Mechatronics and Automatic Control Laboratory (MACLAB) University of Genova

Prof. Giorgio Cannata

Introduction

These notes are a short presentation of the *DIST* department of the University of Genova (Italy), and of the activities carried out at the *MACLAB* laboratory.

Purpose of these notes is to provide useful information and highlights of the research activities carried on at *MACLAB*, in view of possible research co-operation and joint partnership in forthcoming European research programs.

DIST (*Department of Communication, Computer and System Science*)

The Department of Communication, Computer and System Sciences (*DIST*) is part of the Faculty of Engineering of the University of Genova. DIST operates since 1984 in the areas of *Computer Sciences*, *Automation*, *Robotics*, *Bioengineering* and *Communications*.

DIST has a staff of over 50 members (2/3 teaching and research, 1/3 technicians and administrative), and it offers graduate and Ph.D. curricula, in Computer Science, Robotics, Bioengineering and Communications.

DIST is strongly involved in *International* and *National Research Projects* granted by the *European Commission* and by *Italian Research Agencies* which, along with a significant number of research contracts with Italian industries and companies, ensure an annual average research budget of about € 1.5 million.

Research at *DIST* is organized into 15 laboratories, providing a number of facilities for research in the areas of advanced robotics, automatic control, industrial automation, computer vision, bioengineering, artificial intelligence and communications.

Furthermore, an electronic and a mechanical workshop support most of experimental development activities carried on in the various laboratories.

MACLAB (*Mechatronics and Automatic Control Laboratory*)

MACLAB has been established in 2001 with the goal of supporting research activities in the area of automatic control of electro-mechanical systems. In particular the primary areas of interest include embedded control systems, distributed control and sensing architectures for robots.

Current Work (2001 - 2004)

Currently the experimental activity at *MACLAB* is focused on the study of distributed control architectures based on field-bus networks and microcontroller-based computers. Current application targets are robotic systems and technologies for humanoid robots and man-robot interaction.

Robot Eye-Head System

The system consists of two human like tendon driven robotic eyes equipped with miniature cameras for stereo vision experiments. This activity is the first stage of the development of a whole humanoid robotic head for man machine interaction experiments.

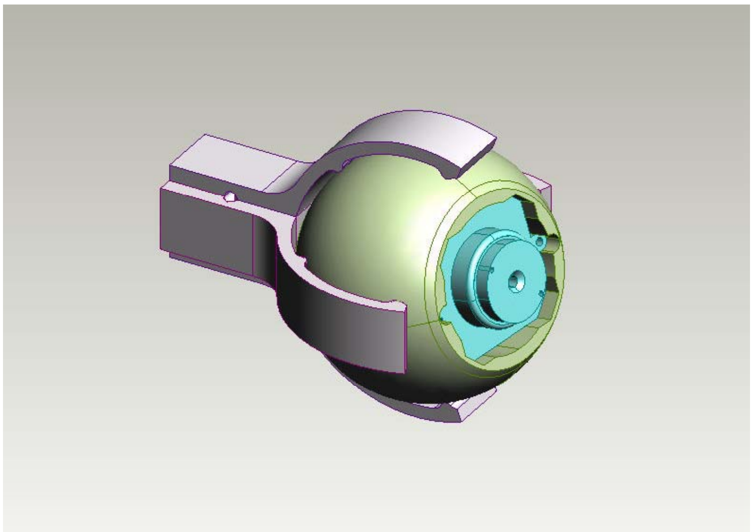


Figura 1 CAD model of the eye-ball and its support.

The eye design has been driven by the attempt of emulating the actual kinematics and muscle/tendon based actuation of a human eye. In particular it has been studied a suitable configuration of tendon and (fixed) pulleys to emulate the tissue pulleys which are believed to be the responsible of the *Listing saccadic* motions.

The systems consists of two twin devices integrating actuators and special optical sensors to measure the tendons' mechanical tension to be controlled to avoid tendon slackness. These sensors are currently being engineered to be integrated within other robotic devices including a *dextrous mechatronic hand* (see below), also in view of a possible patenting of the sensor.

The eye ball is a machined PTFE sphere hold by a PTFE bearing-like support. The design features smooth motion and low dry friction required to low speed motion control.

Eye ball motions are generated by four tendons *sliding* along the sphere and driven through four

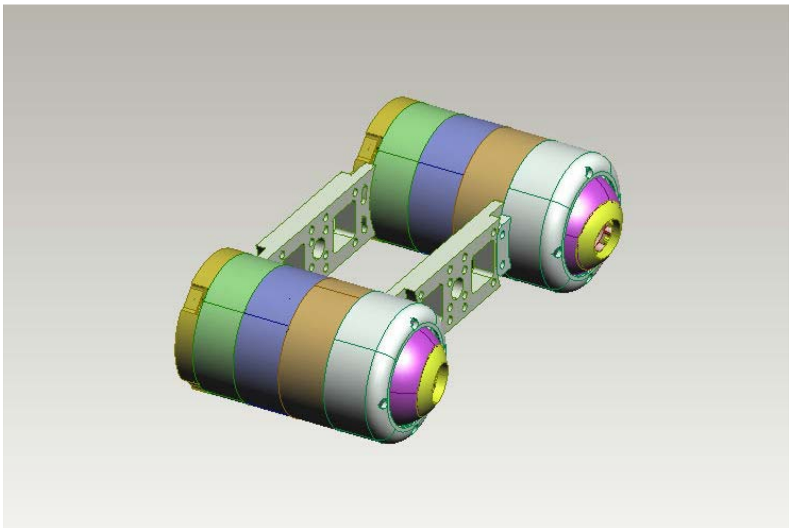


Figura 2 Complete assembly of the system (preliminary - without electronics). Motors and sensors embedded within the structure.

Figura 3 MACEYE - first prototype (july-september 2004). Tendon sensors not shown.

independent actuators. A highly non linear kinematic models allows to map the eye orientation with respect to the head into insertion tendon points and in turn into motor angles/velocities.

The low level control is currently based on a local motor position feedback and a tendon tension control loop.

The control architecture is hierarchical and partly embedded onto the device. A supervisor (implemented on a host computer) generates coordinate reference commands to the eye via a field bus connection. Two distinct embedded controllers integrated with the robot perform the actual motion control of the device. Each embedded controller features a five microcontrollers communicating through a high speed serial link.

Figura 4 MAC Eye assembled prototype (summer 2004)

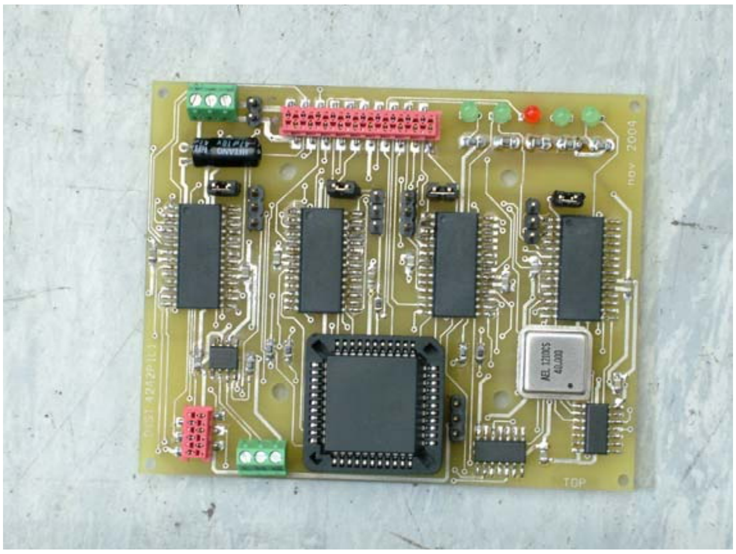


Figura 5 MACEYE embedded controller. Four microcontrllers coordinated by a master controller drive the actuators and acquire data from encoders and optical tendon sensors. A CAN bus link connects the module with the host PC.

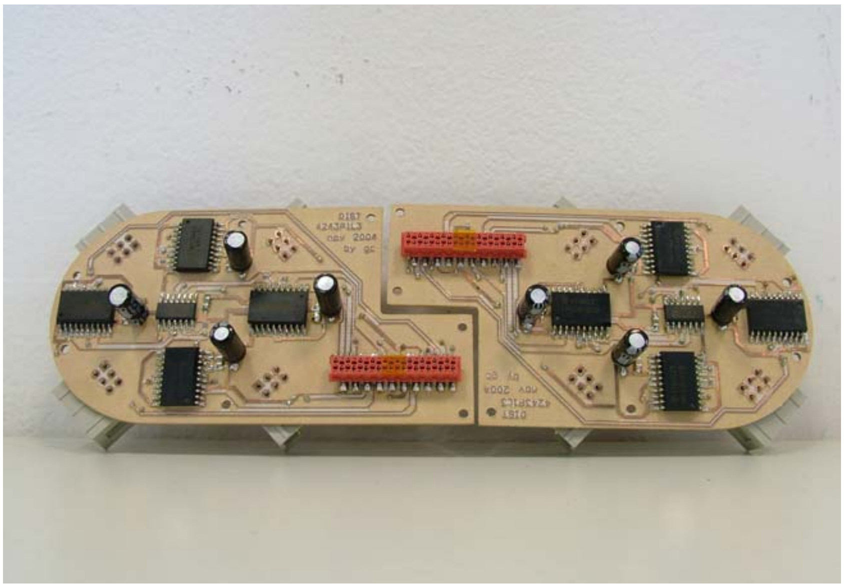


Figura 6 MACEYE motor amplifiers

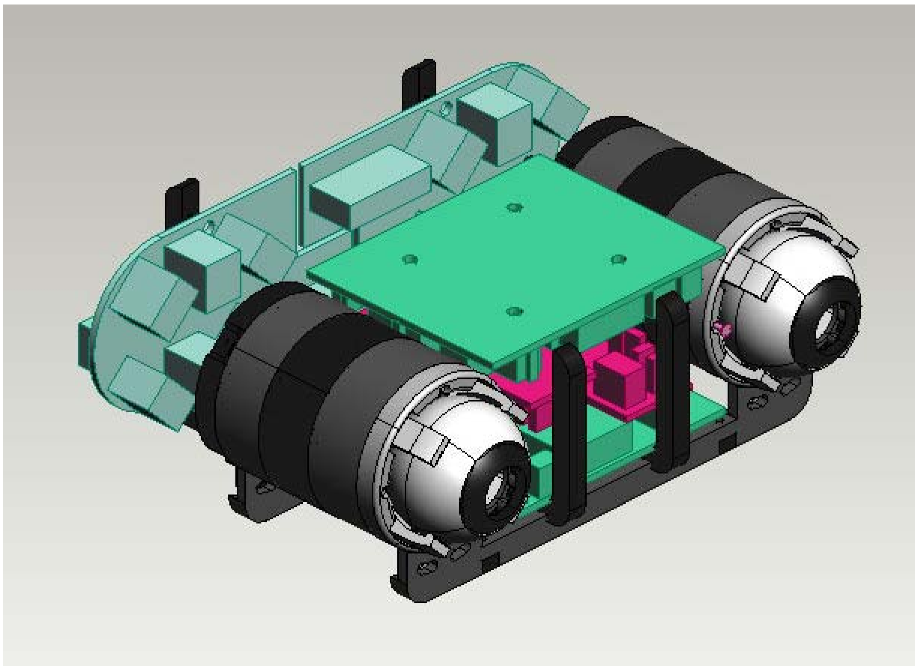


Figura 7 MACEYE Complete assembly (CAD model – December 2004)

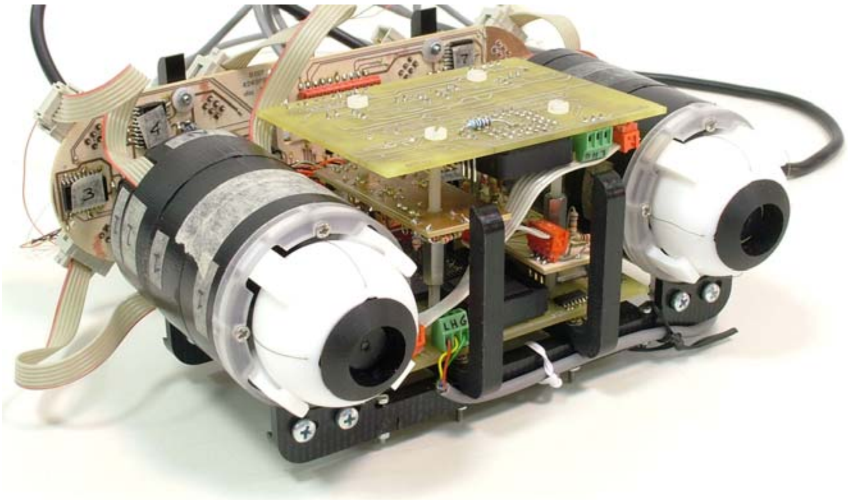


Figura 8 MACEYE Complete assembly (Prototype – February 2005)

Currently a solid state three axial linear accelerometer and three axial angular velocity sensor is under development to provide feedback for active eye-head stabilization. Also a custom camera including early image processing devices to be embedded on board is currently being built.

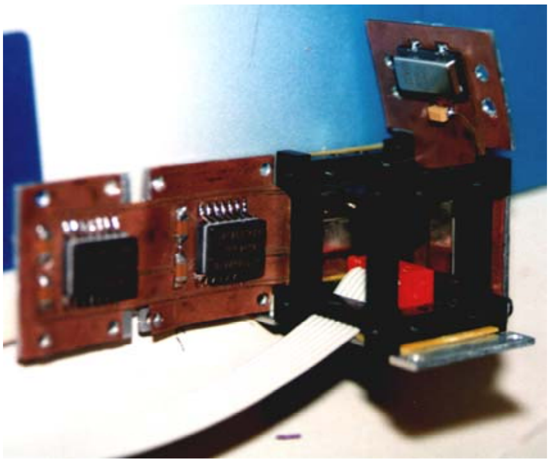


Figura 9 Inertial sensor (open) needed for active eye-head stabilization. Usage of flexible PCB allowed to abtain a compact design.

Dextrous mechatronic hand.

A dexterous robotic hand fully developed using CAD-CAM techniques designed for supporting contact sensors and deeply embedded electronics for data acquisition and transmission.

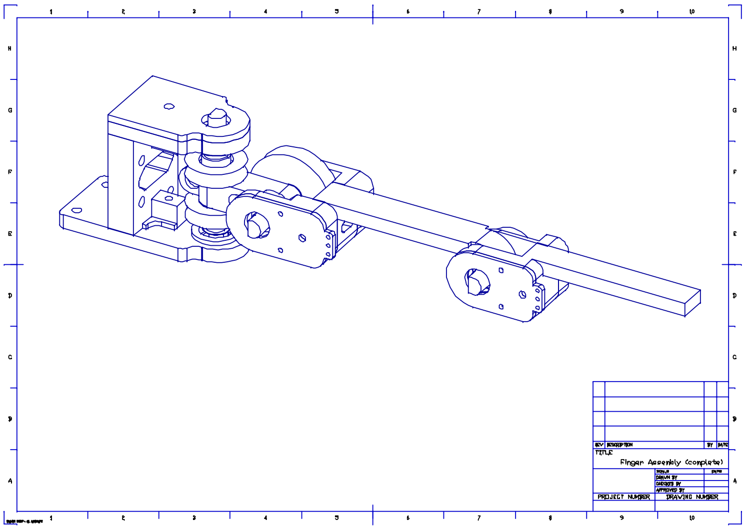


Figura 10 CAD model of the finger. Geometric design considered routing of wires and room for sensors and embedded electronics

The goal of the project is to prove the feasibility of developing a low-cost reliable robotic dexterous manipulator. The kinematic design is a simplified version of a former gripper built by Giorgio Cannata and Andrea Caffaz at DIST. The focus is to design a finger/hand geometry suitable for integrating on board of each finger miniature tactile sensors as well as embedded electronics (analogue and digital). The study of custom miniature tactile sensors (distributed and lumped) is currently in progress.

The hand is fully modular. From the mechanical point of view CAD-CAM tools have been adopted to achieve a fully in-house development of almost all the system components. Also the adoption of light plastic materials instead of aluminum has been experienced. The control architecture feature a distributed network of micro-controllers connected through a CAN based bus. Custom electronics has been designed

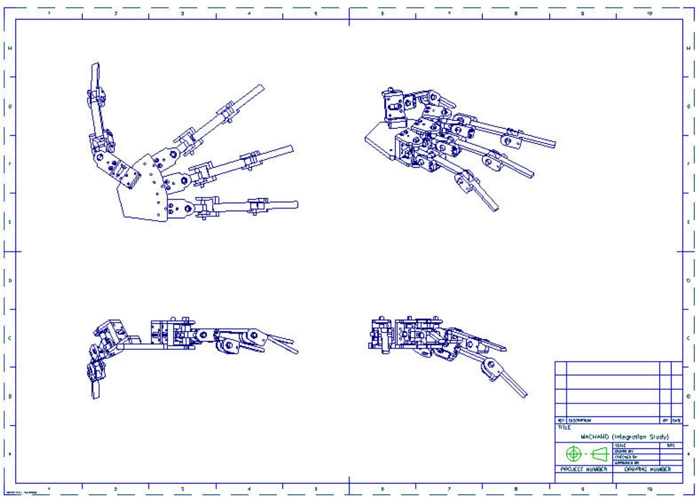


Figura 11 Study of the assembled hand. Modularity has been pursued at all design stages and module development

for data acquisition and filtering, as well as for motor drives. Software design at micro-controller level and supervisory level is currently developed using rapid prototyping and automatic code generation tools.

Figura 13 CAD Models

Figura 12 First finger prototype (july 2003)

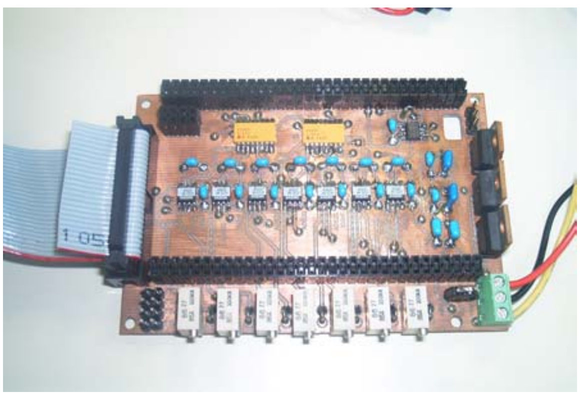


Figura 14 Electronic interface for data acquisition and motor control.

Figura 15 Machined parts. Adopting CAD-CAM tools allowed rapid prototyping of small series of parts.

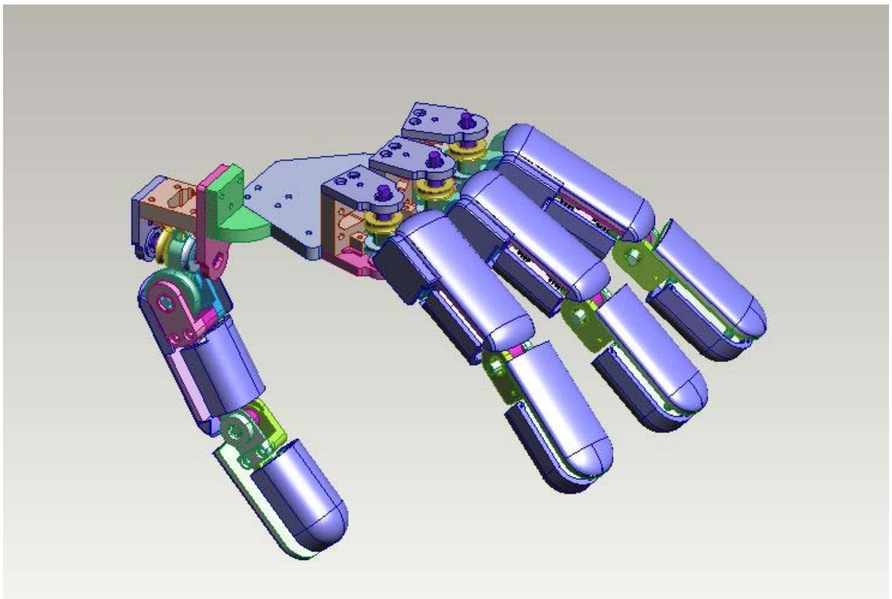


Figura 16 MACHAND – CAD model including tactile and force sensors (december 2004). Each phalange embeds a three axis force sensor, conditioning amplifiers and a microcontroller for data acquisistion and transmission. Distributed skin like tactile sensors are currently under development (January 2005).

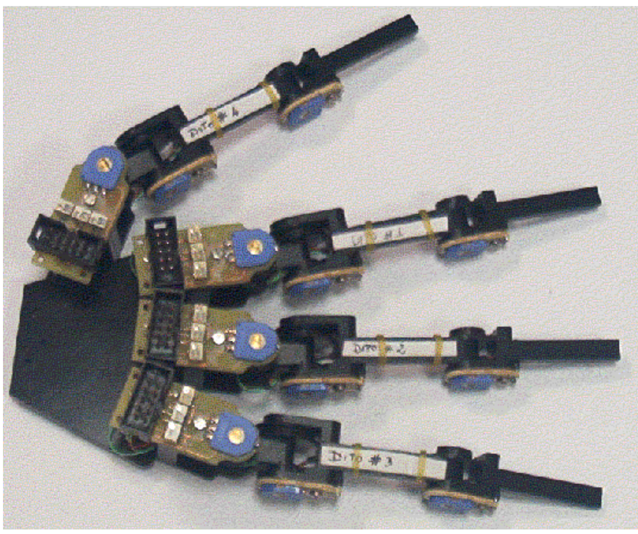


Figura 17 Prototype Assembled

A redundant (8 degrees of freedom) highly sensorized robotic arm with fully embedded and distributed control architecture.

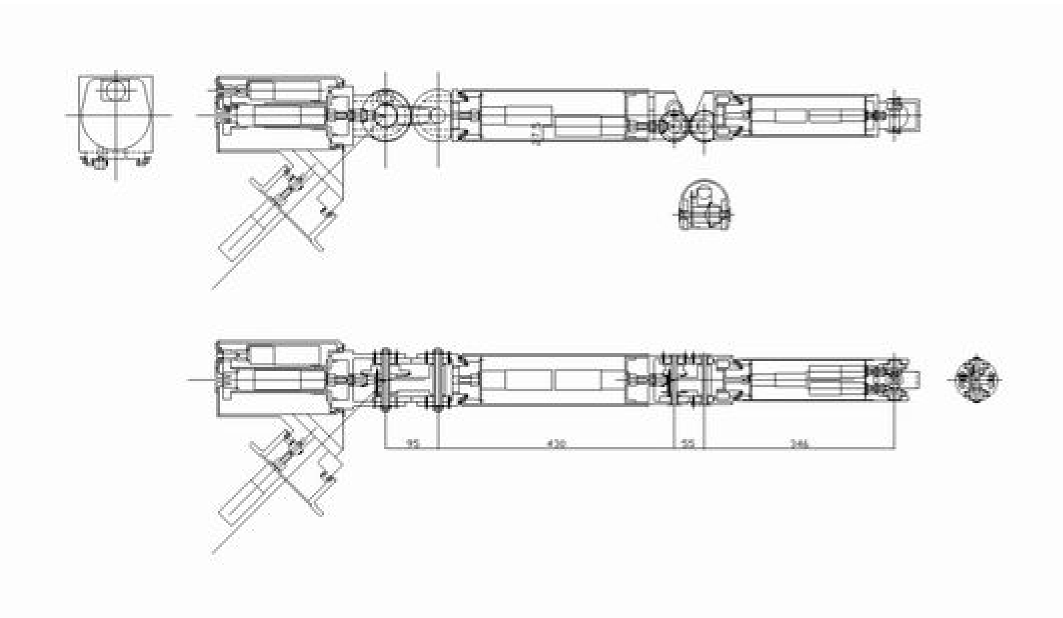


Figura 18 Drawing of the robot arm under development.

The goal of the project is to develop a human like robotic arm, controlled using a distributed network of embedded controllers and sensors. The adoption of deeply embedded electronics for control and sensing should allow to develop smaller and lighter robot manipulators featuring higher dexterity and sensing capability. Embedding and distributing electronics within the robotic structure will reduce wiring harness (which represents a critical constraint to develop highly sensorized manipulators), and will hopefully make possible control redundancy where needed.

Other research and development topics include

- study of minimal wiring distributed sensors (e.g. tactile sensors) and related electronics and data processing
- tools and methods for developing deeply embedded sensor and control systems

Figura 19 Prototype of the arm (4 d.o.f.). Elbow and wrist demonstrator

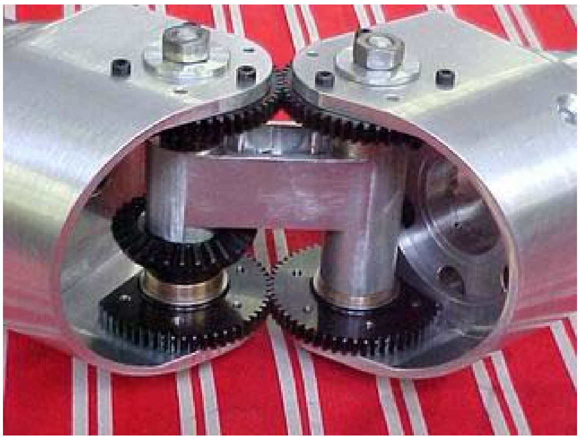



Figura 22 A particular elbow joint has been designed to allow complete flexion of the forearm.

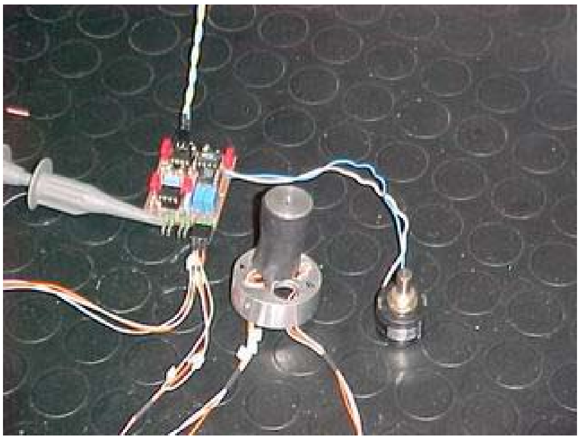



Figura 21 Prototype of joint torque sensor (and custom electronics)

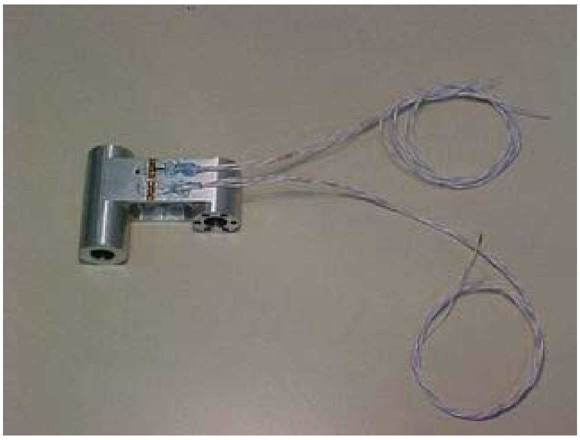



Figura 20 Prototype of torque sensor for the elbow joint.

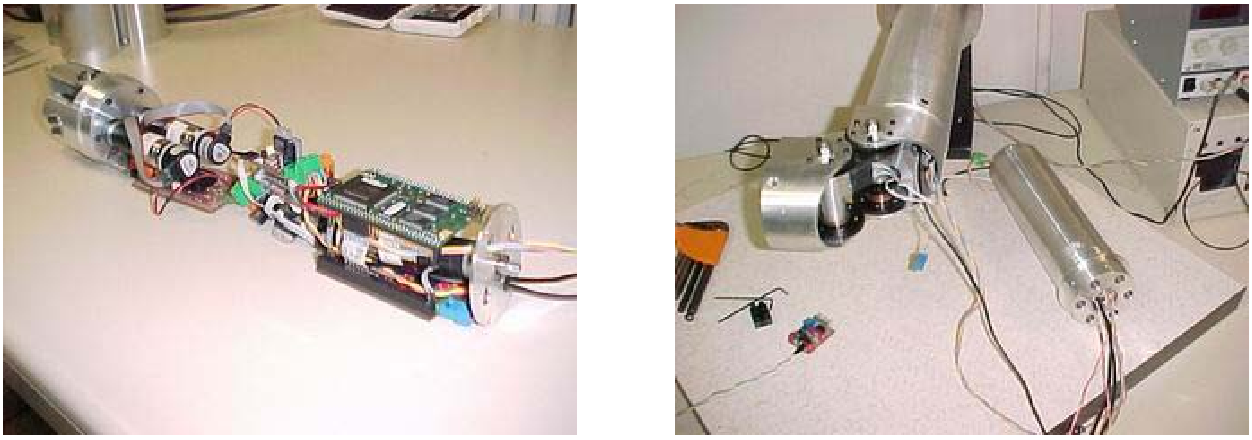


Figura 24 Preliminary integration and tests of the control nodes. Each node controls a single joint and nodes communicate through a CAN serial bus.

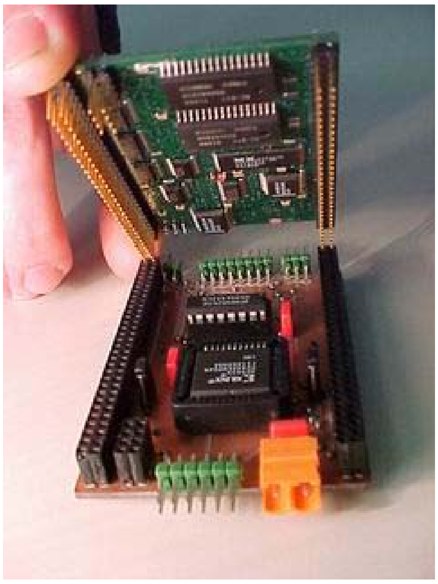
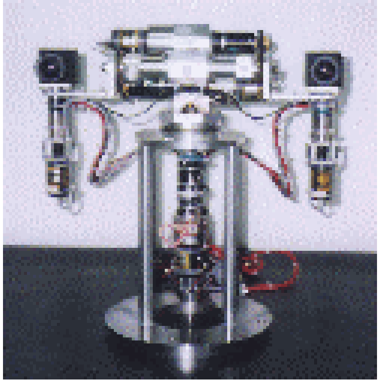


Figura 23 Each node consists of a custom digital interface (below) and an INFINEON C167 based mini-module (commercial). Other custom electronics include drive for motors and modules for signal conditioning.

Previous Work (1994-1999)

Previous work (by Prof. Giorgio Cannata at a former laboratory) has focused on the development of various embedded robotic devices including: a general purpose control VME based parallel architecture for robots, a dexterous robotic hand, underwater robot arms, a robotic head, an embedded matrix tactile sensor for underwater applications.



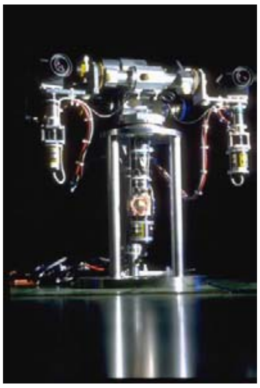
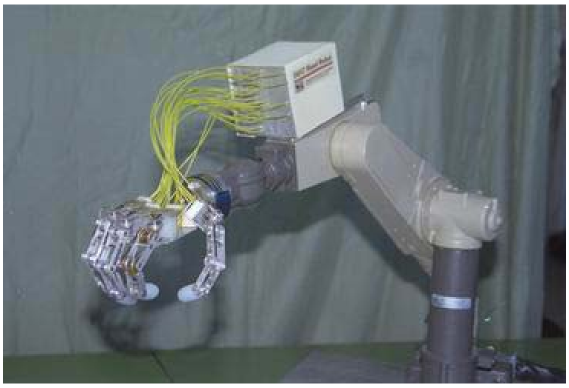


Figura 27 Robotic head-eye system, four degrees of freedom (1997-1998)



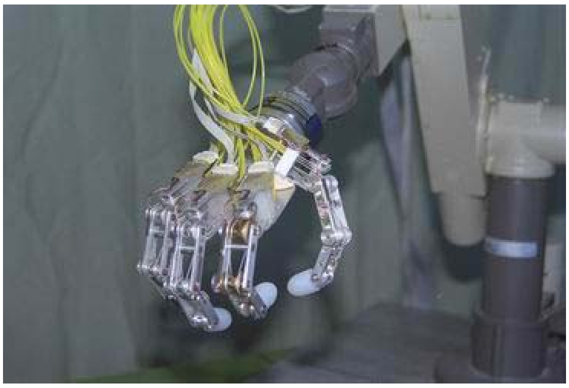


Figura 26 Dextrous robotic hand integrated with a PUMA 260 robot (1995-1999).

Figura 25 Dual arm underwater work-cell. Each arm has 7 degrees of freedom (1996-1999).

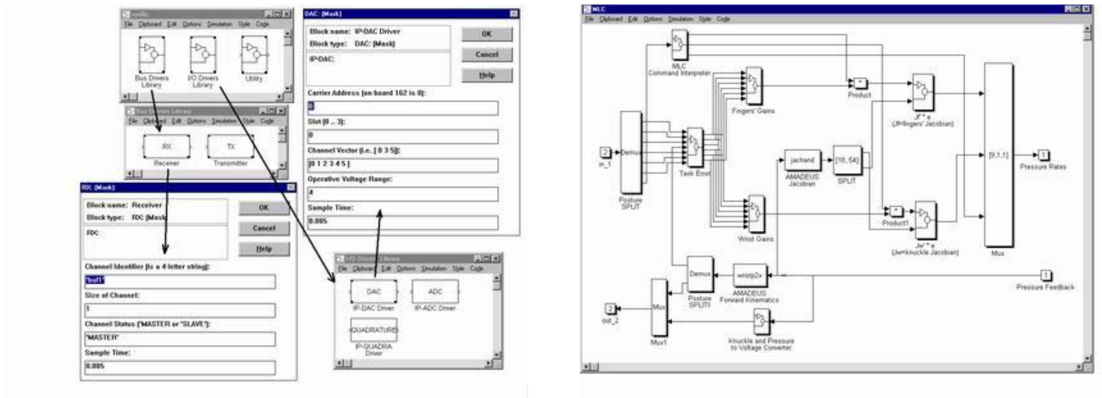


Figura 30 VME/VxWorks robot programming using Simulink RT-Workshop (1995-1996).

Figura 29 Underwater pressure compensated matrix tactile sensor (1999-2000).

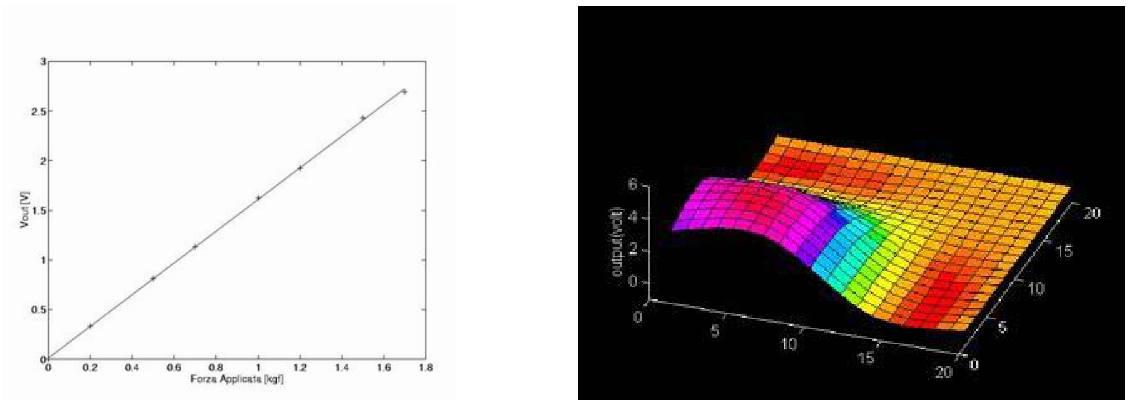


Figura 28 Linearity characteristics of each tactel, and geometry reconstruction from tactile images (contact with a cube).

Prof. Giorgio Cannata

Giorgio Cannata was born in Genova, Italy in 1963. He received the master degree in Electronic Engineering from the University of Genova in 1988.

From 1989 to 1995 he has been *research scientist* at the Naval Automation Institute (I.A.N.) of the Italian National Research Council, working in the area of the underwater robotics.

From 1995 to 1998 he has been assistant professor at the Department of Communication, Computer and System Sciences (*DIST*) of the University of Genova.

He is currently Associate Professor at *DIST*, teaching *Digital Control* and *Engineering and Technologies of Control Systems*.

His main research interests are in the area of automatic control systems and real-time distributed control architectures for robotic and mechatronic systems. His research interests include also robotics and robot control theory, control of mechanical systems, dynamic simulation, theory of dynamic implicit systems.

He has been principal investigator in various *European* and *Italian* research projects.

European Commission Projects

- EC "MAST II" program: AMADEUS project (1993-1996) on underwater robot manipulators technology;
- EC "MAST III" program: AMADEUS phase II project (1996-1999) on underwater robot manipulators technology;
- EC "ESPRIT-BRA" program: FIRST project (1989-1992) on basic research in robot sensing and control;
- EC "ESPRIT-BRA" program: SECOND project (1992-1995) on demonstration of technology on robot sensing and control;

National Projects

- MURST project (1999-2000) on visual servoing for manipulation and vehicle navigation;
- MURST project (2000-2001) on underwater robotics;
- CNR project (2000-2001) on advanced tactile sensors.

Giorgio Cannata is scientific responsible of the *MACLAB* laboratory of *DIST* at the University of Genova.

Last but not least he is *proud* father of two *wonderful* babies (☺).

Figura 31 Maddalena and Chiara

Recent publications (1997-2001)

J1. AICARDI M., CANNATA G., CASALINO G., INDIVERI G., "Cusp-free, Time Invariant, 3D Feedback Control Law for a Non-holonomic Floating Robot", Int. Journal of Robotic Research, Apr. 2001. pp. 300-311.

J2. BALESTRINO A., CANNATA G., "The Inversion of Matrices and Matrix Functions as a Non Linear Discrete System: Stability and Sensitivity Analysis", IEE Proc. Control Theory and Applications, vol. 148, n. 1, Jan. 2001, pp. 43-48.

J3. AICARDI M, CANNATA G., CASALINO G., "Attitude Feedback Control: Unconstrained and Non-holonomic Constrained Cases", Journal of Guidance, Control and Dynamics, vol. 23, n. 4, Jul 2000, pp. 657-664.

J4. CANNATA G., GROSSO E.: "On Perceptual Advantages of Active Robot Vision", Journal of Robotic Systems, vol 16, n.3, 1999, pp. 163-183.

J5. ANGELETTI D., CANNATA G., CASALINO G.: "The Control Architecture of the AMADEUS Gripper" International Journal of Systems Science, vol 29, n. 5, 1998, pp. 485-496.

J6. ANGELETTI D., BOZZO T., CAFFAZ A., CANNATA G., CASALINO G, RETO S., "Design of Task Level Robot Control Systems", Automazione e Strumentazione (in Italian), anno XLVI, Sept. 1998, pp. 127-134.

J7. D. LANE, CANNATA G. et al.: "AMADEUS: Advanced Manipulation for Deep Underwater Sampling", Robotics and Automation Magazine, Dec. 1997.

C1. CANNATA G., BARRECA A., DENTONE L., GIORGI F.: "Embedded Control Architecture for a Redundant Robotic Arm", IFAC 2002 World Congress, Barcelona, 2002 (to appear).

C2. CANNATA G., BARRECA A., DENTONE L., GIORGI F.: "Design of a Human Like Robotic Arm with Embedded Control Architecture", Porc. of IEEE Humanoids 2001 Conference, Nov. 22-24 2001, Tokyo, Japan.

C3. CANNATA G., CASALINO G., PANIN G., CAFFAZ A.: "On a Two Level Hierarchical Structure for the Dynamic Control of Multifingered Manipulation", 2001 IEEE ICRA, Seoul, Corea, May 2001, pp. 77-84.

C4. AICARDI M., CANNATA G., CASALINO G., INDIVERI G.: "Guidance of 3D Underwater Non-Holonomic Vehicle Via Projection on Holonomic Solutions", 2000 World Automation Congress, 8th Int. Symp. On Robotics with Applications, Maui, Hawaii, June 11-16, 2000.

C5. AICARDI M., CANNATA G., CASALINO G., INDIVERI G.: "On the Stabilization of the Unicycle Model Projecting a Holonomic Solution", 2000 World Automation Congress, 8th Int. Symp. On Robotics with Applications, Maui, Hawaii, June 11-16, 2000.

C6. ANGELETTI D., CANNATA G., CASALINO G., MARANI G.: "On the Functional and Algorithmic Architecture of the AMADEUS Dual arm Robotic Workcell", 2000 World Automation Congress, 8th Int. Symp. On Robotics with Applications, Maui, Hawaii, June 11-16, 2000.

C7. LANE D., CANNATA G. et al., Advanced Manipulator for Deep Underwater Sampling: The AMADEUS Research Project", 1998 IEEE Int. Conf. On Control Applications, Trieste, Italy, Sept. 1998, pp. 1068-1073.

C8. ANGELETTI D., CANNATA G., CASALINO G., et al.: "AMADEUS: Dual-Arm Workcell for Co-ordinated and Dextrous Manipulation", 1998 IEEE OCEANS Conference, Nice, France, Sept. 1998.

C9. BOZZO T., CANNATA G., , et al. “On the Design of Task Level Control Architectures for Complex Robot Systems”, 4th Int. Conf. On Advanced Robotics, Moscow, Russia, Aug. 1998, pp. 332-337.

C10. BRUNO A., CANNATA G., CASALINO G., RETO. S.: “Design of a New Tactile Sensor”, 4th Int. Conf. On Advanced Robotics, Moscow, Russia, Aug. 1998, pp. 300-305.

C11. CAFFAZ A., CANNATA G., PANIN G., RETO S.: “Towards Fully Sensorized and Controlled Robotic Hand”, 4th Int. Conf. On Advanced Robotics, Moscow, Russia, Aug. 1998, pp. 446-451.

C12. CAFFAZ A., CANNATA G., “The Design and Development of the DIST-Hand Dextrous Gripper”, 1998 IEEE ICRA, Leuven, Belgium, May 1998, pp. 2075-2080.

C13. CANNATA G., CASALINO G., INDIVERI G. “Analytical Synthesis of Least Curvature 2D Paths for Underwater Applications”, 6th Mediterranean Control Int. Conference, Alghero, Italy, June 1998, pp. 502-506.

C14. LANE D., CANNATA G., CASALINO G., et al., “Advanced Manipulators for Underwater Applications: The AMADEUS Program”, 6th Mediterranean Control Int. Conference, Alghero, Italy, June 9-11, 1998, pp. 496-501.

C15. LANE D., CANNATA G. et al.: “AMADEUS: Advanced Manipulation for Deep Underwater Sampling”, IEEE Int Conf. On Robotics and Automation, Albuquerque (NM), April 20-25, 1997.

C16. G. CANNATA, G. CASALINO “Design of Task Level Robot Control Systems”, Atti 41o Convegno Naz. ANIPLA, Torino, 5-7 Nov. 1997.

C17. CAITI A., CANNATA G., CASALINO G., RETO S., “Teleoperations with Shared Explicit Contact Force”, Int. Symp. On Telemanipulator and Telepresence Technologies IV, Pittsburgh, PA, October 1997.