BRAZIL STATUS REPORT

21th JOINT COORDINATING FORUM

INTERNATIONAL ADVANCED ROBOTICS PROGRAMME

IARP JCF 2002

Index

COPPE – Federal University of Rio de Janeiro

GSCAR
Research Group for Simulation and Control in Automation and Robotics
Control Systems Laboratory

http://www.coep.ufrj.br/gscar

The GSCAR develops theoretical and applied research in the areas of Industrial Processes and Robotics.

Projects

To make electrically driven industrial robots viable for underwater operations/interventions.

Research activities

Stabilization, contact and automation of ROV and manipulator for underwater intervention

- Motion control of mobile manipulators
- Visual servoing of mobile manipulators
- Mobile base navigation: mapping and localization
- Sensor fusion
- Internet telerobotics

Objectives

To make marinization technology of industrial robotics available and useful for Petrobras underwater activities; develop technical alternatives and refinements for the existing systems; develop research activities aiming at the results in real intervention operations; create human resources and specialist training centers.

Members

- Prof. Liu Hsu, COPPE/UFRJ - liu@coep.ufrj.br
- Prof. Ramon R. Costa, COPPE/UFRJ - ramon@coep.ufrj.br
- Prof. Fernando C. Lizarralde, DEL/UFRJ - fernando@coep.ufrj.br
- Prof. José Paulo V. S. da Costa, UERJ

Collaborators

- Prof. Eugenius Kaszkurewicz, COPPE – Electrical Eng. Dept.
- Prof. Amit Bhaya, COPPE - Electrical Eng. Dept.
- Prof. Vitor Romano, COPPE – Mechanical Eng. Dept.

Students

Undergraduate: 6 **MSc**: 10 **PhD**: 3 **Post Doc**: 1

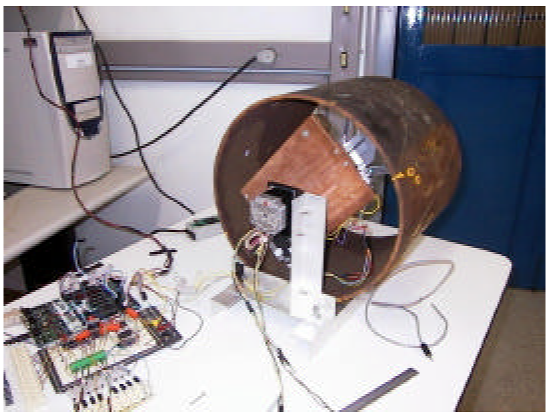
External Associate Researchers

- Eng. Ney Robinson Salvi dos Reis, CENPES Petrobras, Brazil
- Prof. John T. Wen, Rensselaer Polytechnic Inst., USA
- Prof. Romeo Ortega, SUPELEC, France

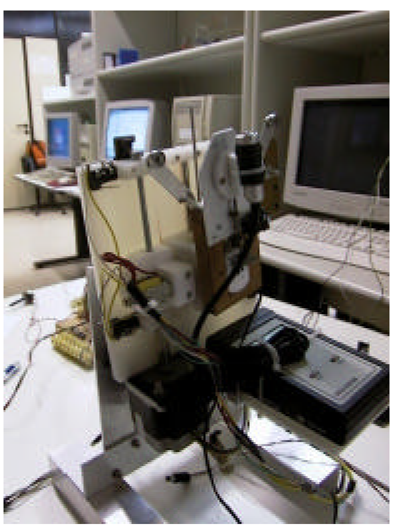
Main Robotic Project

- **CTPETRO – GSCAR/CENPES – Petrobras**

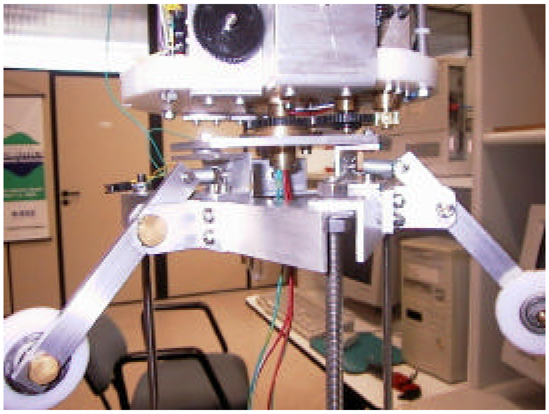
Viabilization Study of Industrial Robot use for underwater operation and interventions



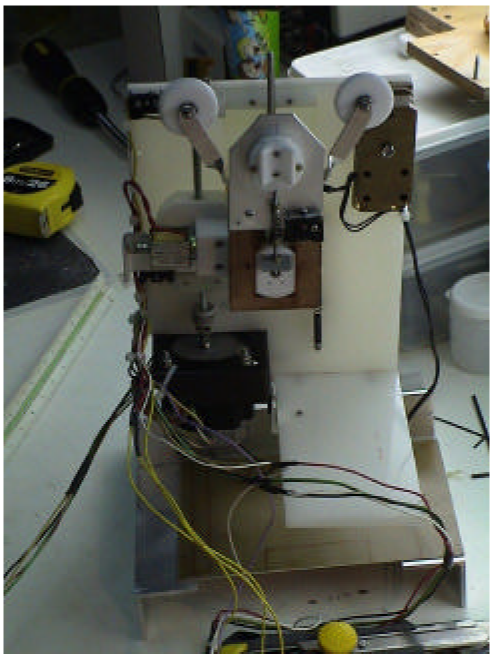
Caption: Testing the first prototype of the robotic paint-layer and internal pipe deformation measuring system (SIMCRODUTO).



Caption: Testing the second prototype of the SIMCRODUTO.



Caption: Assembling view of the SIMCRODUTO (third prototype) with the guiding cart.



Caption: View of the SIMCRODUTO mechanical assembling (second prototype).

Instituto Militar de Engenharia-IME/RJ
Unmanned Vehicles Control

University/Research Center	Contact	Research Area
IME /RJ Instituto Militar de Engenharia Departamento de Engenharia Mecânica e de Materiais	Armando Morado Ferreira armando@epq.ime.eb.br	1. Unmanned vehicles systems for civilian and military use. 2. Trajectory planning and control of unmanned vehicles.

Introduction

The Instituto Militar de Engenharia, IME, is a traditional military engineering school located at Rio de Janeiro, its origin tracing back to 1792. IME currently offers engineering degrees in eleven different areas and several graduate courses, including two PhD granting programs.

Robotics research at IME has been being undertaken by researchers in several disciplines – computer sciences, mechanical engineering, electronics and control, and an effort is taking place towards starting a new joint Robotics Laboratory. Currently there are two PhDs in robotics, plus one in training and a vacant position to be filled, as well as several dynamics and control researchers active in the field.

Robotics research at IME encompasses the following activities:

Undergraduate Research Program

In this program, undergraduate students are stimulated to do research work in the field, often supported by scholarships provided by a CNPq special program to initiate researchers. Typical studies include mobile robotics, manipulators, dynamic analysis, planning and control. The engagement of the students in prototyping is encouraged.

Gradate Research Program

Unmanned vehicles systems are an area of increasing research interest, having a wide range of applications, both civilian and military. Several master thesis at IME have been focused on this area, and the current efforts include modeling, trajectory planning and control of such systems as unmanned ground vehicles, mobile manipulators, and unmanned aerial vehicles. Other research areas in the field of robotics include house automation and manipulator remote operation.

CT – Amazônia/TISCOFA

CT - Amazônia is a special program of the Brazilian Government aimed at developing technologies for the Amazon region. TISCOFA, an acronym for intelligent technologies for supervision and control in Amazon river operations, is an approved project under CT-Amazônia, which focuses on developing unmanned aerial vehicles to be used as sensor platforms, according to a scenario depicted in the figure. The project is currently in its initial prospective phase.

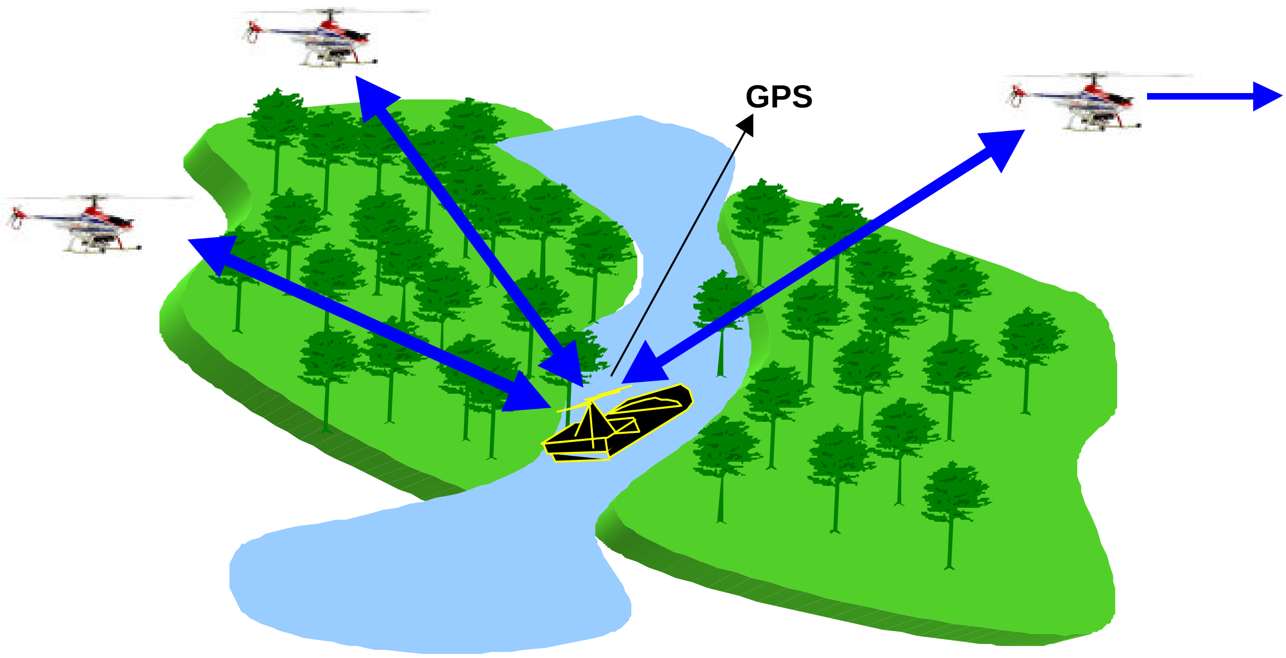


Figure: TISCOFA scenario.

Instituto Militar de Engenharia-IME/RJ
Systems Engineering Department

Research Group:

Paulo Fernando Ferreira Rosa, PhD (Niigata University – Japan, 1997)

Associate Professor, Systems Engineering Dept., Military Institute of Engineering, Rio de Janeiro

- Graduate Students

Ricardo Eder
Flávio Augusto Coutinho Correia
Cléber Lemos da Rocha
Paulo Renato da Costa Pereira
José Antônio de Souza Fernandes
Alexandre Fitzner do Nascimento

- Undergraduate Students

Emanuel José Pacheco Freire
Laios Felipe Barbosa
Max Silva Alaluna
Fábio Miranda Cordovil
Marlos de Mendonça Côrrea

Research Topics:

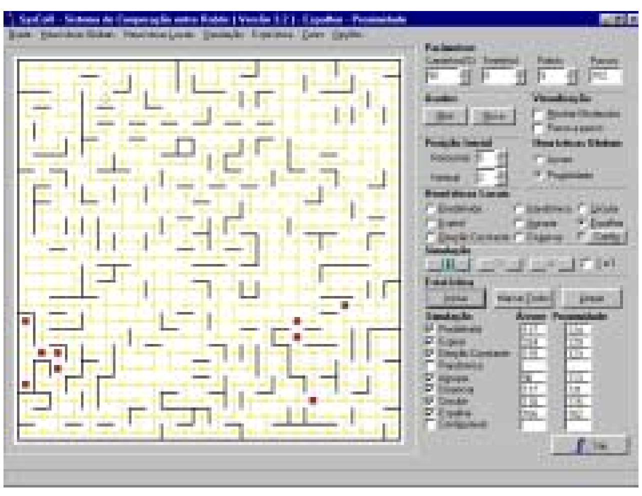
(1) A Dynamic System for Housing Automation

A Dynamic System for Housing Automation was projected to provide an increase in comfort, security and to give more energy saving. The initial goal of this research is to reduce the consumption of energy keeping the an adequate level of comfort. This energy saving can be accomplished by using the dynamic system of residential automation that controls the lighting system, the air conditioning system and many other loads. The dynamic system of housing automation would bring other benefits if there were an integration between the security systems and the private or government companies, such as the electricity or the gas companies.To achieve the best of its functioning, the behavior of the system can not follow a pre-defined program, but it will have to interact dynamically with the environment, changing the system’s answer after recognizing a resident or his/her action, accomplishing the goals of economy and satisfaction. The necessary characteristic to tell apart people will be raised and discussed in order to obtain the various patterns. From now on, all the systems (lighting, air conditioning, water heating, etc..) will have to act in a different way, depending upon the recognized pattern, attending the needs of the users with a minimum of energy.

The motivation of this research is to seek a way to distinguish the people and, by doing that, how to personalize each one of the subsystems that run under the main system. None of the existing recognizing systems attends the needs of a home system. For this purpose the recognizing system must be no-invasive , natural and independent of natural conditions (minimum sound or light) or human behavior (talk or gesture). As a solution, was projected a recognizing system based on weight and on the way a person walks (step frequency, step length, angle of the right and the left foot). The system developed is formed by: (1) a sensory network, (2) step algorithm and (3) a neural network. The function of the sensor network is to transmit the signals of the transducers triggered by the person's walk. The step algorithm, formed by the step angle algorithm and the step frequency algorithm, must have to organize the signals from the sensor network and calculate the desired characteristics. A neural network was developed to recognize the patterns of the characteristics in order to tell apart the individual. The characteristics of the neural network are plasticity and stability, being able to insert, constantly, new patterns and after noticing variations of the already known patterns, adapt to their new changes. A simulation of the recognizing system was made and proved to be efficient to identify the individuals. As a demonstration, a control lighting system was personalized for each one of the residents, and by using simulations, it was proved that an energy saving can be accomplished.

(2) <u>Robot Cooperation for Navigation on Unstructured Environments</u>

The objective of this work is to explore an unstructured environment with a cooperative team of robots. Our approach models the workspace in regular regions that can be pictured as a graph. The objective is to visit the nodes of the graph and know its arcs in a minimum number of steps. The robots are autonomous and exchange information about the trajectory and obstacles founded in the exploration. A group of heuristics to determine the actions of individual robots are proposed and is divided in two groups: global and local heuristics. We propose eight types of local heuristics and two types of global heuristics. The use of a global and local heuristics are not sufficient to solve the problem to explore an unstructured environment with a team of robots. We propose a routine that order the decision of movement to avoid collisions and maximize the exploration of nodes that are not visited. A simulator was developed to analyze and validate the heuristics described above.



(3) Virtual Manipulator: The transmission of the Haptics Perception

The development of tele-robotic systems consists mainly of a topic of great current interest because of its applicability in areas considered dangerous and that bring human risk. Thus, the Virtual Tele-operated Manipulator, was conceived to assist humans in these activities. It is a system with three distinct subsystems: master, slave and communication. The master subsystem acts directly on a part of the body of a human operator, and has as main purpose to perceive its movements, which, by their turn, will be the commands for the slave; as well as, receiving from it the haptics sensations, to transfer to the operator. The slave subsystem corresponds to a robotic rejoinder of the part of the body of the human being that is being monitored for the master, and has the purpose to interact with the environment. Finally, the communication subsystem is a bracket system, which possess the objective to allow the communication of the necessary signs to the functioning of the two previous subsystems. The evaluation of the performance of this system was made through an experiment using a simplified model of the processes considered in this work, with one degree of freedom, at first. Currently, a system with three dof and a more accurate communication protocol is been developed.

(4) INDIMADA: An Algorithm to Control the Transmission System of a Vehicle trough Data Inference

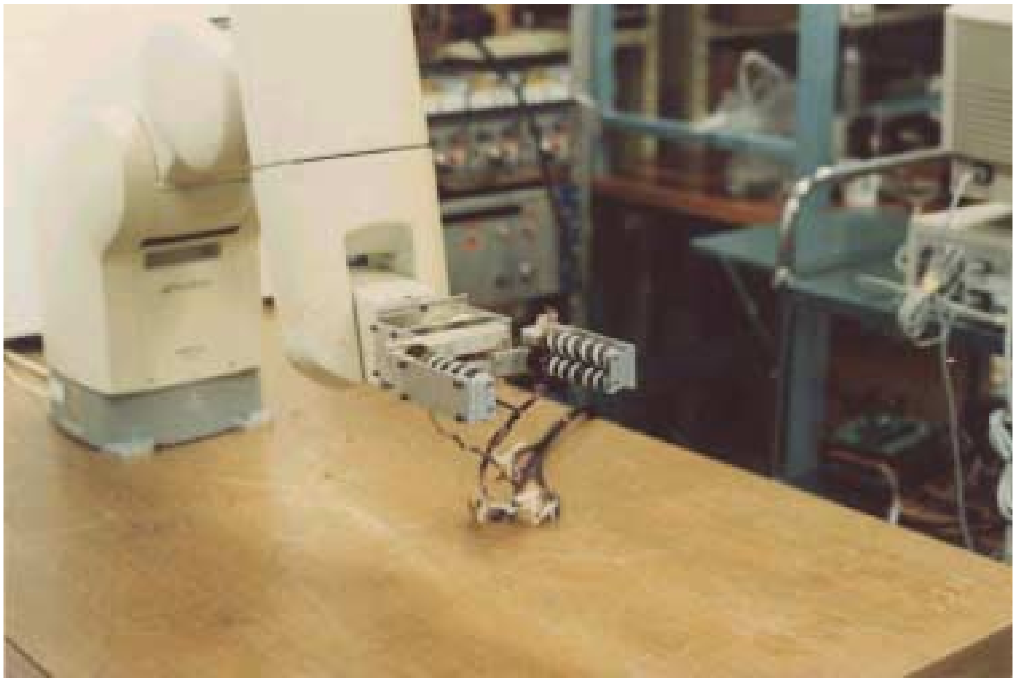
This work proposes an algorithm to control the transmission system of a real vehicle. It merges the system input an output data in the same structure named "data" and organize those data in the system input vectorial space allowing a fast navigation through them. Then the algorithm calculates parameters that characterizes the system local behavior for each data collected and store these parameters in the respective data. Finished these two steps, the algorithm is able to navigate through the system vectorial input space and infers the correct command for a new input using the parameters calculated on the second step and stored on the data set. As the number of data inserted in the organized data mass is increased the performance and correctness of the algorithm is increased too.The algorithm was tested in the control of the clutch and the change of the gears of a virtual vehicle. A model of a transmission system available nowadays was developed to evaluate the efficiency of the algorithm. Although the results reached are insufficient for an efficient control of the system, they show that the algorithm is able to execute intelligent tasks and show that the improvement of the algorithm can make it able to execute the control task in an efficient way.

(5) Scrollic Grippers: dexterous manipulation with rolling and compliance

Articulated and multifingered robotics hands can dexterously manipulate objects within a grip, by changing the contact configuration through the appplied torques on their controlled joints, aimed at ahieving steady grasps and dominating position and orientation of the grasped object.

Parallel-jaw grippers, on the contrary, rely upon the squeezing and frictional constraints only to doubtfully reach the same goal, for there are situations in which the parallel-jaw grasp configuration model is not sufficient to grant a firm grip,especially for objects with particular local geometry,such as a prismatic cone that yields to a highly unstable grasp when constrained through its inclined face. However, parallel-jaws are very useful and widely utilized for a great variety of robot manipulation tasks,due to the attractiveness of their simple mechanism and control. Therefor,it is of utmost importance to improve the dexterity of these grippers, so they can be able to overcome uncertainties on the object’s boundary conditions, such as,position, local shape and orientation.

The purpose of the present research is to introduce a new family of grippers, named as scrollic grippers, that give an additional degree-of-freedom(DOF) to the conventional parallel-jaw through rolling contacts at the fingers. The word scrollic is not a word on its own; it stands fot the acronym syncronously closing with rolling constraints and claims to be sel-explanatory of the gripper's functioning. Two versions of the scrollic gripper were designed and implemented, along with theoretical studies and experiments to verify their improvements concerning dexterity in unstructured object handling and manipulation.One version of the scrollic gripper developed a mechanism to transmit both rotation and translation velocities to a pair of regulus in parallel. This characteristic enabled the gripper with an additional DOF, and improvedthe graspability of the standard parallel-jaw by the performance of form-closure,as well as, force-closure grasps. The other version of the scrollic gripper developed independent torques for the rotation and translation of a pair of cylinders in parallel, aimed at grasp acquisition and manipulation of arbitrary objects, based in a control algorithm that benefited from active compliance.



Technological Institute of Aeronautics-ITA-SP-Brazil
Navigation and Control of Autonomous Mobile Robots- NCROMA

University/Research Center	Contact	Research Area
ITA Technological Institute of Aeronautics Navigation and Control of Autonomous Mobile Robots	Elder Moreira Hemerly hemerly@ele.ita.br Altamiro V. da Silveira Jr. silveira@ele.ita.br	1. Adaptive control applied to robotic vehicles 2. Software for robotic systems

Introduction

The NCROMA's group belongs to the Electronics Division of the Technological Institue of Aeronautics-ITA, an institution of the Brazilian Aeronautics Command. This group was created in 1992 and has its focus on research and development on autonomous robotic systems and computer vision methods. The NCROMA's group makes its research results available to the society through cooperative work with FAPESP and CNPq. The laboratory currently has one mobile robot (Magellan, equipped with sonar, infrared, odometry, encoders and touch sensors, laser rangefinder and a vision system) and several Pentium workstations.

Some works concerning simulations and real time experimentations with adaptive controllers are now under way, by using neural and wavelet networks. A summary is presented in what follows.

Kinematic and Dynamic Control

In this work, mobile robot is described by two different models : kinematic and dynamic ones.

The kinematic model is described in Cartesian coordinates. It supposes an ideal robot, without mass, dynamics parameters and movement restriction. Hence, kinematic controller can not compensate for any extern perturbation.

The non-holonomic restrictions, mass, inertia, unmodeled dynamic and disturbances are considered in the dynamic model. Both Yamamoto and Lewis models are employed.

The dynamic controller is composed by a robust and adaptive term, a neural or wavelet network, which should compensate external perturbations, such ad unmodeled dynamic or limited disturbance. Both trajectory tracking and point stabilization were considered.

It was deduced the stability proof for the adaptive control system system, based on second method of Lyapunov, using neural or wavelet networks based controllers. The weights in the neural and wavelets networks are adapted on line.

An example of trajectory tracking is shown in fig. 1.

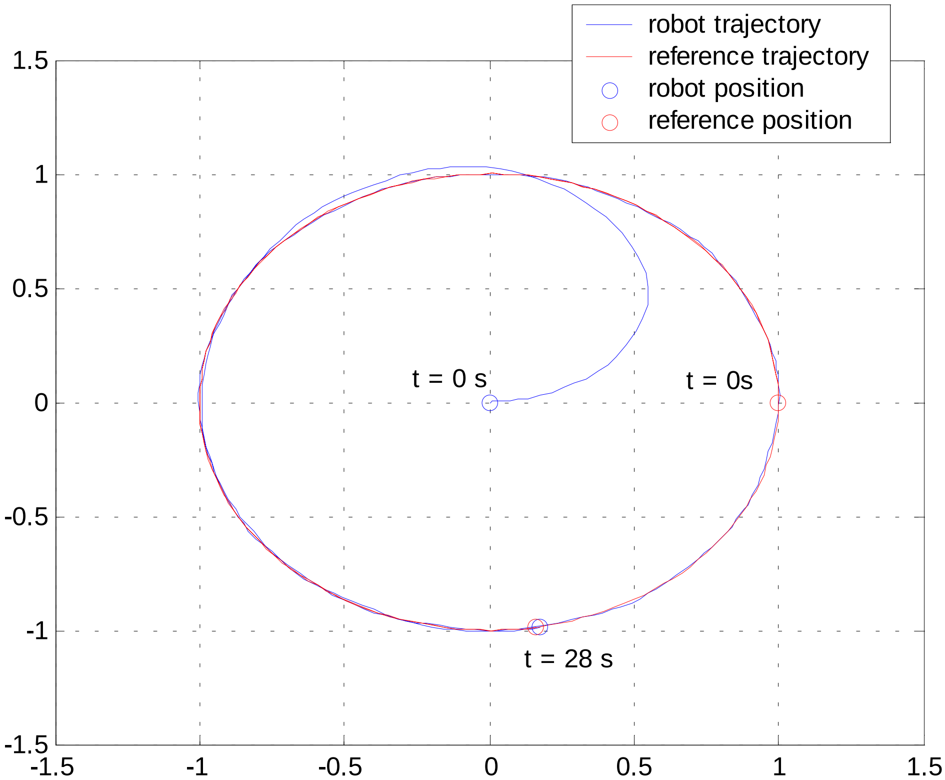


Fig..1 – Magellan robot with trajectory tracking controller.

Universidade Federal de Minas Gerais
Instituto de Ciências Exatas
Departamento de Ciência da Computação

Vision & Robotics Laboratory – VERLab

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1 Introduction

Robotics and Vision research has been carried out by the Lab since its foundation in 1992. The Lab is currently equipped with:

- PUMA 560 6 dof manipulator, that besides VAL, can also be used with RCI/RCCL.
- Nomad 200 mobile robot, equipped with ultra-sound, infra-red and touch sensors, as well a color cameras and electronic compass. The Nomad is connected to the lab's LAN via wireless Ethernet.
- Three indoor helium filled dirigibles (blimps). A smaller one, with 1,4m in length and a larger one, with 2,1m in length.. Both dirigibles are equipped with micro-cameras and a RF link. Thy are remotely controlled by standard model airplane R/C servos.
- 3D linear laser scanner, which was developed and built at the lab. This device has an imaging volume of 400mm.
- Several frame-grabbers.
- CCD cameras – black and white and color
- SUN Workstations running Solaris 2.5
- PENTIUM class processors
- Local Area Network with fast (100Mbps) connection to the Internet-2

2 Robotics and Vision Research

The next items briefly describe the main research directions in robotics research.

2.1 Autonomous Mobile Robots

We are focusing on new strategies and sensory integration for mobile robots navigation, moving towards full autonomy with the usage of exploratory procedures and real time experiment evaluation. The Nomad 200 has been used as testbed for testing our navigation and path generation algorithms.

We consistently make use of several sensors in the robot within a robust probabilistic framework. The techniques have been developed in such a way that that they can be extended to other modalities of mobile robots, such as aerial and underwater.

2.2 Aerial Robots

This work, in collaboration with the GRASP LAB and CenPRA, has as goal the development of a fully autonomous dirigible for environmental applications. We have started with the control of small indoor blimps, equipped with micro-cameras and RF links. These small dirigibles are currently being remotely controlled by a computer, where the kinematic and dynamic models are processed. The computer receives and processes a video stream coming from the onboard camera, and controls the blimps actuators accordingly. The experience acquired in the control of these small dirigibles, under controlled environmental conditions will be used on the navigation of larger blimps such as CenPRA AS800, using other sensorial modalities such as INS (Inertial Navigation System) and GPS. Research on cooperation among AUV's and AGV's is currently being conducted at the lab.

2.3 Cooperative Robotics

Under this initiative we have been looking into the problem of cooperative tasks performed by more than one robot, acting upon the same object(s) or interacting in the same environment. This also includes the cooperation between mobile robots, as well as between manipulators and mobile robots. Force and torque interactions between and among robots are being studied. Recently we have been looking at cooperative sensing and communication issues that appear naturally when a group of highly instrumented mobile robots are working together. Although the evaluation of some cooperative behaviors are difficult for practical implementations we use a powerful home made simulator and move towards the analysis and control of groups of hundreds or thousands robots. Some of the behaviors are being evaluated in the context of soccer playing micro-robots. We have two sets of such robots, and several strategies are being tested under different configuration strategies. We also use assembly block kits (LEGO) to construct teams of mobile robots and test some simple behaviors. We have close collaboration with Prof. Vijay Kumar and his team at GRASP LAB. University of Pennsylvania.

2.4 Visual and Haptic Collaborative Tele-presence

The focus of this research is to provide the core of a successful sense of presence by endowing the tele-user with visual, aural and haptic experience. More specifically we are concentrating on the visual-haptics enabling, by providing the user with correct visual perception of the virtual collaborative environment augmented by information of force and torque actually applied in the real environment. This research area is being conducted under collaboration with the GRASP Lab, University of Pennsylvania.

2.5 Rehabilitation Robotics

We are working on projects in this area in cooperation with the group of Prof. Vijay Kumar, of the GRASP LAB and professors from the Department of Biomechanics, at UFMG. A hand orthesis is currently under development at the lab. This orthesis was

developed in order to restore some of the grasping ability to the user, namely the pinch type of prehension. It is controlled by wrist movements and by visual feedback of the user.
The device is built around an inexpensive microcontroller and simple eletro-mechanical devices. Careful studies are being performed on the evaluation of characteristic and profile of the applied forces, skin wear implications, usability by the handicap as well as eletro-mechanical characteristics.

2.6 Robotic Vision

The focus here is on algorithms and vision systems for robotic applications, such as, but not limited to, navigation and map building. Two- and three-dimensional tracking algorithms have been developed at the lab. Due to application demands, these algorithms have implementations that run from 10 fps to near frame rate (30fps). We have successfully developed and implemented tracking, pose estimation algorithms for use in the robotics domain. An inexpensive, but sufficiently precise and robust range laser scanner was developed at the lab. This scanner can be used in three-dimensional shape acquisition and mobile robot navigation. More general computer vision problems are also being tackled at the lab. These include scene reconstruction via stereo, shape from motion, and other techniques.

2.7 Robot Development

We have also been envolved in the design and development of custom taylored robots to solve real life problems. Our robots are in general used to substitute or help human workers in a variety of tasks. Our methodology consists in using off-the-shelf components to introduce a simple and inexpensive robotic solution. A successful robot was recently developed, built and tested was a mobile manipulator used to install and remove aircraft warning devices on aerial power transmission lines. The robot uses the ground cable as a path and is capable of autonomously installing and removing the signaling spheres. The robot was built under a contract with the state power company and it is being used as a replacement for the costly operation performed with helicopters of signaling transmission lines.

3 Collaboration

We participate in a cooperative network named MANET (Manufacturing NETwork), which gathers several robotics researchers in Brazil. We also have collaboration with Dr. Samuel Bueno from the Automation Institute, of the Centro Tecnológico para a Informática – CTI, Campinas, Brazil.

Many of the research topics described above have been developed under close collaboration with Professors Vijay Kumar, Jim Ostrowski, Kostas Daniiliidis and James Gee from the GRASP LAB, at the University of Pennsylvania, USA.

We also work jointly with professors from several departments within the University, such as Electrical Engineering, Electronic Engineering, Mechanical Engineering and Sport Biomechanics. Our group is currently composed of 14 graduate students (6 PhD and 8 MSc) and 13 undergraduate students.

Federal University of Rio Grande do Sul
Mathematics Institute

Research Activities in the Field of Autonomous Mobile Lab Robots

Identification:

Project Title: Autonomous Mobile Lab Robot Path Planning based on Global Vision and Voronoi Roadmaps

Project coordinator: Prof. Waldir L. Roque
Mathematics Institute
Federal University of Rio Grande do Sul
Porto Alegre, Brazil
Email: roque@mat.ufrgs.br

Project support: CNPq/CTPetro

Short Project Description:

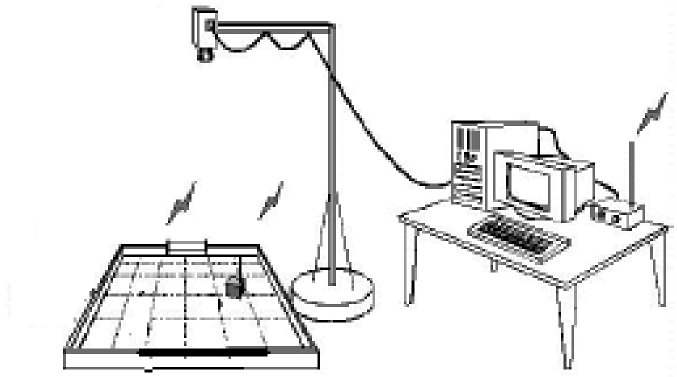
The research in autonomous mobile robots (AMR) has shown a great progress in the last decade. Despite all the progress only few actual commercial applications are available in the market place. On the other hand, the number of companies producing AMR for laboratory research has increased significantly. The potential of applicability of mobile platforms are high and their demand will be raised in the near future, with the cost benefit relation becoming much more favorable than today.

There are still many problems that have to be solved and better understood in mobile robotics. One of these is concerned to autonomous navigation in an unstructured environment, which requires a precise navigation system. Even in structured environments the so called path planning problem plays an important role for autonomous mobile robots.

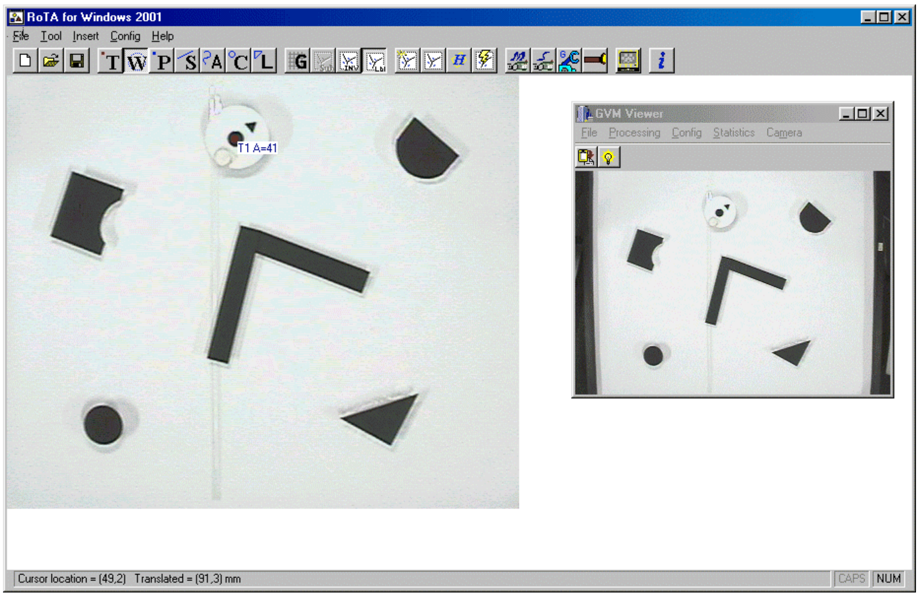
Several techniques have been proposed in the literature to deal with this problem, among them the generalized Voronoi diagram (GVD) has been largely studied as it has some good properties, like the generation of a roadmap with maximum clearance from the obstacles and its corresponding graph is fully connected for bounded workspaces, which provides a safe navigation among the obstacles. The application of the GVD has somewhat a drawback as to generate the roadmap the geometry of the workspace should be known a priori. In other words, it is important to know the obstacles and the robot configurations space to obtain the corresponding configuration free space. This drawback may be circumvented if, by some means, the robot can get to know the geometry, either locally or globally. This may be achieved by the use of sensorial data of the workspace, which may apply different sensors to construct the geometry. An application of the GVD to generate a roadmap based on sonar sensor and laser scanning readings has been done by some researchers. However, in this approach only local sensorial information of the workspace geometry is captured. An alternative approach to get the whole workspace geometry is getting sensorial data from a global vision system and then letting the roadmap to be generated based on this sensorial data. An advantage of the local sensing is that the sensors can normally be set on board of the robot, while for global vision it is somewhat more difficult. However, with the current wireless communication the sensorial data can be transferred to the robot or to a host computer in real-time, providing fully autonomy.

In this project we are developing the techniques related to image processing and Voronoi roadmap generation and their implementation in a path planning system which is composed of three modules: i) global vision module (GVM), ii) trajectory planning module (TMP) and iii) navigation control module (NCM).

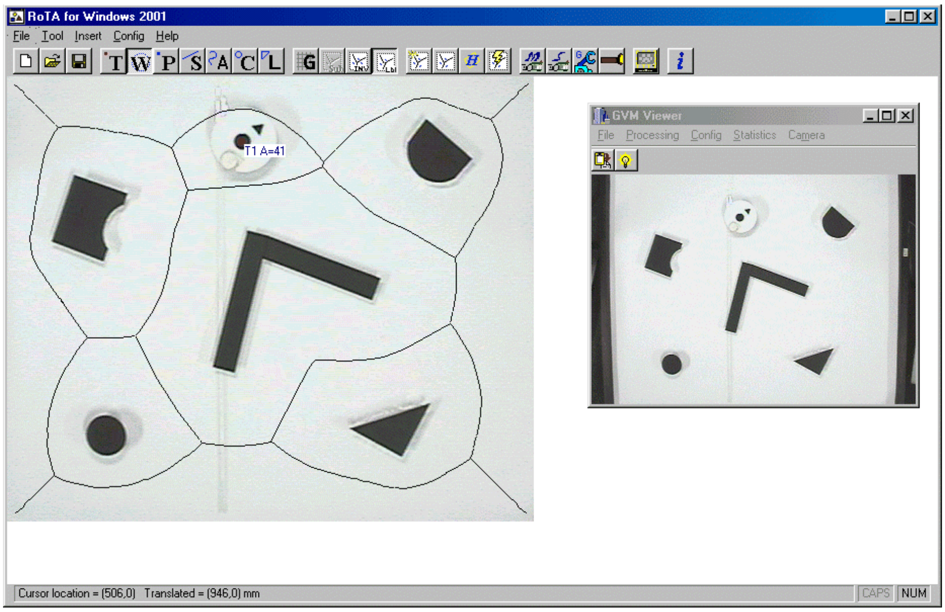
Illustration of the GVM Physical Device



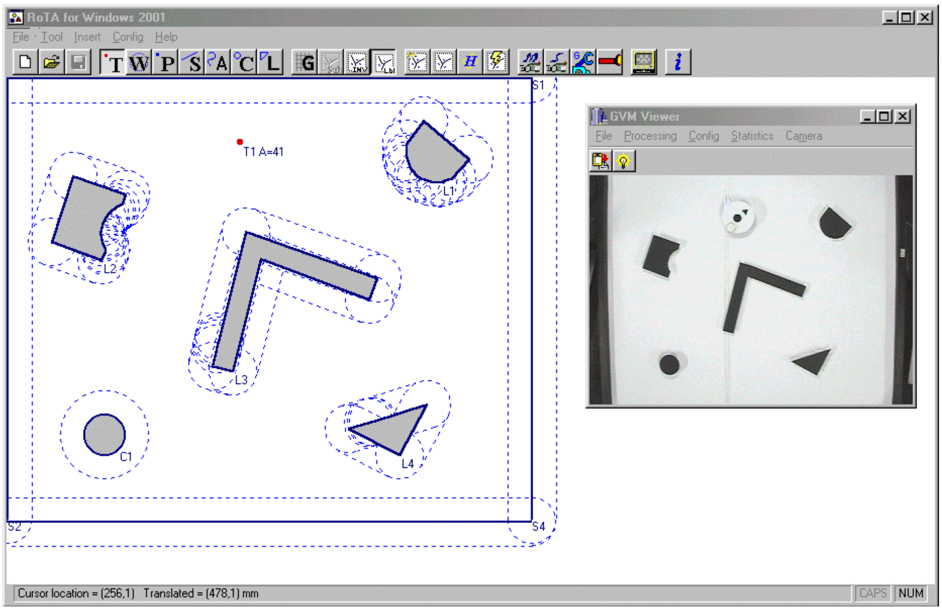
Workspace Image and Viewer of RoTA System



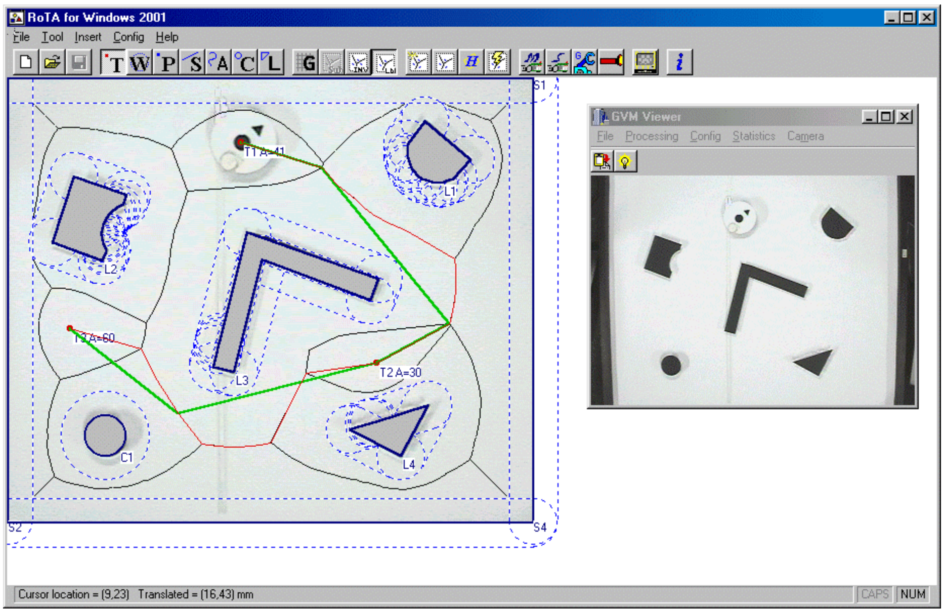
Generalized Voronoi Roadmap



Isotropic Expansion of Obstacles due to Robot Dimension



Maximal Clearance Shortest Feasible Path (in red) and the Visibility Pathway (in green)



Recent publications:

1. Roque, W. L. and Doering, D., Multiple Visiting Stations Trajectory (Re)Planning for Mobile Lab Robots based on Global Vision and Voronoi Roadmaps. In *Proceedings of the 33rd International Symposium on Robotics, paper ISR02*, Stockholm, Sweden, 07-11 October, 2002.
2. Roque, W. L. e Doering, D., Sistema de Planejamento de Trajetórias para Robôs Móveis com base em Visão Global. In *Anais do II Congresso Nacional de Engenharia Mecânica, paper CPB1168, João Pessoa, Paraíba, 2002.*

University of São Paulo (USP)
São Carlos – Brazil

Intelligent Systems Laboratory - LASI
Electrical Engineering Department

Professor Marco Henrique Terra (terra@sel.eesc.sc.usp.br) coordinates several researches in Robotics in the Intelligent Systems Laboratory – LASI/USP. The main problems that have been solved in his laboratory are related with fault detection and isolation of manipulators and control of underactuated manipulators.

Nonlinear and Markovian H-infinity Controls of Underactuated Manipulators

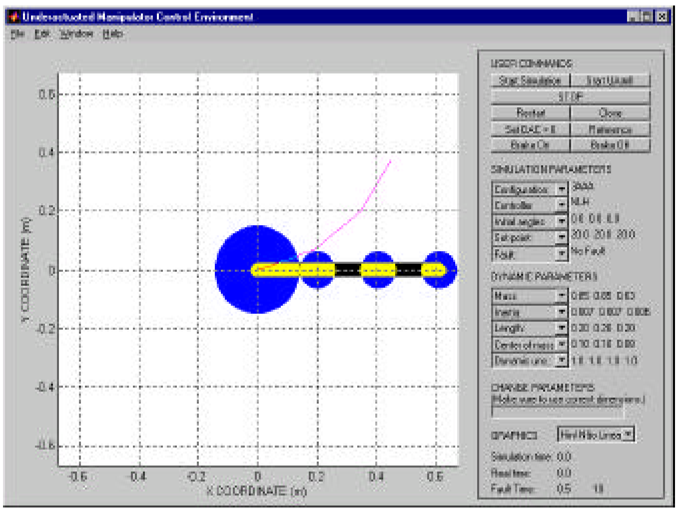
Parametric uncertainties and exogenous disturbances increase the difficulty of reference tracking control for robotic manipulators. Additionally, actuator fault can suddenly occur during the manipulator control and, if the robot is working in hazardous or unstructured environment, the movement must be completed according to the manipulator fault configuration. Among the actuator fault types, the free torque fault, where the torque supply in the motor of each joint breaks down suddenly, can turn the system uncontrolled with the possibility of damage for the manipulator components. When a free torque fault occurs the fully actuated manipulator changes to a underactuated configuration. We have developed three H-infinity control strategies for underactuated manipulators.

We have used Markov theory to incorporate abrupt changes on the manipulator configuration, and Markovian controllers are designed to guarantee stability. With this, the necessity of utilize breaks when a fault occur (procedure that has been presented in the literature) is eliminated. The Markov theory is based on stochastic linear systems subject to abrupt variations, namely, Markovian jump linear systems. The nonlinear system is linearized around operation points, and a Markovian model is developed regarding the changes in the operation points and the probability of a fault occur. The control strategy is developed based on the fact that with deterministic controllers there is no guarantee of stability when the system is subject to abrupt changes.

For the case when the breaks are used, for the underactuated case, we have compared two nonlinear H-infinity control techniques. Nonlinear H-infinity control that consists in guarantee that the L2 gain between the disturbance and the output be bounded by an attenuation level gamma. We have used the linear parameter varying (LPV) technique that provides a systematic way to design controllers that schedule on varying parameters of the system and satisfy the known L2 gain condition, and game theory to solve the H-infinity control problem, for underactuated manipulator, that provides an explicit global solution for this problem, formulated as a mini-max game.

This comparative study is motivated by the observation that both classes of nonlinear H-infinity controllers are different in nature: the first technique, via quasi-LPV representation, provides a gain, after the solution of several coupled Riccati inequalities, that changes in time, and the second technique provides a gain, via analytical solution based on game theory, that is constant in time, similar to the results obtained in feedback linearization procedure. We have investigated the robustness of both controllers.

Even though these nonlinear H-infinity controllers are designed to attenuate uncertainties and disturbances, the stability of the manipulator control, when the configuration is changed after a fault occurrence, is not guaranteed. To use these controllers in a fault tolerant robot system, it is necessary to use brakes after the fault detection, restarting the movement from the zero velocity.



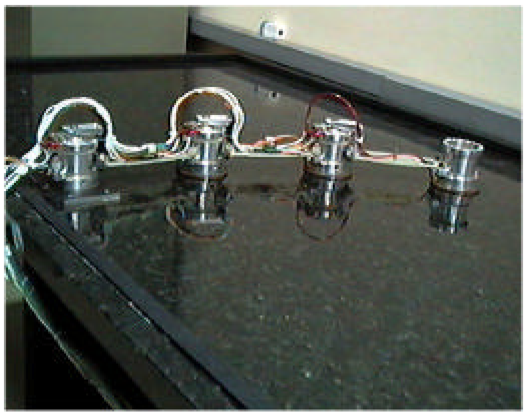


Figure 1: Manipulator control environment and the underactuated manipulator - UArmII, designed and built by H. Ben Brown, Jr. of Pittsburgh, PA, USA. This 3-link manipulator has special-purpose joints containing each an actuator and a brake, so that they can act as active or passive joints. The manipulator configuration can be changed enabling or not the DC motor of each joint.

Fault Tolerance Framework for Cooperative Robotic Manipulators

Nowadays, robots are being deployed in an ever growing number of unstructured and/or hazardous environments, such as outer space, deep sea, and hospitals. Robots are used in these environments to avoid the exposition of human beings to danger or due to the reliability of robots in executing repetitive tasks. However, faults can put at risk the robot, its task, and the working environment.

Faults in robots are mainly due to their inherent complexity. There are several sources of faults in robots, such as electrical, mechanical, and hydraulic. In an industrial environment, the robot can be repaired after the fault detection and isolation - FDI. There are some environments, however, where human beings cannot be sent to make the necessary repairs, and, thus, fault tolerance must be provided to the robot. This is the case of robots operating in hazardous or distant places. Fault tolerance is also necessary when the robot must be kept continuously operating even with a fault, such as robots used to disarm explosives.

As in the human case where the use of two arms presents an advantage over the use of only one arm in several cases, two or more robots can execute tasks that are difficult or even impossible for only one robot. For example, cooperative robots can be used in the manipulation of heavy, large, or flexible loads, assembly of structures, and manipulation of objects that can slide from only one robot. Actuation redundancy makes the use of cooperative robots in unstructured and/or hazardous environments very appealing. On the other hand, as in single manipulators, fault tolerance is crucial for cooperative arms in these environments.

Because of the dynamic coupling of joints, inertia, and gravitational torques, the faulty arms can quickly accelerate into wild motions. As the cooperative system's controller is not projected to operate with faults, the internal forces increase and cause damage to the load or instability to the system. While the problem of fault tolerance in single robotic arms have been studied in the last years, it was not studied in cooperative manipulators yet to the best of the authors' knowledge.

Four faults have been considered: free-swinging joint faults, locked joint faults, incorrectly measured joint position faults, and incorrectly measured joint velocity faults. First, the faults are detected by an FDI system based on the kinematic constraints of the cooperative system and on neural networks. Then, the control system is reconfigured according to the isolated fault.

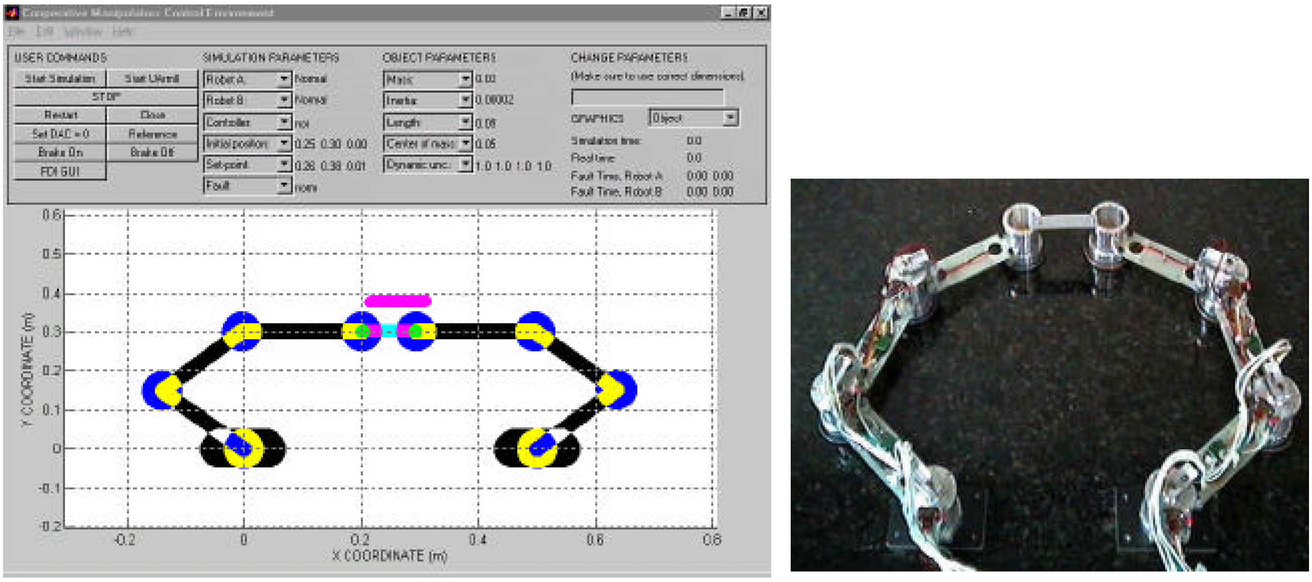


Figure 2: Cooperative manipulator control environment and the cooperative system with two arms. Each arm is a three-joint, planar manipulator that floats on a thin air film on an "air table". The two arms are equal and the axis of each joint is parallel to the gravity force. The cooperative system is controlled by a PC running Matlab. This is possible because the drivers for the UArmII servo board are written as Matlab mex-files. Each joint of the UArmII contains a brushless DC direct-drive motor, an encoder, and a pneumatic brake.

Federal University of Espírito Santo/UFES
Graduation Program on Electrical Engineering
Robotics Research Group

Main Research Topics

- Robotic systems, robot modeling, robot control, mobile robots, autonomous robots, underwater robotics, sensing, computer vision, and visual-based robot navigation.

- The research is developed in connection with the **Laboratory of Intelligent Automation – LAI**, which was created to give the experimental support to this research line.

Faculties

- Prof. Hans-Jorg Andreas Schneebeli, Ph.D.
- Prof. Mário Sarcinelli Filho, Ph.D.
- Prof. Paulo Faria Santos Amaral, Ph.D.
- Raquel Frizzera Vassallo, M. Sc., currently working towards Ph.D. degree
- Prof. Teodiano Freire Bastos Filho, Ph.D.

Foreign Associate Researchers

Through international cooperation projects funded by bilateral agreements involving CAPES (a foundation of the Brazilian Ministry of Education), researchers of some other countries participate in our research activities. Currently, these researchers and their institutions are:

- Institute of Automatics of the National University of San Juan, Argentina (INAUT/UNSJ):
    - Prof. Ricardo Carelli, Ph.D.
    - Prof. Vicente Mut, Ph.D.
    - Prof. Oscar Hermínio Nasisi, Ph.D.
    - Prof. José Postigo, Ph.D.

- Superior Technical Institute of the Technical University of Lisbon, Lisbon, Portugal (IST)
    - Prof. José Alberto Santos-Victor, Ph.D.
    - Prof. Alexandre Bernardino, M. Sc., currently working towards Ph.D. degree

Students Enrollment

- Ph.D. Level
    - The Ph.D. students supervised by the professors in our group are currently eight. Two of them have qualified for the Ph.D. degree, and one of them is now writing the thesis for presentation next November or December. The first Ph.D. thesis in our group was approved in last August, so that we have already formed one doctor.
- Master Level
    - There are six students working towards the Master degree under the supervision of the researchers of our group. In addition, since 1991, when the Master Program started, nine Master Theses supervised by the researchers of our group has been approved.
- Undergraduate Level
    - Five undergraduate students are currently working on projects going on in our lab. Their activities are not part of their undergraduate program. Instead, they are intended as scientific opening activities.

Main Projects

- ### Optical Flow-Based Mobile Robot Navigation
    - The experimental setup consists on a Pioneer 2 DX wheeled mobile platform, from ActivMedia Robotics (USA);
    - The optical flow technique is used to determine the time to collision of the robot to an obstacle (or various obstacles) in its path, and thus to guide the robot to the direction opposed to the direction in which the closer obstacle is detected;
    - The only external sensor used is a single CCD camera. It acquires two consecutive image frames to allow detecting the movement occurred between both image frames;
    - The proposal is to implement a reactive navigation system onboard the robot to allow it to avoid obstacles in its path;

- A suitable algorithm to be programmed on the limited computer resources onboard the robot is proposed, which is now implemented using the INTEL computer vision library, in order to optimize its performance;
- From the optical flow calculated, the image is then segmented to detect distinct objects in the scene. The visual field of the robot is divided in columns, each one 10 pixels wide. Then the minimal time to collision is detected in each column, which characterizes the risk of a collision in that range of the visual field of the robot;
- A sketch of the time to collision is thus generated, which will give the robot the necessary angular speed reference in order to make it to deviate from the obstacle.

PHOTO OF THE PIONEER II – DX MOBILE ROBOT

- ## Four Legged Mobile Robot Prototype (ROQUE)
  - Each robot leg is controlled by an INTEL 8096 micro controller;
  - Each robot leg has currently two DOF, which means to control two motors (in this configuration it is able to follow a straight line only);
  - One of the four micro controllers is also responsible for controlling the leg synchronization;
  - The autonomy is about 40 minutes with two 7 Ah batteries;
  - A new prototype is now being developed, with four DOF per leg, with the objective that the prototype can follow a nonlinear path;
  - A new control architecture based on a network composed by various micro controllers is also been discussed;
  - After, force sensors should be added to each leg in order to allow the robot to detect obstacles. The final objective of using such sensors is to give the robot the ability to go upstairs, for example.

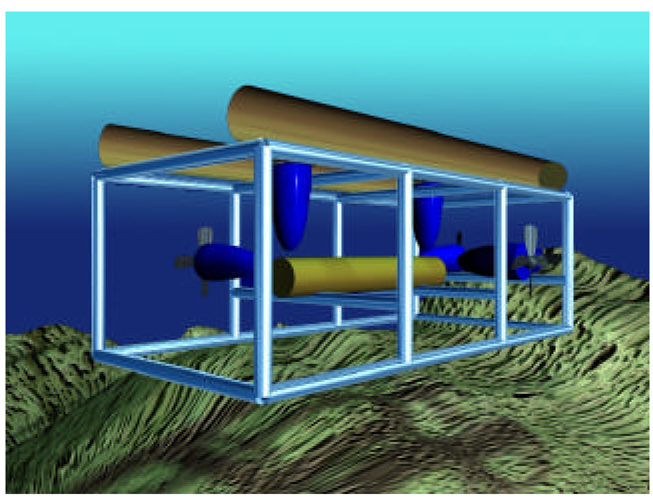
PHOTO OF THE FOUR LEGGED PROTOTYPE "ROQUE"

(Current version, able to follow a straight trajectory)

- ## Underwater ROV Prototype

The research group in Robotics of UFES is building a small remotely controlled underwater robot, which is designed to have 5 DOF and onboard batteries to allow driving the toasters. It will be controlled through an optical cable. Its dimensions are 150 cm x 70 cm x 50 cm, and the weight is about 55 Kg, with a payload of 50 Kg. Currently, the system is being simulated in order to get a good model of it and to design the controllers for the toasters, for 3D movements.

A view of the designed ROV is shown below.



- **Lab equipment available**

  The Laboratory that gives support to the researches in Robotics is equipped with a computational support suitable for attending all the demands in the area, as well as two Pioneer 2-DX mobile robots dotted with onboard computational and visual setup, two additional analog cameras and three additional digital cameras (fire wire standard). This support plus the bibliographic support guaranteed by CAPES has been enough for our developments.

Other Meaningful Information

- Ph.D. Thesis currently under supervision: 8 (eight)
- M.Sc. Dissertations currently under supervision: 6 (six)
- Ph.D. Thesis approved in the period 1997-2002: 1 (one)
- M.Sc. Dissertations approved in the period 1998-2002: 5 (five)
- Papers recently published (from January 1999 to now): 48 (forty eight)

Automation Research Group
Tiradentes University

University/Research Center	Contact	Research Area
UNIT – Tiradentes University	Eduardo Oliveira Freire Eduardo_freire@unit.br	1. Mobile robots control 2. Control architecture for mobile robot navigation 3. Computer vision system for mobile robot navigation

Introduction

The Automation Research Group of Tiradentes University (GPA/UNIT) was created in 1999 and since then we have been working on neural networks, image processing and robotics. In robotics our work is focused on mobile robots navigation. Our laboratory, the Control and Automation Laboratory (LAC), situated on the Research and Technology Institute (ITP), owns now two mobile robots: one of them was built based on the LEGO® Mindstorms development kit (Fig. 1), and the other, called UNIT-EXPLORER 1 (Fig. 2), was built by Symphony Educational Robotics, with our participation.

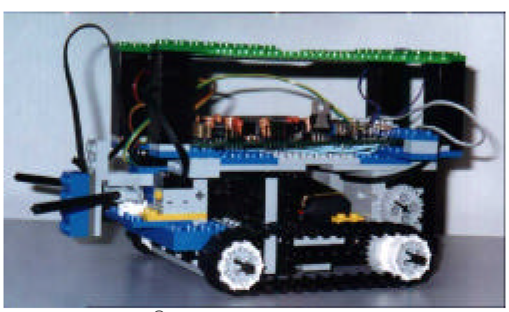


Fig. 1: LEGO® based mobile robot

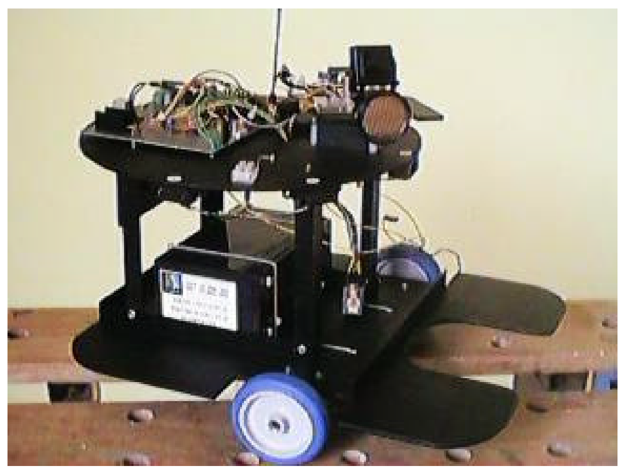


Fig. 2: EXPLORER-UNIT 1

Mobile Robot Navigation

We are about to start a new project which consists on design and implement a control system for the EXPLORER-UNIT 1 mobile robot. Such control system must be designed based on a new control architecture that we have been working in the last three years [1][2][3][4]. The new architecture consists in design one controller to deal with each environment navigation contingence, as avoiding obstacles, wall following and corridor following. Each controller is designed based on the well-known non-linear systems theory and the use of each one of them separately conducts to a stable system in the Lyapunov sense. After finish the controllers design, they are putted together and their outputs are fused using a decentralised information filter (DIF), also proposed by us [1]. The control system that we will develop to the EXPLORER-UNIT 1 mobile robot should be able to allow the robot to follow corridors and walls, while avoiding obstacles.

Visual Servo Control of Mobile Robots

We are now working on a scientific initiation project that consists on controlling a simple mobile robot (the one shown in Fig. 1) using just visual information.

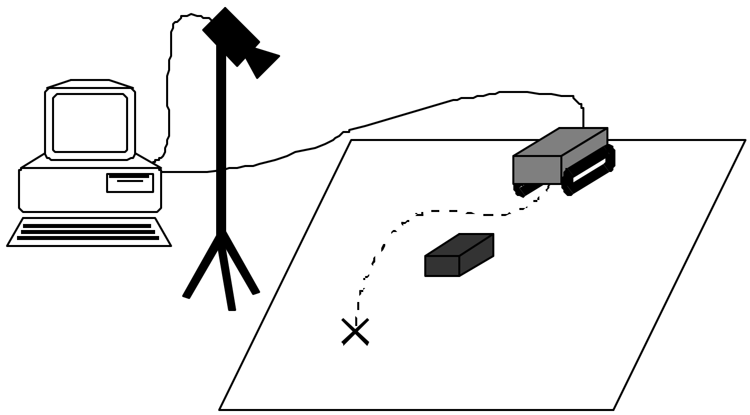


Fig. 3: Visual-servo control.

We are using a common webcam connected to a PC to acquire images showing the robot operation environment. The images are processed to detect the robot, the destination point and the obstacles that may be present in the robot operation environment. Their position, and besides, the robot orientation are passed to the control system, that is composed by two controllers: an obstacle avoidance controller, that receives the obstacles position with respect to the robot current position and should allow the robot to keep away from them, and a final position controller, that receives the robot position and orientation and the final position co-ordinates, and should be able to take the robot from its current position to its destination point. The control system is also designed based on the control architecture previously mentioned, what means that the two controllers outputs are fused using the DIF.

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[4] E. O. Freire, T. F. Bastos-Filho, M. Sarcinelli-Filho, R. Carelli e O. Nasisi, "A new mobile robot control architecture via control output fusion," *Proceedings of the XV IFAC World Congress*, Barcelona, Spain, 2002.

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There are about fifteen years, a multi-disciplinary group of researchers of the Department of Systems and Control of Energy */FEEC/UNICAMP*, Department of Mechanical Projects - *DPM/FEM/UNICAMP*, *DEMA/FEM/UNICAMP*, Department of Electrical Engineering of the Federal University of *Pará*, *Escuela Técnica Superior de Ingenieros de Telecomunicación* of Polytechnic University of Madrid - Spain, and the Department of Computer Science of Santiago's University - Chile, come working integrated in projects of modular robotic systems with the objective of studying the several possible forms of robots' conception, considering the diversity of applications for such kind of machines.

The researches and developments by the group have special attention in the generation of more efficient didactic levels in the transmission of the knowledge generated, manly for graduation and post graduation students, and the assembly of experiments for laboratories with perspectives to support the teaching of disciplines linked with the researched areas. Great priority is given for the production of experimental proceedings for laboratory classes, and the production of equipments and experiments to demonstrate the occurrence of the important physical phenomenons involved in the operation of automatic machines, being also given support to the theoretical classes for the most complete teaching of mechatronics engineering.

Believing that these machines come to be paradigms for intended systems with intelligent control, we have been accomplishing researches and obtained good results about the construction of automatic machines with structures in open and closed chains in the sense of technology creation and applications for approaches centered in nonlinear optimal control, control with adaptive neuromorph strategies, feedforward control based on heuristics rules for path tracking, creation of models for applying robust control techniques, and identification/control of systems that present chaotic dynamics, real time observers, sensor fusion, evolutionary electronic circuits, switching driven systems, self-organizing techniques and control based on fuzzy rules, nonlinear optimization, classifiers' systems, electronic neural networks, and genetic algorithms.

The vanguard of our researches is maintained in the modularization ideas and subsystems integration on architectures that can offer the maximum of possibilities to a same machine with respect to the job that it will execute.

In the pictures below are some views of the Modular Robotic Systems Laboratory located in the Electrical and Computer Engineering School of the State University of Campinas - São Paulo - Brazil.