DIS Research Activity in Robotics — 2008

Robotics research at DIS is committed to the development and experimental validation of planning and control techniques for manipulators and mobile robots. The DIS Robotics Laboratory (`http://www.dis.uniroma1.it/labrob`) was established in 1987. Available facilities include two manipulators, two underactuated systems, two four-legged and seven wheeled mobile robots with various sensing equipments. Active grants include the EU FP-6 STREP projects *CyberWalk* and *PHRIENDS*, and the national PRIN 2007 *SICURA* project (with A. De Luca as national coordinator). In 2008, we have cooperated with the following foreign institutions: *DLR* (Germany), *TUM* (Germany), *MPI* (Germany), *ENSTA* (France) and *IRISA/INRIA* (France). In Italy, we have collaborations with *Fondazione Santa Lucia* in Roma, *Università di Bologna*, *Università di Cassino*, *Università di Napoli Federico II*, *Università di Roma Tre*, and *Università di Pisa*. In 2008, a member of this group (G. Oriolo) has co-authored a robotics textbook [7, 36].

Group members.

Faculty members: Alessandro De Luca, Leonardo Lanari, Giuseppe Oriolo, Marilena Vendittelli
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Robots with Elastic Joints Joint elasticity is the main source of vibration in industrial robots, with harmonic drives, belts, or long shafts as transmission elements. An overview on modeling and control techniques for robots with joint elasticity is given in a chapter of the Springer *Handbook of Robotics* [6], the largest editorial effort in our field.

Friction is a critical issue in any robotic system. A disturbance observer and an associated stable control law have been proposed for friction compensation on the motor side of elastic joint robots [19], without using an explicit friction model. The method has been successfully implemented on a 7-dof arm for medical applications.

Novel actuation/transmission devices with on-line variable stiffness have been recently developed for safe physical human-robot interaction. Simultaneous and decoupled control of both link motion and joint elasticity of multi-dof robots equipped with such devices can be obtained by means of either static or dynamic feedback linearization [20]. In particular, the static feedback linearization technique has been applied to a specific experimental device, the VSA-II developed in Pisa, in [23].

Robots with Flexible Links Lightweight manipulators with very slender mechanical design usually imply the presence of vibrations due to distributed link flexibility. Modeling and control techniques for robots with link flexibility are surveyed in the second part of a chapter of the Springer *Handbook of Robotics* [6]. For a single flexible link, we improved our previous results on planning a rest-to-rest motion in given time and without residual oscillations. Based on the definition of a suitable output, a smoothed bang-bang torque profile can be designed that uses at best the bounded actuator capabilities [13].

Redundant Manipulators A robot is kinematically redundant with respect to a task when the number of its degrees of freedom is larger than the number of task variables. An overview of kinematic/dynamic planning and control techniques for redundant manipulators is presented in a chapter of the Springer *Handbook of Robotics* [5].

Redundancy has been used in [14] for preserving the execution of end-effector trajectories, despite the occurrence of a physical collision along the robot structure. Robot reaction to collision (see also the section on Human-Robot Interaction) is projected into a dynamic null-space, thus not affecting the original end-effector task whenever possible.

A task-constrained motion planning method for redundant manipulators has been presented in [34]. Based on the principle of kinodynamic planning, the proposed planner allows to execute a given task with arbitrary precision while avoiding obstacles.

Nonholonomic Systems Robotic systems subject to nonholonomic constraints (e.g., due to rolling contact of wheels or balls) pose challenges in motion planning and control tasks.

A distance function which takes into account the nonholonomic constraints and the non-symmetric nature of the Dubin's car (a mobile robot moving only forward) has been defined in [35] where an analytical method for its computation is also provided.

An approximate algorithm for motion planning of generic (i.e., not transformable in canonical forms) nonholonomic systems has been devised in [33].

A closed-form solution to the simultaneous calibration of the odometry and of a range sensor mounted on a differential-drive wheeled mobile robot has been given using a maximum-likelihood approach in [9]. The method does not require specific motion trajectories and has been tested on a *Khepera III* robot with HOKUYO laser rangefinder.

Visual Servoing Visual servoing (VS) is a very active research area in robotics. In particular, in the image-based (IB) VS framework, error signals are directly computed from image features, thus obtaining control schemes which do not need a 3D model of the scene and are robust to calibration errors. In [12], a general approach for redundancy exploitation in IBVS tasks has been proposed and experimentally evaluated.

On-line estimation of the depth of visual point features, and integration of such information in IBVS schemes, is the subject of [3]. The same technique, which is based on nonlinear observation theory, has been extended to non-point features (image moments) in [21]. Also, depth estimation has been used as a component of a VS scheme for assembling complex planar parts in [22].

For wheeled nonholonomic mobile robots equipped with an on-board camera, we have considered the path following problem; both position-based and image-based schemes have been devised, which use only a small set of features extracted from the image plane. The performance of the controllers has been theoretically analyzed and experimentally verified in [10, 11].

Autonomous vehicle navigation based on a database of previously recorded images is considered in [24]. In particular, six different appearance-based (one position-based, five image-based) controllers are proposed and compared for a nonholonomic vehicle equipped with a monocular camera. Simulation and experimental results show that the two controllers based on the image jacobian, that exploit the epipolar geometry to estimate feature depth, outperform the others.

Motion Planning Modeling robot motion planning with uncertainty in a Bayesian framework leads to a computationally intractable stochastic control problem. In [8], we show how to reduce the stochastic control problem to path planning in the extended space of poses and covariances; the transitions between states are modeled through the use of Fisher information matrix. In this framework, two problems are considered and solved: minimizing the execution time, and minimizing the final covariance with an upper bound on the execution time.

Sensor-based Planning and Exploration The task of exploring unknown environments typically requires a robot to use the information provided by its sensory system to cover an unknown area while learning a model of the environment. A simple and effective idea is that the robot should always move towards the boundary between already explored and still unknown areas to maximize the utility of the motion. Building on this idea, we have proposed both decentralized exploration strategies for teams of mobile robots [15, 29] and methods for exploration with general robotic systems, such as fixed-base and mobile manipulators [16, 32].

A relevant problem for merging maps acquired by multi-robot teams is mutual localization. In [30, 31] we have considered in particular the situation where each robot is equipped with a sensory system that detects the relative position of other robots, but does not provide neither their identity nor their orientation. To solve the problem, an innovative algorithm is proposed that builds sets of possible relative pose hypotheses, whose output is processed by a data associator and a multiple EKF to select the best hypothesis.The performance of the developed localization system is assessed using both simulations and experiments.

Human-Robot Interaction Safety issues in the physical human-robot interaction have to be addressed at the mechanical and control levels. A survey on the status of technologies and methodologies for safe human-robot interaction has been presented in [4]. We have further developed our fast and reliable method for detection and reaction to unexpected collisions. In particular, a modified recursive Newton-Euler method has been introduced for the efficient numerical computation of the residual vector used for the detection [26]. Moreover, the residual-based collision detection technique was shown to work well also for variable stiffness actuation (VSA) devices, without the need of joint torque measurements [23]. Several post-impact reaction strategies were compared in terms of sensitivity, response times, and associated energy transfer, with collision experiments between the *KUKA/DLR* lightweight manipulator and a crash-test dummy, as well as human chest, arm, and head [17] (this paper was awarded as Best Application Paper at IROS'08). The safety of the approach has been evaluated also when the robot is equipped with sharp tools and hits on soft biological tissues [18].

Locomotion Platforms A new aspect of cognitive human interaction is to allow unconstrained locomotion for a user exploring virtual worlds while walking on a platform. For a linear threadmill, we have developed control laws (including an observer of the user's intentional motion) for keeping the user at the platform center and limiting the perceptual effects due to threadmill motion [37]. The control method has been then extended to the omnidirectional 2D platform *CyberWalk*, the largest locomotion device in the world intended for 'natural walking' in VR [27]. The *CyberCarpet* is another 2D small-scale locomotion device developed within our *CyberWalk* European project. It is a non-holonomic platform consisting of a turntable with a linear treadmill and a ball array carpet mounted on it. The mechanical design, the visual localization of the walker, and various nonlinear control laws for smoothly keeping the walking user around the center of the platform under perceptual constraints are presented in [28].

Service Robotics Assistive technology is an emerging area where robotic devices can be used to strengthen the limited abilities of individuals with motor impairment or to help them achieve independence in the activities of daily living. In [2] we present a project (funded by the Italian *Telethon Foundation*) aimed at developing a system that provides remote control of home-installed appliances, including robotic devices such as the Sony *AIBO*. The design of the robot navigation system is described in [1]. Single step, semi-autonomous, and autonomous operating modes have been realized to provide different levels of interaction with the *AIBO*. The performance of the navigation system has been tested in simulation as well as experiments. The system underwent clinical validation, in order to obtain a definitive assessment through patient feedback.

Another area of activity of our group are robotic games, and in particular humanoid soccer robot for the *RoboCup* competition. In [25], two learning methods are presented for humanoid walking gaits based on the Policy Gradient algorithm. It is shown that an extension of the classic Policy Gradient algorithm that takes into account parameter relevance yields improved solutions when only a few experiments are available.

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