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Robotics Research at the GRASP Laboratory

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Abstract

The General Robotics and Active Sensory Perception (GRASP) Laboratory of the University of Pennsylvania does research in various areas of robotics including coordinated control of multiple robot manipulators, strategics for robotic sensing, multi-sensor integration, distributed real-time operating systems, telerobotics with communication delays, image understanding, and range image analysis.

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Robotics Research at the GRASP Laboratory

Xiaoping Yun and H. Anderson

The *General Robotics and Active Sensory Perception (GRASP)* Laboratory of the University of Pennsylvania does research in various areas of robotics including coordinated control of multiple robot manipulators, strategies for robotic sensing, multi-sensor integration, distributed real-time operating systems, telerobotics with communication delays, image understanding, and range image analysis. Major equipment includes three PUMA250's, two PUMA560's, two custom sensorized robotic hands, two grippers, a foveal/peripheral pair of robot-mounted Sony CCD cameras, a robot-mounted structured light laser rangefinder, and other range measurement devices and cameras. Computational equipment includes Sun4's, SparcStations, Sun3 workstations, MicroVaxes, HP workstations, a Personal Iris, IBM workstations, a DataCube, a pyramid processor, and a Connection Machine CM2a with a dedicated Sun4/280 front end.

The GRASP Laboratory has approximately thirty graduate students, seven faculty members, five staff members and five undergraduate employees.The students and faculty are from four departments (Computer and Information Science, Systems Science and Engineering, Mechanical Engineering and Applied Mechanics, and Electrical Engineering). The multidisciplinary approach of the GRASP Laboratory reflects the mission of the University of Pennsylvania's School of Engineering and Applied Science, where students participate in the creation of knowledge at the leading edge of their particular fields of interest, and integrate knowledge to create new devices and systems. Funding for the GRASP Laboratory comes from governmental and industrial sources

•Coordinated Control of Multiple Manipulators

Dynamic coordination of multiple manipulators is investigated to enhance the capability of manipulators for grasping and manipulating large, heavy, and irregularly shaped objects. Using differential geometric control theory, a coordinated control algorithm, which explicitly controls both the interaction force and motion trajectory, has been developed. The algorithm utilizes a dynamic nonlinear feedback to exactly linearize and decouple the nonlinear system of multiple manipulators. The control of contact conditions (rolling and sliding) in multi-arm manipulation and multi-handed grasping is also being studied. To demonstrate the approach, the Two Robotic Arm Coordination System (TRACS) has been developed, using two PUMA 250 robots and an IBMPC/AT based controller. Using two instrumented open-palm end effectors developed in the lab, the TRACS is capable of grasping and dynamically transporting large objects such as cardboard boxes, not graspable by individual manipulators.

•Design of Robot Manipulators

We have been investigating techniques for improving robot manipulator performance. We have developed a method of passive and energy conserving mechanical gravity compensation, which can be applied to a wide range of manipulator geometries. Also, we are working on modifying the transmission characteristics for a robot manipulator to improve the predictability of actuator response. We have developed and built several new manipulators, such as a four degree of freedom mechanical hand with 14 tactile sensors, a two link arm with gravity compensation, and a three-degree of freedom pneumatic wrist or ankle joint

•Active Sensory Perception

The ultimate goal of robotics in the GRASP Laboratory is to build robotic systems that function in completely unstructured environments. Active perception makes use of robot-mounted CCD cameras, range imaging systems, and tactile sensors.

Mobile cameras seek to position themselves in the best viewing location for maximum information extraction. Robotic devices with attached sensors manipulate an object to learn about the object itself. This technique, employing passive sensors in an active fashion, purposefully changes the sensor's state parameters according to sensing strategies. The active sensing paradigm includes taking multiple measurements and integrating them, and including feedback not only on sensory data but on complex processed sensory data. Irrespective of the actual control algorithms used, a complete model of the system is absolutely essential. Such a model of a robot system must account for the dynamics of the robot manipulator, the end effector, the sensor devices, the environment or external object, and the controller itself. An example of this work is the construction of a complete spatial map of a 3-D scene using a robot-mounted structured light (laser) rangefinder. A single range image is taken, then a strategy is developed to select the appropriate next view. A PUMA 560 moves the scanner, a new range image is taken, and the new data is integrated with data from the first view. The process continues until a complete spatial map is obtained.

Another area of research is the investigation of geometric and mechanical properties of objects, such as identifying movable and removable parts of an object. Also, we are working in the areas of color image segmentation, combined 2-D and 3-D shape analysis, and texture analysis.

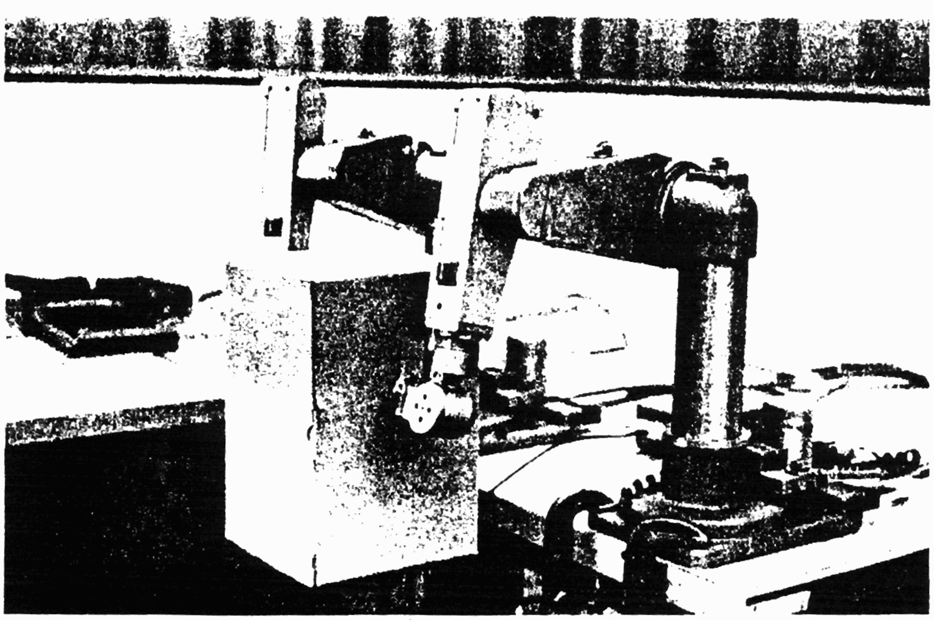
•Multisensor Integration Theory and Application

The combination of sensor data can be modeled as a statistical problem and then analyzed using statistical decision theory. Robust sensor fusion can be used in an environment with sensor noise and inexact statistical descriptions.

The GRASP Laboratory has developed techniques which allow us to accommodate uncertainty in real sensor noise distributions, to gain significant improvements in estimation of location (range) data. In addition to work on range data, which is one dimensional, work is being extended to the multi-dimensional case. For each uncertainty class of real noise distributions, we need to obtain a minimax rule based on a zero-one loss function. These rules minimize the maximum probability that the absolute error of estimation is greater than an error tolerance. At the GRASP Laboratory, these developing theories of multisensor integration are applied to real sensor data

•Teleoperation with Feedback Delay

Delay occurs with earth-based teleoperation in space and with surface-based teleoperation with untethered submersibles when acoustic communication links are involved. The delay in obtaining position and force feedback from remote slave arms makes teleoperation extremely difficult. We use a combination of graphics and manipulator programming to solve the problem by interfacing a teleoperator master arm to a graphics based simulator of the remote environment coupled with a robot manipulator at the remote, delayed site. The operator's actions are monitored to provide both kinesthetic and visual feedback and to generate symbolic motion commands to the remote slave. The slave robot then executes these symbolic commands delayed in time. While much of a task proceeds error free, when an error does occur the slave system transmits data back to the master and the master environment is be "reset" to the error state.



•Real-time Distributed Systems

Our multi-sensor multi-robot systems execute in real-time on a number of different processors linked by a local area network. We have been investigating the programming, operating systems and formal specification issues of distributed real-time systems. For real-time systems to be correct, they must not only be functionally correct but also satisfy timing constraints. Our approach is to treat "time" explicitly within programs so that their temporal behavior can be specified and reasoned about. We have been developing programming concepts of temporal scope for expressing timing constraints, timed communication for predictable delay, and timed atomic commitment for coordinating subsystems. We have developed a real-time kernel called Timix, which uses integrated scheduling of processes and messages based on timing constraints, and are implementing it for a distributed two-robot system. Also, we are developing a formal resource-based computation model of time dependent processes and a process algebra, called Communicating Shared Resources.

For further information about research activities at the GRASP Laboratory, contact Dr. Xiaoping Yun (215-898-6783, yun@central.-cis.upenn.edu). Laboratory reports and publications are available upon request.