1. **Title**: First Workshop on Autonomous Underwater Robotics for Intervention (Sponsored by the Marine Robotics Technical Committee of the IEEE Robotics and Automation Society)

2. **Format**: full day workshop structured as follows:

- session 1 - state-of-art on autonomous underwater robotics for interventions, with talks from people which participated in relevant research projects on underwater manipulation validated through experimental experiences.
- session 2 – surveys on underwater intervention tasks, with invited talks from current or potential end-users (like off-shore industries, underwater archeological people, defense center), presenting currently performed activities and providing indications on desirable future capabilities.
- session 3 - state-of-art on the enabling technologies required for autonomous underwater intervention (robust localization, mapping, acoustic/optical image processing, GNC, free-floating manipulation, high-level reasoning, etc...)
- a final interdisciplinary discussion on the main open problems and their viable potential solutions

3. **Abstract** (<200 words)

An increasing number of marine applications requires underwater intervention tasks. Teleoperated robots represent a consolidated solution, however their use induces issues related with the management of the umbilical cable and requires the continuous presence of pilots for driving the vehicle and the robotic arm(s). Nowadays potential end-users, not only from the industrial world, but also interested in other kinds of operations (like marine rescue or maintenance of submerged archeological sites), start pushing for systems capable of performing intervention missions in a totally autonomous way.

To this aim, a number of enabling technologies are required, like robust navigation techniques, multimodal map building algorithms, acoustic/optical image processing for object recognition and pose estimation, advanced manipulation capability (possibly in a free-floating context), effective knowledge representation models for the high-level reasoning governing the whole mission.

First experiments of manipulation with autonomous vehicles (AUVs) have been successfully performed within some interesting research projects and this workshop will share the state-of-art on underwater intervention through the contributions of distinguished invited speakers. Successive talks from active researchers in the above enabling technologies will present their recent achievements. A final interdisciplinary discussion will try to draw a research roadmap for the realization of innovative intervention AUVs.

4. **Organizers** (complete address, phone, and email)

Jun-Ku Yuh, Korea Aerospace University
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5. Presenters with affiliations and status of confirmation

Name	Institution	Status	Title
Session 1			
Giuseppe Casalino	University of Genova	confirmed	"The Pioneering AMADEUS Project"
Giacomo Marani	WVU-NASA Robotic Center	confirmed	"Workspace optimization in autonomous underwater intervention: experimental results with SAUVIM"
Pere Ridao	University of Girona	confirmed	"The RAUVI Project: A reconfigurable Autonomous Underwater Vehicle for Intervention"
Alain Fidani	Cybernetix	confirmed[1]	"The ALIVE project: Autonomous Underwater Vehicles for Interventions"
Pedro J. Sanz	Jaume Primero University	confirmed	"The ongoing TRIDENT Project"
Session 2			
Stefano Fioravanti	NATO Underwater Research Center	confirmed[2]	"USV and UV integration for mine disposal"
Pierre Drap	Université de la Méditerranée	confirmed	"Underwater photogrammetry for artefact measuring and seabed representation"
Giuseppe Conte	Università delle Marche	confirmed	"Integrated robotic system for underwater activities"
Erin Potrzebowski	Chevron	tbc	"Integration of Advanced AUV Technology into Everyday Operations"
Session 3			
Hyun-Taek Choi	Korean Ocean R&D Institute	confirmed	"Visual and acoustic recognitions for intelligent underwater robot"
Gaurav S. Sukhatme	University of South California	confirmed	"Monitoring and Intervention with Underwater Robots: Algorithms and Experiments"

Yvan Petillot	Heriot Watt University	confirmed	"Service-Oriented Agents for Intelligent Control Architecture of Autonomous Marine Vehicles"
Andreas Birk	Jacobs University	confirmed	“Effective Underwater 3D Mapping via Sonar Data”
Alessio Turetta	Graal Tech s.r.l.	confirmed	"Modular Underwater Manipulators"

[1] The final confirmation from Cybernetix is still pending, but in the case of a negative feedback from the Company a talk on the same topic will be given by Yvan Petillot from Heriot Watt university which participated to the ALIVE project.

[2] A confirmation of great interest in participating has been received from NURC but the availability of Stefano Fioravanti is not yet guaranteed for a possible scientific cruise in the same period. In such a case NURC will do anything possible for delegating another person with analogous expertise.

6. List of topics

- Autonomous underwater vehicles
- Underwater manipulation
- Underwater intervention tasks
- Localization
- Guidance, navigation and control
- Cooperative control architectures
- Acoustic/optical image processing algorithms
- Multimodal map building algorithms
- SLAM techniques
- Underwater mechatronics

7. Motivation and objectives (<300 words)

Research activities in Autonomous Underwater Robotics have been so far mainly focused on vehicles performing exploration and observation missions, with important applications in the fields of oceanographic sciences, environmental monitoring and security.
Autonomous Underwater Intervention, involving grasping, manipulation and transportation tasks, did not yet registered the same rate of growth and has been experimented just within some pioneering research projects.

It is however deemed that the interest of the international community on autonomous intervention systems is currently registering a significant growth. The recent dramatic accident of the Gulf of Mexico has just contributed to evidence the importance of working on the realization of smart underwater robots executing intervention tasks in a totally autonomous way.

Performing underwater operations like maintenance, repairing, rescue and items recovery, without the human supervision is certainly not an easy task. However today the field of Underwater Intervention could benefit from several technologies developed for exploration and monitoring missions. Results registered in fundamental topics like underwater localization, acoustic communications, optical and acoustic imagery, guidance navigation and control, mission planning and mapping seem to be ready for being efficiently integrated with the achievements in the field of manipulation tasks, and more generally intervention activities.

Moving from the above considerations, the workshop has three objectives: i) evidencing and possibly classifying the current and future needs of underwater intervention applications; ii) evaluating the existing enabling technologies, their current status of development, and their potential improvements for being tailored to the specific application field; iii) having a better look at the market opportunities that autonomous underwater intervention could open in a mid-term time horizon.
As a final goal, the workshop aims to strengthen and extend the underwater community, by stimulating also the interest of others researchers, not working in the field, toward an area that certainly provides significant research challenges.

8. Primary/secondary audience

The primary audience is constituted by robotics researchers, from both academy and industry, mainly working in the fields of underwater systems and marine technologies. Industry members possibly interested in the exploitation of research results represent the secondary audience, together with any other robotic researcher not (yet) involved in marine applications.

9. Relation to the previous IROS or ICRA

The workshop is sponsored by the Marine Robotics Technical Committee of the IEEE Robotics and Automation Society, which organized also the “Workshop on Recent Developments in Marine Robotics” at ICRA 2009 in Japan. The Committee promotes the current initiative, as it represents the first attempt of establishing a panel of experts, for specifically discussing the main aspects of one important sub-field of marine applications, which never before has been the subject of a dedicated workshop during an important event like IROS or ICRA.

Integrated robotic system for underwater activities

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San Francisco

Integrated robotic system for underwater activities

G. Conte
A. M. Perdon
D. Scaradozzi
G. Vitaioli
S. M. Zanoli

UNIVERSITÀ POLITECNICA DELLE MARCHE
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DIPARTIMENTO DI INGEGNERIA INFORMATICA, GESTIONALE E DELL'AUTOMAZIONE
Lab MACS
Laboratory of Modeling, Analysis and Control of Dynamical Systems

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- Underwater sites of interest in e.g. biology or archaeology often present characteristics that can be damaged by rough intrusion.
- This motivates the interest in developing “low signature” (in a broad sense) robotic systems for underwater intervention.
- At the present level of technology, a viable solution to reduce signature consists in keeping dimensions small.
- This may limit work capability, in particular at high depth, and ultimately reduce the possibility of intervention.

Integrated robotic system for underwater activities

1. Introduction and motivations
2. Overal system
3. Control architecture
4. Mechatronic structure
5. Position measurement system
6. MiniROV guidance system
7. ROV guidance system
8. Supervisory Control System
9. Conclusions

- A solution is offered by the development of composite robotic systems that integrate in a single mechatronic structure components of different kinds.

- In the field of ROVs, a system of the above kind can be realized by coupling a larger vehicle, which can provide load and work capability, with one (or more) much smaller vehicle(s), which can intervene with low impact on the site.

- The resulting structure can be viewed as a small ROV supported by a garage whose potential is augmented by the presence of actuators and sensors for guidance and control, or as a large ROV equipped with a versatile, movable and semi-autonomous appendix for precise intervention.

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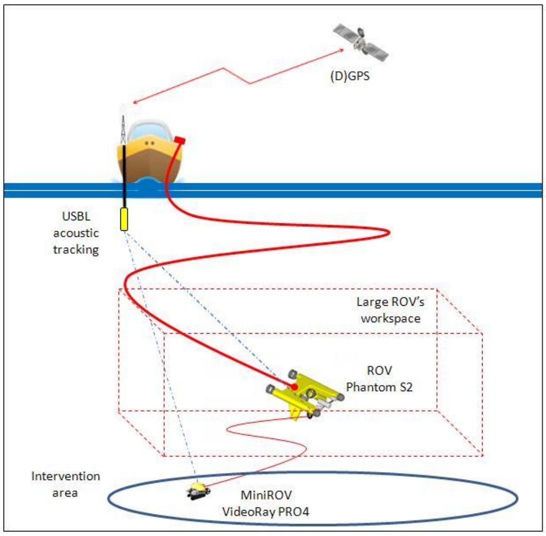
- Overall view of the system currently under development at LabMACS



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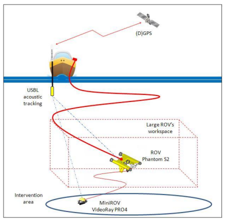
- Conceptual operational scheme:
- ROV carries the MiniROV in the proximity of the intervention area;
- MiniROV is deployed and, then, it is tele-operated by a human operator, within a given range from the ROV, from the surface supply vessel;
- ROV moves autonomously, complying with the operator controlled MiniROV's motion, in order to let the MiniROV work on a large area without going out of the given range.



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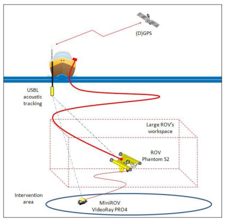
- Conceptual operational scheme:
- (D)GPS-USBL system provides information about the position of the vehicles in terrestrial coordinates;
- NGC system of the ROV exploits information coming from the (D)GPS-USBL system and from navigation sensors (compass, depthmeter, IMU, sonar);
- Operator exploits primary information coming from MiniROV's video-cameras and auxiliary information coming from the (D)GPS-USBL system and from navigation sensors (e. g. compass, depthmeter, IMU, sonar, ROV's video-cameras).



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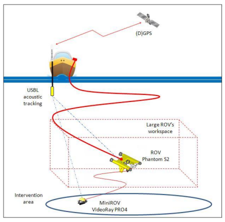
- Advantages of the system:
- the MiniROV can be deployed at high depth and/or far from the supply vessel without imposing the burden of a long umbilical;
- the motion of the Garage/ROV is decoupled from that of the supply vessel (that can be, for instance, moored), increasing autonomy and capability of the whole system;
- the situation awareness of the operator in guiding and controlling the MiniROV is facilitated by the possibility of exploiting also the set of sensors mounted on the ROV, like video-cameras and sonar that, during intervention, provide an external, remote point of view.



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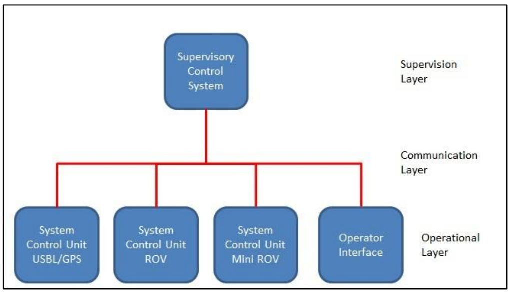
- Control architecture of the system:
- The control architecture has a hierarchical, modular structure, organized over five modules
  - Supervisory Control System Module
  - SCU USBL/GPS Module
  - SCU ROV Module
  - SCU MiniROV Module
  - Operator Interface Module

  and three layers.



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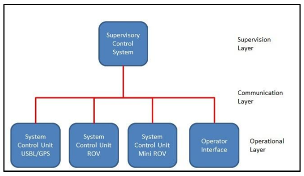
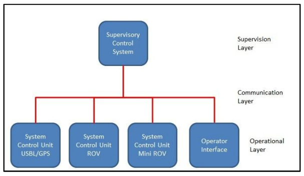
Integrated robotic system for underwater activities

- The Supervisory Control System takes care of
  - synchronizing and monitoring the operations of the other modules;
  - processing and dispatching information and commands;
  - assigning low level tasks and governing the behavior of the SCU of the ROV and of the MiniROV.
- The Operator Interface Module gives to the Operator the possibility to exchange information and commands for
  - interacting at high level with the SupCS;
  - remotely guiding and controlling the MiniROV through the dedicated SCU.
- The dedicated SCU's take care of the low level control of the various apparatus.



Integrated robotic system for underwater activities

- Normally, the SupCS and the Operator work simultaneously and independently.
- The SupCS monitors the positions of the vehicles and, accordingly, it can assign motion tasks to the ROV's SCU and modify behavioral parameters of the MiniROV's SCU.
- The Operator, beside guiding and controlling the MIniROV, can interact with the SupCS in order to modify parameters and/or strategies of the ROV control. In addition, he can take control of the overall system at any time.



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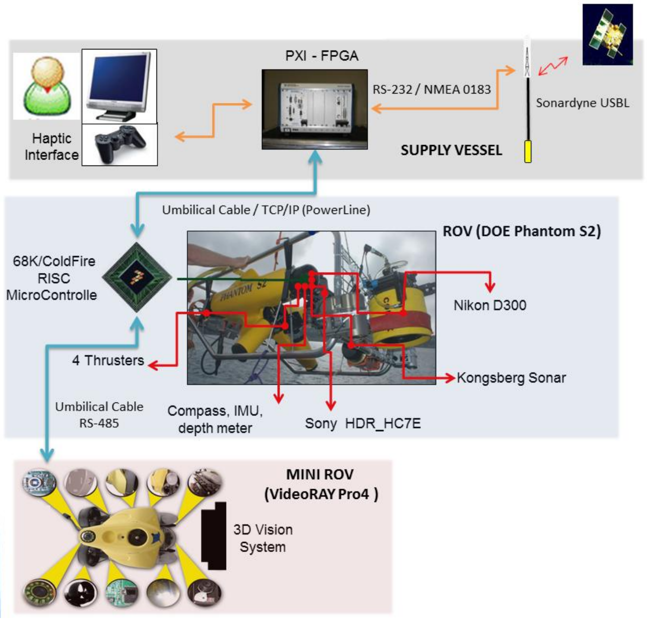

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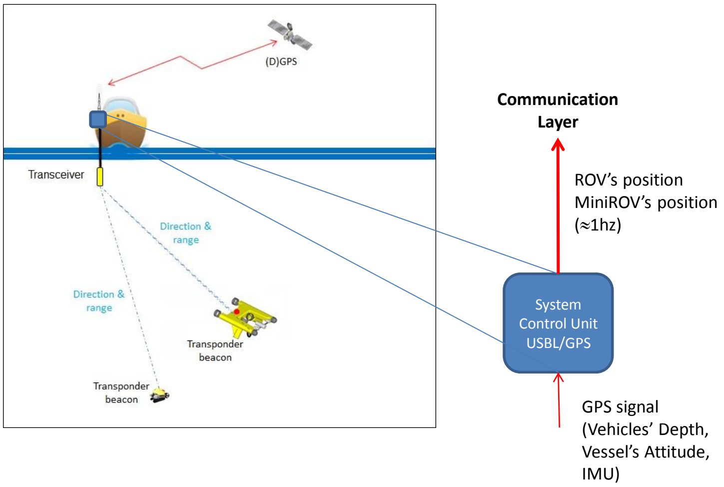
- Position measurement Sonardyne USBL system and SCU.
- Measurement errors can be reduced by keeping the supply vessel's position close to the vertical of that of the ROV.



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Integrated robotic system for underwater activities

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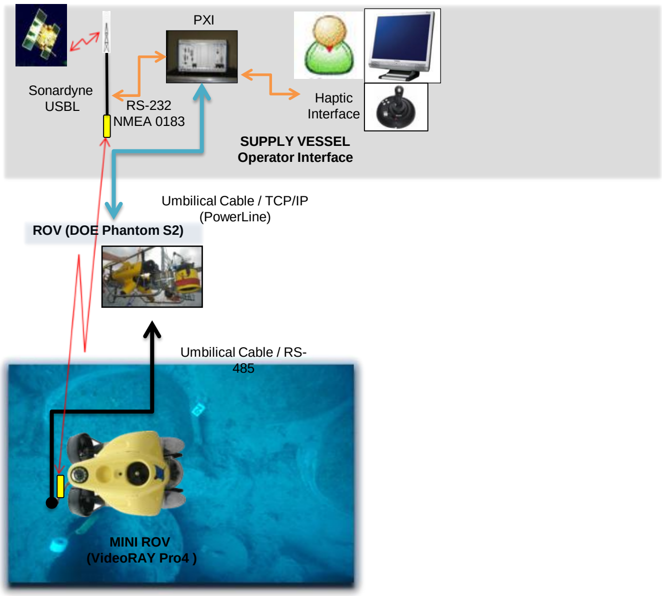
- SCU MiniROV and Operator Interface



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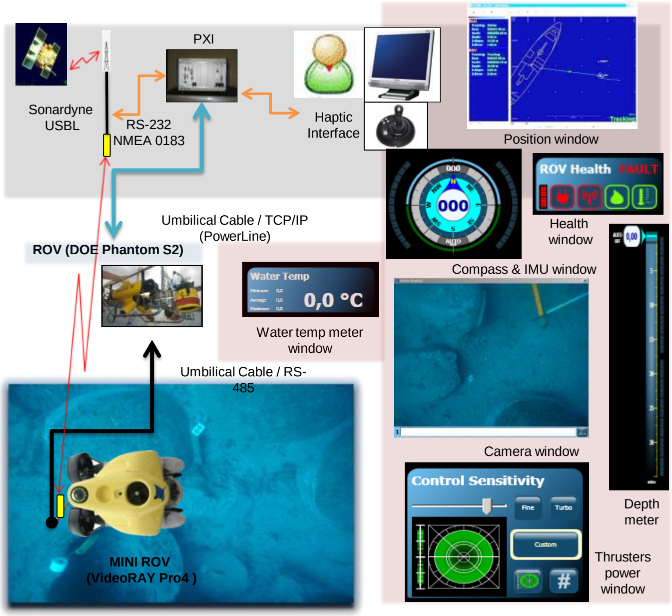

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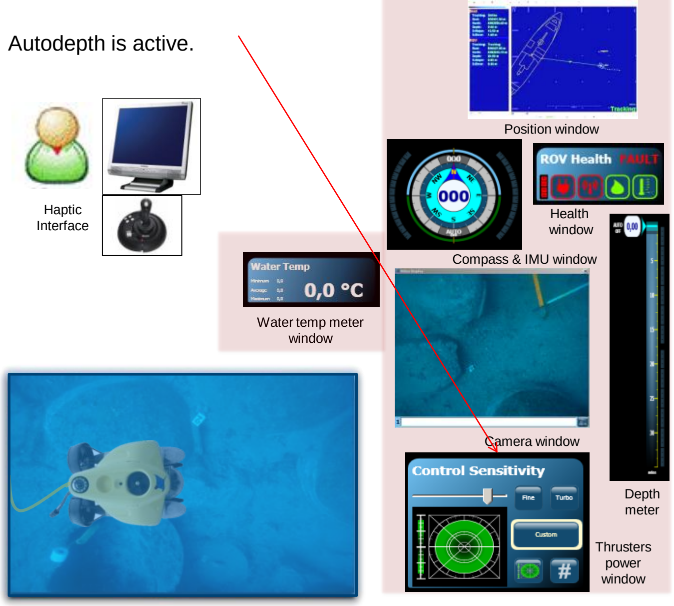
- Joystick resistance increases with distance from ROV.
- Autodepth is active.



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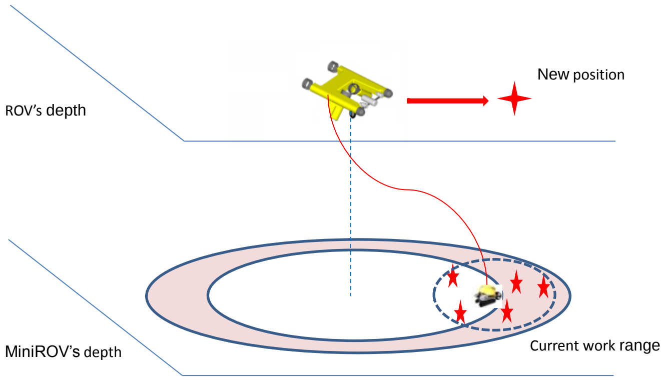
- ROV and MiniROV authodepth systems are active.
- Positions for the ROV are determined by the SupCS on the basis of the past (Operator driven) behaviour of the MiniROV: mean and variance of the positions occupied by the MiniROV in the last T seconds are computed and, if mean is “far” (red area) and variance is “small” (dotted circle), a new position is determined.



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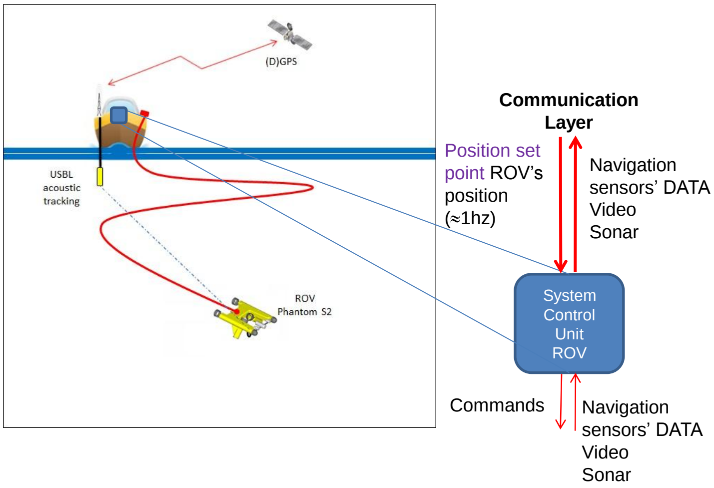
- The SCU ROV stabilizes the ROV at the position indicated by the SupCS, using the feedback information coming from the USBL.



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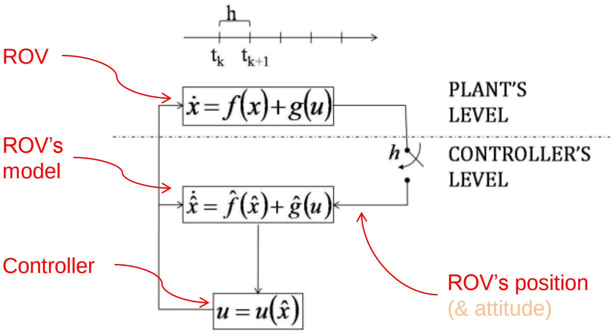
- ROV control scheme: derived from a MB-NS control scheme.



- Under suitable hypothesis (f(.) is Lipshitz in a ball, the model is "sufficiently good"), if the controller drives asymptotically to 0 the state of the model, the above control scheme assures local asymptotic stability for h sufficiently small.

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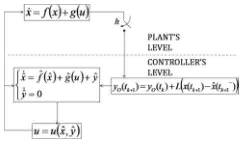
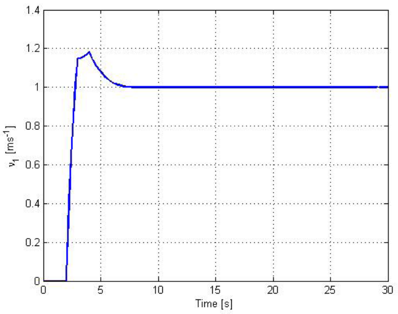
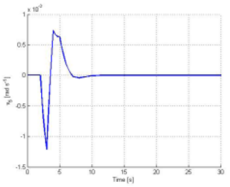
- ROV control scheme: simulation results about motion and attitude control by means of a suitable MB-NC scheme [Conte, Perdon, Vitaioli; Proc. MED’09, Thessaloniki, Greece]

- ROV $M\nu = C(\nu)\nu + D(\nu) + u$
- ROV’s model $\hat{M}\nu = \hat{C}(\nu)\nu + \hat{D}(\nu) + u$ (coefficients altered by 10%)
- Control objective ν=(1,0,0,0,0,0) (surge 1m/s)
- Controller [Conte, Serrani; IEEE Robotics Automation Magazine, 6, 1999]
- h=1s







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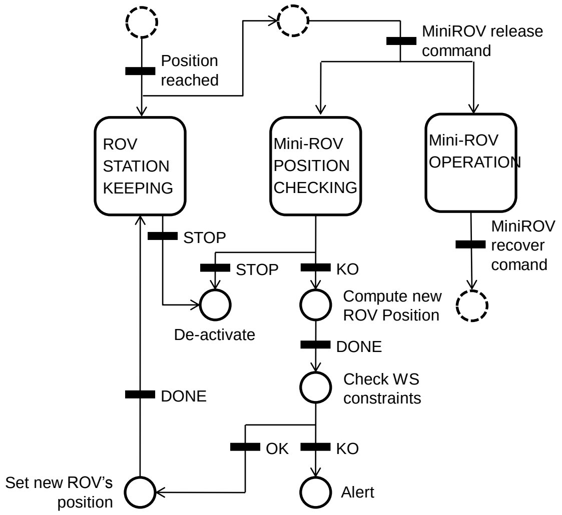
- Supervisory Control System operation



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Integrated robotic system for underwater activities

- System development and construction:

➢ mechatronic components of the system have been acquired/realized/assembled and individually tested;

➢ control software (SupCS, SCU ROV, SCU MiniROV) has been realized and tested in simulations;

➢ data processing and communication structures have been realized and tested;

➢ integration of components;

➢ experiments and testing.

AMADEUS

Advanced Manipulators for Deep Underwater Sampling

EU-Mast II Phase I 1994-1996
EU Mast III Phase II 1997-1999

(1) G. Bartolini
(2) G. Bruzzone
(3) G, Cannata
(4) G. Casalino
(5) B. Davis
(6) D. Lane
(7) G. Veruggio

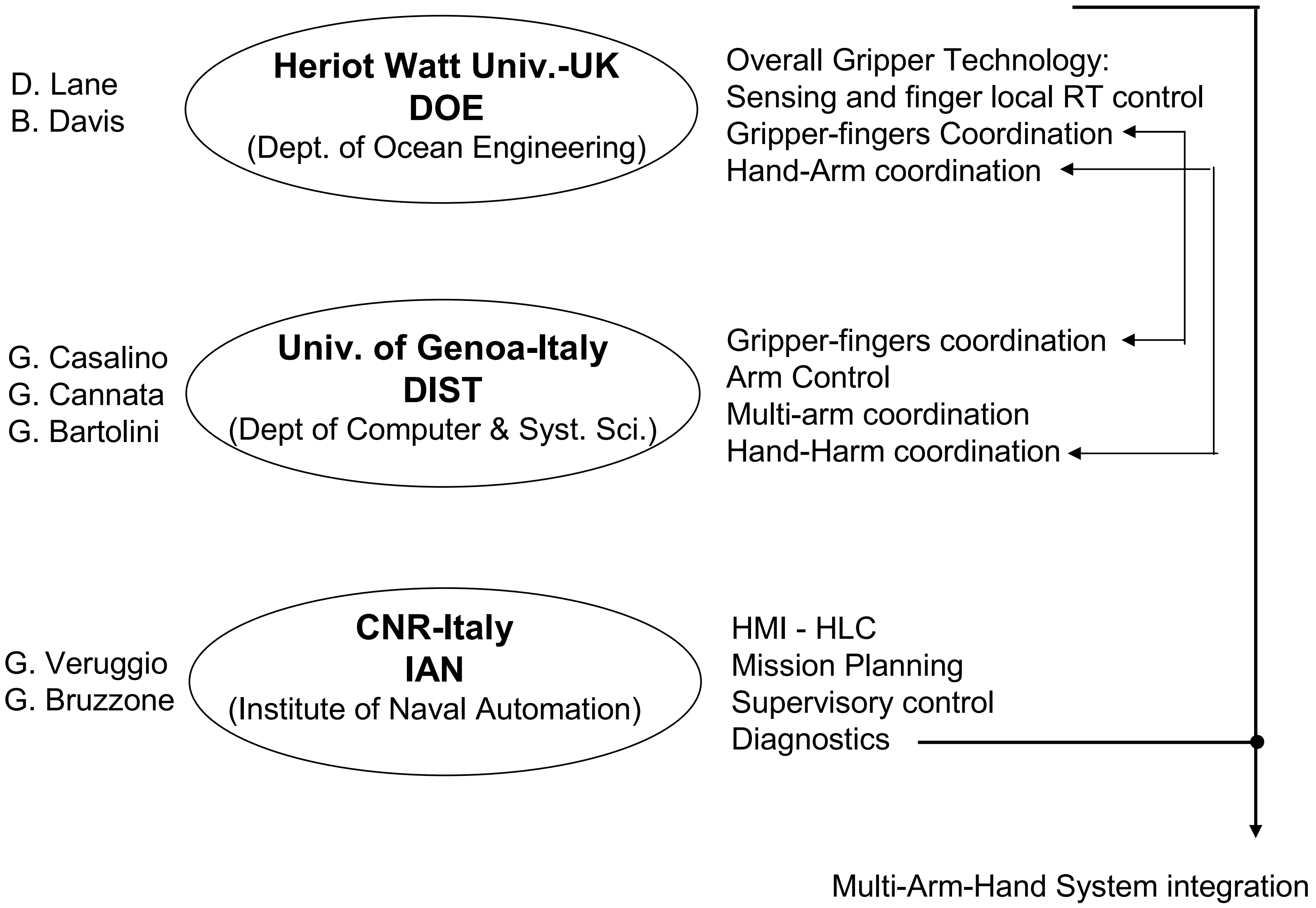
Focused on manipulation within underwater environments

Developing	Hw technology	(System, Actuation and Sensing)
	Hw architectures	(Distributed Processing)
	Sw architectures	(Modular Sw Eng. Technques)
	RT control Architectures	(Hierachical, Modular, Distributed)
	RT specific algorithms	(RT Signal processing & Control)
	HMI-C2	(Planning & supervisory control)

For

Advanced Multi-fingered Underwater Grippers
Advanced Underwater Arm Systems
Multi-fingered Gripper coordination
Multi-arm System coordination
Arm-Gripper integration & coordination (Hand-Arm system)
Multi-Arm-Hand system integration & coordination

Principal Developers and Roles



D. Lane
B. Davis

Heriot Watt Univ.-UK
DOE
(Dept. of Ocean Engineering)

Overall Gripper Technology:
Sensing and finger local RT control
Gripper-fingers Coordination
Hand-Arm coordination

G. Casalino
G. Cannata
G. Bartolini

Univ. of Genoa-Italy
DIST
(Dept of Computer & Syst. Sci.)

Gripper-fingers coordination
Arm Control
Multi-arm coordination
Hand-Harm coordination

G. Veruggio
G. Bruzzone

CNR-Italy
IAN
(Institute of Naval Automation)

HMI - HLC
Mission Planning
Supervisory control
Diagnostics

Multi-Arm-Hand System integration

Subsystems 1

Finger: Technology & Actuation

Elephant trunk paradigm

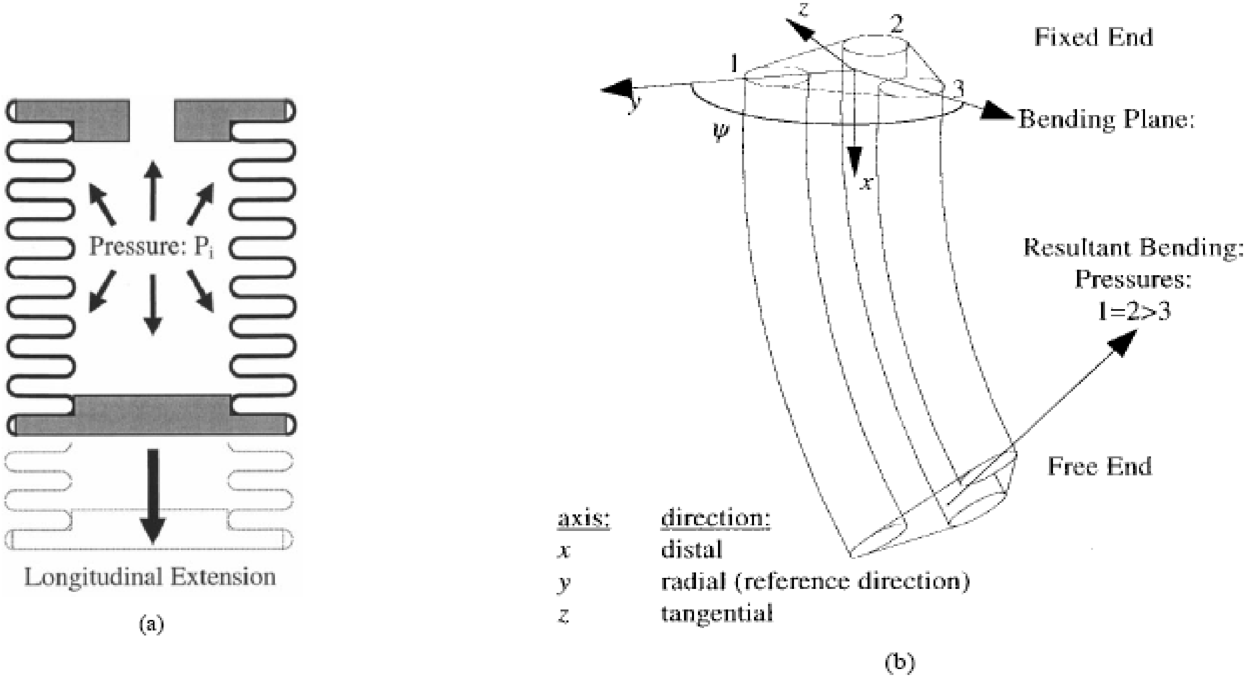


Fig. 3. (a) Internal pressure causes mainly longitudinal extension. (b) Bending of flexible actuator caused by internal pressure differential.

Subsystems 2

Finger: Force & Slip sensing Technology

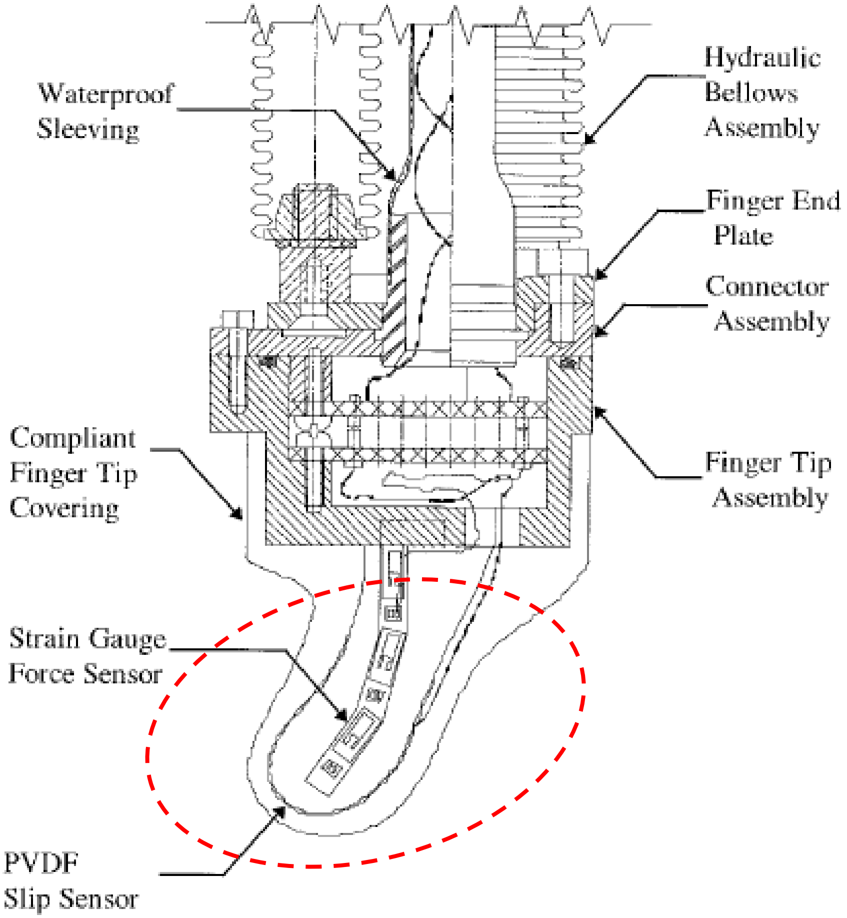
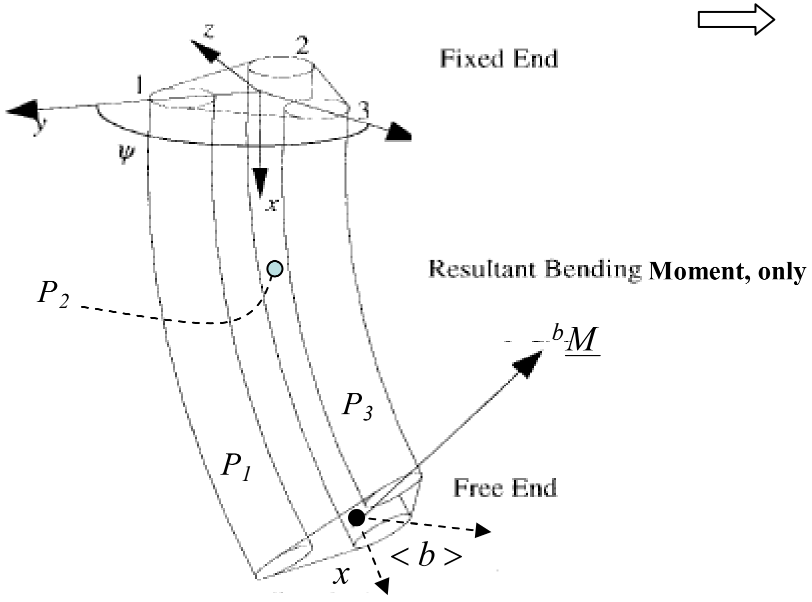
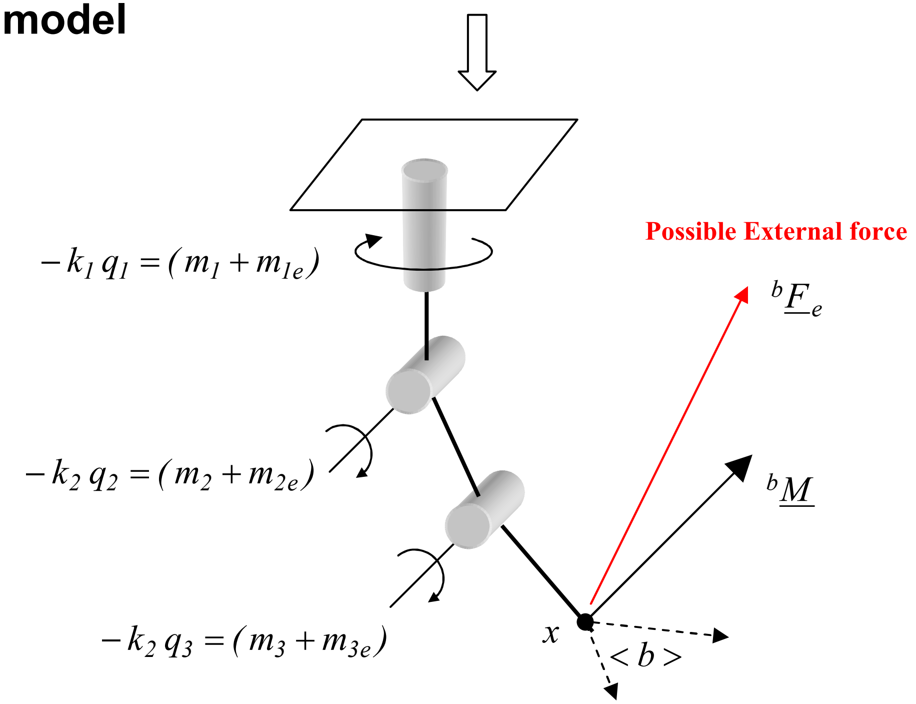


Fig. 4. Detachable finger tip, with force and slip sensors.

Subsystems 3

Finger: Approximated static lumped model





$$\left.\begin{array}{l} (P_1,P_2,P_3) \doteq P \quad \Leftrightarrow \quad {}^b\underline{M} \\ (P_{1e},P_{2e},P_{3e}) \doteq P_e \quad \Leftrightarrow \quad {}^b\underline{F}_e \end{array}\right\} \longrightarrow \quad ({}^b\underline{M},{}^b\underline{F}_e) \quad \Leftrightarrow \quad (q_1,q_2,q_3) \doteq q \quad \Leftrightarrow \quad x$$

At the equilibrium

Subsystems 4

Finger: Position & Force control

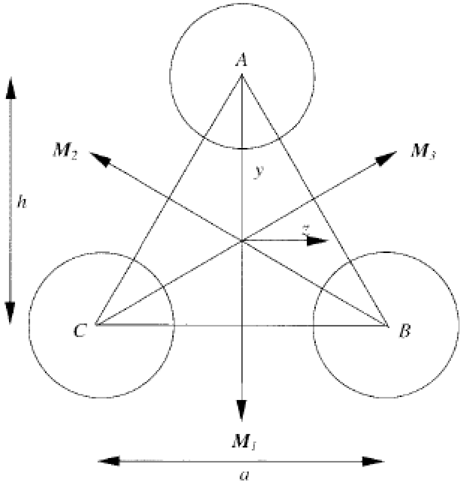


Fig. 7. Plan view of a single finger.

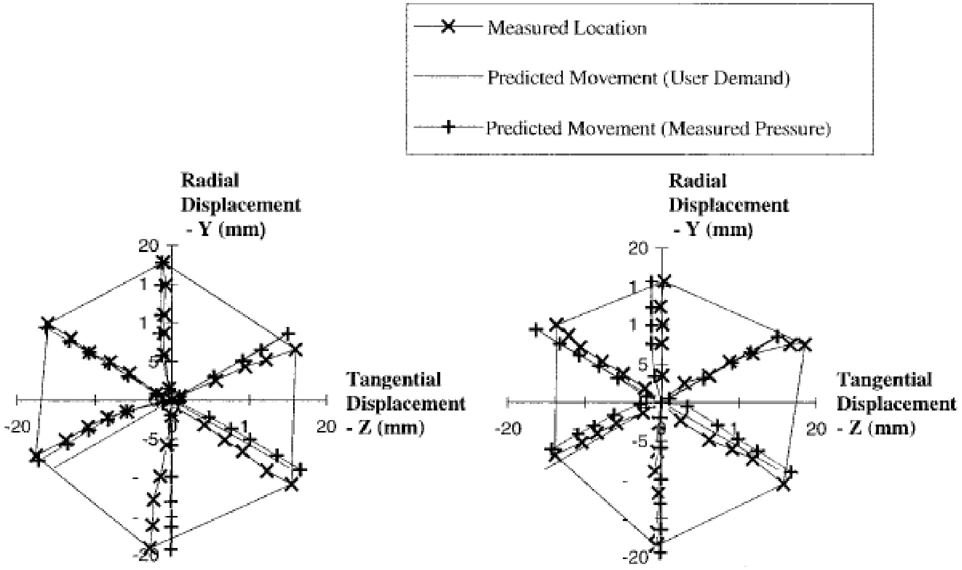


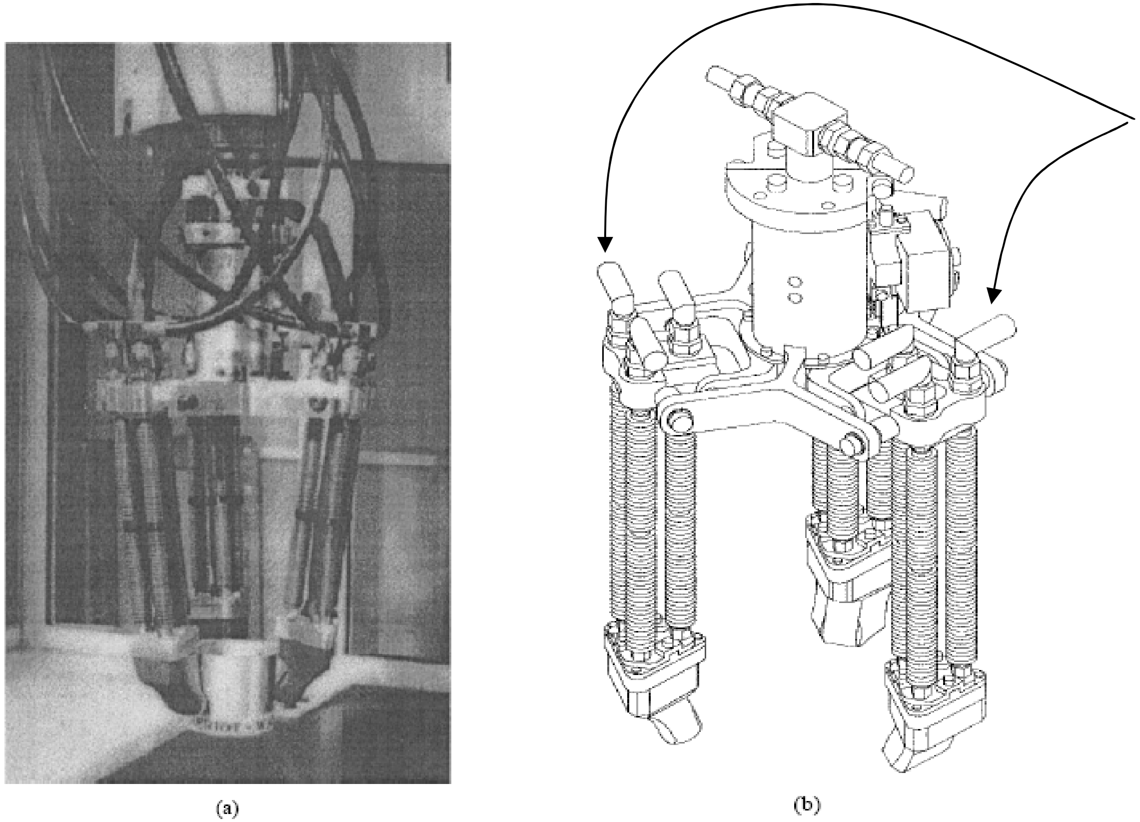
Fig. 8. Measured and predicted finger motions with demanded and measured pressures.

Position only control: No position sensors available
Open loop control via (well tuned) lamped static model for bending
Smooth and slow motion command required
(no excitation of higher-frequency effects)
(smooth time-response also favored by natural damping)

Position/force control: Force closed loop via sensed external forces
Position open loop via (well tuned) lamped static model for bending
Moderately smooth force/position commands required
(no excitation of higher frequency effects)
(smooth time-response also favored by natural damping)

Subsystems 5

Gripper: Three fingers arrangement



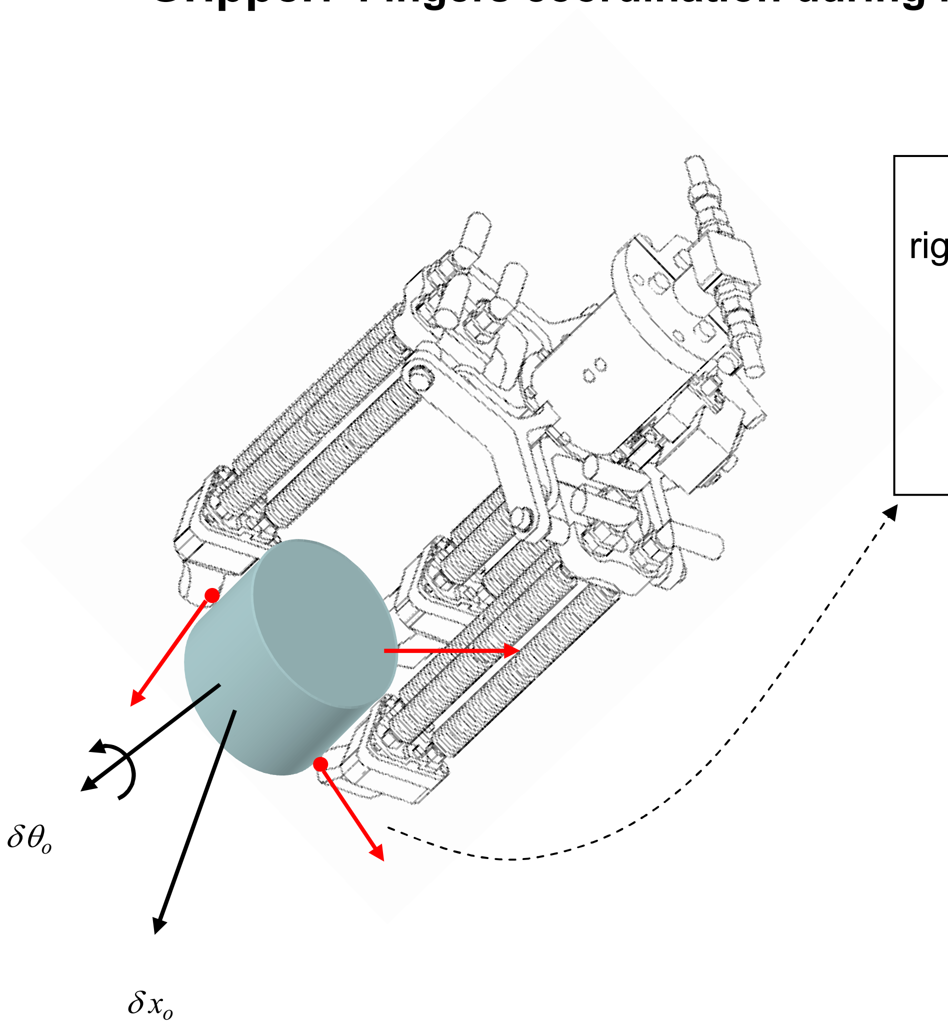
Nuckle joints

(a) (b)

Fig. 2. AMADEUS phase I prototype gripper. (a) Hardware. (b) Schematic.

Subsystems 6

Gripper: Fingers coordination during manipulaion



Tip's desired differential motions obtained as
rigid body transformation of the objet desired ones
(kinematically consistent)

+

Desired grasping forces
(not shown)

LLC: gripper independent

Coherent bending and grasping
pressures at the bellows

VLLC: gripper dependent

Subsystems 7

Gripper: Fingers coordination during manipulation (VIDEOS)

With standard grippers

1- Pose control

With AMADEUS gripper

2- Pose control

3- Turning a ball & slippage control

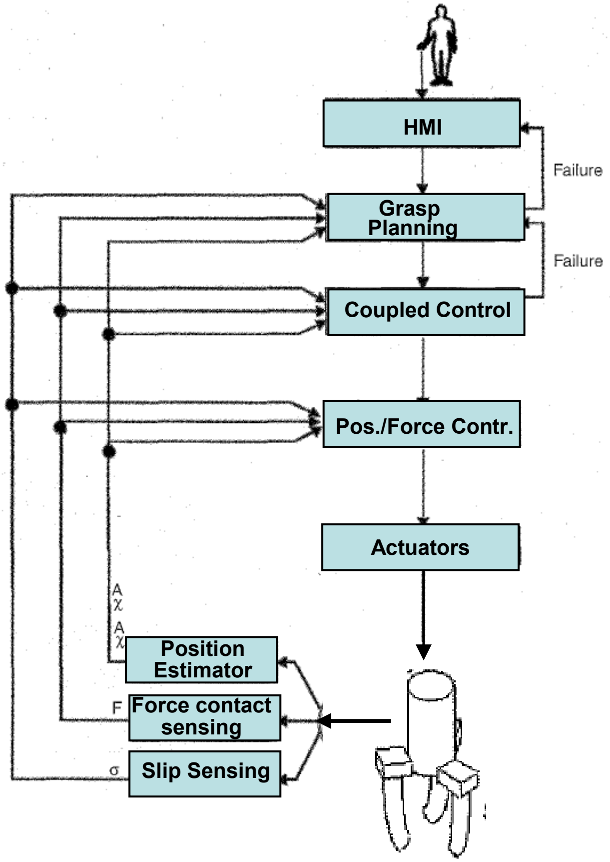
4- Turning a nut

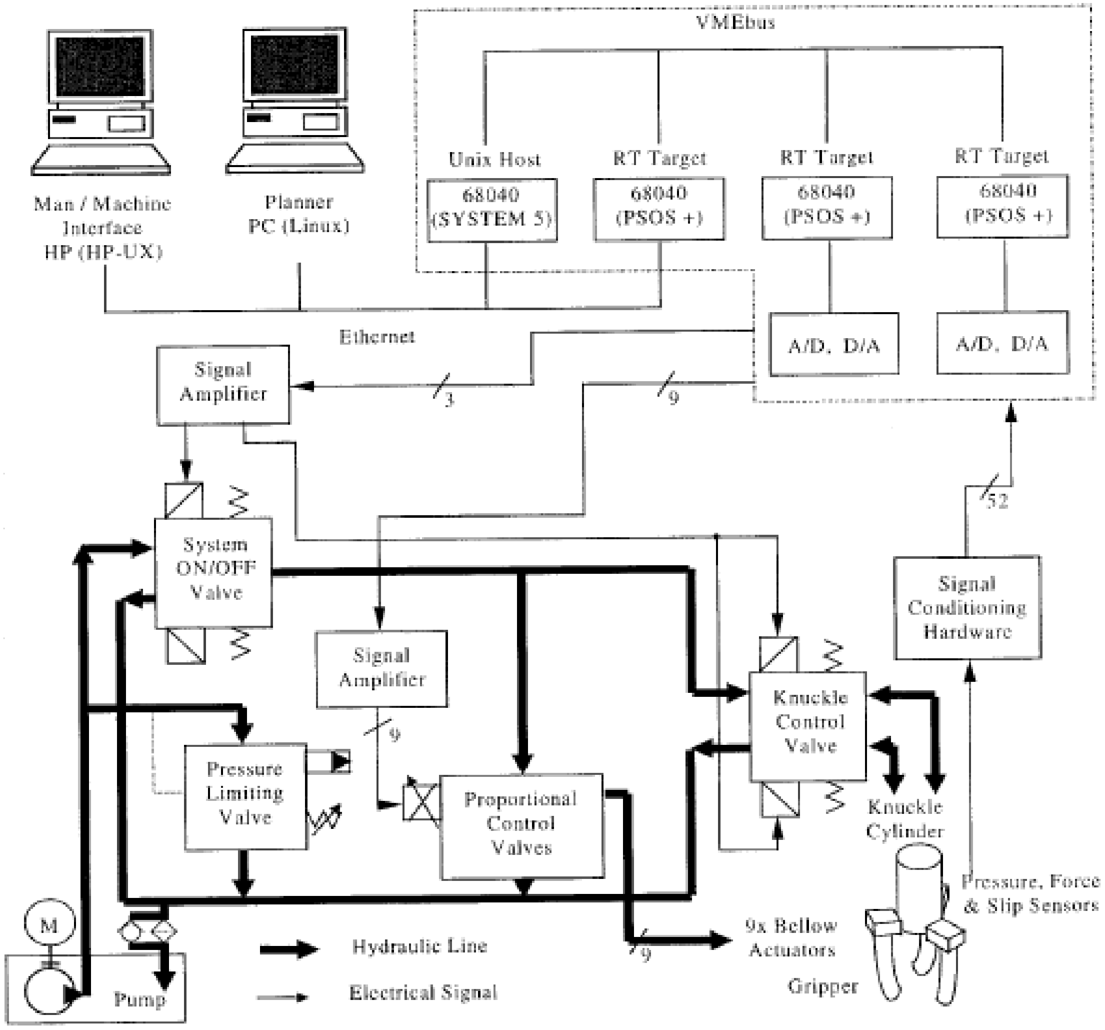
Low level Control (LLC) layer is the same independently from the specific gripper and its Very Low Level Control (VLLC) layer.

At that time this was considered a big step toward control architectures modularity

Subsystems 8

Gripper: Overall Functional and Hw control architecture



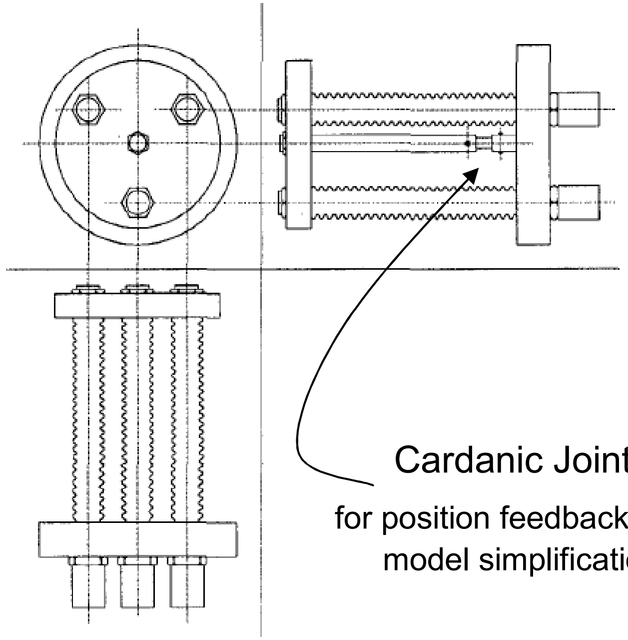


Subsystems 9

Gripper: Enhanced Bandwidth

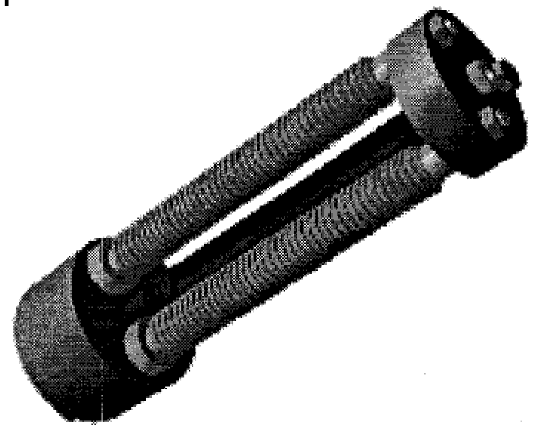
Substitution of the former hydraulic circuit controlled in pressure by valves with an other one at lower pressure, whose volume is driven by a linear actuator: Voice coil motors

- Total absence of backlash
- Very high bandwidth
- Suitable to be controlled via fast VSC techniques
- Control amplitude reduced via filtering out the “equivalent control”



Cardanic Joint

for position feedback and
model simplification



Video: **Enhanced bandwidth Gripper**

Subsystems 10

Gripper: Lessons learned (pros-cons in year 1999)

- The technology for “elephant-trunk” principle based gripper was proven viable
- Accurate position sensing eventually available
- Bandwidth enlargement was achieved successfully in later versions
- Eventually no more need of accurate model in the later version
- Control & coordination was successfully proven be feasible
- Modularity of the functional and algorithmic Hw/Sw also was successful

- Modularity of the functional and algorithmic Hw/Sw also was successful

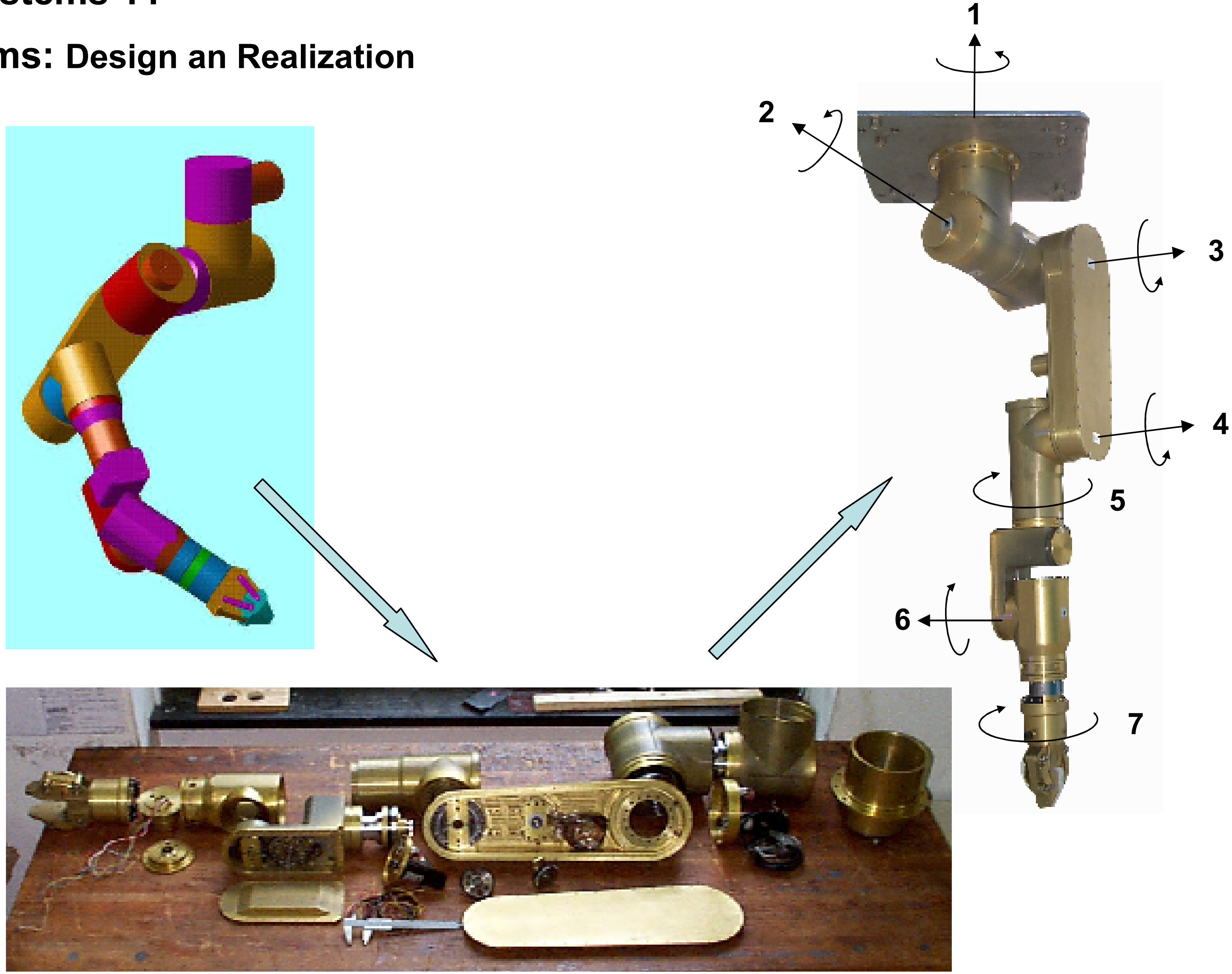
- Hydraulic circuitry still heavy and voluminous
- Finger bending still limited (need of more cascade stages and/or different bending materials)
- Envelop grasping therefore still problematic

Up-to-date Opportunities continuous actuation

- Successive and current literature on Bio-inspired. actuation systems (Fishes, Lampreda, Octopuses, etc.) might contribute to technological improvements

Subsystems 11

Arms: Design an Realization



Subsystems 12

Arms: Electro-mechanical characteristics

Max length:	1400 mm
Weight (in air):	53 Kg
Payload	50 N
Accuracy	< 1 mm
Load excess	100 N
Max Depth	500 m
Gripper max Force	300 N
No Dof	**7+1 for the gripper**
Gear reductions	Harmonic Drives
Marine Aspects	Anti-corrosion anodization Pressure balance oil filled

Electrically driven

Resolvers for calibration

Incremental encoders

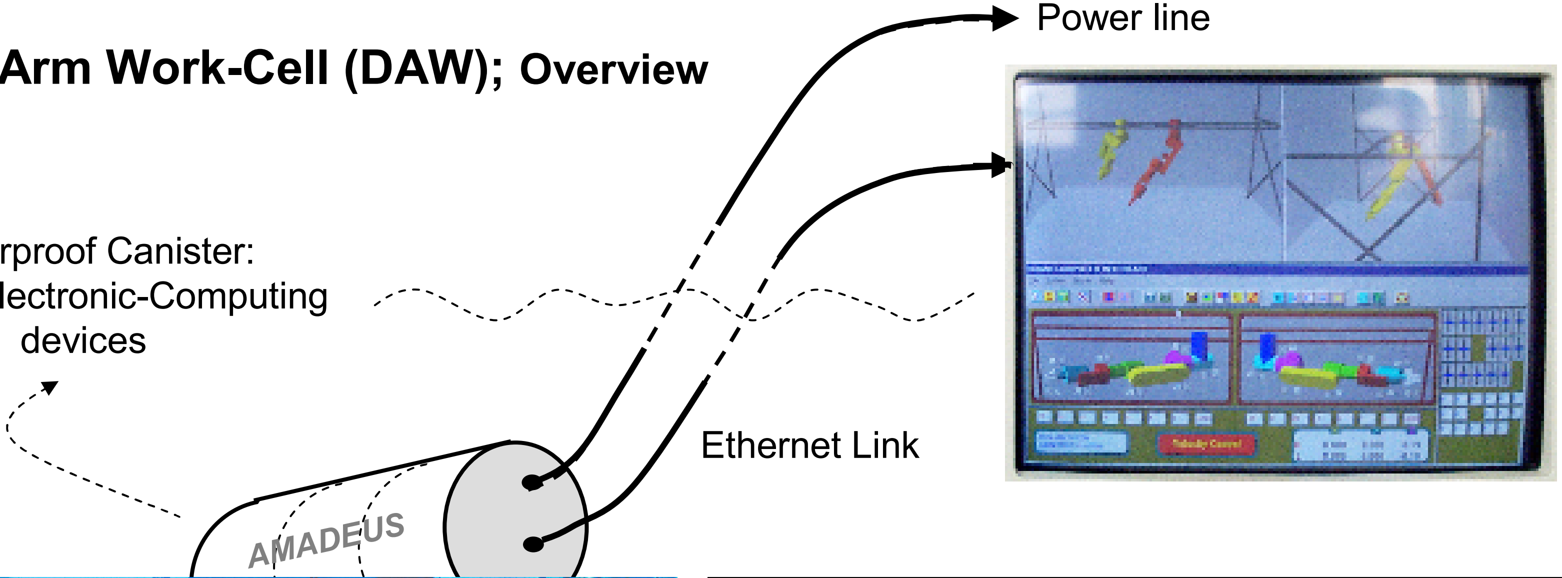
F/T sensing at the wrist

Additional internal cabling	**Wrist camera** **Tactile sensing at the jaws**

Manufactured by ANSALDO – DNU, Genova-Italy

Subsystems 13

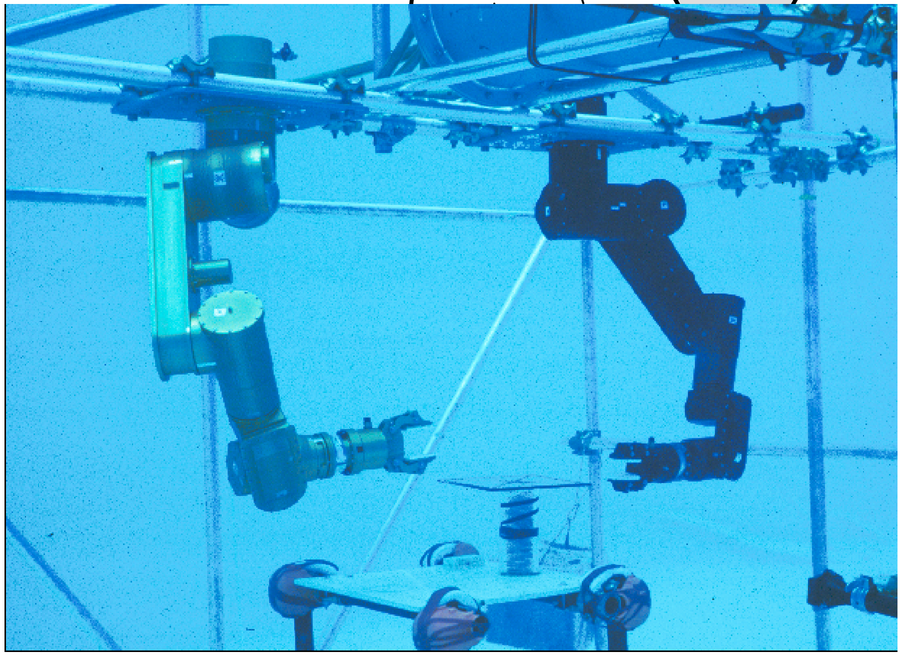
Dual-Arm Work-Cell (DAW); Overview

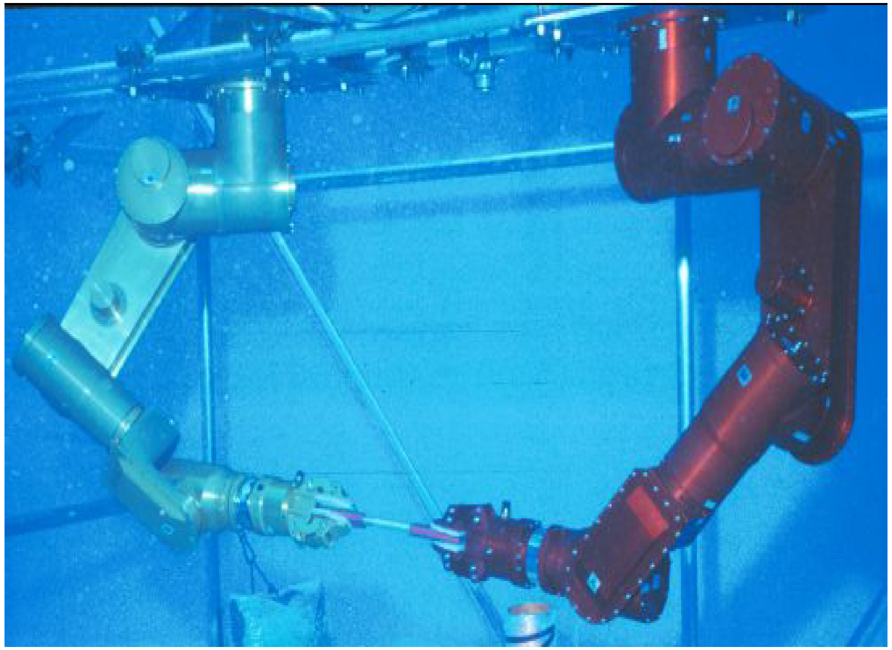


Waterproof Canister:
Electric-Electronic-Computing
devices

Power line

Ethernet Link

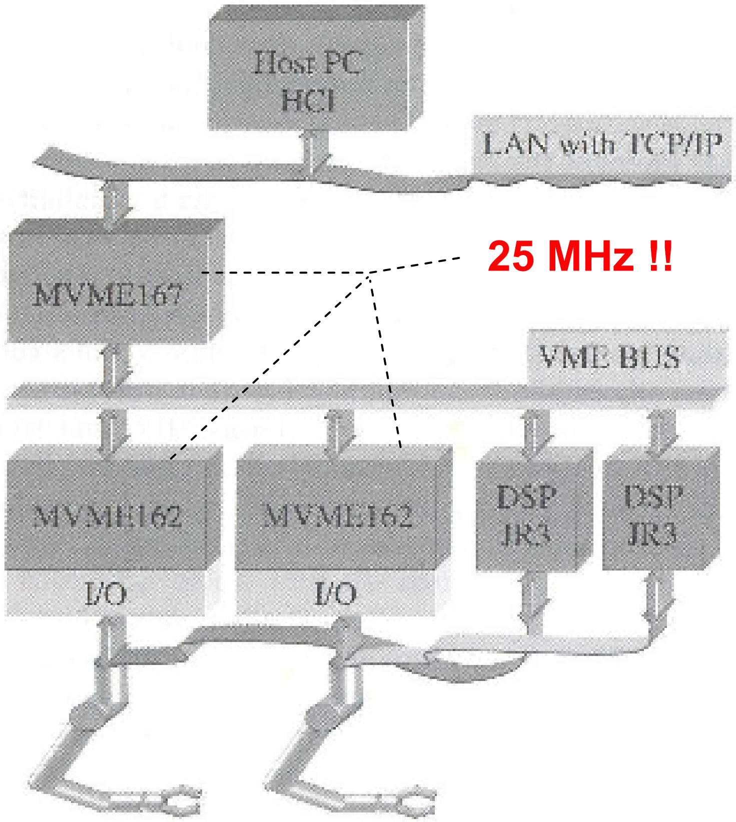




Subsystems 14

DAW: Functional Control & Hw Computing Architectures

Figure 2.1. Functional architecture for the dual arm workcell

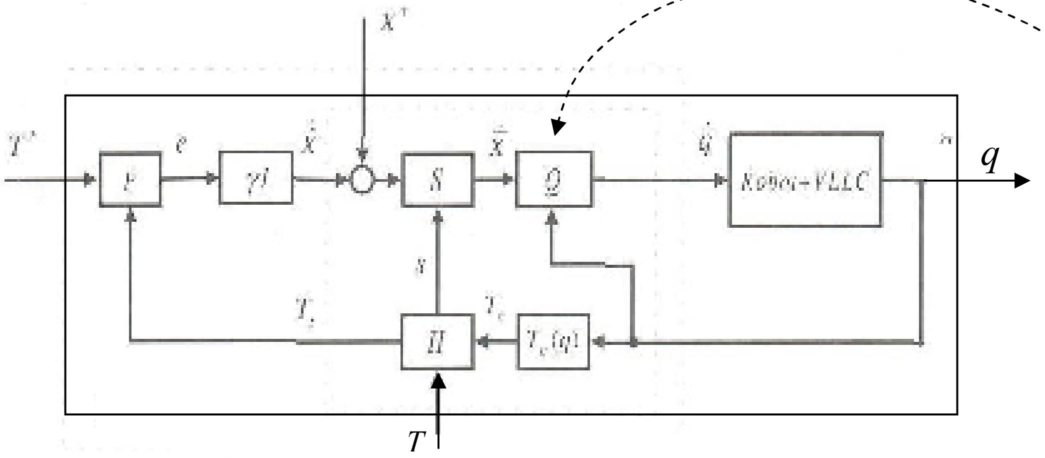


25 MHz !!

Figure 3.1. Hardware architecture description

Subsystems 15

DAW: Single arm LLC



Single arm control scheme

Kin. Inversion + Singularity management

$$\dot{q} = W^{-1}J^T[JW^{-1}J^T+\lambda(\mu)I](\dot{\tilde{X}} - h_4\,\dot{\tilde{q}}_4) + \dot{\tilde{q}}$$

$$\dot{\tilde{q}} = [0, 0, 0, \dot{\tilde{q}}_4, 0, 0, 0]^T$$

$$\dot{\tilde{q}}_4 = -k(q_4 - \bar{q}_4)$$

$$\dot{\tilde{q}} = [1, 1, 1, (1+k), 1, 1, 1]^T$$

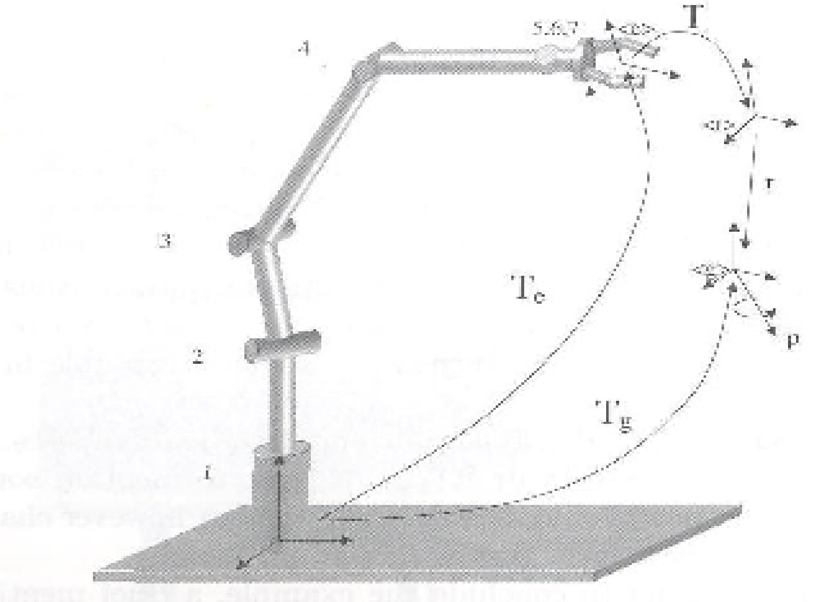


Figure 4.1. Schematic representation of a single arm

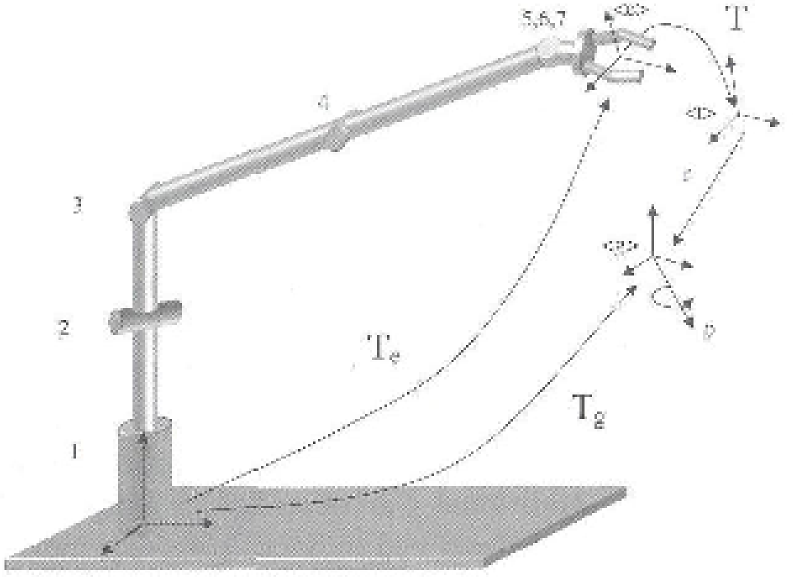
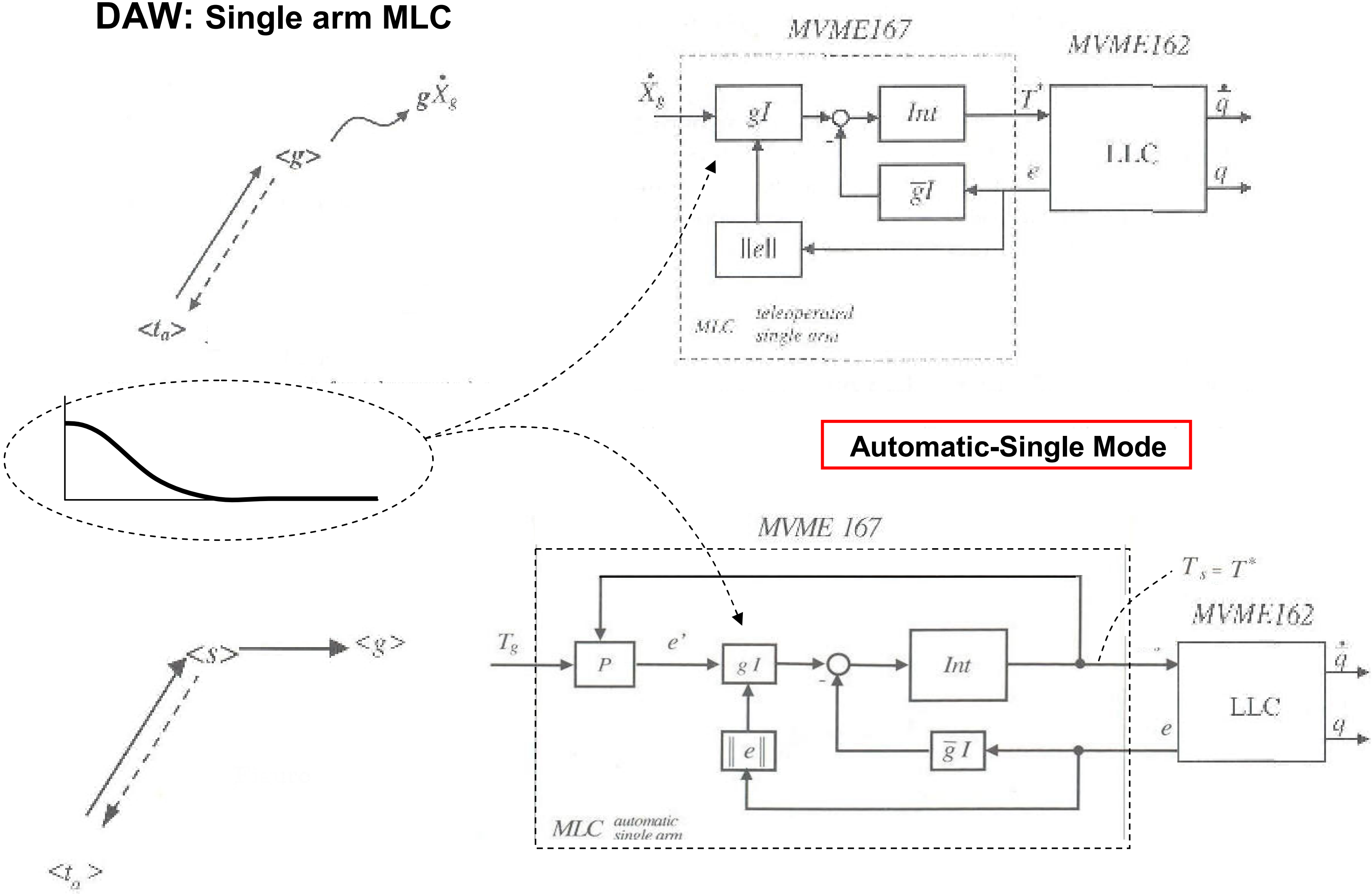


Figure 4.3. Singular configuration

Subsystems 16

DAW: Single arm MLC



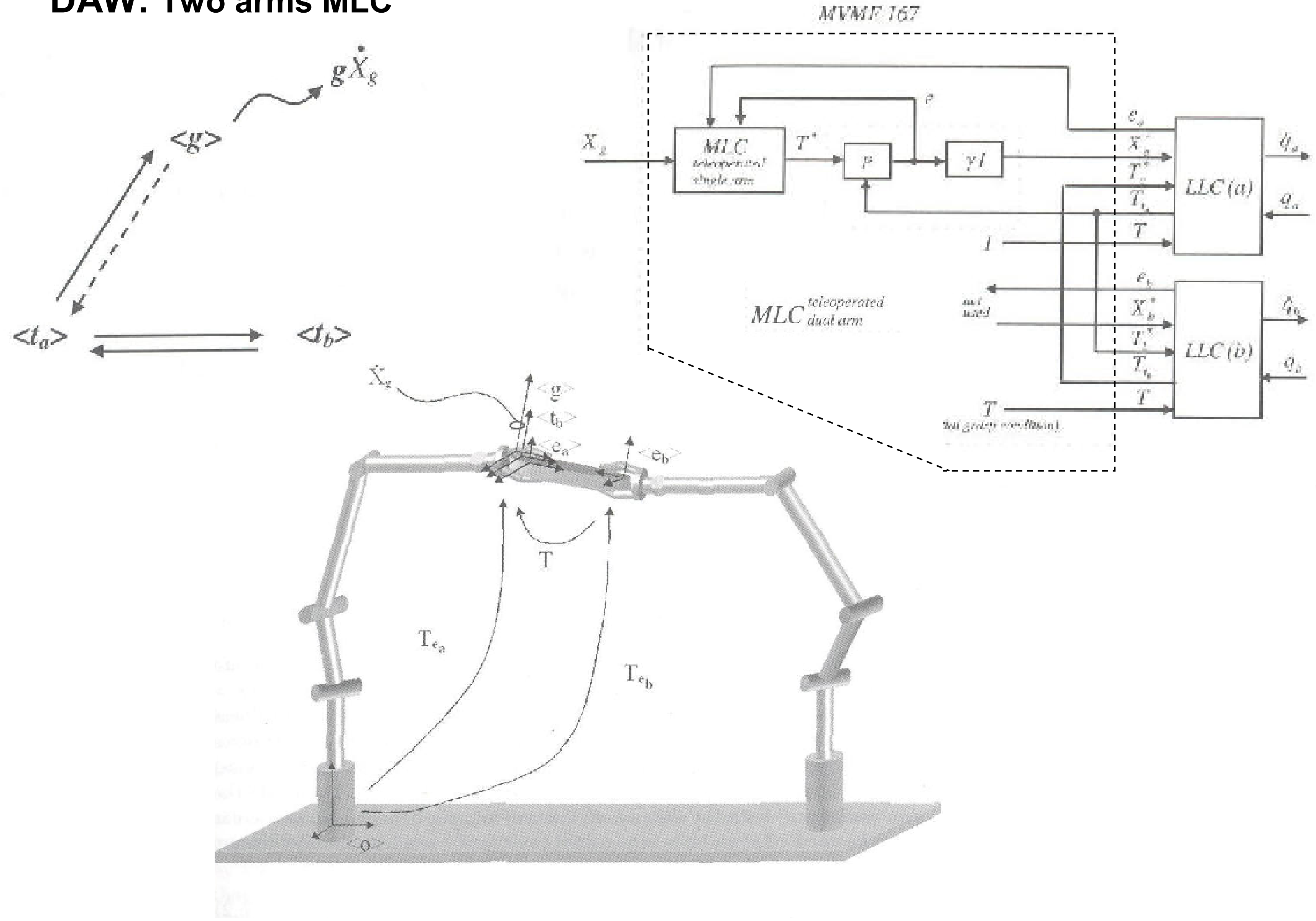
Teleoperated-Single Mode

Automatic-Single Mode

Subsystems

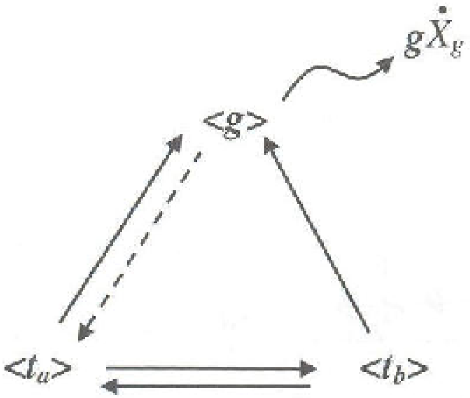
DAW: Two arms MLC

Teleoperated-Coordinated Mode

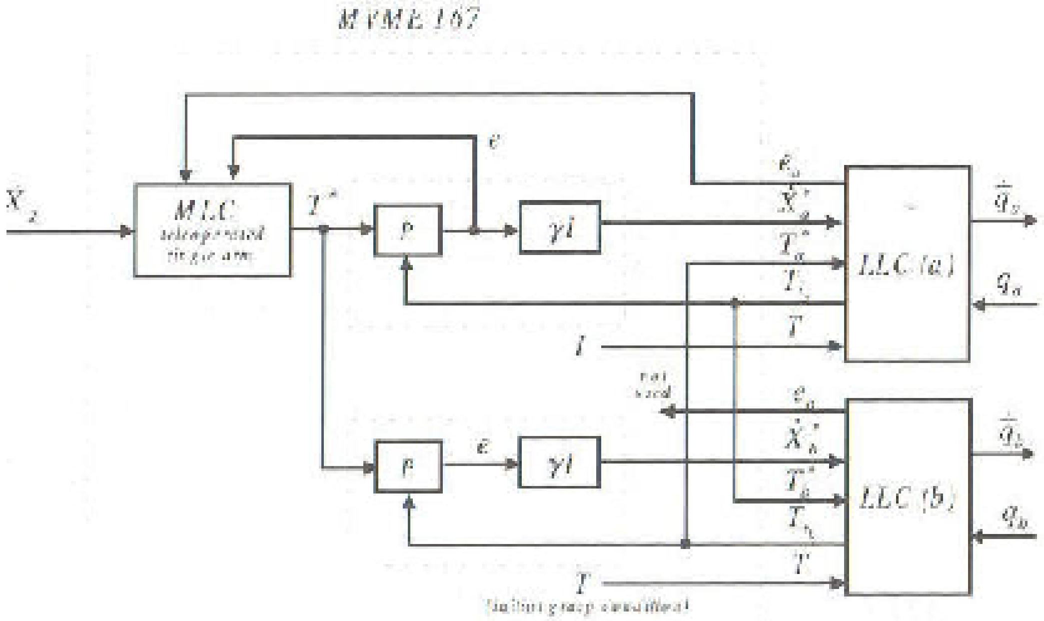


Subsystems 17

DAW: Two arms MLC



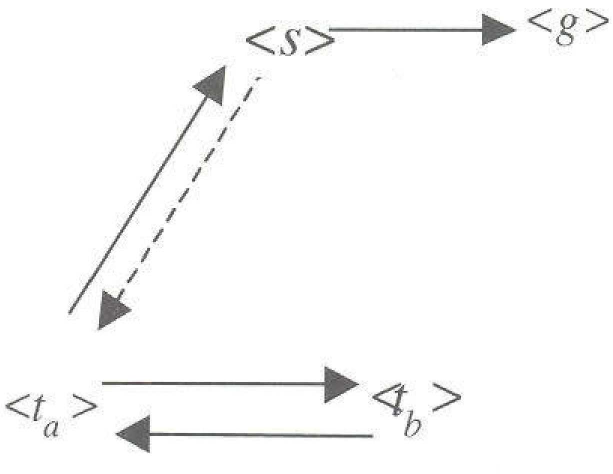
Teleoperated-Coordinated Mode



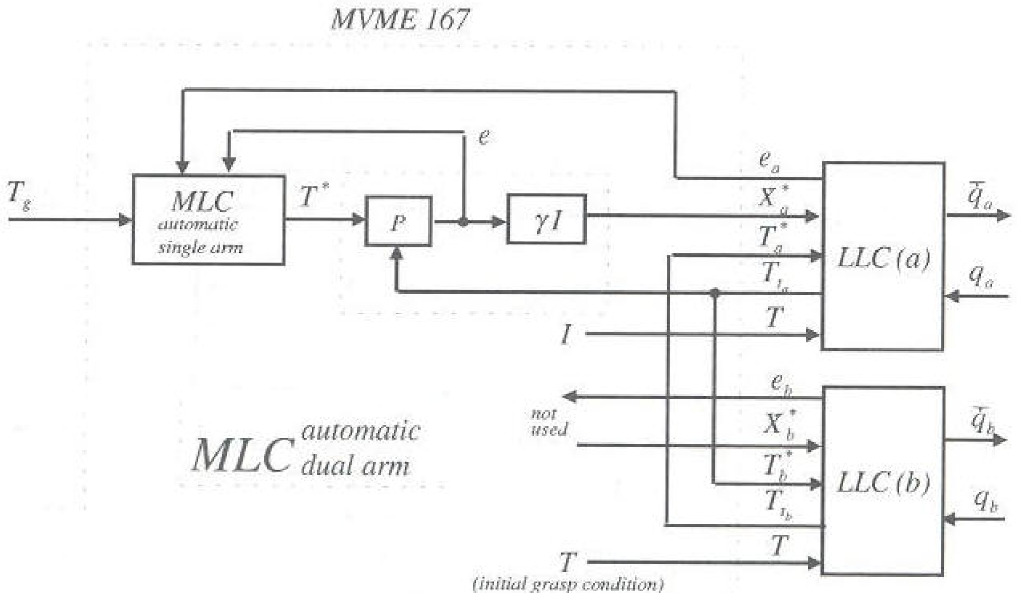
Subsystems 18

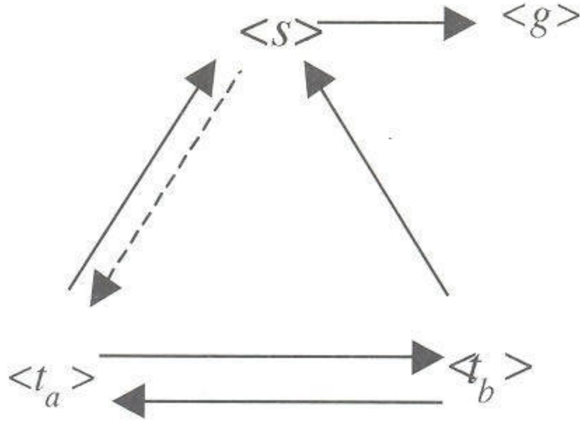
DAW: Two arms MLC

Automatic-Coordinated Mode

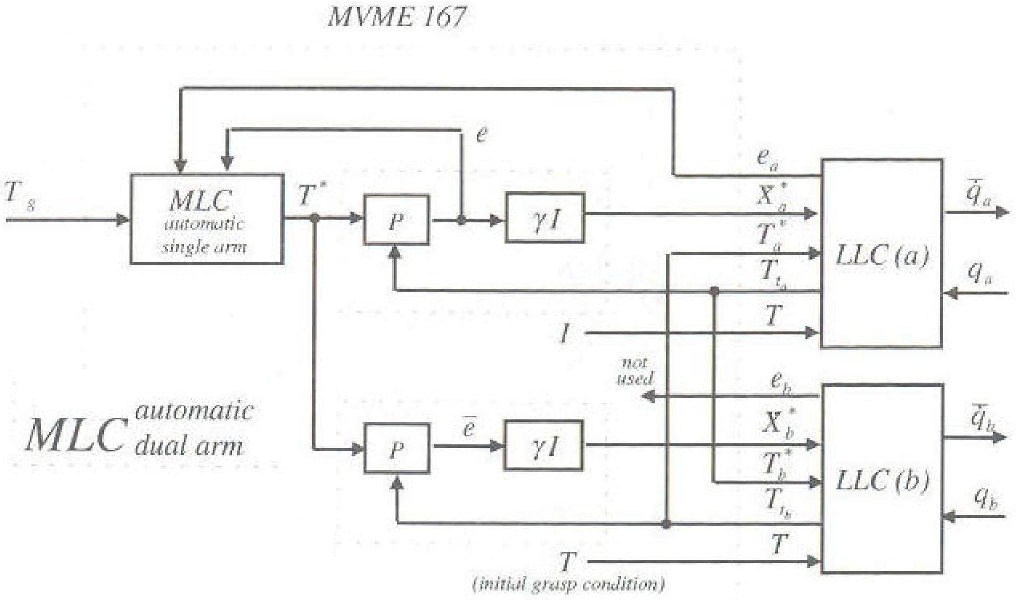


(a)



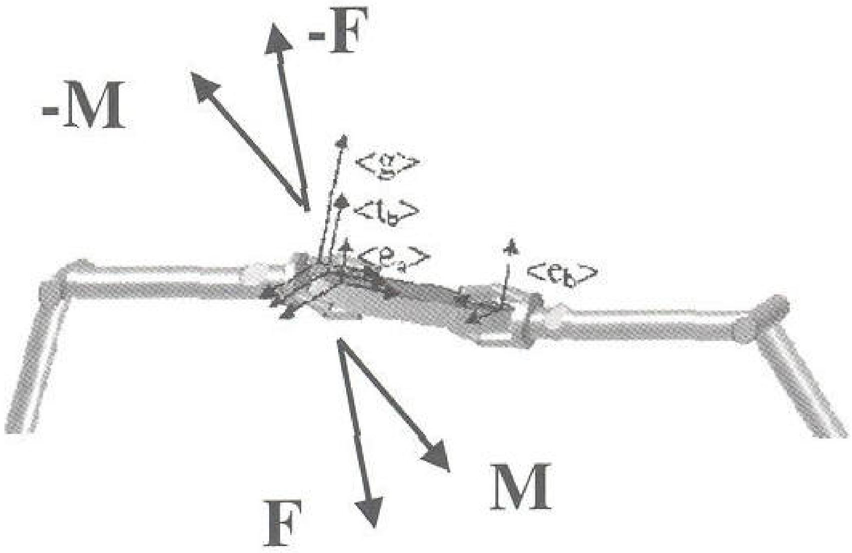


(b)

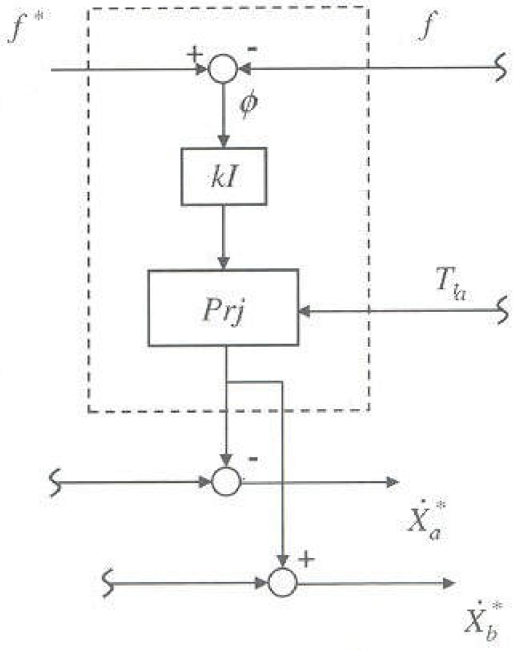


Subsystems 19

DAW: Two arms MLC



Interaction Control



Subsystems 20

DAW: VIDEOS

In-Air

1- Single-arm
2- Teleoperated single-arm
3- Teleoperated dual arm

Underwater

4- Teleoperated single-arm
5- Teleoperated dual-arm

Subsystems 21

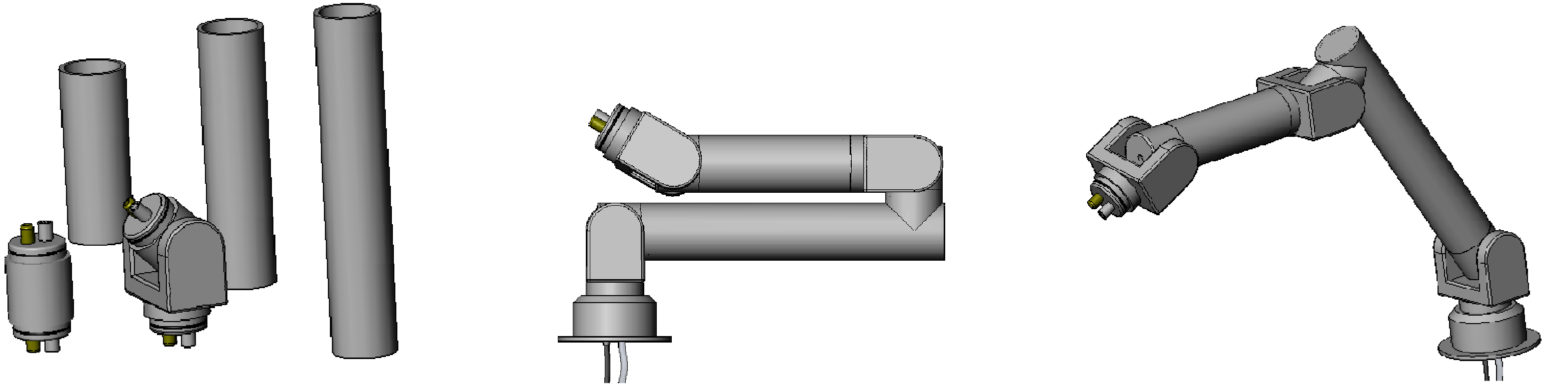
DAW: Lesson learned (pros-cons in year 1999)

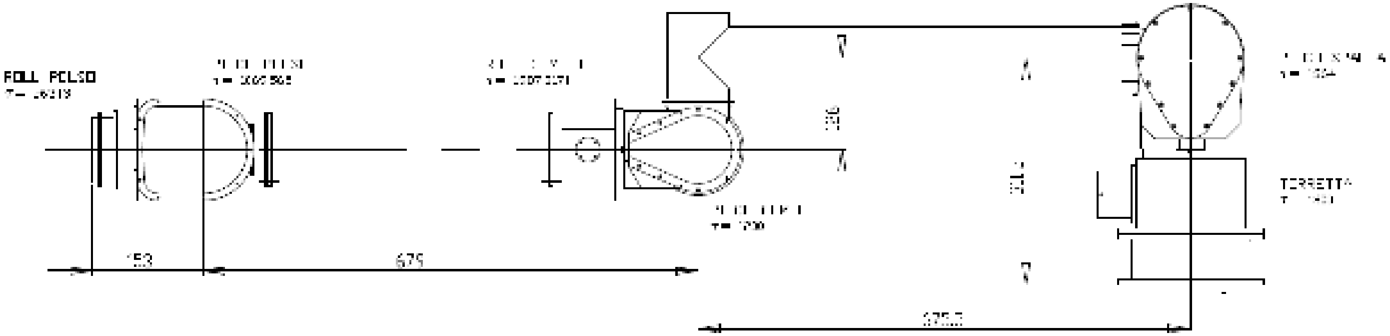
- The developed technology for electrically driven underwater arm was successful
- The arm wrist should however be improved in order to have it more compact (earning more dexterity from having joint 5 closer to joints 6,7)
- Control & coordination was successfully proven be feasible
- Modularity of the functional and algorithmic Hw/Sw control architecture was successfully achieved (within the bounds established by the at-the-time-available computing technology)
- Control & coordination was made adequately performing by:
  - Exploiting the at-the-time-available multiprocessor architectures
  - Reducing the computing power and the inter-processor communication overhead via selection of as much as possible self standing RT manageable algorithms.
- Control & coordination was however achieved via " circuit modular composition" and "circuit switching"; with resulting possible limitations such as:
  - General need of achieving the right initial conditions when shifting from one "circuit" to an other (task transitions are generally slow since subjected to different safety checks)
  - Possible difficulties in managing tasks different from "end-effectors reaching" ones (for instance satisfying inequality constraints).
  - In case, possibly too numerous "control circuits" have to be managed
  - Singularity avoidance during coordinated motion still problematic
  - Possible difficulties in in extending the approach to "agile" vehicle-manipulator systems (non-hovering cooperating base) with subsequent "agility losses".

Up-to-date Opportunities for UW manipulation 1

Arm technology:

lightweight
Modular (mechanical-electronic-electrical)
Local-Bus based
Multisensory modularly equipped
(presentation follows)



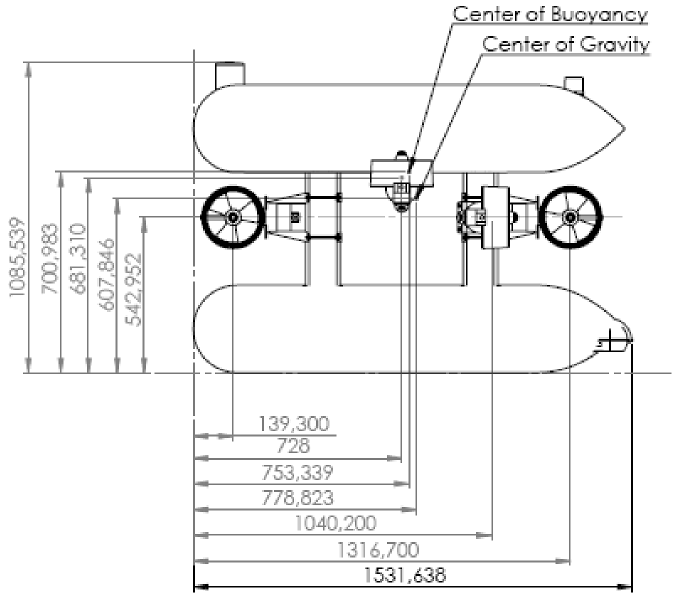


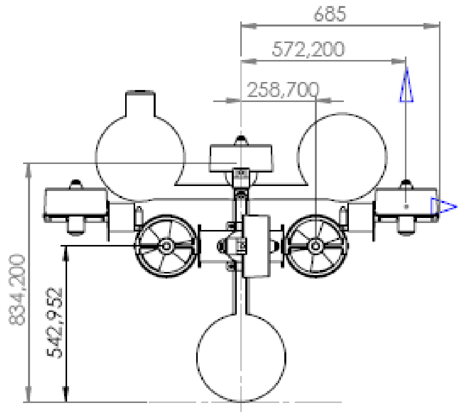
Curtesy of GraalTech s.r.l., Genova, Italy

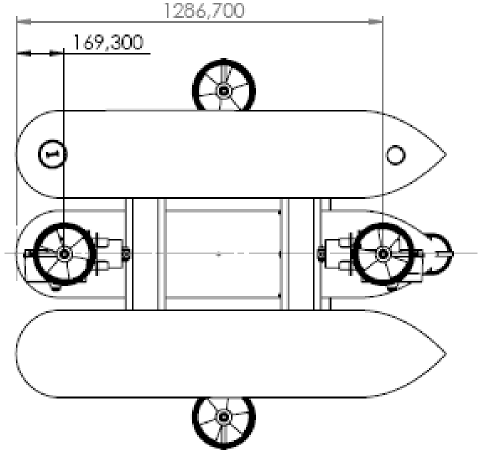
Up-to-date Opportunities for UW manipulation 2

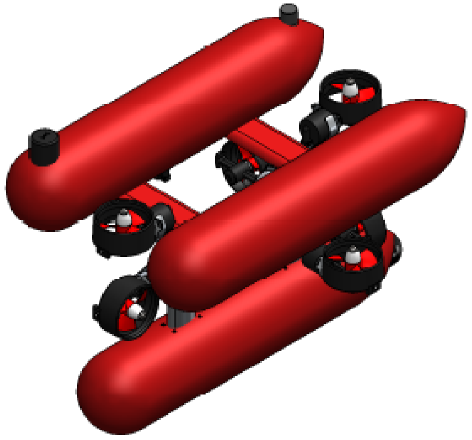
Vehicle technology

lightweight, small volume
fully actuated
Multisensory equipped
(presentation follows)









Curtesy of Prof. Pere Ridao, University of Girona, Spain

Up-to-date Opportunities for UW manipulation 3

Coordinated control methodologies:

(adding “agility” to the system)

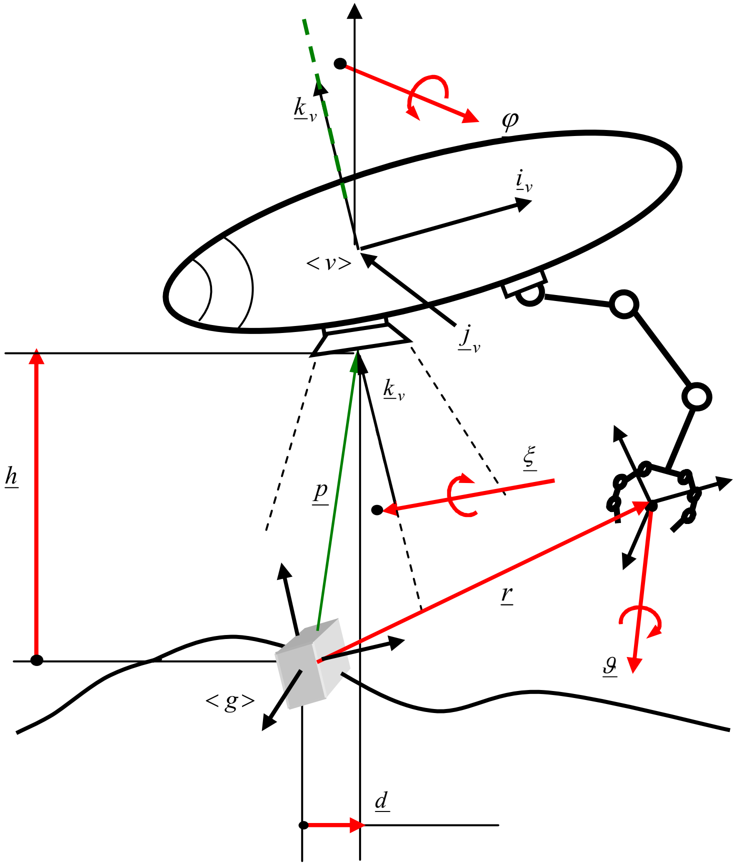
Prioritized task-based

Set-tasks (S) (ultimate inequalities)
Precision-tasks (P) (ultimate equalities)

Prioritized subsystem-based

(leads to Dynamic Progr. along the chain)
Arms
Vehicle

The TRIDENT Example



Task types and priorities

S	*1*	*Joint limits*
S	*2*	*Manipulability*
S	*1*	*Camera centering*
S	*2*	*Camera distance*
S	*2*	*Camera height*
P	*3*	*End-effector approach (distance)*
P	*4*	*End-effector approach (orientation)*
P	*5*	*Horizontal attitude*

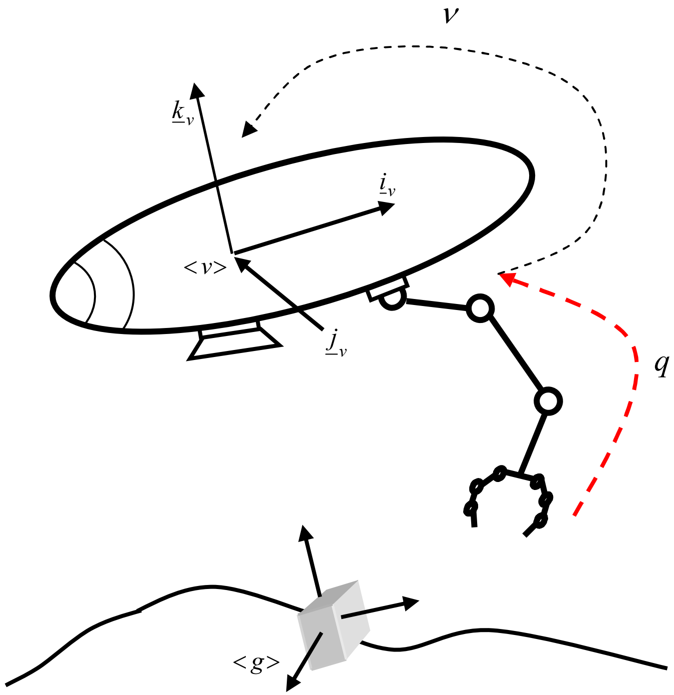
Sub-system types and priorities

1	*Arm*
2	*Vehicle*

Up-to-date Opportunities for UW manipulation 4

The TRIDENT Example: ***Dynamic Programming for subsystems priorities***

Arm backward path



- *Subdivide the overall system into its basic sub-systems (in our case the arm and the vehicle)*
- *Chose a "direction of exploration" of the resulting sub-systems (in our case from the arm to the vehicle)*
- *Starting from the arm a sequence of prioritized rate-task is extracted from the centralized one obeying to the following rules*
    - *The velocity ν (linear ν_1 and angular ν_2) of the vehicle is considered as a given parameter*
    - *Only the rate-tasks directly involving the arm joint velocity vector $\dot{q}$ must therefore be accounted.*

*Then the following sub-table of prioritized tasks is consequently Obtained at **Arm level***

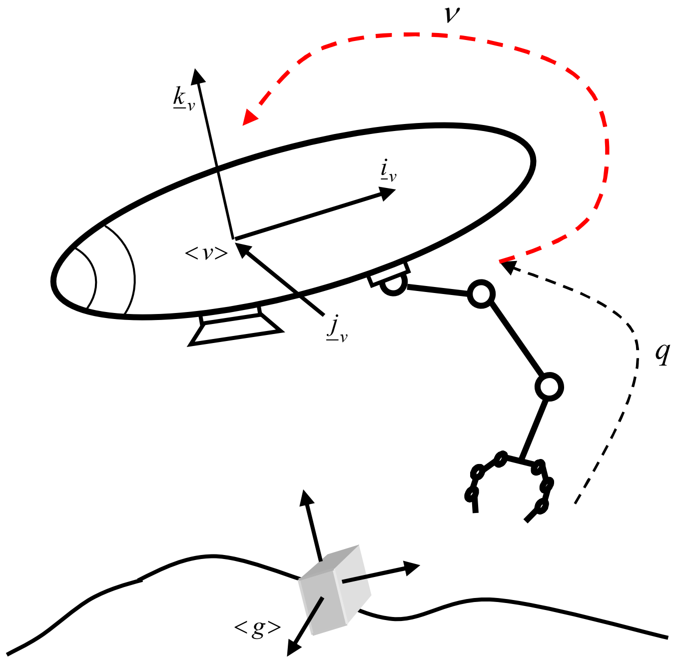
Arm level task types and priorities

S 1a Joint limits
S 2a Manipulability
P 3a End-effector approach (distance)
P 4a End-effector approach (orientation)

Up-to-date Opportunities for UW manipulation 5

The TRIDENT Example: *Dynamic Programming for subsystems priorities*

Vehicle backward path



- *By proceeding as before, a sequence of prioritized rate-task is now extracted from the centralized one obeying to the following rules*
    - *the sequence of minimizations has to be performed within the conditioning provided by the previously devised (parameterized by* v *) arm kinematic control law* $\dot{q}(\bar{x}_e, \dot{\bar{\sigma}}_\mu \dot{\bar{q}}, v)$
    - *only the tasks directly depending from* v*, or indirectly depending from* v *via the arm control law , have to be accounted*

The following sub-table of tasks is consequently obtained at ***vehicle level***

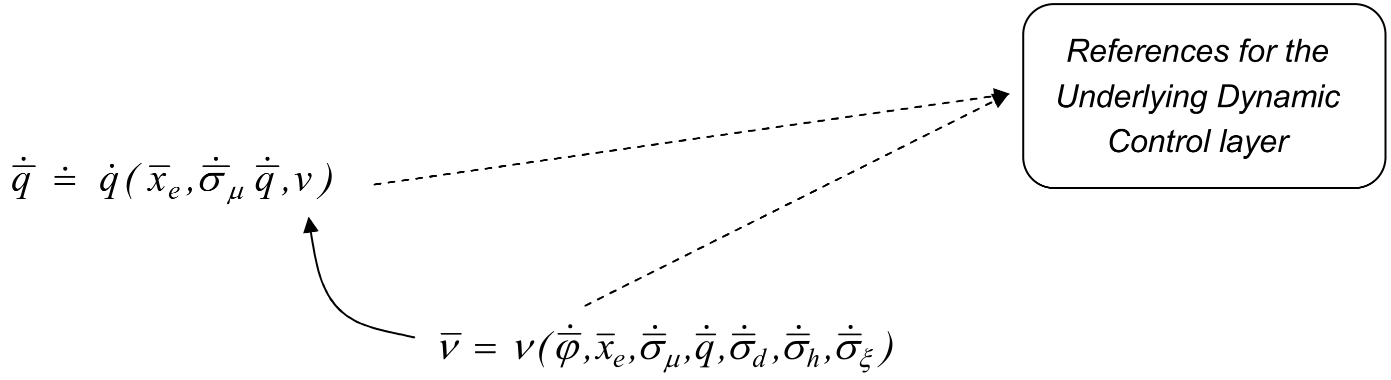
Vehicle level task types and priorities

S   1v Camera centering
S   2v Camera distance
S   2v Camera height
P   3v End-effector approach (distance)
P   4v End-effector approach (orientation)
P   5v Horizontal attitude

Up-to-date Opportunities for UW manipulation 6

The TRIDENT Example: Dynamic Programming for subsystems priorities

Overall forward phase



$$\dot{\bar{q}} \doteq \dot{q}(\bar{x}_e, \dot{\bar{\sigma}}_\mu \dot{\bar{q}}, v)$$

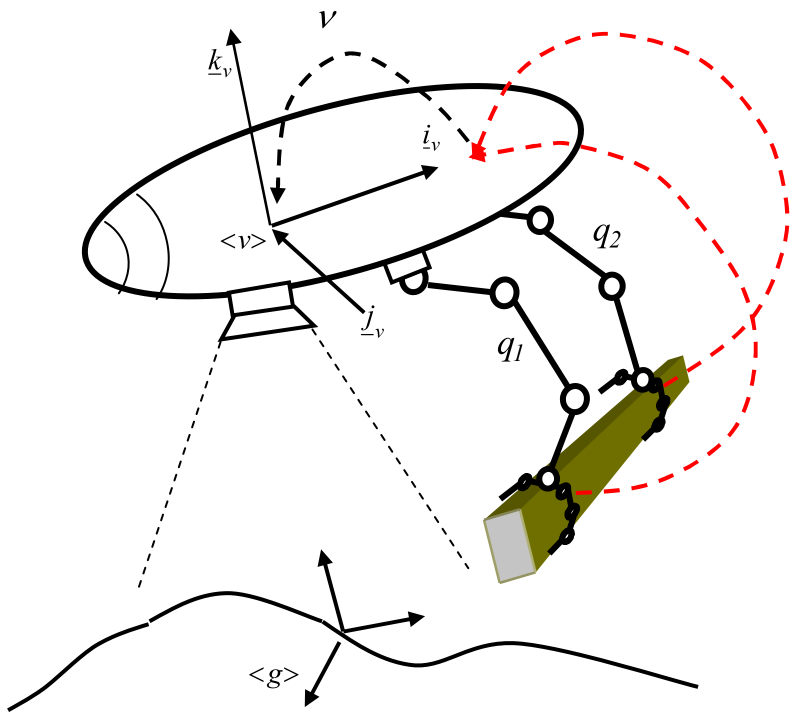
$$\bar{v} = v(\dot{\bar{\varphi}}, \bar{x}_e, \dot{\bar{\sigma}}_\mu, \dot{\bar{q}}, \dot{\bar{\sigma}}_d, \dot{\bar{\sigma}}_h, \dot{\bar{\sigma}}_\xi)$$

References for the Underlying Dynamic Control layer

- *The resulting control action are* ***Linear*** *in their arguments.*
- *The DP procedure can be easily translated into computational efficient* ***operative algorithms (no more control scheme switching)***
- *Tasks can be can be added, subtracted, changed;; even "on-fly"; as well as their the priority list.*
  Without changes in the underlying algorithmic structure

Up-to-date Opportunities for UW manipulation 7

Extension to UW Floating Multi-arm Systems



- *Kinematic constraints (grasp constraints) can be kept into account as the* ***Highest*** *Priority Precision "tight" tasks.*

Arm level task types and priorities

P	*1a*	***Keep the grasp***
S	*1a*	*Joint limits*
S	*2a*	*Manipulability*
P	*3a*	*object approach (distance)*
P	*4a*	*Object approach (orientation)*

Vehicle level task types and priorities

S	*1v*	*Camera centering*
S	*2v*	*Camera distance*
S	*2v*	*Camera height*
P	*3v*	*Object approach (distance)*
P	*4v*	*Object approach (orientation)*
P	*5v*	*Horizontal attitude*

- *The DP for the two arms must be run in* ***parallel*** *(different implementation possibilities actually exists).*
- *Highest priority precision "tight" tasks (constraints)* ***do not alter*** *then underlying algorithmic structure*

Up-to-date Opportunities for UW manipulation 8

Simulation VIDEOS

1- Terrestrial single arm Mobile manipulator

2- UW dual arm floating manipulator

Conclusions

1- the R & D activities performed during the entire duration (1994-1999) of the EU funded project AMADEUS have been reviewed

2- Lesson learned (pros and cons) at the time of the project conclusion (1999) have been identified together with the technological development at that time needed

3-Up-to-date technology based new opportunities has been indicated as now viable

4-On going projects (TRIDENT) on autonomous underwater floating manipulation are now on-going pursuing the new perspectives

Modular Underwater Manipulators

Alessio Turetta

GRAALTECH

1st Workshop on Autonomous Underwater Manipulation
San Francisco September, 25th 2011

Who is Graal Tech

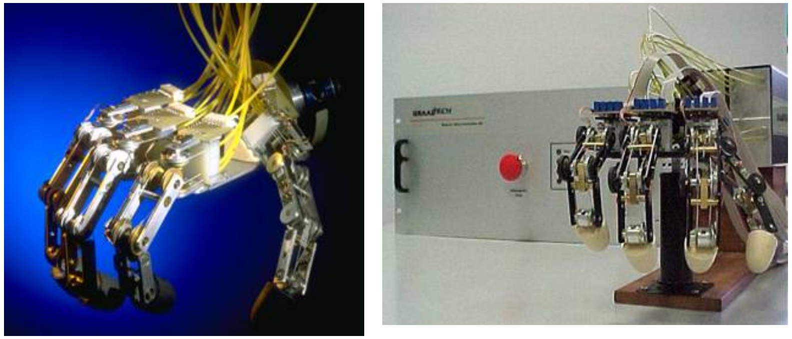
Company overview

- A spin-off company from the Department of Communication, Computer and System Sciences (DIST) of the University of Genova
- Established in 1998
- Based in Genova, Italy
- Personnel
  - 4 Ph.D engineers
  - 3 engineers
  - 1 senior technician
  - 1 administrative
  - 4 collaborators

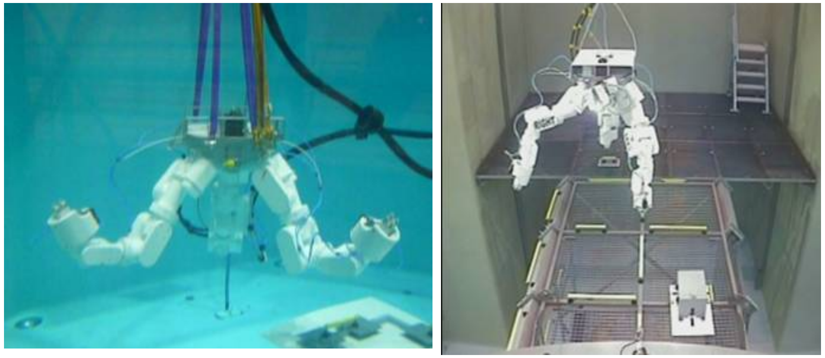
Who is Graal Tech

Main skills

- Mechanical design and development of robotic systems
- Custom sensor design and development
- Modeling and simulation
- Advanced control algorithms
- Real time software design
- Embedded systems architectures based on MCUs, DSPs, FPGAs



Anthropomorphic robotic hand
(customers: Fraunhofer Institute, Bonn - University of Genova, Genova - CNR, Palermo)

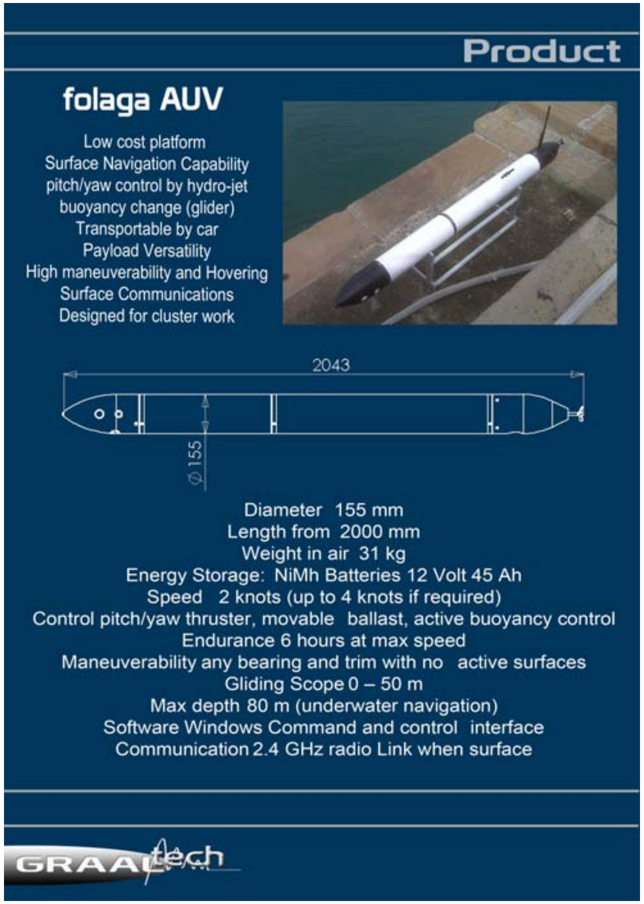


Eurobot Wet Model
(customer: Thales Alenia Space for ESA)

Who is Graal Tech

Main application areas

- Robotics for non standard applications (education, medical, space, inspection,...)
- Underwater Robotics



Product

folaga AUV

Low cost platform
Surface Navigation Capability
pitch/yaw control by hydro-jet
buoyancy change (glider)
Transportable by car
Payload Versatility
High maneuverability and Hovering
Surface Communications
Designed for cluster work

Diameter 155 mm
Length from 2000 mm
Weight in air 31 kg
Energy Storage: NiMh Batteries 12 Volt 45 Ah
Speed 2 knots (up to 4 knots if required)
Control pitch/yaw thruster, movable ballast, active buoyancy control
Endurance 6 hours at max speed
Maneuverability any bearing and trim with no active surfaces
Gliding Scope 0 – 50 m
Max depth 80 m (underwater navigation)
Software Windows Command and control interface
Communication 2.4 GHz radio Link when surface

GRAAL tech

Outline

- A modular approach to underwater manipulators
- Conceptual Design
- Final Design
- Robot Development
- Next Steps

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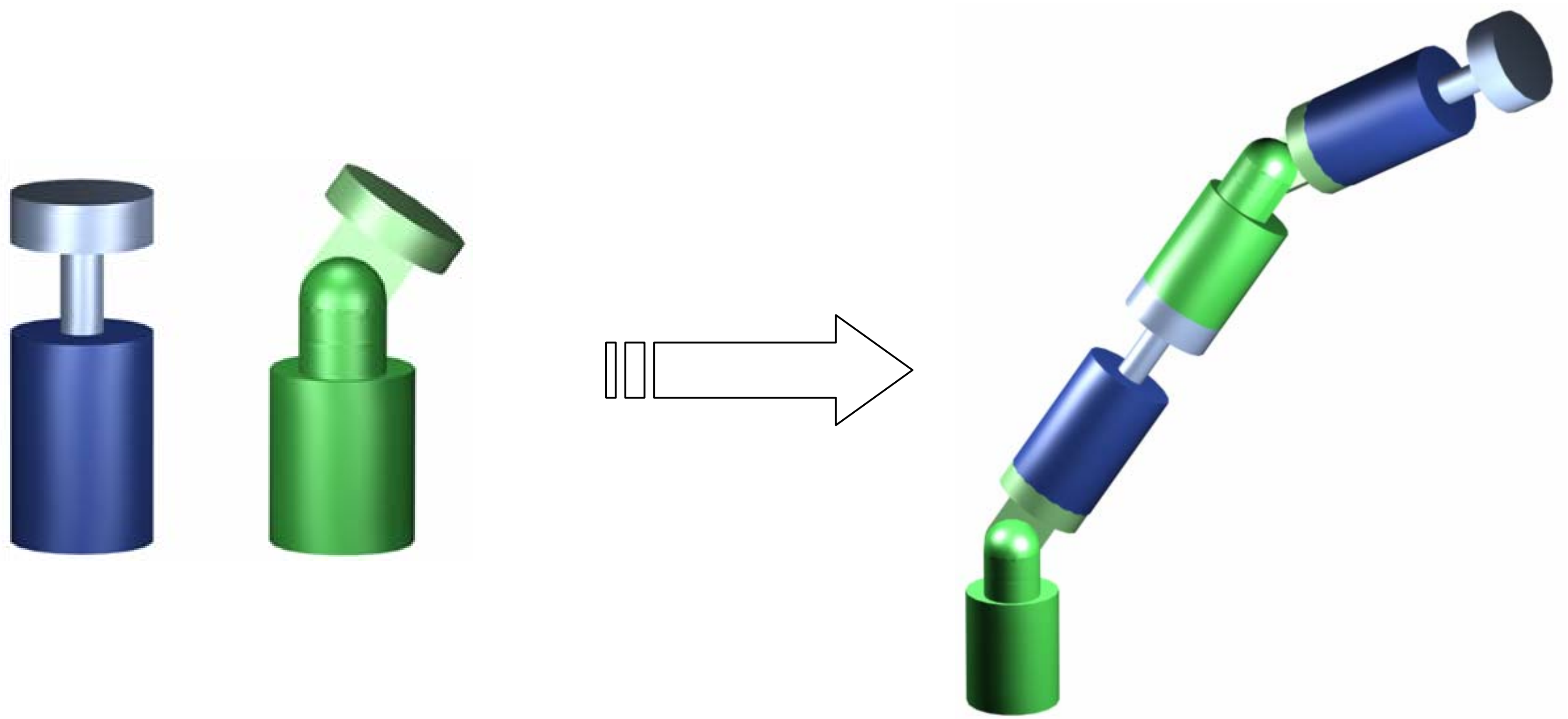
What is a Modular Robot

Modular Robotic Systems: robotic structures composed by atomic single (or few) d.o.f. modules, which can be assembled in different configurations



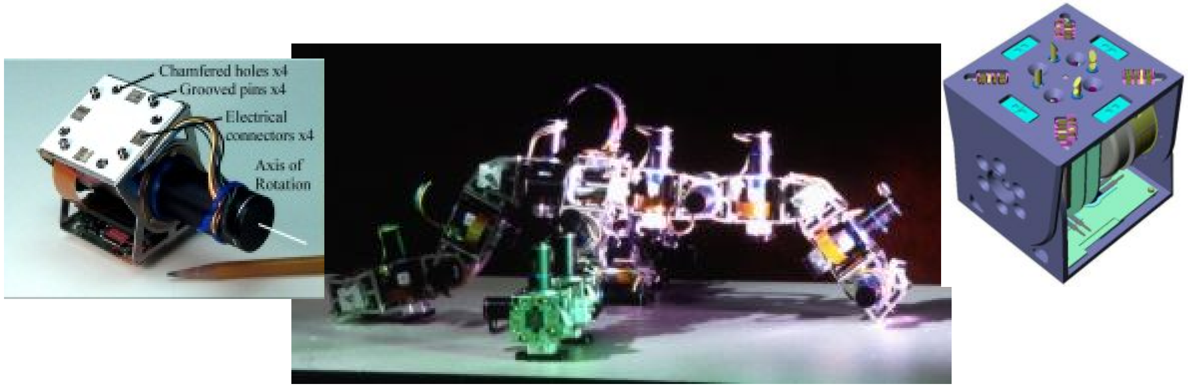
Few Examples

- Asia - UT

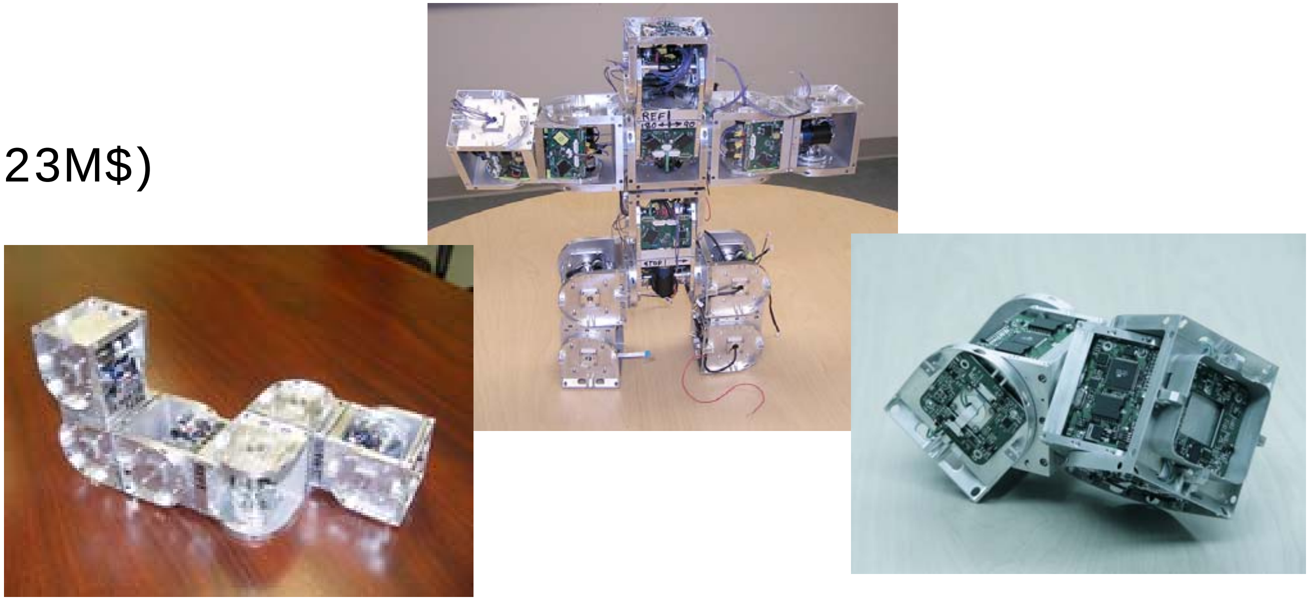
- Asia - TIT

Few Examples

- U.S.- Palo Alto



- U.S.-USC (4.23M$)



Few Examples

- Europe – DLR/KUKA

Why a Modular Underwater Arm?

- Different kinds of underwater manipulation tasks can be supported:
  - Number of required d.o.f.’s can be selected on the basis of the supporting vehicle’s motion capabilities
  - Arm mechanical characteristics (kinematic structure and dimensions) can be tailored to the considered mission needs

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Modular Kinematic Structure

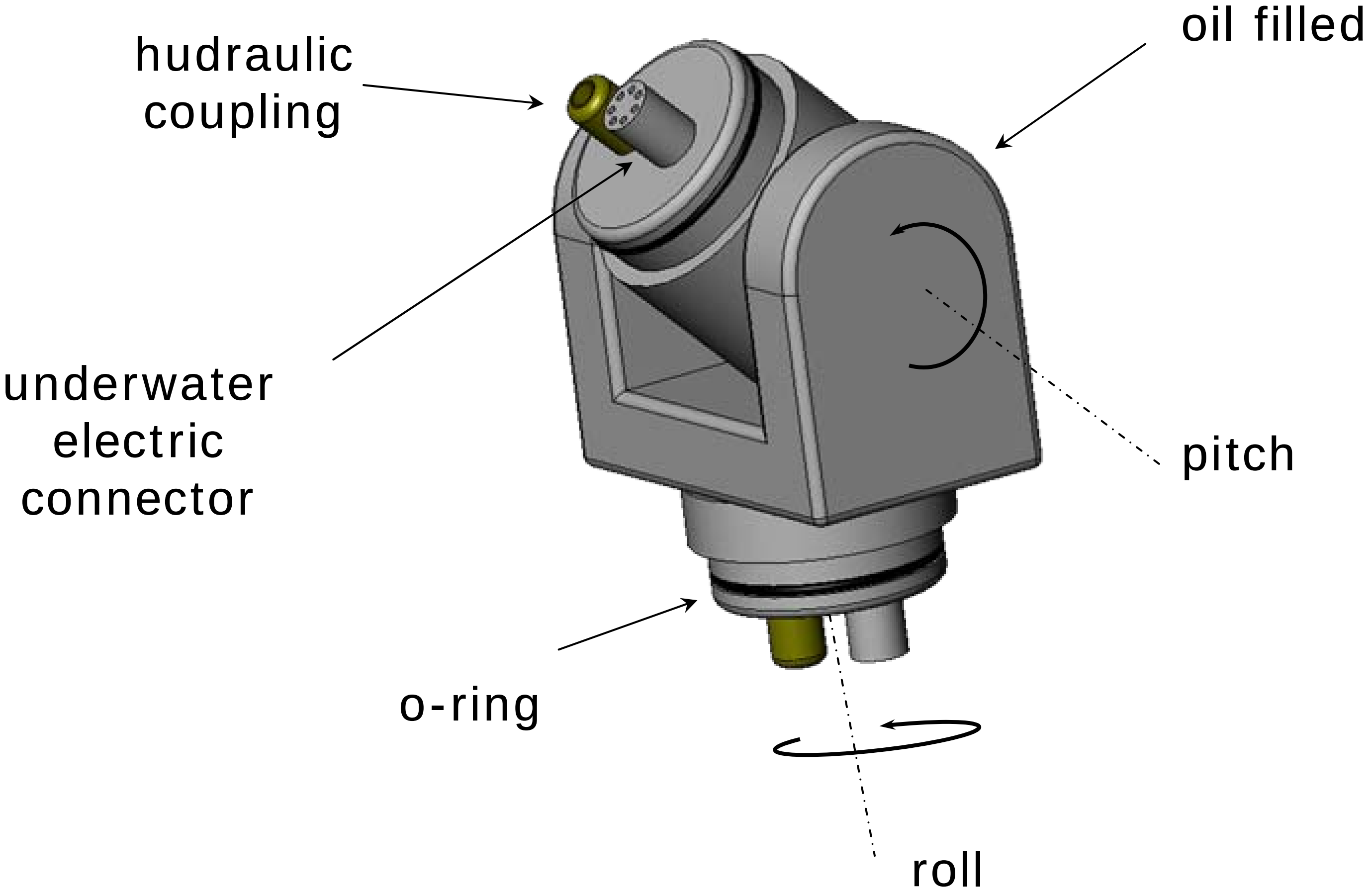
Basic Idea: Modular Design

-two kinds of joints

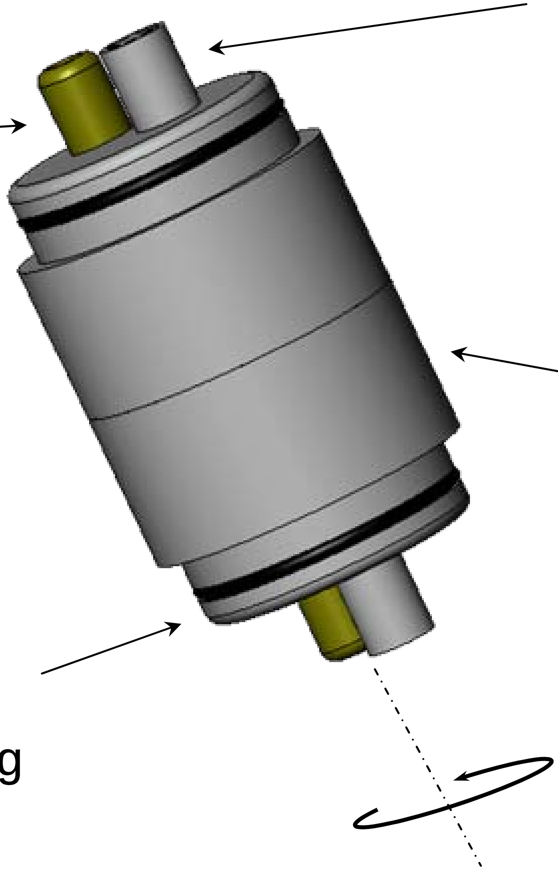
  - 2 d.o.f.’s roll-pitch
  - 1 d.o.f. roll

- cylindrical links of variable length

Roll-Pitch Joint Concept



Roll Joint Concept



underwater
electric
connector

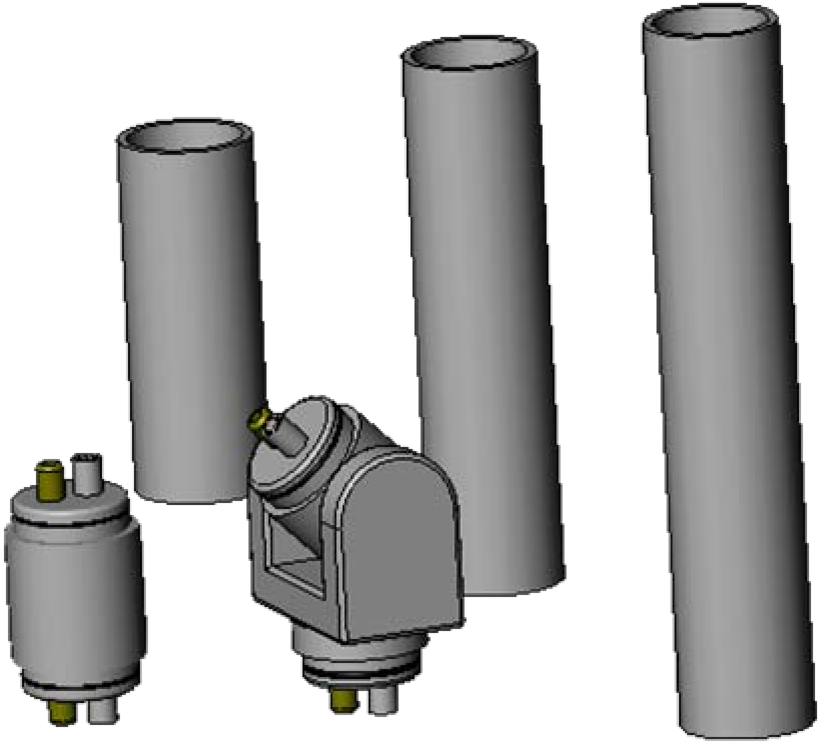
hudraulic
coupling

oil filled

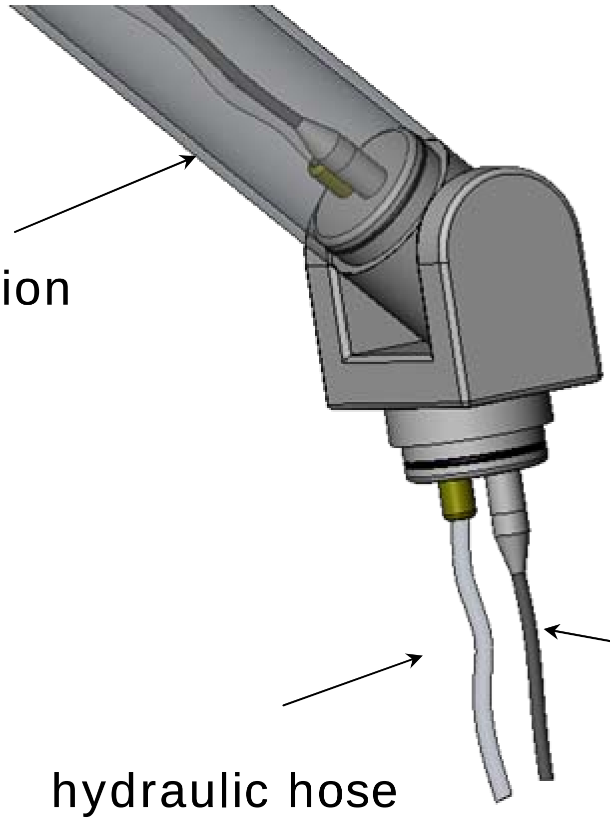
o-ring

roll

Set of Components



Module Connection



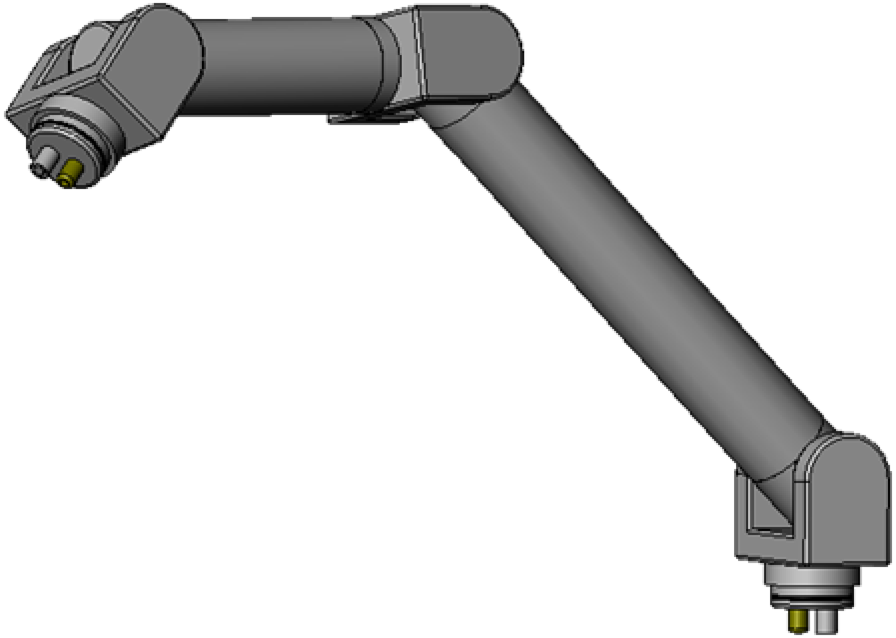
dry section

hydraulic hose

electric cable

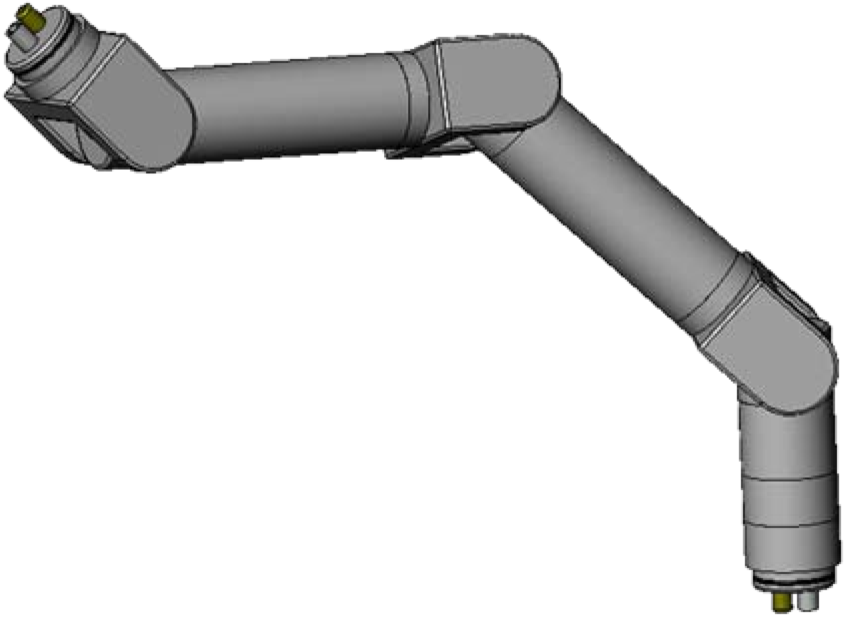
Possible Configurations

6-d.o.f's arm



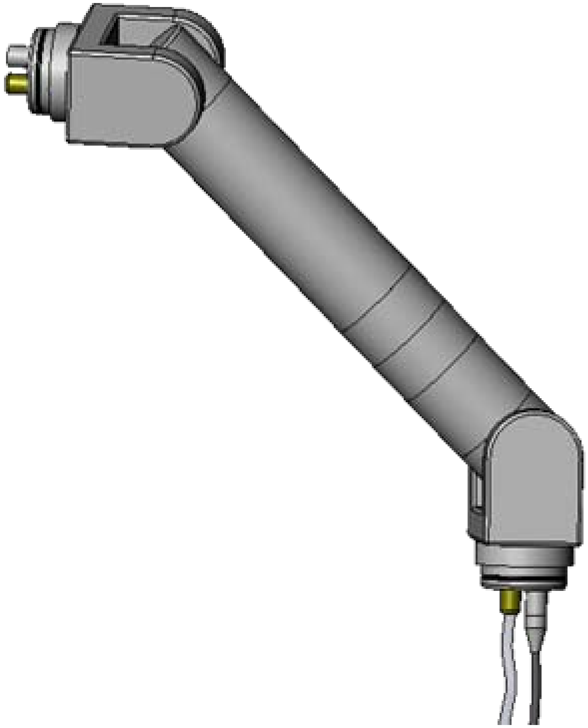
Possible Configurations

7-d.o.f’s arm



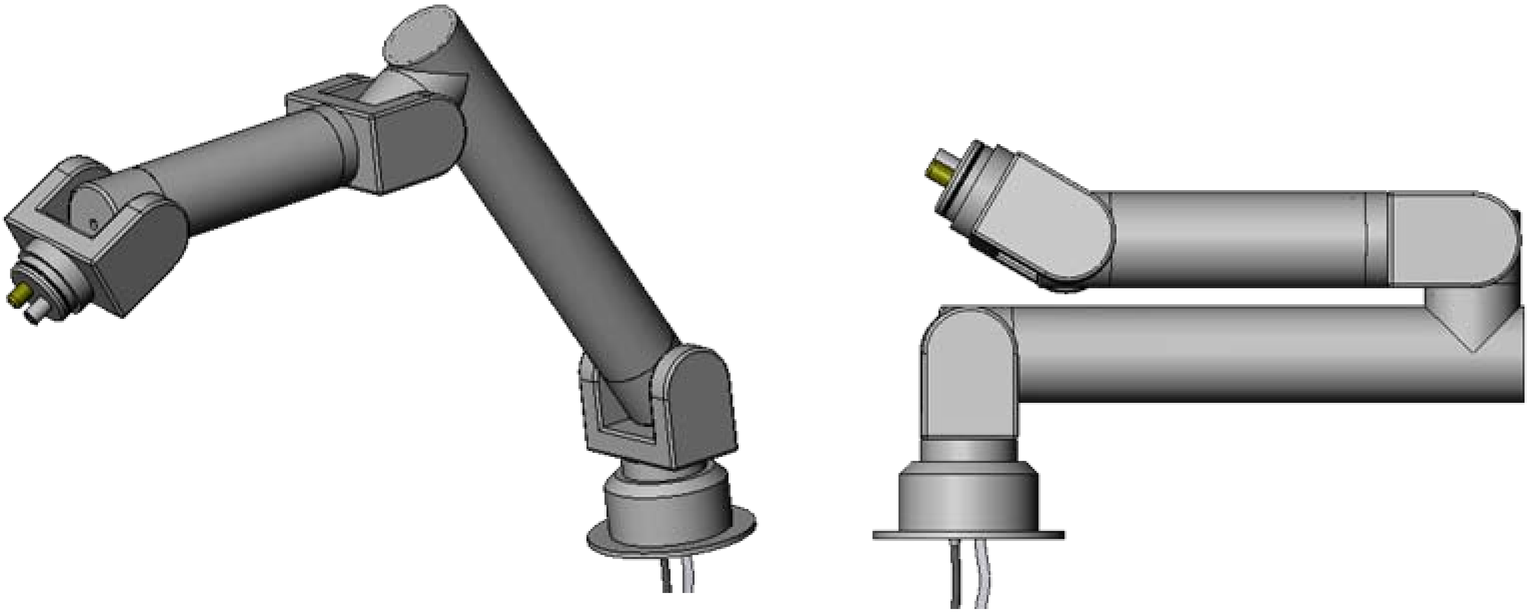
Possible Configurations

5-d.o.f’s arm



Possible Configurations

7-d.o.f's arm with an elbow-offset



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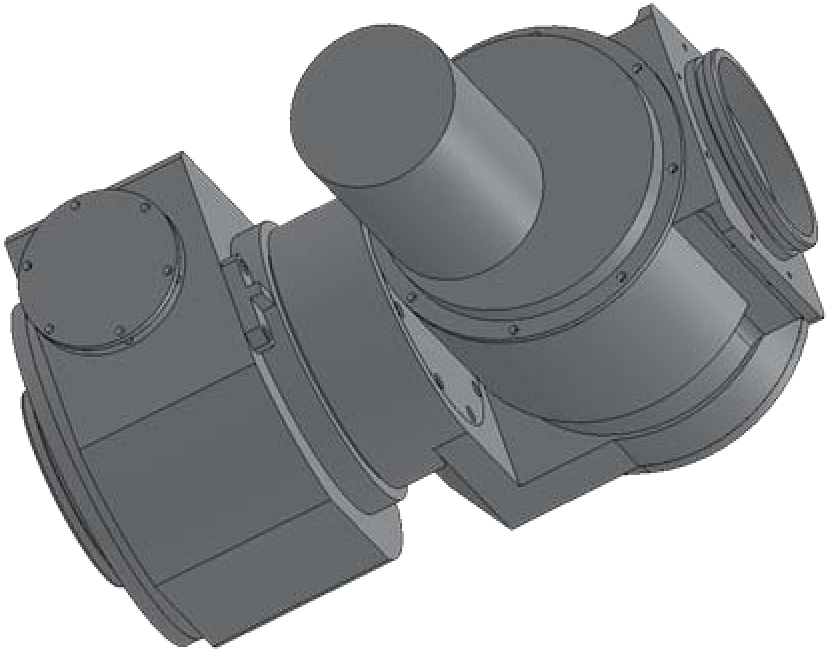
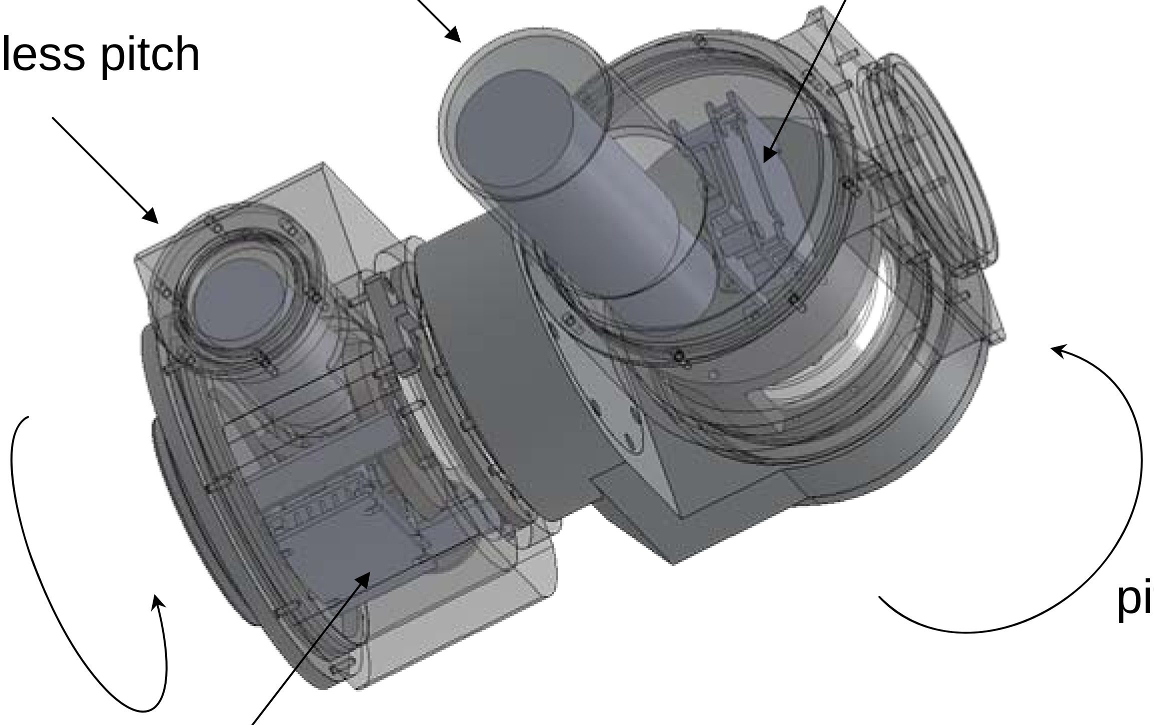
Final Design of 2 DOF Roll/Pitch



Roll/Pitch joint

Final Design of 2 DOF Roll/Pitch



Brushless pitch motor

Controller pitch

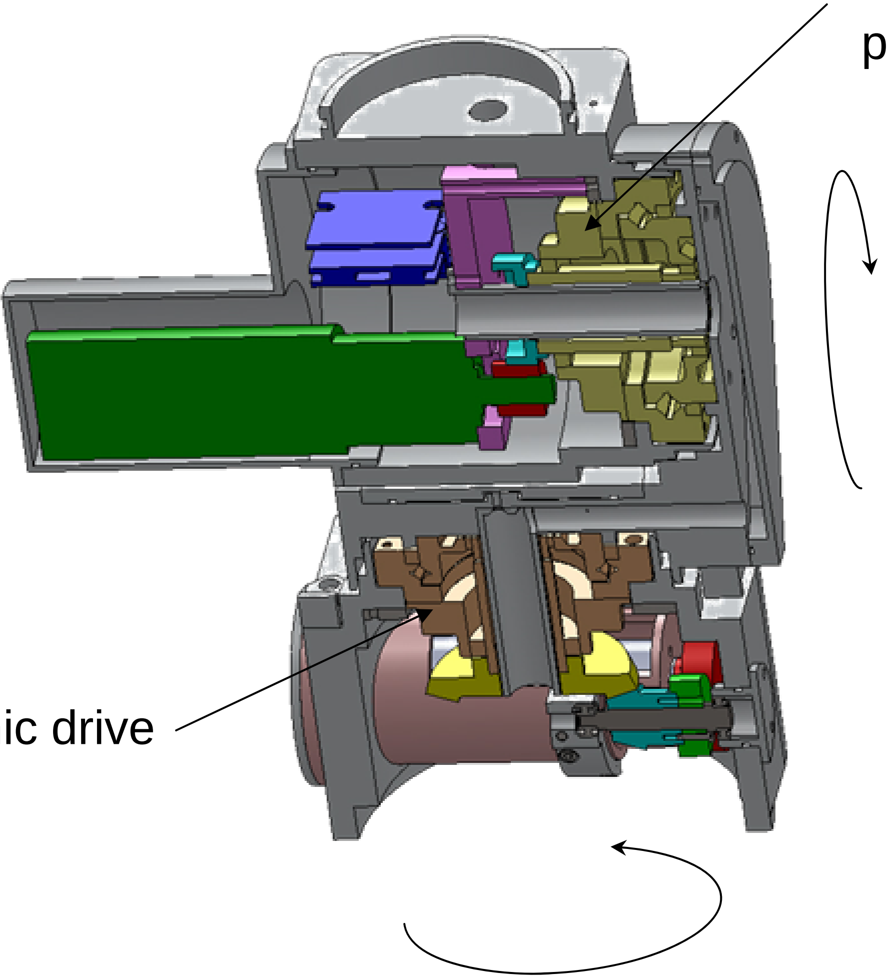
Brushless pitch roll

roll

pitch

Controller roll

Final Design of 2 DOF Roll/Pitch



Harmonic drive

pitch

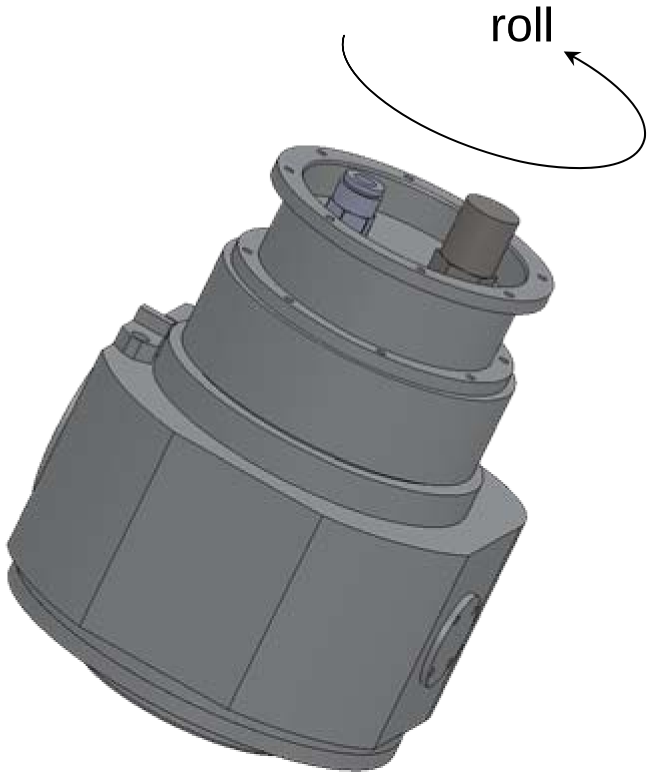
pitch

Harmonic drive

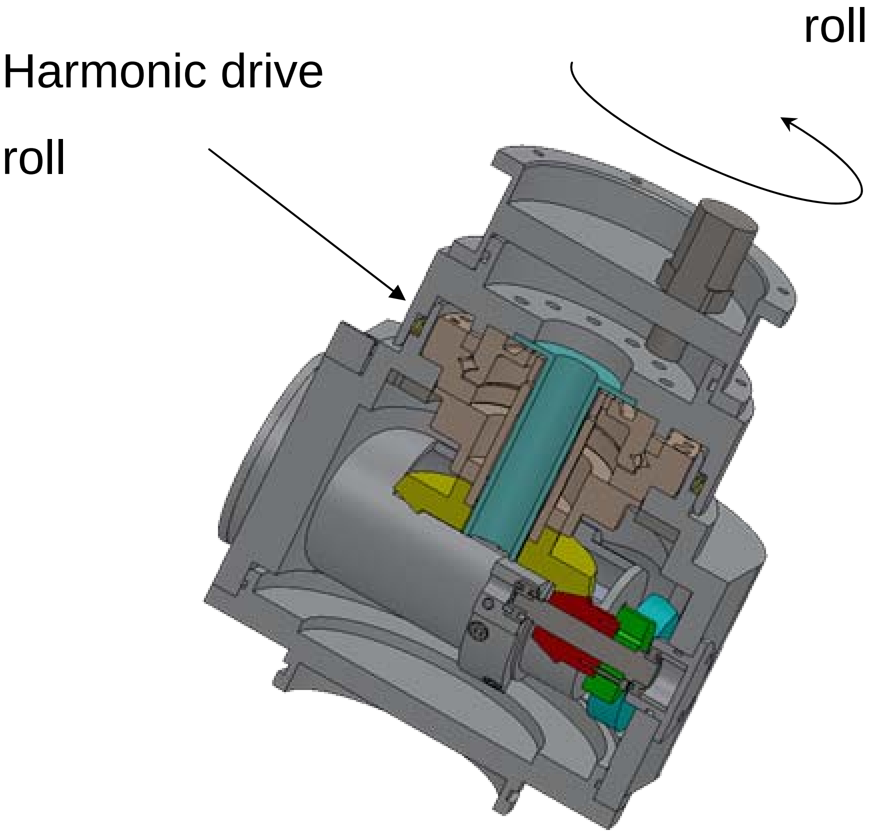
roll

roll

Final Design of 1 DOF Pitch



Final Design of 1 DOF Pitch

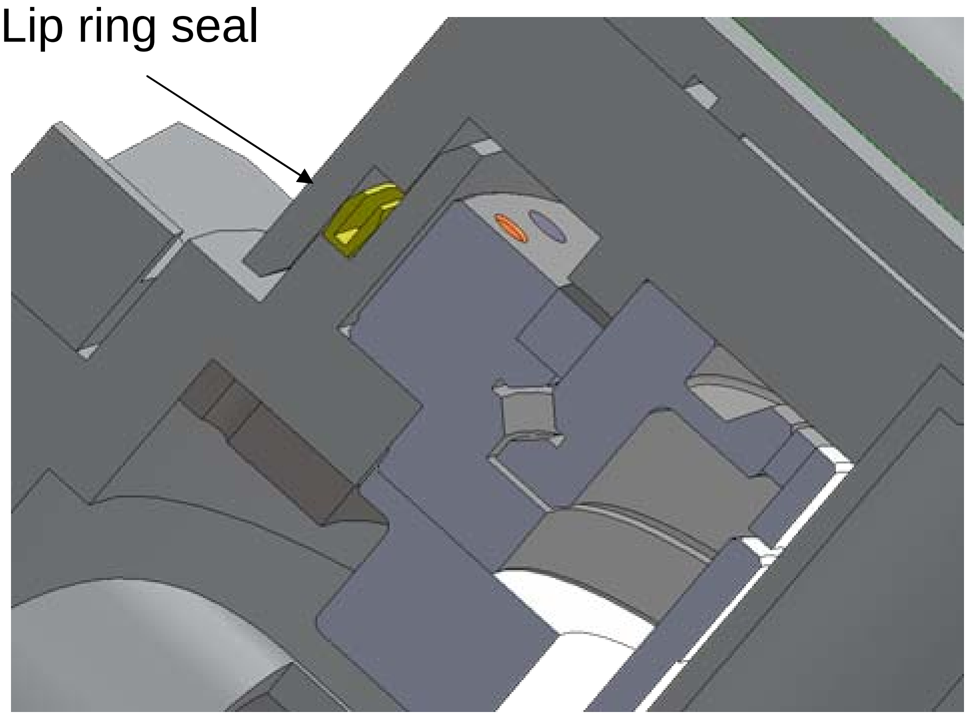


roll

Harmonic drive

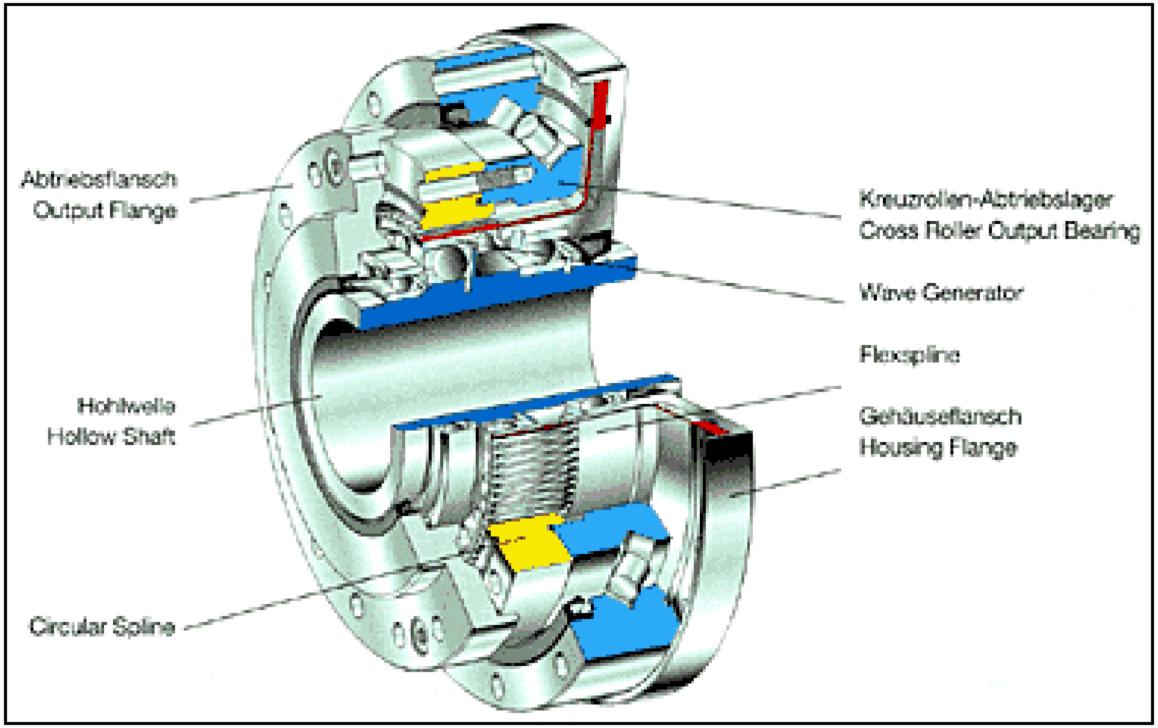
roll

Sealing system

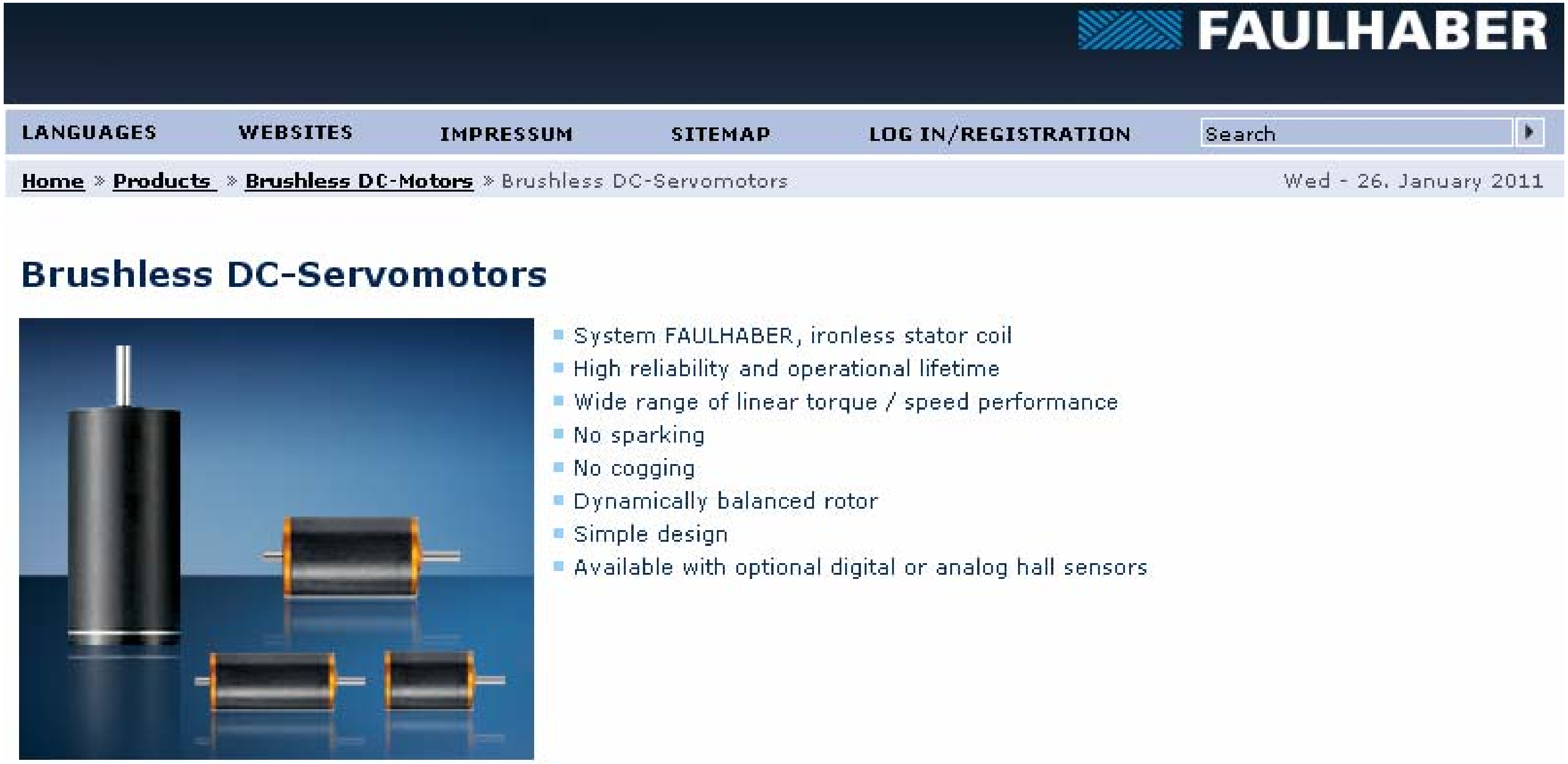


Lip ring seal

Harmonic Drive



Brushless DC Motors

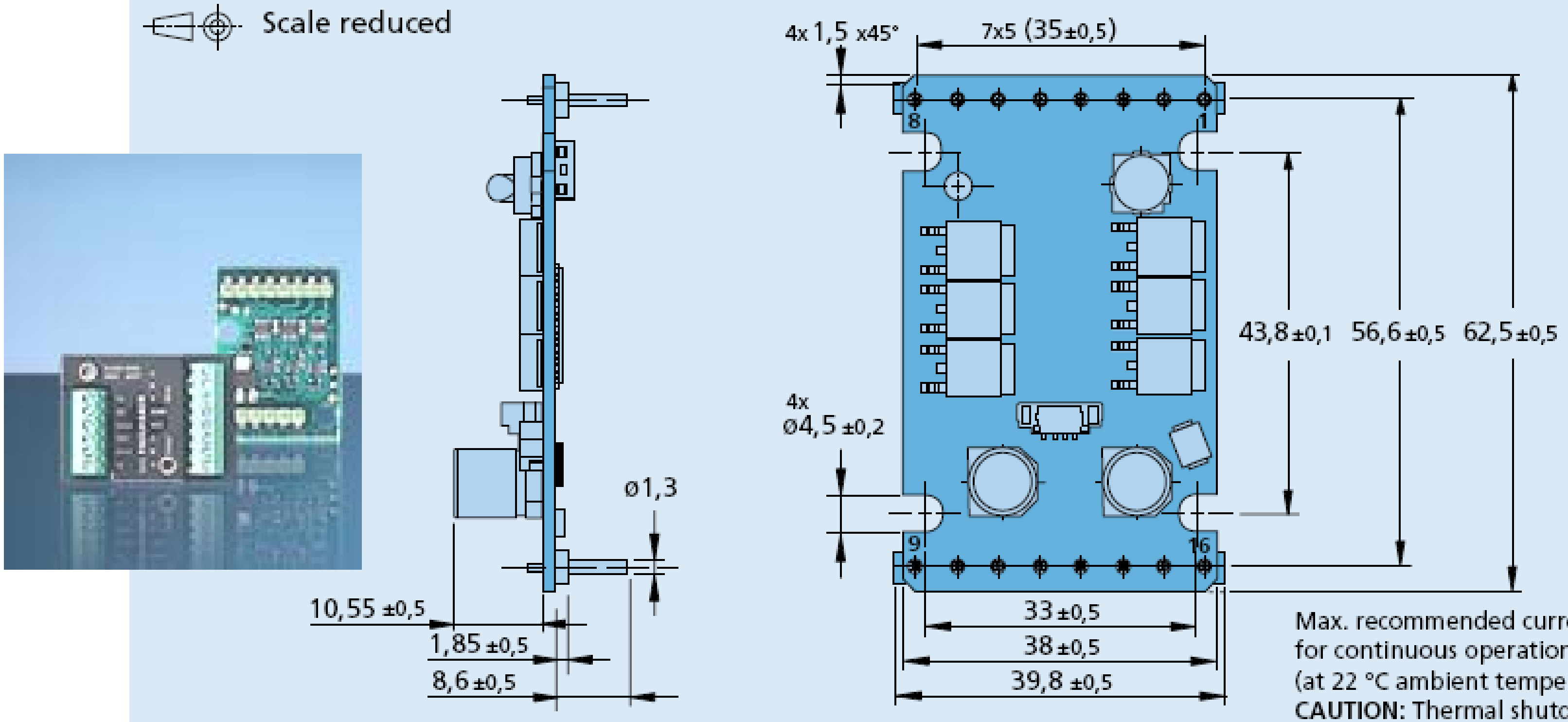


Brushless DC-Servomotors

- System FAULHABER, ironless stator coil
- High reliability and operational lifetime
- Wide range of linear torque / speed performance
- No sparking
- No cogging
- Dynamically balanced rotor
- Simple design
- Available with optional digital or analog hall sensors

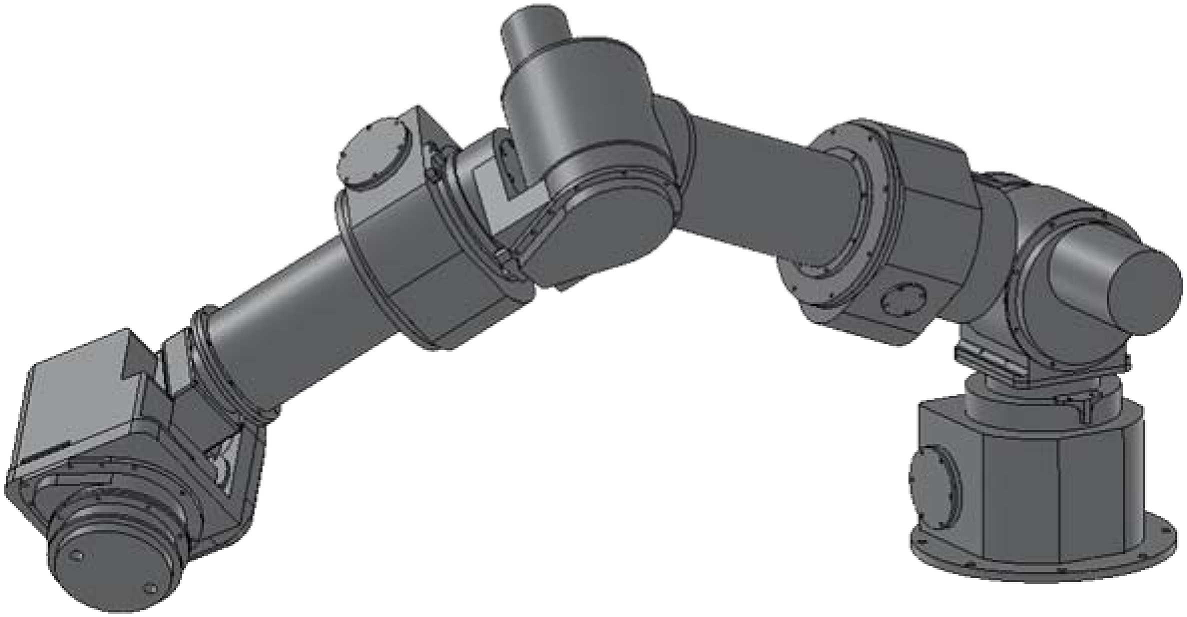
Faulhaber Motion Controller

Dimensional drawing and connection information for MCBL 3003 C

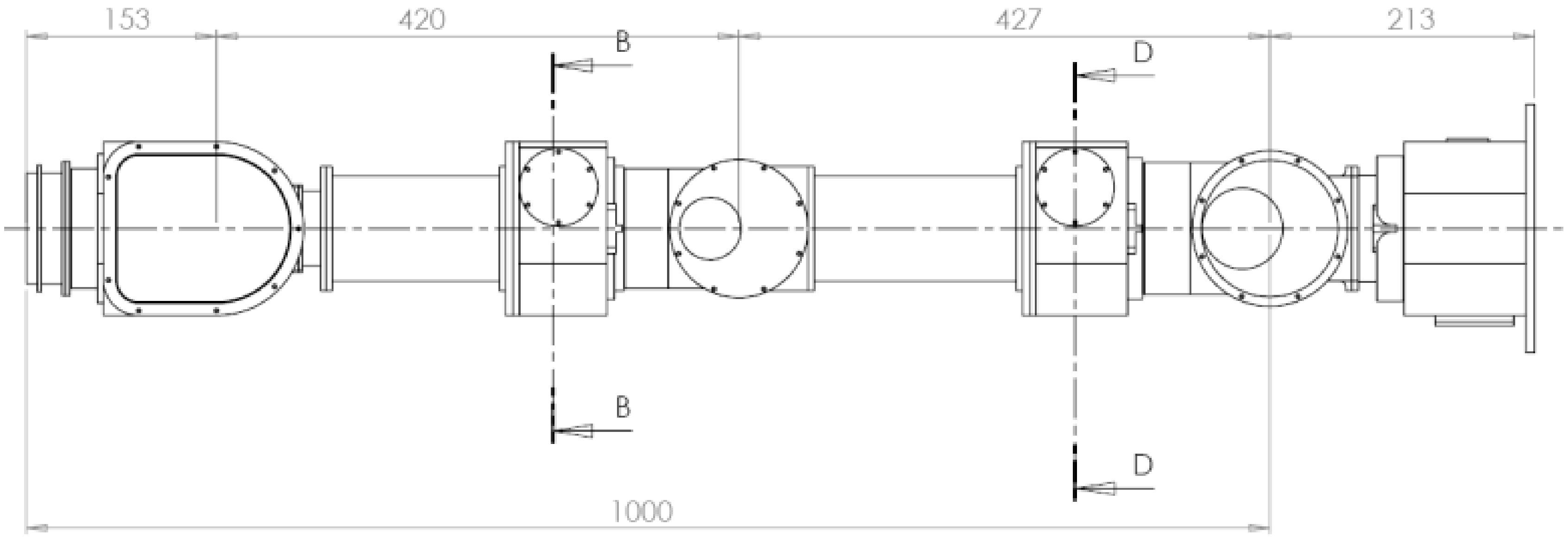


Max. recommended current
for continuous operation: 3A
(at 22 °C ambient temperature)
CAUTION: Thermal shutdown is
NOT guaranteed!

7 DOF robotic arm

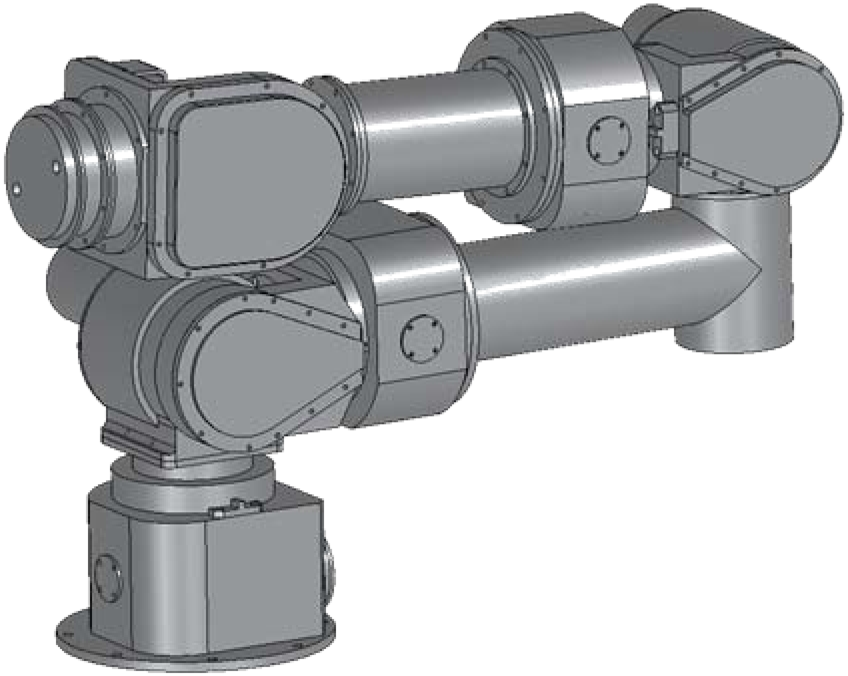


7 DOF robotic arm

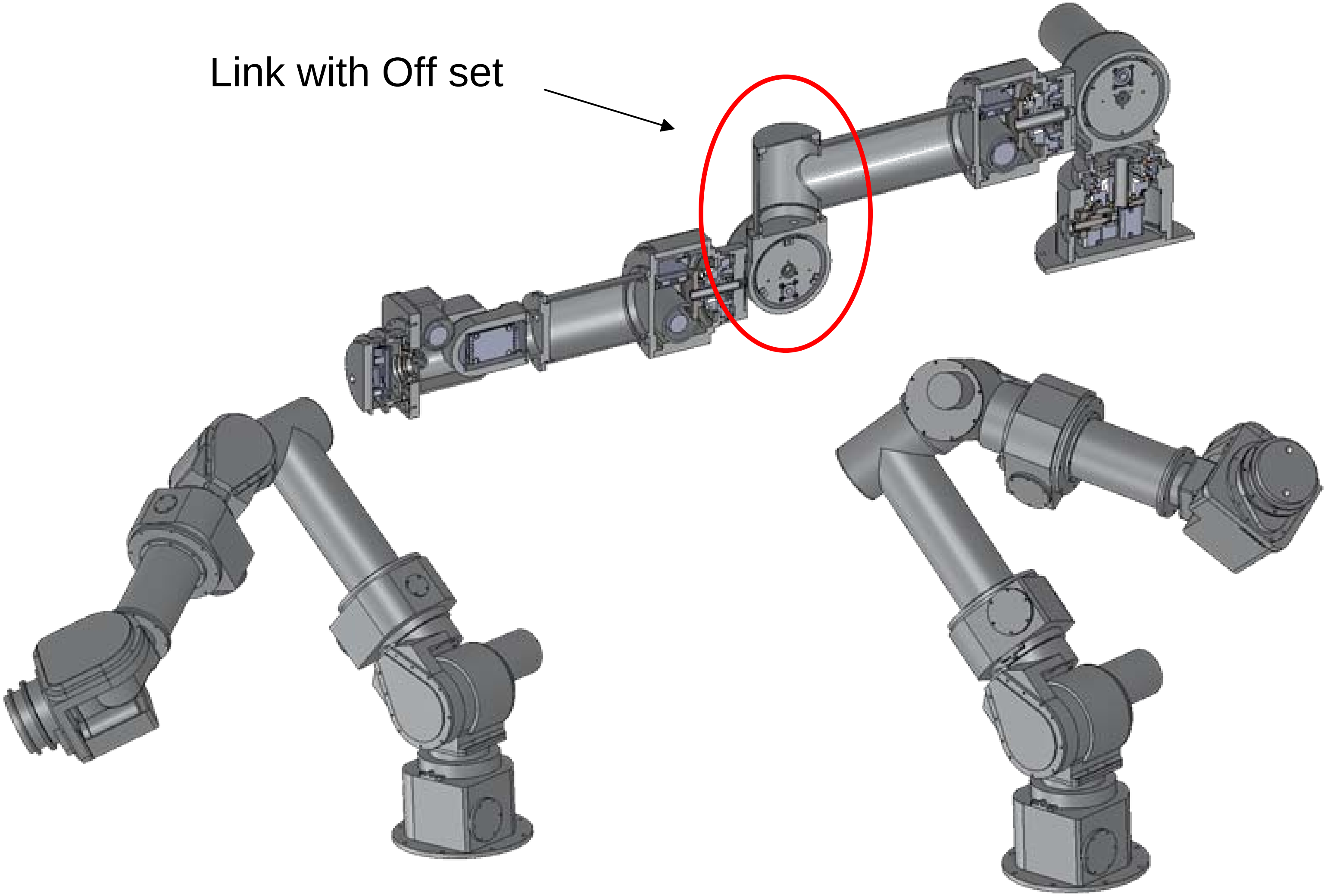


7 DOF robotic arm

7 DOF robotic arm with off-set



7 DOF robotic arm with off-set



Link with Off set

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The Joints

Set of Components

A 6 D.O.F. Configuration

A 6 D.O.F. Configuration

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Next Steps

- Arm Integration on board the Girona AUV
  (in few weeks)

- Pool Tests and Sea Trials

- Completion of the TRIDENT Project

- Possible Commercial Exploitation
  (crossing our fingers...)