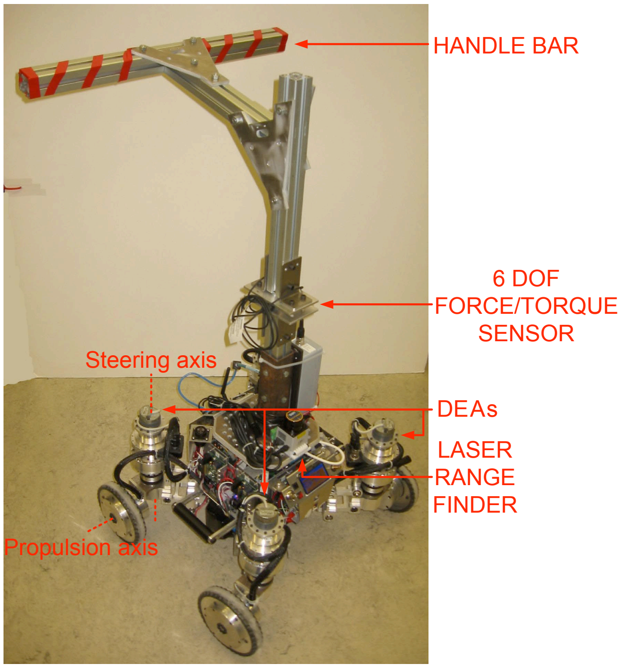

Fig. 2. AZIMUT-3 equipped with a handle bar

propulsion commands are generated to assist motion in the intended direction, creating an intuitive and natural way to guide the robot. This can be seen as motion resistance compensation, similar of what can be seen in gravity compensation for robotic arms [10]. As shown in the video, moving a motorized platform that is designed to keep its position is hard to move around, unless we have access to some form of teleoperation modality such as a remote control. Fig. 2 illustrates AZIMUT-3 equipped with a handle bar to make it easier to push the robot along. The 6 DOF force/torque sensor installed on the handle bar is only used for validation of the torque derived from the DEA [9].

In this presentation, we first intend the platform to behave as if the robot was supported by low-friction caster wheels. Pushing the robot will make it gain and retain speed according to the magnitude and direction of the forces sensed at the chassis. The command is obtained by applying a simple, first-order low-pass filter to the output of the force model. For demonstration and stability purposes, we constrain the commanded speeds in one dimension. The first part of the demonstration shows how responsive the system is in rotational speed. The second part shows the same effect on linear speed. It demonstrates how this system provides a natural way to move the robot between two humans by pushing it back and forth. It also shows how it reacts to obstacles, i.e., unintentionally applied forces. Finally, the same force sensing feature can be used in guidance applications. In this configuration, the speed control has more damping and is designed to react to both applied forces and torques. It can be used to implement an active walker, assisting the user's motion [9].

The whole system is implemented using Willow Garage's Robot Operating System (ROS) framework [11] as a set of distinct nodes for force sensing, command generation and motion control. Our system also generates visual cues for *rviz*, the ROS visualization interface, that displays the sensed forces at the chassis in real-time. In future work, we intend to extend these modes to combine force-guided control with obstacle avoidance detected by a laser range finder, and by making more use of the omnidirectionality of the platform.

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