ROBotic Open-architecture Technology for
Cognition, Understanding and Behavior

Project no. 004370

RobotCub

Development of a cognitive humanoid cub

Instrument: Integrated Project
Thematic Priority: IST – Cognitive Systems

First Periodic Activity Report

Period covered from **01/09/2004** to **31/8/2005** Date of preparation: **9/10/2005**

Start date of project: **01/09/2004** Duration: **60 months**

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Project coordinator organisation name: **University of Genova**
DIST – LIRA-Lab

Revision: **1**

Table of Contents

1 Publishable executive summary

RobotCub's Background
Until a few years ago the study of cognitive processes and of the neurophysiological basis of human behaviour was the subject of many (and usually unconnected) disciplines such as psychology, neurophysiology, computer science, information theory, and philosophy to name a few. Mental processes were mainly studied in the framework of abstract theories, mathematical formulation, and classical artificial intelligence. More recently it has become clear to scientists in these various disciplines, investigating cognition, that the *so-called* mental processes supporting the interactions with objects and other human beings are, in fact, profoundly shaped by the structure of the body, and the morphology and physical properties of its components. Among the consequences of this change of perspective is that the study of cognition and intelligence is becoming a multidisciplinary effort involving, among others neuroscience, information theory, psychology, and robotics, and is more and more dependent on the use of "physical bodies" such as humanoid robots.

Even if research in the field of humanoid robots has many possible goals, from the scientific and technological perspective humanoids are, in this view, essential tools to study human cognition and to investigate the related technologies (reasoning, cognition, learning, adaptation, associative memories, language, and communication). From this point of view, not only artificial systems are deeply influenced by the current neuroscientific knowledge, but, in turn, they are influencing more and more the neurosciences, by defining new challenging problems of extraordinary impact.

The RobotCub humanoid project represents a significant opportunity to move this research agenda forward: through open collaboration, on the common theme of embodied cognition, enabled by a shared humanoid platform, and supported by a multidisciplinary research team.

RobotCub's Objectives
RobotCub is an *Integrated Project* funded by European Commission through the E5 Unit (Cognition) of Information Society Technologies priority of the Sixth Framework Programme. The pre-proposal was submitted in June 2003 and the project started the 1st of September 2004 with duration of 60 months. The consortium is initially composed of 11 European research centres plus two research centres in the USA and three in Japan specialized in robotics, neuroscience, and developmental psychology.

RobotCub has two main goals: (1) to create an open robotic platform for embodied research that can be taken up and used by the research community at large to further their particular approach to the development of humanoid-based cognitive systems, and (2) to advance our understanding of several key issues in cognition by exploiting this platform in the investigation of cognitive capabilities.

The scientific objective of RobotCub is, therefore, to jointly design the mindware and the hardware of a humanoid platform to be used to investigate human cognition and human-machine interaction. We call this platform iCub. It is worth remarking that the results of RobotCub will be fully open and consequently licensed following a General Public (GP) license to the scientific community. The underlining goal is that of building a critical mass of scientists addressing, from a multisciplinary perspective but a common framework, the still unknown aspects of human cognition. We believe that the results of such effort will open up the road to new technologies with applications not necessarily limited to the field of humanoid robots.

RobotCub's International Scope

The RobotCub consortium is a multidisciplinary group of leading laboratories in the world. The commonality between the groups is the interest in understanding human cognitive processes. Collaboration is between the groups bringing in specific expertise in Humanoid Technologies (Genova, Pisa, Lausanne, Zurich, Salford, Lisbon, Cambridge, Tokyo and Kyoto), in Developmental Psychology (Uppsala), Neuroscience (Ferrara and Rome), and human-humanoid interaction and social behaviour (Hertfordshire). In short we could say that the consortium addresses aspect of *Cognitive Neurosciences*.

The RobotCub consortium is an open consortium because about 2 Million Euros have been reserved for future partners and will be assigned by the project (starting at year 3) with a public call for proposals aimed at exploiting the robotic platform.

The 11 European Partners and the five non-EU partners participating in the project at this time are listed below.

Name	Main Expertise in Project	Contact
University of Genova – LIRA-Lab, Dipartimento di Informatica, Sistemistica e Telematica – Genova – Italy	Cognitive Humanoid Robotics – Vision and Manipulation	Giulio Sandini
Scuola Superiore S. Anna – ARTS Lab – Pisa – Italy	Robotics and Mechatronics – Manipulation Hardware	Paolo Dario
University of Zurich – Artificial Intelligence Lab, Department of Information Technology Zurich – Switzerland	Cognitive Robotics – Audition and Touch	Rolf Pfeifer
University of Uppsala – Department of Psychology – Uppsala - Sweden	Cognitive development of manipulation skills in babies	Claes von Hofsten
University of Ferrara – Department of Biomedical Science – Human Physiology - Ferrara – Italy	Physiology of Manipulation control in humans.	Luciano Fadiga
University of Hertfordshire – Department of Computer Science - United Kingdom	Cognitive Behavior and Interaction	Kerstin Dautenhahn
IST Lisbon - Computer Vision and Robotics Lab Lisbon – Portugal	Cognitive Robotics – Eye-head coordination	Jose Santos-Victor
University of Salford - Centre for Robotics and Automation – Salford – United Kingdom	Robotics – Locomotion	Darwin Caldwell

Ecole Polytechnique Federal de Lausanne – Autonomous Systems Lab Lausanne – Switzerland	Cognitive Behavior and Interaction, Locomotion	Aude Billard
Telerobot S.r.l. Genova - Italy	Mechanical design and prototype manufacture	Francesco Becchi
European Brain Research Institute Rome – Italy	Sensorimotor Coordination and motor cognition	Emilio BIzzi
NON-EU Partners		
MIT Computer Science and Artificial Intelligence Laboratory	Cognitive Humanoid Robotics	Rodney Brooks
University of Minnesota School of Kinesiology, Dept. of Neurology	Developmental Psychology	Juergen Konczak
Communications Research Laboratory, Japan	Humanoid Robotics and Development	Hideki Kozima
Universty of Tokyo - Department of Mechano-Informatics, Intelligent Informatics Group	Humanoid Robotics	Yasuo Kuniyoshi
ATR Computational Neuroscience Laboratories – Kyoto	Neuroscience and Humanoid Robotics	Gordon Cheng

RobotCub's Main Achievements of the first year

The main achievements of RobotCub are the following:

1. The progresses towards the modelling and production of cognitive abilities in iCub. For the past year, the partners have been working on several contributions leading to the eventual creation of a model of cognition and an associated cognitive architecture which will facilitate the development of cognitive capabilities in the iCub humanoid robot.
2. The establishment of a common repository of documents and design drawings and the selection of key standards for the exchange of design and documentation.
3. The agreement on the overall architecture and mechanical and sensory specifications of the iCub. In summary; iCub will have 53 degrees of freedom, a weight of 23 Kg or less, and a height of about 95 cm. Besides the mechanical components, the consortium spent a considerable amount of time discussing about the sensory requirements of the iCub in relation to the cognitive experiments that all partners are planning.
4. The design of the iCub components and the initial integration exercise performed by assembling the individual CAD files. The following figure includes to snapshots from the CAD of the iCub.

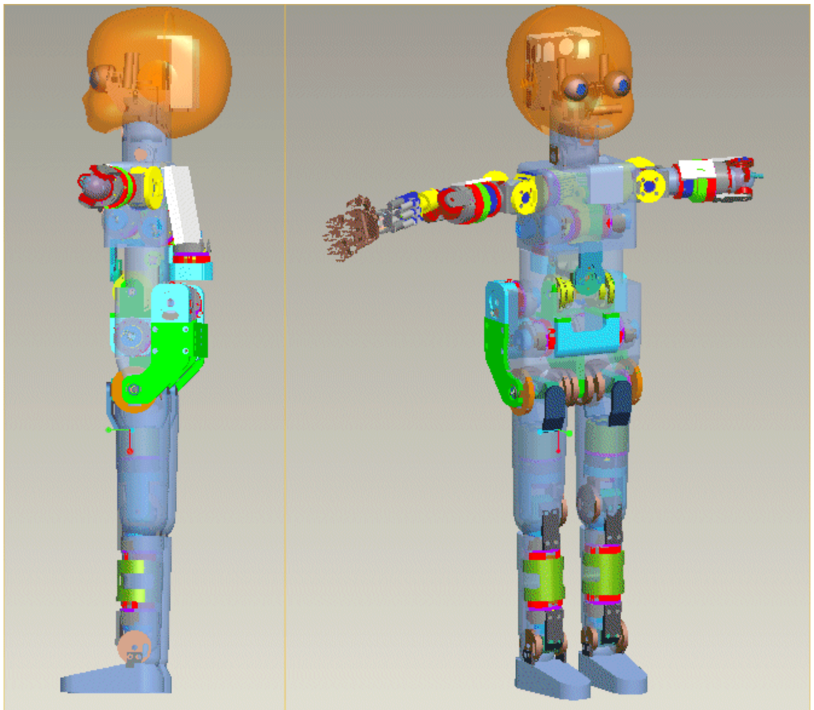


Figure 1: the iCub, status of the integration at the moment of writing.

5. The initial implementation of cognitive abilities in the partner's individual platform. While designing the iCub Platform, all partners have been involved in experiments investigating different aspects of cognition by using the platforms and experimental set-up already available.
6. The establishment of a good relationship and the acquisition of mutual knowledge of scientific backgrounds of partners. This was obtained through four plenary meetings organized in places facilitating both formal and informal discussion. Agendas, documents and slides produced for all these meetings are available in the project's website (http://www.robotcub.org).
7. The definition and acceptance of the licensing schema for the open system. This was a particularly important point (even if not a scientific one) because of the goal of the project to design an "open" system.
8. Visibility of the project in the scientific community as well as the general public. In the first year the project produced 56 scientific publications, was mentioned 18 times in articles published by general press, and was invited several times to present its goals at scientific meetings.

2 Project objectives and major achievements during the reporting period

For the sake of readability the **list of partners with their acronym** is reported below.

Name	Acronym
University of Genova – LIRA-Lab, Dipartimento di Informatica, Sistemistica e Telematica – Genova – Italy	**UGDIST**
Scuola Superiore S. Anna – ARTS Lab – Pisa – Italy	**SSSA**
University of Zurich – Artificial Intelligence Lab, Department of Information Technology – Zurich – Switzerland	**UNIZH**
University of Uppsala – Department of Psychology – Uppsala - Sweden	**UNIUP**
University of Ferrara – Department of Biomedical Science – Human Physiology – Ferrara – Italy.	**UNIFE**
University of Hertfordshire – Department of Computer Science - United Kingdom	**UNIHER**
IST Lisbon - Computer Vision and Robotics Lab Lisbon - Portugal	**IST**
University of Salford - Centre for Robotics and Automation – Salford – United Kingdom	**UNISAL**
Ecole Polytechnique Federal de Lausanne – Autonomous Systems Lab Lausanne – Switzerland	**EPFL**
Telerobot S.r.l. – Genova - Italy	**TLR**
European Brain Research Institute – Rome – Italy	**EBRI**

2.1 Overview

The Project Objectives (PO-n) described in the Technical Annex, can be summarized as[1]:

PO-1 the realization of a professionally documented, reproducible **open platform** shaped like a child-humanoid.

PO-2 the understanding through real-world implementation of **exploratory and manipulation-based cognitive skills** integrating perception, reasoning, representation, and learning.

PO-3 the study and implementation of the initial period of human **cognitive development** in an embodied artificial system

PO.4 the **building of an international scientific community** addressing aspects of embodied cognition

The Specific Objectives (SO-n) of the first **18 months**, as defined in the Technical Annex, can be summarized as[2]:

[1] See pages 5 to 8 of the Technical Annex for a more detailed description of the 60-months objectives

[2] See pages 63 to 64 of the Technical Annex for a more detailed description of the 18-months objectives.

SO-1 A **model of human infants' cognitive development** based on recent and well documented experimental results (contributing to PO-3).
SO-2 The complete design of all CUB components and a suitable integration plan (Contributing to PO-1)
SO-3 Results of the initial implementation of cognitive abilities in an artificial system (Contributing to PO-2)
SO.4 Results of the testing of new technologies to be used in the CUB platform (Contributing to PO-1)
SO-5 The Community Building activities mainly focused on establishing the initial contacts with similar projects worldwide (Contributing to PO-4)
SO-6 Update of the Open System legal aspects and definition of the organization (Contributing to PO-1)

The project's objectives were pursued within the Workpackages defined in the Technical Annex and produced the deliverables listed below:

Work Package		**Responsible Contractor**	**Deliverables**	
No.	**Title**		**No.**	**Title**
WP1	Project Management	UGDIST	D1.1.1	Interim Report
			D1.1.2	Annual Report
			D1.2	CUB's Licensing Strategy
			D1.3	Cost Statement
			D1.4	Project meetings
			D1.5	Review meeting
WP2	Cognitive Development	UNIUP	D2.1	Developmental Roadmap and Cognitive Architecture
WP3	Sensorimotor Coordination	UNIFE	-	No deliverable at month 12
WP4	Object's Affordance	IST	-	No deliverable at month 12
WP5	Imitation	EPFL	D5.1	Interpreting the Kinematics of Arm Motion
			D5.2	Visual recognition and Imitation
WP6	Gesture Communication	UH	D6.1	Results from computational models of gesture communication
WP7	Mechatronic of the CUB	TLR	D7.2	Analysis and pre-selection of the sensor's and actuator's technologies
WP8	Open System	UGDIST	D8.1	Initial Specification of the CUB Open System
			D8.2	Definition of Documentation and Manufacturing Procedures
WP9	Community Building	UGDIST	D9.1	Proceedings of the Initial Scientific Meetings

With respect to the project's objectives we believe we have progressed significantly in both the engineering aspects of the project (the design and initial integration test of all components is well under way) as well as in the difficult task of defining an implementable cognitive architecture for iCub[3]. The cooperation between the partners is developing very well as it is the integration of multidisciplinary backgrounds contributing to the project's objectives.

2.2 Recommendations

This is the first year of the project. No previous recommendations were received.

2.3 Objectives of reporting

This report covers the activities carried out during the first **12 months** of the projects and this section summarizes the main achievements of this initial period. Because of the multidisciplinarity of the project, there is no simple one-to-one correspondence between the achievements and the Specific Objectives of the first 18 months. However for the sake of clarity, we will make reference to the Specific Objectives that better represents the goals of the individual activities. In section 2 of this report the description of the work carried out within each single Workpackage is detailed with reference to the contribution of each individual contractor.

2.4 Major Achievements

Eight Major Achievements (MA-1 to MA-8) are reported here.

MA-1: The progresses towards the modelling and production of cognitive abilities in iCub (contributing to SO-1);
Our goal in the project is to create an emergent embodied cognitive system, equipped with a rich set of innate action and perception capabilities, which can develop over time an increasing range of cognitive abilities by recruiting ever more complex actions and thereby achieving an increasing degree of prospection (and, hence, adaptability and robustness) in dealing with the world around it.
For the past year, the partners have been working on several contributions leading to the eventual creation of a model of cognition and an associated cognitive architecture which will facilitate the development of cognitive capabilities in the iCub humanoid robot. These contributions are based on the phylogenic capabilities and developmental process of human neonates, and on the partners' embryonic models of constituent cognitive skills, ranging from gaze control, through reaching, grasping, manipulation of objects, imitation, and the social interaction that underpins gestural communication. The modelling and production of these individual cognitive skills have been addressed individually for the moment in Workpackages 3, 4, 5, and 6, while the overall framework which will allow these to be brought together and integrated (or, ideally, unified in one model) is being investigated and developed in Workpackage 2.1.

[3] iCub is the name given to the robotic platform being developed within RobotCub.

During the past year, it has been decided that this cognitive framework will be developed in five stages (and reported on over time in several releases of Deliverable 2.1).

The first stage, now complete, presents the conceptual foundations of the RobotCub project, identifying the broad stance taken in the project to cognitive systems - emergent embodied systems that develop cognitive skills as a result of their action in the world - and drawing out explicitly the strong consequences of adopting this stance.
The second stage surveys what is known about cognition in natural systems, particularly from the developmental standpoint, with the goal of identifying the most appropriate system phylogeny and ontogeny. This stage is now nearing completion.
This is followed by an investigation of neurophysiological and psychological models of some of these capabilities, noting where appropriate architectural considerations such as sub-system interdependencies that might shed light on the overall system organization. This investigation is on-going.
The next stage (which is also being worked on at present) will provide a synopsis of the current models that the RobotCub partners are working with, placing them in a two-dimensional space of ontogeny, spanned by actions and prospective capabilities that are traversed by a cognitive system as it develops from its initial phylogenically-endowed state towards greater cognitive ability. This activity is informed to a great extent by the on-going work in Workpackages 3, 4, 5, and 6.
The final stage is the creation of a roadmap that uses the phylogeny and ontogeny of natural systems to define the innate skills with which the iCub must be equipped so that it is capable of ontogenic development, to define the ontogenic process itself, and to show exactly how the humanoid robot should traverse the two-dimensional space of ontogeny. It will also include an agenda for subsequent research - the RobotCub roadmap - and will put forward an architecture for cognition which will facilitate the operational integration of discrete cognitive capabilities and, ideally, the theoretical unification of distinct models. This architecture will then inform the work that needs to be done in the future in Workpackages 3, 4, 5, and 6.

MA-2: The establishment of a common repository of documents and design drawings and the selection of key standards for the exchange of design and documentation (contributing to SO-2).
The common repository has been implemented in the form of a website. The relevance of this activity is related to the fact that the website has to fulfill the following needs:

a) Window of the project to the outside world.
b) A repository of the project’s formal deliverables.
c) A repository of documents for ongoing activities. This includes not only reports but also software code, electronic and mechanical drawings.
d) The official repository of the “open” design and documents.

Therefore, besides the standard need for a “public” part and a “private” part, even though at the moment we still have not released any “open” document the structure of the website has to support the upload/download of documents with different standards including CAD mechanical and electronic drawings, software code with support for versioning, etc. For this reason along with the design of the website, the consortium had to agree on the use of documentation standards to be used to exchange data. Our guiding principles here have been on one side the adequacy of the standard but also the availability of, at least, “free viewers”. Results of these activities are described in this report within WP8. At present the “private” area of the website is accessible to all partners (including the non-EU partners) plus to a group in Karlsruhe (lead by Prof. Dillman) with whom we already started the exchange of design solutions.

MA-3: The agreement on the overall architecture and mechanical and sensory specifications of the iCub (contributing to SO-2 and SO-4).
As a matter of fact this has been, probably, the most time- and effort-consuming activity of the project in its first year. In fact, considering that the most important scientific goal of RobotCub is to study the development of cognitive manipulation and gesture abilities in a humanoid robot, the timely realization of the humanoid platform is obviously of fundamental importance. The scientific needs (e.g. the kind of experiments we would like to perform with the robot) have driven the consortium during the initial phases of definition of the main global features of iCub:

- Degrees of freedom
- Overall size and weight
- Sensory requirements
- Electronics and control structure

The main points of this important activity are described in the report of WP7 and WP8 but altogether we set as a guideline that the robot will have 53 degrees of freedom, a weight of 23 Kg or less, and a height of about 95 cm.
Besides the mechanical components the consortium spent a considerable amount of time discussing about the sensory requirements of the iCub in relation to the cognitive experiments that all partners are planning. This turned out to be a somewhat difficult task (as expected) because, on one side it is easy to ask for “artificial skin” or “stereo vision” but on the other it is important to define what is really feasible and, to some extent, easy to use. This exercise is still ongoing but it has produced already a list of requirement which is now under further scrutiny. Within this topic it is worth mentioning that during our discussion about the sensorimotor requirements of the iCub it turned out that, for the study of the “communication” skills it would be very interesting if the iCub could express a limited set of emotions through facial expressions. This has produced an activity (at the moment led by UNIHER in conjunction with IST) to investigate what could be the simplest yet effective way of implementing this possibility.

MA-4: The design of the iCub components and the initial integration exercise performed by assembling the individual CAD files. (contributing to SO-2 and SO-4).
After the definition of the iCub’s general specifications, the partners involved, started the design of the iCub mechanical components. The group at IST has coordinated the work on head design implementing three prototypes to compare different kinematics solutions. The group at SSSA has been concentrating in the design of the upper and lower arm and comparing the solution proposed with implementations made by other partners. UNISAL has investigated solutions for the lower-limbs and spine that will support the crawling and the changing from crawling to sitting. It is worth mentioning here that crawling, which initially looked as if it would have been easier than walking, is turning out to be quite complex because it imposes more demands than expected on some of the mechanical components. Also the action of crawling is not very simple but it poses challenging problems from the computational and control point of view. In this respect, a very useful activity has being carried out by EPFL, in simulating the dynamics of crawling to test the best crawling strategy but also the mechanical requirements. This activity has generated an initial dynamic model of the body of the iCub which is being

used, among other things, to estimate the torques generated/required by crawling at each joint. During our general meeting at Estoril on the 17-19th of March, a first attempt at integrating the mechanical components of the head, arm, spine and hand was done by integrating the CAD files[4] prepared by different partners (SSSA, DIST, IST, UNISAL and TLR) into a single CAD project. At the end of the first year we are able to show the "almost final" version of this integration exercise, which, considering the small size of the iCub and the fact that it required the integration of the work of five partners, we consider a successful example of research collaboration. As mentioned before IST has already realized a functioning prototype of the iCub head. The following figure includes to snapshots from the CAD of the iCub.

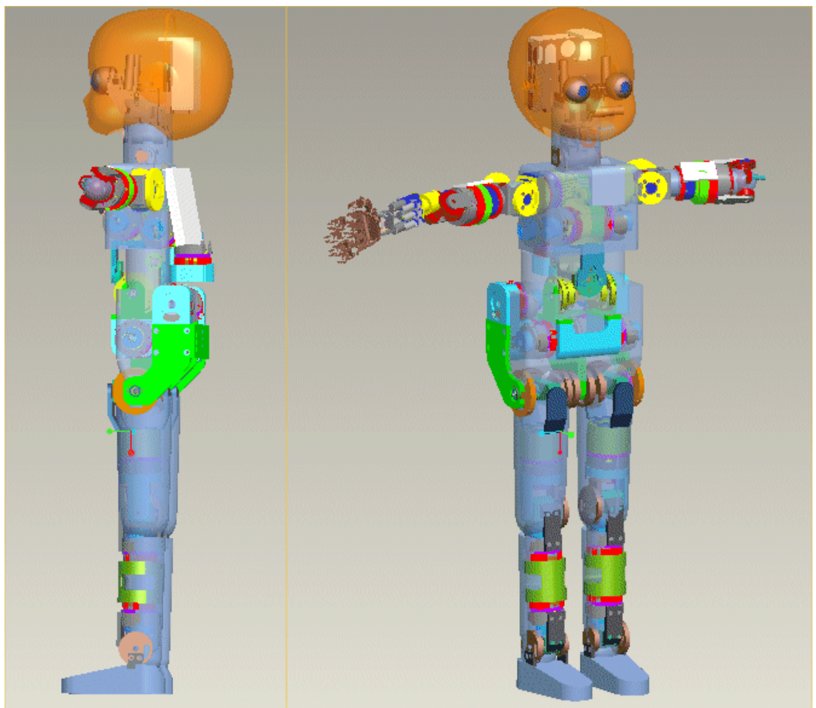


Figure 2: the iCub, status of the integration at the moment of writing.

MA-5: The initial implementation of cognitive abilities in the partner's individual platform (contributing to SO-3). While designing the iCub Platform, all partners have been involved in experiments investigating different aspects of cognition by using the platforms and experimental set-up already available. The results are detailed in the reports referring, more specifically to WP3, WP4 (Affordance), WP5 (Imitation) and WP6 (Communication). UGDIST has continued working with the Babybot platform implementing grasping behaviors based not only on the position but also on the shape of objects. This is considered a first step toward grasping algorithms learning and exploiting object's affordance. Work on visuo-haptic and visuo-acustic integration has been performed. UNIZH has performed experiments on object's affordance particularly investigating the correlation between visual information and proprioceptive/haptic

[4] The consortium agreed to adopt the Pro-E standard for the exchange of CAD files.

information acquired by looking and holding objects with different affordances (shape, size and material). UNIFE and UNIUP have continued their experiments investigating motor representation in rats and humans and the development of sensorimotor and manipulation abilities in infants. For example UNIUP has conducted a series of experiments where toddlers' understanding of the affordances related to object manipulation is investigated by studying how children go about when trying to fit objects into each other, how they learn to pile objects on the top of each other, and how they learn to fit lids on pans. UNIHER has completed preliminary study of space of robot-child interaction and analysis of requirements for sustaining interaction and extended sensorimotor learning work using information-theoretic methods. IST has continued behavioral experiments implementing on the Baltazar platform some of the developmental behaviors implemented by UGDIST on Babybot as well as implementing some basic components of low-level imitation (mainly the exact reproduction of the observed gesture).

EPFL has contributed principally through the development of ANN-based algorithms for recognition and reproduction of arbitrary gestures, as well as for a robust imitation of goal-directed reaching motions. It also worked towards neural modelling of the brain mechanisms underlying human ability to imitate.

MA-6: The establishment of a good relationship and the acquisition of mutual knowledge of scientific backgrounds of partners (contributing to SO-5).
This was obtained through four plenary meetings organized in places facilitating both formal and informal discussion. The attendance has been excellent and the discussions very stimulating. The meetings were open to our International Research Panel and their participation has been very active in offering suggestions and ideas for collaboration. For example in the project's website the group of MIT already uploaded mechanical drawings of one of their most recent robots to be used as guideline and source of suggestions and inspiration for the mechanical solutions. The same has happened for existing mechanical designs of EPFL, UGDIST and IST. The attitude of all partners toward the "openness" of the project has been enthusiastic and, in some sense, even greater than what was hoped for. During this initial period the exchange of information and acquisition of mutual knowledge has been developing both with reference to the "bodyware" and in relation to the cognitive aspects of the project, the knowledge about human development and sensorimotor representation of actions in humans. Besides the four plenary meetings, another meeting specifically devoted to discussing some general issues of the iCub body was called in January. Agendas, documents and slides produced for all these meetings are available in the project's website (http://www.robotcub.org).

MA-7: The definition and acceptance of the licensing schema for the open system (contributing to SO-6).
This was a particularly important point (even if not a scientific one) because of the goal of the project to design an "open" system. It must be said that all partners have been always very supportive of this idea and the discussion has been on the "methods" to

use to open the CUB-Knowledge[5] to everybody and this required some understanding of the licensing mechanisms that was not a common background for most of us. The main difficulty to overcome was that of finding a solution which, on one side, protects the "openness" of the results and on the other it is not too burdensome to implement. The solution, which, we believe is very satisfactory, is described in our first deliverable D1.2.

MA-8: visibility of the project in the scientific community as well as the general public (contributing to SO-5)
The main results here have been on different aspects:

e) Establishing joint laboratories with international research centers devoted to co-development of iCub. A formalized collaboration funded by the Italian Ministry of Research for the exchange of students and researchers between UGDIST and MIT-CSAIL will enter into effect starting on November 2005. A similar agreement is under negotiation with the two Japanese labs led by Gordon Cheng and Hideki Kozima. The activities organized within these agreements are open and can be shared with the RobotCub partners.
f) Cross-fertilization started with other projects of the "cognitive systems" initiative as well as with national projects in Italy and Germany. For example members of the research group at Computer Science Department of the University of Karlsruhe (Prof. Ruediger Dillmann and Dr. Tamim Asfour) already participated actively in two of our general meetings.
g) Formalized support planned in the framework of training activities for two multidisciplinary scientific events in the form of fellowships for young students.
h) Two new EU-supported initiatives led by UGDIST and related to the RobotCub objectives are starting (or will be starting soon). The first is a collaborative project supported under the NEST initiative (project called CONTACT) and aimed at investigating the development of speech understanding, could have important fall-out for the implementation of speech understanding aspects of iCub (iCub will be the platform adopted by this project). The second is the start of a coordination action euCognition.
i) In July 2005 we also organized the first RobotCub Open Day to present the preliminary results of the project and to collect feedback/suggestions about our initial choices.

[5] CUB-Knowledge is formally defined in the Consortium Agreement and in the D1.2 on the licensing of the RobotCub results.

2.5 Progress toward Milestones

In the following table the milestones for the first 24 months of the project, taken from the Technical Annex, are reported with reference (last column in the table) to the Major Achievements described in section 2.4.

Month	Milestones	Main Achievement No.
12*	MX: preliminary results of the mindware activities	MA-1, MA-5
	MX: preliminary results of the internationalization activities	MA-7, MA-8
18	M1: initial design of the robot parts and plan for integration	MA-2, MA-3, MA-4, MA-6
	M1: implementation of the scenario described in section **Error! Reference source not found.**	MA-1, MA-5
	M1: creation of the core components of the international community and plans for the international project	MA-7, MA-8
24*	MY: general sketch of the full humanoid, not yet executive drawings	MA-3, MA-4
	MY: initial integration of some imitation and communicative skills	MA-1, MA-5

(*) the milestones at month 12 and 24 are given to allow the evaluation of the first year achievements. The project more naturally can expect consistent results after the first 18 months and after 36 months.

The achievements described shows that the project is progressing very well toward the associated milestones at month 12 and, more importantly toward the critical milestones at month 18.

2.6 Problems

While no serious problems have occurred in the past year, a number of adjustments have been made to the work-plan for the forthcoming eighteen months. The main ones are as follows.

It was decided to extend the scope of WP2 to address the issue of integration of the several strands of work in the development of the iCub cognitive architecture. This work will be encapsulated in Deliverable D2.1 which will now be delivered in several stages, beginning at Month 12, and updated every six months thereafter.

It was decided not to address the production or interpretation of speech in WP6 and, instead, to expend additional effort on the development of the pre-requisites for (non-verbal) interactive and communicative behaviour grounded in sensorimotor experience and interaction histories. This work will provide the foundations for the emergence of communication in interaction before proceeding at a later stage to develop computational models of gesture communication. These models will then be solidly grounded on the paradigm of emergent cognitive systems adopted by the project.

It has become apparent that the software engineering issues associated with the iCub will be extremely complex and, consequently, we have decided to add a new task focussed specifically on the specification, design, and implementation of an iCub Software Architecture.

Finally, in order to help ensure that deliverables are of real and practical use in the project, and not simply a time-consuming mechanism for reporting progress, we have decided to reissue many of the deliverables planned for the first eighteen months over the period of the project. This means we reduce the proliferation of deliverables and allow each one to be built incrementally, consolidating, adding to, and sometimes amending previous work as our research evolves. Of course, new deliverables will be added where appropriate.

3 Workpackage progress of the period

3.1 WP1 – Management

The activity and results of this Workpackage are reported in section 4 of this report.

3.2 WP2 – Cognitive Development

3.2.1 Workpackage objectives

In this Workpackage, we study the development of early cognition and how to model the relevant aspects of such process within the boundaries of an artificial system. In particular, we investigate the timeframe of a developmental process that begins to guide action by internal representations of upcoming events, by the knowledge of the rules and regularities of the world, and by the ability to separate means and end (or cause and effect). This research is strongly driven by studies of developmental psychology and cognitive neuroscience and it will result in a physical implementation on an artificial system.
Biologically plausible models of how early cognition evolves are being investigated, taking into account both the brain mechanisms underlying the modeled cognitive processes and the learning procedures used by the child to accommodate new concepts and assimilate already acquired ones to better fit the outside world. These models will be validated against behavioral studies of how young children solve problems of various kinds and how they use internal representations of objects and events to plan actions.

3.2.2 Progress towards objectives

Most of the work in this reporting period has been devoted toward the creation of Deliverable 2.1. A Roadmap for the Development of Cognitive Capabilities in Humanoid Robots. This is due at Month 12.

We believe that we may have underestimated the amount of work involved in this Workpackage, both in breadth and depth. On the one hand, this Workpackage is intended to help specify what we should do in WP3-6 (phylogeny and ontogeny: innate skills, core knowledge, development plan, etc.) and the TA says it is 'fundamental in defining the cognitive architecture'. Indeed, Deliverable 2.1 is intended to be a document 'describing the developmental roadmap and the resulting architecture'. However, the work-plan lacks an explicit task that is devoted to integrating all the work in WP3-6 and creating this architecture. It was probably intended to do it in WP2 (possibly Task 2.2: developmental architecture) but it is not clear and explicit.

Consequently, we have decided to upgrade the WP to address these issues so that it encapsulates the several contributions required for the eventual creation of a model of cognition and an associated cognitive architecture which will facilitate the development of cognitive capabilities in the iCub humanoid robot. These changes will be reflected in the new 18-month Description of Work to be produced at month 12.

Specifically, we have decided to extend the scope of D2.1 so that it now embraces all of the work required for us to specify, design, and implement a cognitive architecture: to encapsulate all the several contributions required for the eventual creation of a model of cognition and an associated cognitive architecture which will facilitate the development of cognitive capabilities in the iCub humanoid robot. As a consequence, it was decided to produce the deliverable in several stages, and in several versions, over time. The first version, D2.1 (V 1.3) will be delivered at Month 12, with subsequent versions being delivered at six monthly intervals thereafter until Month 30.

Deliverable D2.1 will now comprise five parts.

Part I will present a conceptual framework that forms the foundation of the RobotCub project, identifying the broad stance taken in the project to cognitive systems - emergent embodied systems that develop cognitive skills as a result of their action in the world - and drawing out explicitly the strong consequences of adopting this stance.
Part II will survey what is known about cognition in natural systems, particularly from the developmental standpoint, with to goal of identifying the most appropriate system phylogeny and ontogeny.
Part III will explore neurophysiological and psychological models of some of these capabilities, noting where appropriate architectural considerations such as sub-system interdependencies that might shed light on the overall system organization.
Part IV will set out to provide a synopsis of the current models that the RobotCub partners are working with. It will place them in a two-dimensional space of ontogeny, spanned by actions and prospective capabilities, that is traversed by a cognitive system as it develops from its initial phylogenically-endowed state towards greater cognitive ability, such as imitation, gestural communication (and, by extension, deliberation and reasoning).
Part V will present a roadmap that uses the phylogeny and ontogeny of natural systems to define the innate skills with which the humanoid robot must be equipped so that it is capable of ontogenic development, to define the ontogenic process itself, and to show exactly how the humanoid robot should traverse the two-dimensional space of ontogeny. Part V will conclude by setting out an agenda for subsequent research - the roadmap - and addresses the creation of an architecture for cognition: the need for operational integration of discrete capabilities and the challenge of theoretical unification of distinct models.

Of the five parts comprising the document, only Parts I and II are substantially complete at this time, with significant progress having been made in Part III (D2.1, V1.3).

3.2.3 Deviations from the project work-programme

Apart from the re-organization of the work described above, there are no deviations from the project work-program.

3.2.4 List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
D2.1	A Roadmap for the Development of Cognitive Capabilities in Humanoid Robots	WP2	Month 12	Month 12	UNIUP

3.2.5 List of milestones

No specific milestone is planned in this WP at this time.

3.3 WP3 – Sensorimotor Coordination

3.3.1 Workpackage objectives

Activities in WP3 are aimed at the definition and implementation of the development of sensorimotor skills and their contribution to cognitive developments. UNIFE is coordinating the contribution to the activities of this WP. This WP will contribute mostly to the implementation of cognitive abilities in the artificial system. This objective will be demonstrated through extensive testing of the robot's cognitive abilities in realistic situations, implemented in several of the existing robotic platforms, as well as through psychophysical and behavioral studies measuring the robot's interactions with humans. By month 18, we will have investigated to a certain degree the following cognitive aspects underlying the development of infants' manipulation behaviors:

a) The ability of learning and exploiting object affordances in order to correctly grasp objects on the basis of their use.
b) The ability of understanding and exploiting simple gestures to interact socially.
c) The ability of learning new manipulation skills and new communicative gestures.
d) The ability of correctly interpreting and imitating the gestures of a human demonstrator.

3.3.2 Progress towards objectives

The 11th of January we held a meeting in Ferrara devote to share plans and to delineate the coordination and collaboration. To the meeting have participated senior scientists of **UNIFE** (L. Fadiga and L. Craighero) and **UNIUP** (C. von Hofsten and K. Rosander), together with the post-doc and PhD students working at **UNIFE**. Two main lines of research have been identified as particularly relevant at this stage:

1. Study of the ontogeny of the mirror-neuron system.
2. The prediction of action outcome.

A series of experiments has been conceived and in the following three months some pilot trials already started.

Concerning **objective 1**, we have decided to proceed along the following directions:

1.a) It is well known that during action execution and observation there is a desynchronization of an EEG rhythm in the 20 Hz band (mu rhythm) recorded at rest on central derivations. Mu rhythm desynchronization is thus considered a functional correlate of the mirror system at work. We have decided to study the desynchronization of the mu rhythm in developing infants (from 6 months old). At present a collection of video clips have been already prepared, showing goal-directed and non-goal directed hand actions. Some subjects have been already recorded and the data is under analysis.
1.b) The pattern of eye movements during action observation is the same as that recorded during action execution. In both cases, the eyes anticipate the hand and reach the target well before the arrival of the fingers. Thus, saccadic behavior during action observation supports the direct matching hypothesis for action recognition. We decided to study the development of this predictive behavior during action observation in developing infants (**UNIUP**) and in behaving monkeys (**UNIFE**). To this purpose, the

general plans of the two experiments have been designed and UNIFE has purchased an eye tracking system (TOBII, Sweden) to perform the experiments.

1.c) It is well known that brain regional blood flow modifies according to the functional involvement of the measured area. This is the basis of brain imaging experiments, traditionally using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). Unfortunately, these techniques are not usable on infants because of their invasiveness (PET) and because their require subjects' immobility. In the recent years a new technique has been developed to non-invasively measure regional blood flow in infants. It is the near infrared spectroscopy (NIRS), which allow detecting the regional modifications of blood flow by spectroscopically measuring the absorbance of low-power infrared light by regional hemoglobin concentration. We will try to use this technique as substitute approach to brain imaging in infants. The goal is to investigate when, during ontogenesis, the premotor cortex starts becoming active during the observation of actions of others. At present the various technical options have been investigated by discussing possible approach with some leading European groups. It seems that photon counting methods are the most sensitive available with current technology. We are entering now in the practical phase and we are planning to buy the necessary instrumentation within a couple of months. Experiments will be carried out by both **UNIFE** and **UNIUP**. A preliminary testing in monkeys during action execution and observation is planned in order to optimize the various recording/measurement parameters. In order to concretely investigate the applicability of the NIRS technique in the study of cognitive functions and to verify which method is the most suitable, at the end of June a group of researchers from the Politecnico di Milano (Alessandro Torricelli, Antonio Pifferi, Lorenzo Spinelli, Davide Contini), leaded by Prof. Cubeddu, came to the Neurolab in Ferrara carrying their "Photon Counting – Time of flight" NIRS machine. We decided to test the machine by submitting a single subject to a series of experimental conditions while a single recording channel was placed over his hand representation in the left primary motor cortex. The exact location over the skull was determined by using transcranial magnetic stimulation single pulse administration, and by identifying the focus of hand motor representation. Each trial was subdivided into 20 sec baseline, 20 sec experimental condition, 40 sec rest. Each experimental condition was repeated 10 times. The subject was submitted to three different experimental conditions in different sessions:

a) finger tapping self-paced (right hand)
b) observation of finger movements
c) observation of hand movements (10 sec) and subsequent imitation (10 sec)

1.d) Some key questions concerning mirror neurons are: "what is innate and what is acquired?" "What happens to mirror neurons if the animal has never performed the observed action?" This is an incredibly difficult problem to study experimentally. First of all because if one fails to find mirror responses this does not necessarily imply that mirror neurons are not active. A negative result might be due to insufficient sampling or to experimental inaccuracy. Second, it is inconceivable to attempt this study in monkeys because of their cost and of the difficulty to cognitively deprive newborns monkeys (which need the mother continuously). Third, one would need long-lasting chronic single neuron recordings and this is a really difficult problem in neurophysiology. We will try answering these questions by using various approaches. The first one is aimed at simplifying the experimental procedure by studying a simplified animal model (i.e. the rat). Rats are quite skilled in manipulation, learn by observation and, more interestingly, have a rich social life. We are therefore aiming at finding mirror neurons in rats and to investigate their development by using a large scale approach (in terms of number of animals). To this purpose, we projected and realized a multi-electrode amplifier (32 channels) and we started experiments of intracortical microstimulation in the rat, in collaboration with the University of Parma (Italy) and the University of Odessa (Ukraine). A second possible approach concerns long-lasting recordings. We are trying to implant in monkeys area F5 (the cortical region where mirror neurons have been located) an optical recording system which detects regional changes of metabolic activity, and therefore of neuronal one. The advantage of this approach is to reduce the problems arising from the modification of the electrical impedance induced by tissue reaction around recording microelectrodes.

Concerning **objective 2** (the prediction of actions outcome), we have decided to proceed as follow:
2.a) As already outlined in 1.b, during hand action execution (i.e. grasping) the eyes anticipate the hand and reach the target before the fingers. To do that, the motor system must predict the final position of the hand, likely on the basis of target objects and spatial cues. We decided to study the development of this predictive behavior in developing infants (**UNIUP**) and in behaving monkeys (**UNIFE**). The paradigm will be similar of that discussed in 1.b. Various types of grasping and sequential movements will be studied.
2.b) UNIUP already demonstrated that infants can predict the instant at which an object, moving at known velocity, becomes visible after a period of occlusion. This result demonstrates that the predictive capability of the motor system benefits from an implicit knowledge of some physical laws (i.e. velocity, acceleration, etc.). It has been shown by Thierry Pozzo's group in Dijon that among implicitly known physical laws, gravity plays an important role, influencing both actions execution and observation. In order to build a learning artifact such as the iCub, we consider fundamental the study of this aspect. Experiments will thus be performed in this field in the next future.
2.c) The instant at which our fingers touch a to-be-grasped object is foreseen by somatosensory, visual and motor neurons. At **UNIFE** we are studying if the same predictive capability is present during action observation. Different grasping movements seen from different perspectives are being studied by evaluating the reaction time of subjects detecting object touch by pressing a button. Results seem until now really encouraging. The relevance of the agent (human vs. robot) will be also investigated within RobotCub project in collaboration with **UGDIST**.
2.d) At **UNIFE** we are continuing monkey electrophysiology experiments aiming at investigating the role of visual feedback in hand action planning and execution. The experiments started within the framework of a past EC funded project (MIRROR), whose goal was to investigate how we recognize others' actions. Due to the fact that the same question is among the key points of RobotCub neuroscience program, we aim at continuing single neuron recordings in monkeys, in the premotor cortex (area F5). More detailed descriptions will follow in future deliverables.

Contributions from partners to WP3:

UNIFE: (see above)

UNIZH: For the robotic hand, an initial set of grasping reflexes have been implemented and experiments performed. For the active vision system a basic focus of attention mechanism has been implemented, which relies on the saliency of the red colour component and movement detection. Three receptor types were considered: red (r), green (g), and blue (b). A "broadly" colour-tuned channel was created for red: $R = r - (g + b)/2$. This channel yields maximum response for the fully saturated red colour, and zero response for black and white inputs. The negative values were set to zero. Motion detectors were created to detect movements of objects in the environment. These motion detectors are based on the well-known elementary motion detector (EMD) of the spatio-temporal correlation type (Marr, 1982).

UNIUP: Research on human infants to investigate the ontogenesis of gaze control and reaching has been started. Two kinds of experiments have been piloted. First, we have measured infants' looking patterns when observing and conducting actions. Secondly, we started EEG experiments to find out the type of cortical activations that are associated with the observation of actions.

IST: Methods to build visuomotor maps from self-observation have been designed. These maps include both position and velocity (jacobians) maps. While the position visuomotor maps are used for the first phase of grasping, the visuomotor jacobians are used for visual servoing. In the context of visuomotor jacobians (or, in other words, visuomotor velocity maps), the issue of redundancy has been addressed.

EPFL: EPFL spent 4 person/month during month 0-12 on WP3. For the first 12 month, EPFL contributed to the development of controllers for visuomotor coordination in the CUB, and, in particular, for robust goal-directed reaching motions without singularities [Hersch & Billard 2006b]. The controller combines a dynamical systems approach with classical control theory, such as Lagrange optimization of the inverse kinematics.

UGDIST: Besides participating to the discussion and planning some of the experiments. UGDIST contribution to the Workpackage has been by implementing and testing grasping algorithms in the platform Babybot. In particular a robot behaviour composed of two phases: in phase 1 the robot "acquires" visual and kinaesthetic information about the object that happens to be grasped. The object is given to the robot by the experimenter by pushing it in the robot hands (and therefore stimulating the contact sensors of the hand) and, when grasped, it is moved by the robot in different positions of the field of view to acquire visual information which is then processed to acquire robust features for recognition. In phase 2 the robot searches for the object in the field of view, and tries foveate, to reach and to grasp it. Machine learning is employed at various stages of these experiments.

3.3.3 Deviations from the project workprogramme

No deviations are foreseen at the present

3.3.4 List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
No formal Deliverable scheduled for this period in this WP					

3.3.5 List of milestones

No milestone at this time in this WP.

3.4 WP4 – Object's Affordance

3.4.1 Workpackage objectives

Objectives: The goal of this WP is that of exploring and modelling the mechanisms underlying the acquisition of object's affordances. This investigation can be seen developmentally as an extension of WP3. Specific models of how the primate's brain represents affordances will be considered (for example the parietal-frontal circuit) as well as results from psychological sciences. Note how much this is linked to aspects of sensorimotor coordination on one side (WP3) and of imitation and the understanding of goals on the other (WP5 and WP6). Specifically, we will investigate:

1. What exploratory behaviours support the acquisition of affordances, what is the relevant information (visual, haptic, motor, etc.)?
2. We will develop a model of the acquisition of object affordances and how the motor information enters into the description of perceptual quantities.
3. In analogy to what observed is in the brain, we will investigate how the definition of purpose (or goal) participates in the representation of the actions an object affords.

3.4.2 Progress towards objectives

The activity in this WP has been devoted mostly to the continuation of the experiments using the existing experimental set-up. In particular the activity has been concentrating on the following aspects:

1. Implementation of visual algorithms aimed at extracting object's shape features that could be associated to object's affordances. In particular simple 3D shape such as the extraction and measure of the orientation in space of the principal axis of an object.
2. Initial implementation of a reaching algorithm associating the approaching direction to the object's 3D shape (e.g. how to approach a "standing" bottle vs. a bottle lying on the table).
3. Investigation on how to exploit the sensory stimulation induced by sensorimotor coordinated interaction with an object on different sensory modalities, including the integration of motoric signals and sensorial information. This relates to a similar study performed within WP3.
4. A series of experiments are being conducted where toddlers' understanding of the affordances related to object manipulation are investigated (e.g. how children go about when trying to fit objects into each other, how they learn to pile objects on the top of each other, and how they learn to fit lids on pans.

Other results clearly apply to WP4, for instance, the finding of the influence of the sight of the hand to monkey F5 responses during grasping actions (WP2). They were not included here since there has not been a clear integration yet. Other preliminary results show the influence of object affordances in the recognition of grasping actions as observed by a robotic setup. Besides these experimental activities the WP contributed significantly to the initial definition of the arm-hand kinematics of the iCub.

3.4.3 Deviations from the project workprogramme

None

3.4.4 List of deliverables

No formal deliverable scheduled

3.4.5 List of milestones

No milestones planned for this period

3.5 WP5 - Imitation

3.5.1 Workpackage objectives

In this Workpackage, we investigate imitation of goal-directed manipulation task and imitation of simple gestures, such as pointing, waving and simple pantomiming. In particular, we will look at the following cognitive stages underlying children's imitative behaviour:

a) Imitation of goal-directed arm motions (pointing and reaching for objects).
b) Imitation of the functional goal of arm motion (grasping, pushing, dropping objects)
c) Understanding the communication effect of imitation or the passage from being an imitator to become a demonstrator.

We develop functionally biologically plausible models of the brain mechanisms underlying the cognitive processes behind imitation.

3.5.2 Progress towards objectives

In modelling, we follow two major approaches: The first approach uses methods from computational neuroscience (neural networks modelling) to give an account of the functionality and connectivity of the brain areas (Broca, PMd, STS, AIP, etc) involved in imitation, using recent data from brain imaging and neurological studies in humans and monkeys.

Task 5.1: Define roadmap of imitation-based experiments

WP5 follows closely the development of the cognitive roadmap in WP2, in order to pick a number of behavioural studies from human infants (from newborn to 2 years old) and other primates' imitation against which the models will be validated. In order to define precisely the experimental protocols to conduct sets of robotics and behavioural experiments in parallel, a small workshop, consisting of short presentations followed by lively discussions among the major partners of WP5, was held at the occasion of the 4th regular meeting of the RobotCub consortium in Genova on July 15th 2005.

Task 5.2: Early Imitation behaviours

We started by addressing the issue of finding a generic representation of motions that allows both robust visual recognition and categorization of motion and flexible regeneration of motion. Such a visuomotor representation would be at the core of the imitative mechanisms and would explain human propensity to visuomotor imitation. With this goal, EPFL worked on developing a model of human three-dimensional reaching movements. This model generates optimal 3D trajectories, when submitted to various constraints in both the joint space (biomechanical constraints) and the Cartesian space (path to be followed by the hand). The model can adapt on-line to disturbances, including a change in the target's position and in the arm trajectory. The model is consistent with a number of experimental findings on human reaching movement reported in the literature. The model and its results have been reported in deliverables D.5.1 and D.5.2.

IST presented work in the context of a developmental roadmap providing the CUB, with the basic motor and visual skills necessary to arrive to a point where imitation is possible. The kinematics of redundant robots is being studied at IST. The redundancy can be used in static maps to distinguish between task solution and body posture. In dynamic maps, it is included in a visual approach to reach objects.

During the RobotCub meeting in March 2005, EPFL and UNIFE planned a series of experiments, aiming at characterizing the kinematic parameters of arm reaching during execution and imitation of observed actions. From July to Aug 2005, UNIFE conducted a preliminary set of such experiments. A second set of experiments will be conducted from Sep to Oct 2005. The experiments will provide data against which the EPFL model will be validated, starting in October 2005.

During the first year of RobotCub, UNIHER has started research into human robot interaction experiments to contribute to task 5.2 "Early imitation behaviours" within WP5. Work in this area had only started in the second half of the first year Experiments are being designed with a child-sized robot called KASPAR. The robot has been developed as part of WP6 and is described in more detail in Deliverable 6.1. Human-robot interaction experiments with the robot will be performed during months 12-18 in order to contribute to task 5.2 as specified in the 18 months RobotCub implementation plan, and continuing during the second implementation plan of Robotcub.

Task 5.3: Contribution to definition of functional CUB requirements

EPFL provided the partners responsible for the CUB design with a list of requirements in terms of torques for the CUB and a list of potential motors for the CUB, so that the CUB could provide the motions required for the experiments to be conducted as part of WP5. Similarly, IST, being the partner responsible of the head design, defined the head specifications in terms of kinematics and dynamics, as required for the Cub's imitation competences.

3.5.3 Deviations from the project workprogramme

None

3.5.4 List of deliverables

Del. no.	Deliverable name	Date due	Actual delivery date	Lead contract or
D5.1	Evaluation of an algorithm for interpreting the kinematics of arm motion and its relationship to object motion	Month 6	15/04/2005	EPFL
D5.2	Implementation of visual recognition and imitation of goal-directed reaching motion.	Month 12	16/09/2005 DRAFT	EPFL

3.5.5 List of milestones

No milestone planned for this Workpackage in this period

3.6 WP6 – Gesture Communication

3.6.1 Workpackage objectives

Given the project's core scenario this WP focuses on the dynamics of interaction when RobotCub plays with humans. A particular focus will be on the regulation of interaction dynamics, and rhythms of interaction, i.e. turn-taking, and synchronization of movements among interactants, social spaces (approach and avoidance), related to issues of immediate imitation (cf. WP5). The objectives of this WP are three-fold:

1. Development of a computational test-bed for the design of communicative (non-verbal) interactive behaviour.
2. In parallel to the above mentioned computational work, preliminary (small-scale) user-studies will evaluate the suitability of communicative behaviour generated by existing robots.
3. Development of simple verbal communication behaviour, including the acquisition of one word and of simple two-word sentences.

3.6.2 Progress towards objectives

In the first year of the project UNIHER has investigated theoretic methods applied to characterizing and identifying experience (moving towards creating and exploiting enactively grounded dynamic interaction histories). The method of Average Information Distance (AID) Sensory-Motor Phase-Plots for robot self-categorization of experience was developed and validated on the Aibo platform. This work so far has resulted in the publication of 2 conference papers (IEEE CIRA'05 and Epigenetic Robotics 2005).

New "experience metrics" on a broader temporal horizon have been developed and examined in first experiments (2 papers published in IEEE CEC'05).

UNIHER has also been undertaking research into mapping sensor space and learning motor capabilities. Motor babbling is used to learn a sensory layout and applied to learning sensorimotor contingencies using information theoretic measures (IEEE ICDL'05, Epigenetic Robotics 2005). Discussions between UNIHER and UNIFE have begun to relate these information geometries to cortical maps and their development.

Work on defining a structure for research into developmental levels in robot interactions with humans has also been conducted (cf. the contribution of UNIHER for WP2). Pilot studies of Robot-Child interactions in a series of experiments using a semi-autonomous Aibo robot toward mapping interaction space were successfully conducted with an aim to capture requirements for engagement, and the insights published in IEEE ROMAN'05. Work on designing and constructing a minimal expressive head and neck platform (to be extended with arms) for the purpose of studying facial gesture and proto-communication in human robot interaction, was carried out with emphasis on the timing and movement in interactions. The head has a range of expressions using eyes, eyelids, mouth/jaw and neck (paper submitted to ACM HRI 2006) and has contributed also to IST's work on the iCub head design requirements. Initial consultations on the KASPAR design and its development were conducted by UNIHER in consultation with IST and non-EU partners NICT (formerly CRL) and MIT. As part of WP6 activities, EPFL developed a computational model to recognize and reproduce a variety of gestures based in Hebbian learning. A total of 10 papers and 1 technical report have been published in WP6 in this period, with several other papers submitted or in preparation.

3.6.3 Deviations from the project workprogramme

Beginning with the kick-off meeting of RobotCub, a main lesson for this Workpackage concerning gesture and communication over the first Robotcub year has been that part of the original Workpackage description did not sufficiently capture the bottom up perspective needed in grounded development. Rather than "ad hoc" implementation of communication and interaction (which would be "easy" to do and give nice demos, but pointless as far as the state of the art is concerned), these abilities must be grounded in developmental stages via sensorimotor ontogeny and pre-verbal communicative interaction.
In line with this revised understanding, RobotCub has decided to shift to investigating mechanisms that are *prerequisites* for the emergence of communication in interaction under the motto "*before* gesture and communication".

Objective 3 of the original WP6 has therefore been superseded by a new objective:
Development of the pre-requisites for interactive and communicative behaviour grounded in sensorimotor experience and social interaction.

Thus any immediate work on language acquisition mentioned in annex one has been dropped and the resources retargeted to the revised objectives. Starting in this period, this is addressed in the design and experiments with a new experimental prototype robot KASPAR on interaction kinesics (that will also link to WP5) and also experiments with AIBOs, as well as ongoing work on interaction histories in this direction that will eventually address dynamics of internal "physiological variables", which again link more to the social dimension of engagement during interaction.

3.6.4 List of deliverables

Del. no.	Deliverable name	Date due	Actual delivery date	Lead contractor
D6.1	Results from Computational Models.	Month 12	15/09/2005 DRAFT	UNIHER

3.6.5 List of milestones

No Milestones scheduled for this period in this WP.

3.7 WP7 – Mechatronics of CUB

3.7.1 Workpackage objectives

To define the functional specifications for the initial design of the mechatronic components of the CUB, that are the Head-Eye system, the Arm-hand systems, the Spine and Leg system and the Software Architecture. - To identify the roadmap for the overall system integration, in order to guarantee the compatibility of all the CUB subsystems, both from a hardware and a software point of view.

3.7.2 Progress towards objectives

The activities carried out in the year are:

- A common reference model for the mechanical design of the platform has been defined. Final dimension and weight will fit as close as possible this model. A 3D CAD of the model is shared as a common working basis.
- Coding standard for mechanical design and mechanics-related documentation has been defined.
- Existing experiences on mechatronic component have been discussed to define a common database of components to be used in the following design activity.
- High level general rules have been fixed at the meeting in Nice on January 2005. This rules results in the platform specification.
- Kinematic model of the platform with first-trial specification in terms of number of degrees of freedom, range of each joint as well as dynamic performance of each joint has been defined.
- First-trial dynamic simulation and consequent force-torques evaluation has been made for mechanical design dimensioning.
- Several solutions were developed, realized, tested and discussed in the consortium (see below).
- Three different head prototype were made. The latest is currently under test and it is considered approximately final.
- A first prototype of waist joint based on differential tendon driven design (the most stressed joint of the whole robot) was made. From consideration on this prototype a new design of the differential design is under completion.
- A first prototype (dimensional) of finger was made with rapid prototyping to test sensors and cabling integration. A first prototype of tension sensor to be integrated in the fingertip was also tested. A second (functional) prototype of the finger is currently under realization.
- A high integration actuator base on houseless high power brushless motor coupled with Harmonic Drive (HD) frameless gearbox was designed as reference for the main iCub axes. A first prototype is currently under evaluation. A complete shoulder-upper arm CAD based on this solution is also available.
- A new integrated design of the lower body is available based on the houseless motor and HD gearbox.
- The forearm and a tentative hand CAD are also completed.

Consequently, an up to date integrated CAD design has been produced.

3.7.3 Deviations from the project workprogramme

None

3.7.4 List of deliverables

Del. no.	Deliverable name	Date due	Actual delivery date	Lead contract or
D7.2	Analysis and pre-selection of the sensor's and actuator's	Month 12	15/09/2005 DRAFT	UNIHER

3.7.5 List of milestones

No Milestones scheduled for this period in this WP

3.8 WP8 – Open System: iCub

3.8.1 Workpackage objectives

1. Define the activity related to the creation, licensing, and distribution of the "Open Platform".
2. Define the mechanical, documentation, and software standards to ensure the widest acceptability of the platform.
3. Help in defining the platform and coordinate with WP2 for requirements and WP7 for mechatronic and technological issues.

The activity of this Workpackage is devoted to the creation and support of the community of end-users of the open platform. At the outset, the main activity will be to define and establish the infrastructure of the RobotCub initiative. In this respect, the Workpackage will define the various standard and requirements.

***The principal goal of this Workpackage is to maximize the likelihood that the open platform will become the platform of choice for research in embodied cognitive systems*.** Consequently, it is important to establish standards that will facilitate this adoption and foster the continued enhancement of the platform by the community at large, and the open sharing of these enhancements. The creation of an appropriate licensing strategy for the commercial and academic use of the platform is tightly bound up with this endeavor.

3.8.2 Progress towards objectives

Previously-reported progress includes:

- The adoption of the name iCub for the RobotCub humanoid research platform.
- The acquisition of the iCub.org domain name.
- The adoption of the GNU General Public License (GPL) and the GNU Free Documentation License (FDL) for all iCub software and documentation, including the creation of a set of guidelines for developers (see Deliverable D1.2 and D8.2).
- The agreement of naming conventions for both mechatronic drawings and software files (Task 8.1).
- Adoption of a Free Software / Open Source Software (FS/OSS) license for the iCub for both research and commercial use. The distinction between the two uses was dropped and any CUB component will be released under a single, always open, GPL/FDL license framework.
- An initial software repository with a "toy project" was developed both on the main RobotCub website (http://www.robotcub.org) and as a copy on SourceForge (http://www.sourceforge.net). See D8.2.

Task 8.1: Definition of the documentation and CAD standards.

An extensive set of coding and documentation standards has been created to guide software documentation, programming style, and programming practice. Our goal is to strike a balance to avoid developing excessively rigid and prescriptive rules but yet to achieve a homogeneous style and high level of software quality for the entire body of iCub programs. These standards are incorporated in Deliverable 8.2.

Similarly, a set of guidelines for manufacturing and documenting the iCub mechatronic platform has been created. It too is incorporated in Deliverable 8.2.

We have also created a set of guidelines on downloading and uploading iCub software from and to the CVS repository which will be used to facilitate the distributed development of iCub software by all the partners.

Finally, we have begun the design of a software architecture for iCub. It is important to establish this architecture early on so that cognition software developed in the various Workpackages (specifically WP2 – WP6) can be relatively easily integrated later on. This architecture should be amenable to all types of users: those who do not wish to interact directly at a hardware level and those who do. Furthermore, the iCub is intrinsically a parallel machine, with each device (sensor and actuator) operating concurrently. The iCub software architecture must deal with this, but provide user interface facilities with allow researchers to either ignore the complexities of concurrency or to exploit them, depending on their host computing system and programming paradigm.

Task 8.2: Documentation of mechanical design and components.
This task is on-going. Considerable effort has been invested in the design of the mechanical components for the iCub (WP 7). The current designs are reported in Deliverable 8.1: Initial Specification of the Cub Open System.

Task 8.3: Documentation of the design of the electronics and components.
This task is on-going. Again, considerable effort has been invested in the design of the electronic components for the iCub (WP 7). The current designs are also reported in Deliverable 8.1: Initial Specification of the Cub Open System.

Task 8.4: Software documentation.
This task is on-going. An example of iCub software source and documentation has been created (the Log-Polar transformation) and made available on the iCub repository (see Task 8.5 below).

Task 8.5: Legal and administrative issues.
The licensing issues have been concluded and we have now established a distribution mechanism for iCub material. This will be hosted at http://www.robotcub.org/icub/xxx, where xxx stands for the particular subject of interest (source code, licences, binaries, documentation, etc.) This repository is also accessible using CVS at cvs.robotcub.org (secure shell access) and using SourceForge (http://www.sourceforge.net).

In the future, we need to consider procedures for submission of contributions, quality assurance on adherence to standards, formal acceptance and release procedures.

3.8.3 Deviations from the project workprogramme

None

3.8.4 List of deliverables

Del. no.	Deliverable name	Date due	Actual delivery date	Lead contractor
D8.2	Definition of Documentation and Manufacturing Procedures	Month 12	October 2005	UDIST
D8.1	Initial Specification of the Cub Open System	Month 12	October 2005	UGDIST

3.8.5 List of milestones

No Milestone scheduled for this period for this WP.

3.9 WP9 – Community Building and Self Assessment

3.9.1 Workpackage objectives

1. Extend the base of knowledge for the definition of the CUB cognitive and mechatronic architectures and the adopted technologies by co-opting EU and non-EU scientists.
2. Promote an international project on Embodied Cognition supported by national and international funding agencies.
3. Monitor the advancement of the project toward the fulfilment of the project's objectives.
4. Organize training and dissemination activities.

The work in this WP is mostly related to organization of meetings and workshops to reach the four objectives described above. The meetings will be organized as internal or open to the scientific and industrial communities. The management bodies relevant for this Workpackage are the International Research Panel (IRP) and the Board of Management (BM). Jointly they will decide on the topics to be discussed and the format of the meeting. The members of the IRP will be responsible of contacting funding agencies that may be interested in joining the International Project as well as industrial organizations potentially interested in monitoring the results of RobotCub.

3.9.2 Progress toward the objectives

Task 9.1: Internationalization: organize meetings with scientists and funding agencies.

In the first six months of the projects the consortium has presented its objectives and research plans at the following meetings:

1. The kick-off plenary meeting of "Cognitive Systems" in Bled.
2. The kick-off meeting of the project JAST.
3. David Vernon's presentation at the UK Imaging Faraday Partnership Intelligent Imaging Programme Meeting September 14, 2005: "The ECVision & RobotCub Research Roadmaps: What Humanoid Robotics Tells Us About Cognitive Vision".

In July 2005 the consortium has organized an "Open Day" to disseminate the objectives and initial results of the project with the goal of starting to build the community of future "users" of the open platform. The open day was attended by 54 scientists from Europe and abroad and was divided in three parts: i) presentation by the RobotCub Consortium; ii) presentation by external participants; iii) general discussion. The meeting was broadcasted live on internet and the recording of all presentations are available in RobotCub website. The program, the slides and the videos of the presentations can be found at: http://www.robotcub.org/misc/openday/

All non-EU groups involved in the International Research Panel participated at previous meeting in Genova and presented the status of their projects in the field of embodied cognition. Yasuo Kuniyoshi (University of Tokyo, Japan), Gordon Cheng (ATR, Japan), Hideki Kozima (NICT, Japan), Aaron Edsinger-Gonzales (CSAIL-MIT, USA) and Jürgen Konczak (University of Minnesota, USA) participated in the meeting and presented their view about the objectives of RobotCub and the possibility for concrete collaboration. At present, some of the mechanical designs of these groups have been uploaded in the RobotCub website to be shared with the consortium.

The programs and slides presented at all the meetings are available on the project's website at this address:
http://www.robotcub.org/index.php/robotcub/administration/meetings

With the support of RobotCub, UNIFE has organized a meeting in Ferrara on "Phylogeny and Ontogeny of Human Communication", from 2 to 4 June 2005 in the frame of the European Science Foundation Collaborative Research (EUROCORES) Program, the Origin of Man, Language and Languages (OMLL). Nine students coming from different European countries were funded by UNIFE Robot-Cub grant to allow their participation to the Workshop. The program of the meeting, together with videos of presented talks can be found at this address: http://web.unife.it/progetti/neurolab/omll/

RobotCub has also supported the participation of young scientists to the "Research Conference on Brain Developments and Cognition in Human Infants" organized by the European Science Foundation at the beginning of October (http://www.esf.org/conferences/mc05118). At the meeting the scientific framework of RobotCub will be presented to a multidisciplinary audience.

Task 9.2: Training: organize training sessions for the project's participants as well as summer school on topics relevant to Cognitive Robotics.

RobotCub has participated in the organization of a special session on Ontogenetic Robotics at the 6th CIRA symposium, Espoo, Finland on June 27-30th, 2005. See also the following section 3.9.3 for details about change on plans in relation to "training activities".

Task 9.3: Assessment. At least once a year organize a formal assessment of the project.

The review meeting will be held in Genova on October 21st 2005.

3.9.3 Deviations from the Project's workprogramme

The only modification regards the decision to modify the strategy for the training activities of the project. In particular it was planned to organize a summer school related to the RobotCub scientific plan with the objective of making more homogenous the background knowledge of the young scientists working in RobotCub (the consortium is highly interdisciplinary). The reason we changed our strategy is related to the fact that we discovered that in the next few months some very interesting and high quality events were already organized by members of the consortium and it was decided to invest the funds allocated to training activities to support the participation of young researchers by direct participation to the event and by sponsoring fellowships for young researchers. In all the supported events we were assigned time to promote the activities of the RobotCub. In particular, it was decided to sponsor and co-organize the events described in the following table:

Event and Website	Contribution	Robotcub Support
The origin of human communication	Luciano Fadiga	Support 10 travel grants for European Students
Brain Development and Cognition in Human Infants, Acquafredda di Maratea, Italy, 1-6 October 2005 **From Action to Cognition** http://www.esf.org/conferences/mc05118 (RobotCub's and Cogsys logos on all material)	Claes von Hofsten is conference chair and a special session on "Development in Artificial Systems" has been organized with speakers from the RobotCub Consortium	About € 10,000 charged to UGDIST "training budget" for the support of travel and accommodation of young scientists
3rd European Neuro-IT and Neuroengineering School **Neuroengineering of Cognitive Functions** http://www.neuro-it.net/Activities/Venice2005	Lectures by members of the RobotCub Consortium	No financial support provided

3.9.4 List of deliverables

Del. no.	Deliverable name	Date due	Actual/Forecast delivery date	Lead contractor
D9.1	Proceedings of the Initial Scientific Meeting	Month 6	Web-delivery	UGDIST

3.9.5 Press Appearance

The RobotCub project has attracted the interest of the newspapers and press addressing scientific issues.

1. June 2004: Ciao l'ambasciatore", Manchester Evening News, June 2004
2. July 11, 2004: L'Europa che vuole fare le scarpe ai giapponesi. Anzi i Robot (Europe competes with Japan on Robots). Il Venerdi di Repubblica (weekly magazine of a daily newsapper "La repubblica").
3. July 30, 2004: Che bella famiglia sono tutti baby robot! (The family of Babybot includes RobotCub): (weekly special pages for children of the daily newspaper "Il Secolo XIX").
4. July 2004: EU-funds project on humanoid technology and cognitive neurosciences: Cordis Record control number (RCN): 23151.
5. August 10, 2004: European Humanoid is going to conquer the world; Eurelios: Agence de press photographique.

6. August 24, 2004: La realtà dell'Intelligenza Artificiale (reality of artificial intelligence): Il secolo XIX (daily newspaper).
7. September 2004: Michele Catanzaro: Una mente a misura di robot, Galileo-Giornale di Scienza e Problemi Globali. Popular science magazine, September 17, 2004 http://www.galileonet.it/archiviop/magazine.asp?id=5778
8. September 22nd 2004, "il Resto del Carlino", Italian newspaper. Two articles in Italian focusing on the importance of the cognition, and in particular on the possibility to recognize observed actions, to build an artifact interacting with others.
    - "Nasce a Ferrara il 'cucciolo di robot capace di imparare"
    - "Un bimbo robot che pensa"
9. October 2004: Rossella Lorenzi, IIT Focuses on Robotics, *The Scientist,* Daily News (October 15, 2004) Reference to RobotCub research plan and webpage http://www.the-scientist.com/news/20041015/02
10. October 21, 2004: Macchine Antropomorfe, l'ultima forntiera. Che razza di androidi (what kind of androids): Panorama (weekly magazine).
11. Novembre 4th 2004, "il Resto del Carlino", Italian newspaper. Article in Italian on the presentation of the Babybot at the "Festival della Scienza di Genova": "Quilici, Barbujani e il 'baby robot' partorito dall'ateneo estense: così Ferrara diventa la grande protagonista del "Festival" di Genova
12. January 2005: Article on the Italian Newspaper "Il sole 24 ore" (the newspaper of the Italian Confedaretion of Industries - Confindustria)
13. January 2005: News from Honda: Press Release: The Worlds Most Advanced Humanoid Robot Meets Members of the EU, January 25, 2005 (the press release mention RobototCub as "a project aimed at moving research forward in Europe in the field of humanoid robotics and cognitive neuroscience" http://world.honda.com/news/2005/c050125_c.html
14. February 2005: Was wir von Roboter lernen können". *Technology review. Nr. 2. Februar 2005*. German edition, Heise Verlag. **pp.** 56-61
15. March 2005: Spinney L.: Artificial Intelligence Marches Forward: As physiology and neuroscience increasingly inform robotics, maybe robots can return the favor. *The Scientist* **19**(5):18 (14 March 2005).
16. April 2005: Michael Vogel/rr Humanoide wird Versuchstier der Kognitionsforschung: Robotcup-Projekt der EU baut menschenähnlichen Roboter für das Studium mentaler Prozesse. Computer Zeitung Nr 16/18 18. April 2005
17. April 2005: 60 sec segment on North West Tonight, Regional Television programme, 15th April 2005.
18. May 2005: Ilaria Fazi: Scienza e Ricerca – Progetto Europeo: Tre anni per costruire i cuccioli di robot. Il Resto del Carlino (Italian Newspaper) May 3, 2005.

4 Consortium management

4.1 Consortium management tasks and their achievement

The tasks of the management Workpackage are the following:

1. Control of the scientific and technological development of the project.
2. Project's self-assessment.
3. Internationalization and community building. The related activities will be managed by the Research Director and Technical Coordinator with the International Research Panel.
4. Coordination of training and dissemination.
5. Definition of the legal aspects of the licensing strategy.

The project's objectives are pursued through three complementary organizational activities:

1. Monthly assessment meetings of the project directorate primarily concerned with project management, open-system support and licensing, management of IPR, and formulation of occasional calls for expansion of the partner base.
2. Three-monthly meetings of the Board of Management mainly concerned with assessment of progress, cross-area integration, and scientific innovation.
3. Six-monthly workshops involving everyone directly involved in the project, from graduate students right through to the research director. These workshops will concentrate on relatively polished presentations of current results, assessment of scientific progress by external experts, and open 'think-tank' scientific exploration of new avenues of enquiry.

At the kick-off meeting a detailed planning of the project's meeting for the first 18 months was discussed and approved.

Date	set-04	nov-04	gen-04	mar-05	lug-05	ago-05	ott-05	gen-06	apr-06
Month	1	3	5	7	11	12	14	17	20
Duration	3	3	2	2	3	7	4	3	3
Proposed Dates	16-18	25-27	13-14	17-18	13-15	TBD	18-21	18-20	12-14
Place	Genova	Genova	Nice	Lisbon	Genova	TBD	Genova	TBD	TBD
	KICK-OFF	2 days workshop	One day on topical meeting	One day workshop	2 days workshop	Thematic Summer School	two days workshop and annual review	2 days workshop	2 days workshop
		Board Meeting		Board Meeting	Board Meeting		Board Meeting	Board Meeting	Board Meeting
		IRP Meeting			IRP Meeting		IRP Meeting		IRP Meeting

The table above illustrates the meeting strategy of the project which is based upon the frequent plenary meeting (on average every two months) associated to meetings of the Board of Management (one every 3 months) and meetings of the International Research Panel at month 3 and 11. The agendas of the meetings and the collection of the slides presented and important documents discussed are in the project's website at: http://www.robotcub.org/index.php/robotcub/administration/meetings

Among the important decision taken at the meetings in relation to the management of the project:

1. Approval of the project's licensing strategy.
2. Approval of the project's standards for documentation.
3. Approval of the projects standards for data exchange (viewers for all standards are available at this location: http://www.robotcub.org/index.php/robotcub/administration/download/viewers
4. Approval of the project's logo and official name of the project's platform (iCub), preparation of the project's PowerPoint templates (http://www.robotcub.org/index.php/robotcub/administration/misc)
5. Registration of all available related domains (robotcub.com/info/net/org, robot-cub.com/net/org, i-cub.com/info.net/org, icub.org).
6. Application for the protection of the iCub and RobotCub Mark.
7. Decision to open our meetings to people from outside the consortium.
8. Detailed discussion and approval of the project schedule.

Del. no.	Deliverable name	Date due	Actual/Forecast delivery date	Lead contractor
D1.1a	Periodic Activity Report	Month 6	This deliverable	UGDIST
D1.2	CUB's Licensing Strategy	Month 3	March 2005	UGDIST
D1.3	Financial Report	Month 12	In preparation	UGDIST
D1.4a	Project's meeting 1	Month 6	We had three plenary meetings (see above)	UGDIST

4.2 Contractors: comments regarding contributions

The contribution of all contractors has been as described in the Technical Annex apart from the contribution of EBRI which has been smaller than expected because of an unexpected problem of the principal investigator. This problem has been solved and the contribution of EBRI will resume as planned in the second year.

In the following sections the activities of the individual partners are reported.

4.2.1 University of Genova (UGDIST)

UGDIST Contribution to Workpackage 1: Management
From the management point of view, the building of the project's consortium (in the sense of establishing a good cooperative atmosphere) has been the main concern. This was pursued by organizing frequent plenary meetings and setting up a common repository of documents/data where to exchange data and information. The attendance to the meetings has been very satisfactory and also the participation in discussions has been very lively. Part of the management activities (even if informally part of WP8) has been the definition of the licensing strategy and the discussions about how to install an "easy-to-implement" open strategy. UGDIST organized four of the five general meetings in Genova and to a hardware-dedicated meeting in Nice.

UGDIST Contribution to Workpackage 2: Cognitive Development
From the scientific point of view and with reference to WP2 the goal of UGDIST work has been to foster the creation of a baseline review of the different approaches each partner is taking in the modelling of cognition in artificial systems. The goal of this work is to identify the scientific, technical, and technological foundations in much greater detail than provided in the technical annex so as to ensure that the complete space of cognitive development is being spanned, to facilitate complementary work among disciplines, groups, cognitive skills, and experimental scenarios, and to facilitate cohesion among underlying scientific models.

UGDIST Contribution to Workpackage 4: Object's Affordance
Initial implementation of a visual stereo algorithm aimed at providing the reaching/manipulating control algorithms with the shape information necessary to operate on object's affordance. Initial implementation of reaching and gazing behaviours in one of the existing robotic platforms.

Workpackage 8: Open System
Work in this WP has been devoted to establishing a common framework for exchange of data (e.g. file naming conventions and standards for exchange of mechanical, electronic and software code), as well as the definition of the licensing strategy. In order to protect the names "iCub" and "RobotCub" both names as well as the RobotCub logo have been submitted for mark protection.

UGDIST Contribution to Workpackage 9: Community Building and Self-Assessment
Work here has been devoted to the establishment of the links with the International Research Panel of the project (already met once), with on-going projects in the "cognitive systems" action and with other projects interested in adopting iCub as their platform for the study of embodied cognition.
In July 2005, UGDIST organized the first RobotCub "Open Day" during which the intermediate results of the project were presented to persons invited from outside the consortium (see the details in the report of WP-9).

UGDIST Major Achievements

1. RobotCub Web Site and Logo.

2. Contribution to the establishment of standards for coding and documentation, a mechanism for archival and dissemination of open material, and the design of a software architecture for the iCub.
3. Contribution to the definition of file naming conventions for software and documentation.
4. Contribution to the integration of the iCub design and the discussion on the definition of the cognitive architecture.
5. Organization of the four plenary meeting in Genova, a topical meeting in Nice a meeting of the International Research Panel meeting in Genova, the first RobotCub Open Day.
6. Presentation of the RobotCub project at the JAST Opening Conference.
7. Invited presentation of RobotCub Objectives at the Machine Vision and Applications conference in Tsukuba (May 17, 2005).
8. Invited presentation of RobotCub Objectives at the Osaka University International Robotics Symposium (October 1st, 2005).
9. Application for trademark protection of iCub and RobotCub.

UGDIST Published Papers

1. L. Natale, F. Orabona, F. Berton, G. Metta, G. Sandini. From sensorimotor development to object perception. Accepted to the International Conference of Humanoids Robotics. 2005.
2. G.Metta, D.Vernon, G.Sandini. The RobotCub Approach to the Development of Cognition: Implications of Emergent Systems for a Common Research Agenda in Epigenetic Robotics. In Epigenetic Robotics workshop, Nara Japan, July 2005.
3. L.Natale, F. Orabona, G. Metta, G. Sandini. Exploring the world through grasping: a developmental approach. In the 6th CIRA Symposium, Espoo, Finland, June 27-30, 2005.
4. F. Orabona, G. Metta, G. Sandini. Object-based Visual Attention: a Model for a Behaving Robot. In 3rd International Workshop on Attention and Performance in Computational Vision within CVPR, San Diego, CA, USA. June 25, 2005.
5. L.Natale, G.Metta, G.Sandini. A Developmental Approach to Grasping. In Developmental Robotics. A 2005 AAAI Spring Symposium. March 21-23rd, 2005. Stanford University, Stanford, CA, USA.
6. G. Sandini, G. Metta, D. Vernon. RobotCub: An Open Framework for Research in Embodied Cognition. In IEEE-RAS/RSJ International Conference on Humanoid Robots (Humanoids 2004). November 10-12, 2004 Santa Monica, Los Angeles, CA, USA.
7. L.Natale, G.Metta, G.Sandini. Learning haptic representation of objects. In International Conference on Intelligent Manipulation and Grasping. Genoa - Italy July 1-2, 2004.
8. G. Sandini, G. Metta, D. Vernon: RobotCub: An Open Research Initiative in Embodied Cognition. Proceedings of ICDL 04, San Diego, 2004.

4.2.2 Scuola Superiore S. Anna (SSSA)

SSSA Major Achievements

The main effort of SSSA is focused on the mechatronic design, taking in account the technology limitation and the tasks to perform. The previous experience and a new overview in the recent technologies have been exploited to achieve the following:

- Definition of the iCub requirements: according to the task to be performed.
- Survey on anthropomorphic and robotic mechanism concerning shoulder, elbow, wrist, and hand.
- Survey on electrical and non-electrical actuators.
- Survey on the implementation of compliant mechanisms.
- Survey on sensors, focusing on tactile sensors (contact, pressure, thermal) and proprioceptive sensors (torque and joint rotation).

(Please refer to the deliverable 7.2).

The previous activities have been the starting point for the first sketch of the iCub arm: To enable the investigation of relevant cognitive aspects of manipulation the design will be aimed at maximizing the number of degrees of freedom (DOF) of the upper part of the body (head, torso, arms, and hands). The lower body (legs) and the arms will be designed to support crawling "on four legs" and sitting on the ground in a stable position (and smoothly transition from crawling to sitting autonomously). This will allow the robot to explore the environment and to grasp and manipulate objects on the floor.

The arm has two links:

- arm
- forearm

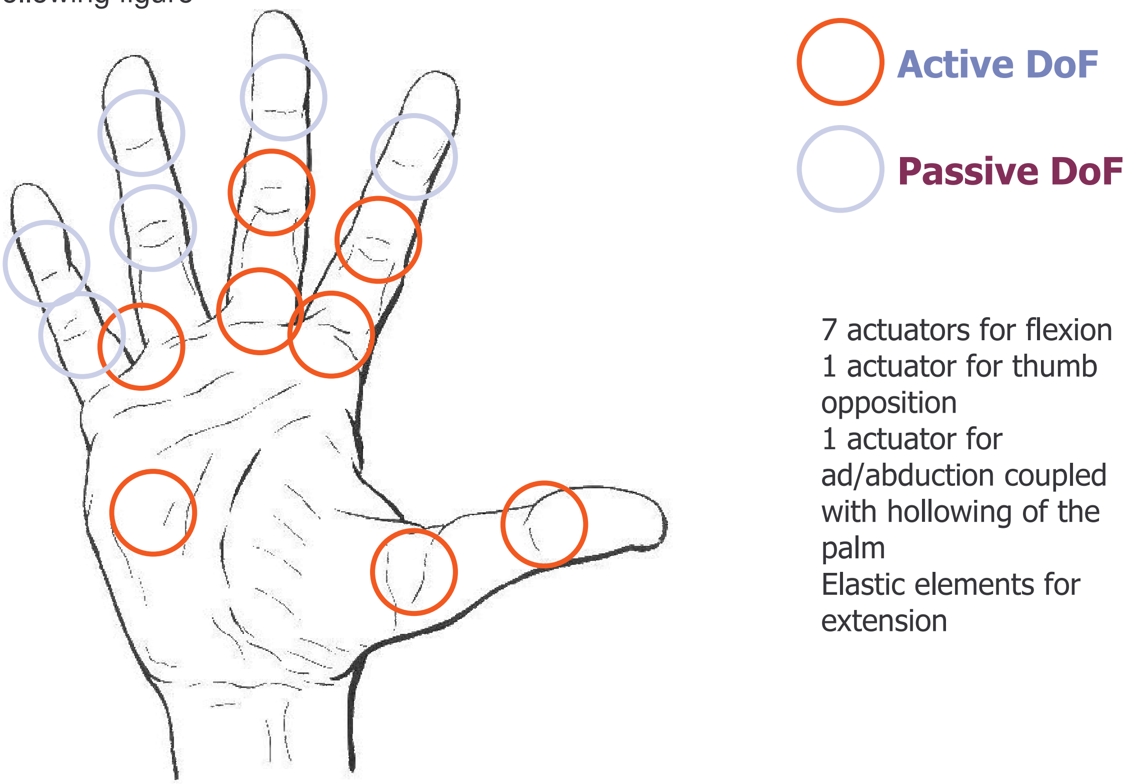
The arm consists of seven joints:

- shoulder (3DoFs)
- elbow (1DoF in flection + 1DoF in prono-supination)
- wrist (2 DoFs)

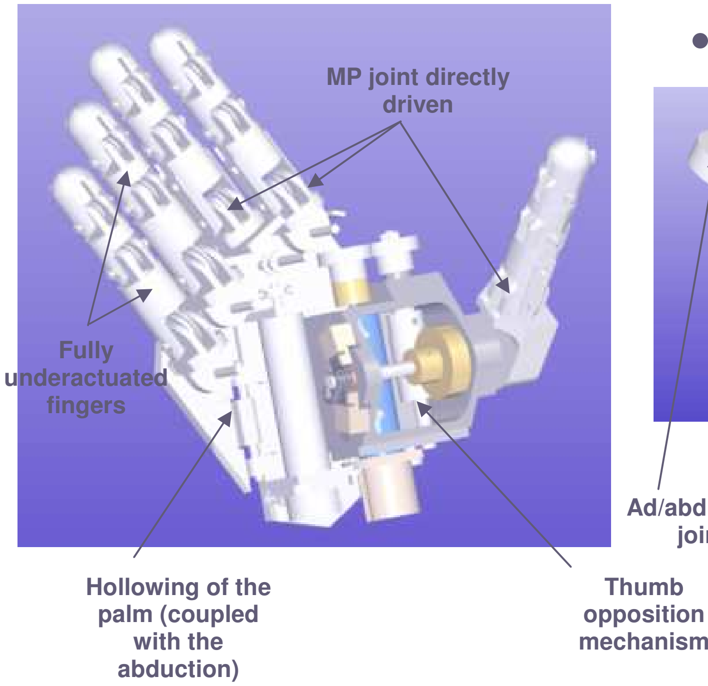
The main design features are:

- Integrated design of head/neck-trunk-arm-hand
- Actuators in the preceding link
- Tendon transmission (and synovial sheats/bowden cable) in the hand and gears or belt in the arm
- Under-actuation (in the little and ring finger and in the distal joint of the finger)
- N joint of a manipulator means at least N+1 actuator (and tendons): one acting as antagonistic tendon. Elastic elements, were allowed, are more suitable
- Exploitation of the mechanical stops during the standing-up phase

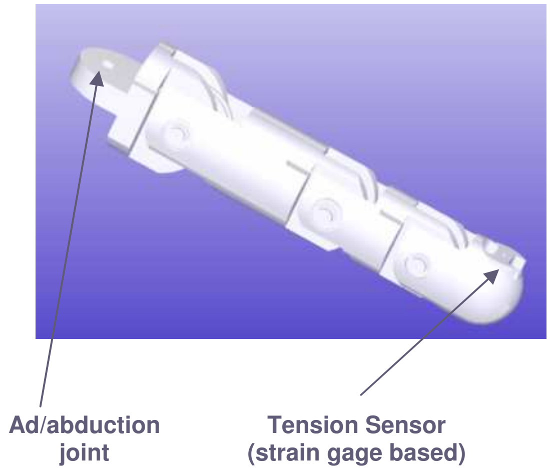
During the months 6^{th}-12^{th} several releases of the shoulder-arm-hand subsystem have been designed. Body parts are as much as possible anthropomorphic, and their design is based on both traditional and innovative mechanical solutions. As the hand represents the most complex and important part of the body, most of the time has been dedicated to find the right kinematics. For the actuation of the hands DC motors has been adopted but the solution to actuate the joints is an innovative "hybrid" combination of direct driven motors, cable driven and underactuated cable driven fingers (9 motors and 20 active and passive DoF). The scheme of the underactuation is depicted in the following figure



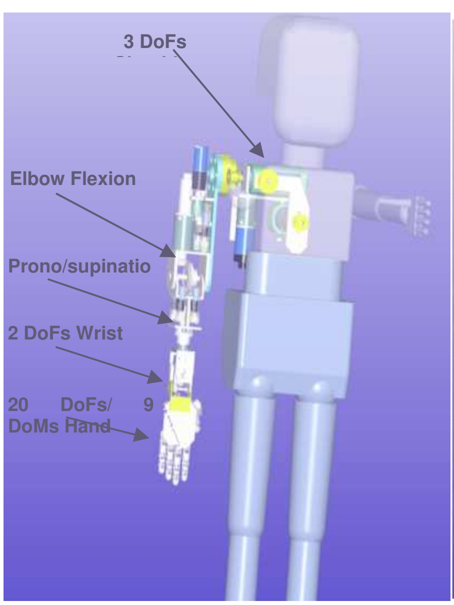
As a consequence the design of the hand is the following.

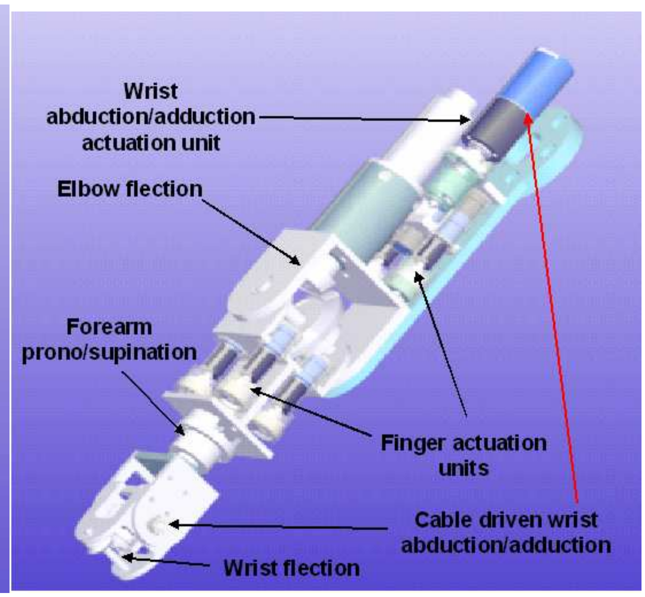


- Prototype of the finger

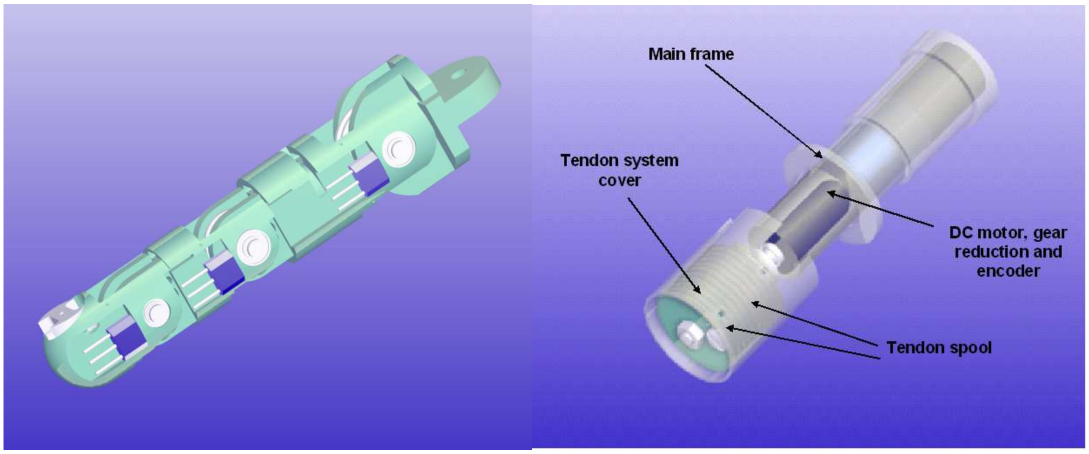


The design of the arm is depicted in the following figure showing the joints, the actuators and the transmission. The design of the shoulder and the arm is serial in order to be robust during crawling.

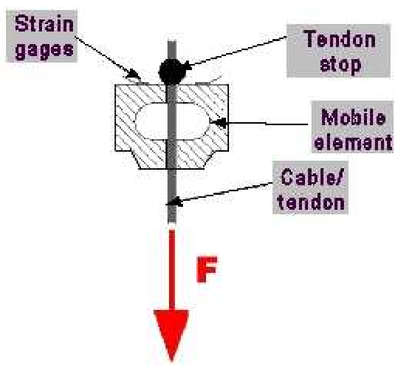


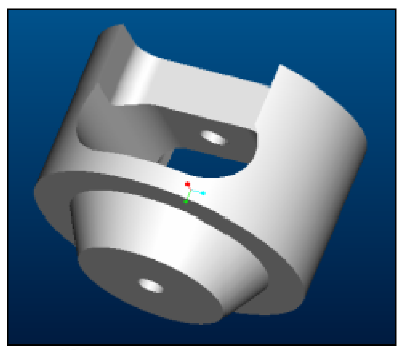


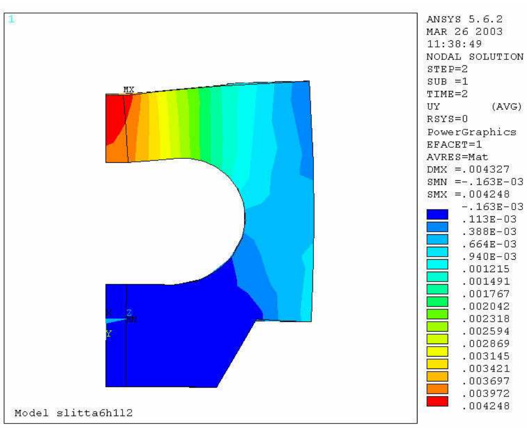
An advanced state of the finger and the finger actuation unit design has been delivered.

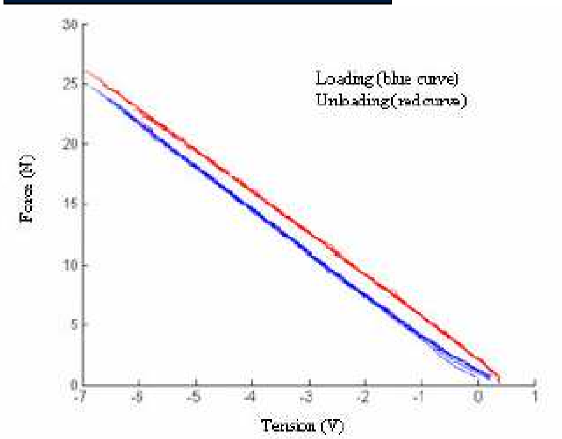


Proprioceptive and exteroceptive sensors are the next issue on which the SSSA will work on. At this time a cable tension tensor strain gage based has been developed (and integrated in the nail of the fingertip). Also, Hall-effect sensors have been employed for the measure and control of the joint position (see previous figure).









SSSA Published Papers

1. M Zecca, S. roccella, M.C. Carrozza, H. Miwa, k. Itoh, G. Cappiello, J.J. Cabibihan, M. Matsumoto, h. Takanobu, P. Dario, A. Takanishi, “On the development of the Emotion Expression Humanoid Robot WE-4RII with RCH-1”,

IEEE-RAS/RSJ International Conference on Humanoid Robots, Humanoids 2004, Los Angeles, CA, USA, November 10-12, 2004

2. M.C. Carrozza, G. Cappiello, G.Stellin, F. Zaccone, F. Vecchi, S. Micera, P.Dario, “A cosmetic prosthetic hand with tendon driver underactuated mechanism, compliant joints and EMG control: ongoing research and preliminary results”, International Conference on Robotics and Automation, ICRA 2005 Barcelona, Spain, April 16-22. 2005.

4.2.3 University of Zurich (UNIZH)

UNIZH Contribution to WP2 - Cognitive development

Inspired by our previous work on the simulation of development by the concurrent increase of sensory, motor and neural complexity, we are planning developmental scenarios where the robotic hand will learn to manipulate objects of different shapes, textures and materials (see Fig. 7b). Starting with some of the fingers coupled together, using a few of the sensors available and a neural network with a small number of neuronal units, over time these constraints will be released to see if learning can be accelerated by following a developmental approach.

Learning Mechanisms

The highly complex developmental processes, which include dramatic changes in morphology, require not only methods for learning, as normally discussed in the neural network community (e.g. in Elman et al., 1996), but integrated methods for learning and development. On the one hand these methods must be more adaptive to adjust to changing morphologies. On the other hand, they must be incremental, meaning that they continuously function throughout the lifetime of an individual. In order to achieve this level of adaptivity, we can get inspiration from nature: the adaptivity of standard neural networks can be substantially increased by introducing the “ligand-receptor” concept. The “ligand-receptor” concept can be easily used by artificial evolution to explore the growth of a neural network, of value systems, and of learning mechanisms systematically for a given task. In our implementation, receptors are “digital” proteins that are attached to neurons. They have specific shapes that are able to recognize their “partner molecules”. Ligands are “digital” signalling molecules moving around, which also have specific shapes, and which are basically used as information carriers for their receptors. The shape of a receptor determines which ligand can stimulate it, much in the same fashion as pieces of a jigsaw puzzle fit together. When a receptor of a neuron is stimulated by a matching ligand, the following mechanisms are elicited on a neuron: the neuron is connected to another neuron expressing a partner receptor, a ligand molecule is released, or a receptor is expressed. As a result of the interaction of these processes, the specification of the neural network (i.e., number of neuronal fields, size of each neuronal field, a set of receptors expressed by each neuronal unit, a set of ligands that can be released by the sensor neurons) can be obtained and then embedded as a neural controller for a robot (e.g. for learning how to grasp, Gomez et al., 2005). Ligand-receptor based networks can continuously grow and change their morphology. With the ligand-receptor concept, several functionalities can be implemented within one and the same network: the network can operate in several distinct “modes”. See the description for WP8 below.

To properly assess the performance of the learning method based on the ligand-receptor concept described above, we started to research modern learning methods as applied to the field of robotics. The goal of this research is a survey paper of learning methods, which is currently under preparation. When completed, the survey can serve as a basis of comparison for our implementation.

UNIZH Contribution to WP3 - Sensorimotor coordination

Through the interaction of an agent with the environment, there is not only sensory stimulation induced, but this sensory stimulation is highly structured, containing correlations within and across sensory channels. The term “information structure” is used to designate these statistical dependencies. For example, when grasping an object, structured sensory stimulation is generated in the haptic, the visual and the proprioceptive channels. Because the sensory data is already structured, and has therefore lower complexity, the task for the nervous system is facilitated: through the embodied interaction; the nervous system has access to “good” stimulation, so to speak. This effect is particularly pronounced for sensory-motor coordinated actions such as foveation, reaching, and grasping. At the moment we have methods for the analysis of the dynamics of the sensory-motor interaction, which are based on information theory (e.g., entropy, mutual information) and on statistics (e.g., Principal Component Analysis, Isomaps), these methods have been used to fingerprint the agent-environment interaction of real robots and simulated robotic agents.

For the robotic hand, an initial set of grasping reflexes have been implemented and experiments performed. For the active vision system a basic focus of attention mechanism has been implemented, which relies on the saliency of the red colour component and movement detection. Three receptor types were considered: red (r), green (g), and blue (b). A "broadly" colour-tuned channel was created for red: $R = r - (g + b)/2$. This channel yields maximum response for the fully saturated red colour, and zero response for black and white inputs. The negative values were set to zero.

Motion detectors were created to detect movements of objects in the environment. These motion detectors are based on the well-known elementary motion detector (EMD) of the spatio-temporal correlation type.

UNIZH Contribution to WP4 - Object’s affordance

In order to investigate an object’s affordance we are investigating how to exploit the sensory stimulation induced by the sensory motor coordinated interaction with an object on the different sensory modalities of our robotic system. Fig. 1 shows the robot hand holding objects of different affordances, as viewed through an inverse log polar transformation of the robot’s active vision system. The available modalities are: proprioception of the arm and each individual finger, pressure sensors on the finger tips, and vision. After correlating the modalities during interaction with the object, we can predict the stimulation of one modality from the excitations of the other channels. This allows us to e.g. identify the affordance of an object without having to test for it, after the robot has had a chance to learn and correlate the sensory stimulations that come with different types of objects.

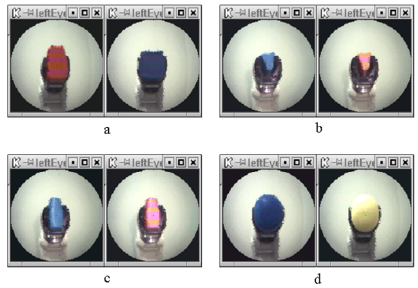


Figure 3: Robot arm holding objects of different shapes, size and material.

UNIZH Contribution to WP5 - Imitation
As part of the aforementioned survey, we are looking at how learning methods are employed in the context of imitation.

UNIZH Contribution to WP7 - Mechatronics
We have improved the tendon driven robotic hand by installing different sensors on it (e.g., pressure for the haptic sensory modality, and bending for proprioception), as well as developing the necessary software (e.g., for online motor control and sensory reading).
Initially the pressure sensors were based on the standard FSR type, but they were not as sensible as we expected, therefore we needed to test a different technology and new pressure sensors were developed in order to get more sensitivity.

Pressure sensors based on pressure sensitive conductive rubber:
We developed a new type of pressure sensors based on pressure sensitive conductive rubber CS57-7RSC (CSA). The conductive rubber contains conductive carbon particles (Figure 3a) that changes the material resistance according with the pressure applied on its surface (Figure 3b).
The pressure sensor in Figure 4 is based on a voltage divider that traduces the changes in resistance into voltage. The voltage-pressure relationship is presented in Figure 5.

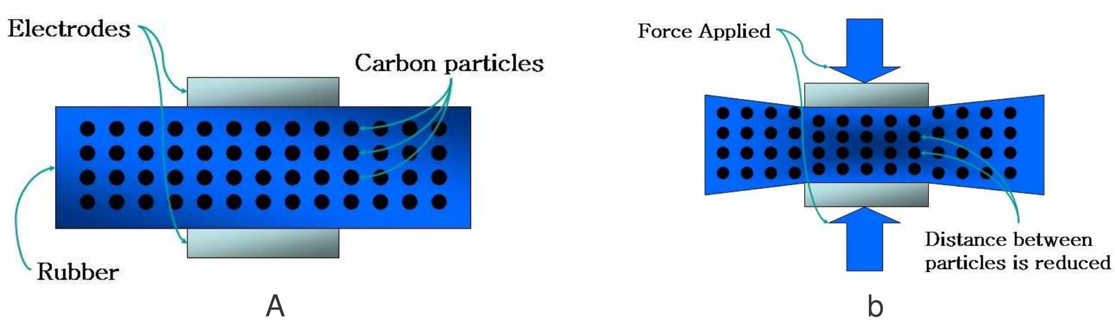


Figure 4: Pressure sensors based on pressure sensitive conductive rubber. (a) Conductive rubber diagram. (b) Inner resistance change due to external pressure applied on the conductive rubber.

Figure 5: Set of five pressure sensors.

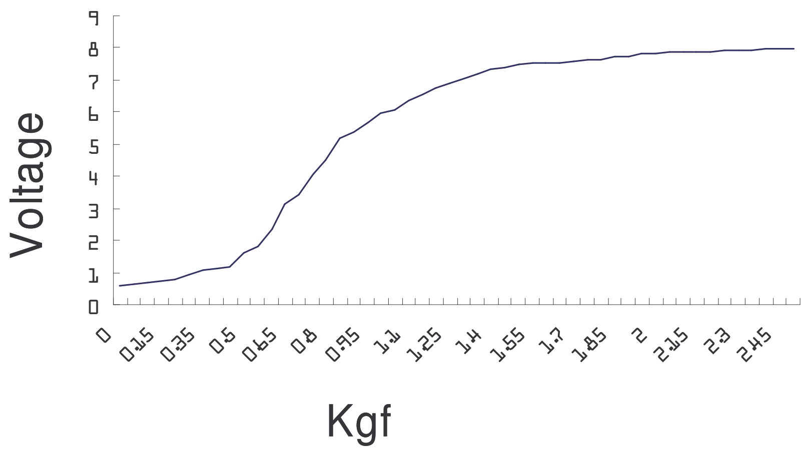


Figure 6: Relation between the pressure applied and the voltage output from the pressure sensor. The voltage increases as the resistance in the conductive rubber decreases with the pressure applied at 9 Volts.

In addition to this, a second prototype of the robotic hand has been built made of plastic material in order to reduce the overall cost and weight distribution and it is proves to be more stable, strong, and has better dexterity (see Figure 6).

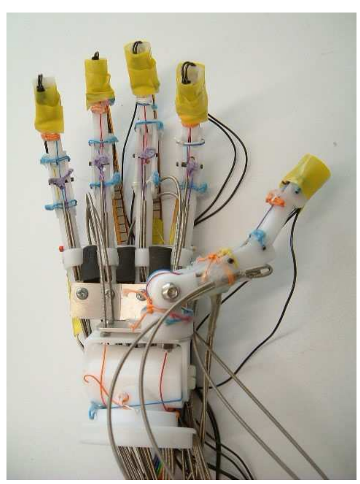


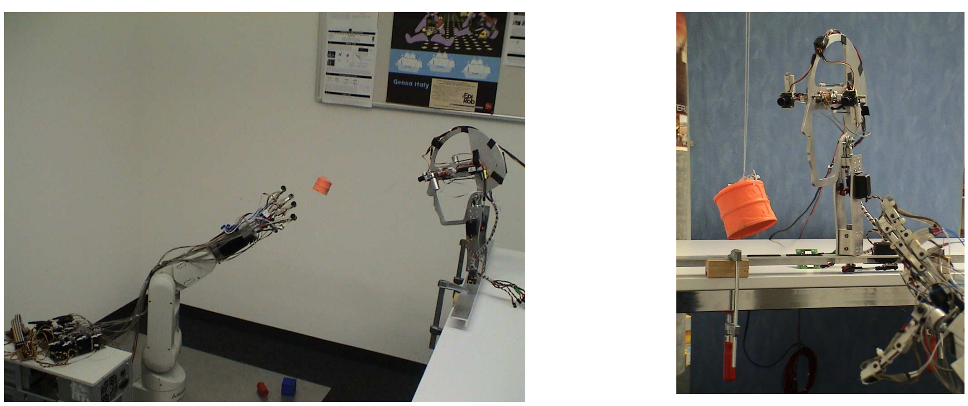
Figure 7: Second prototype of the robotic hand.

UNIZH Contribution to WP8 - Infrastructure of Open System (CUB)

UNIZH has been also investigating the implementation of an adaptive learning framework, using the ligand-receptor concept recently investigated at our laboratory. The framework was designed as a modular and extensible construction kit to allow for flexible experimentation with neurobiologically-inspired neural networks. The underlying neural concepts allow the design of controllers which are adaptable to different platforms and to changes in the morphology (sensory as well as motor systems). The library, which is implemented in C++, consists of efficient algorithms with a low memory footprint, serialization, and a highly-generic, policy-based interface design. At the moment, several timing issues need to be worked out and the serialization layer re-implemented.

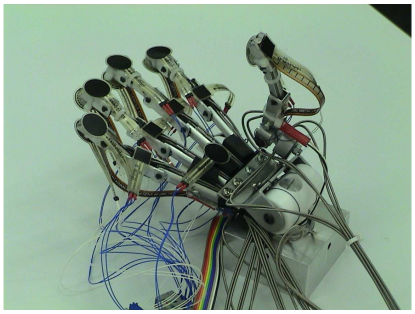
UNIZH Major Achievements

We have established a robotic platform ready to perform initial experiments on sensorimotor coordination, learning and development. The platform consists of a robotic head with a stereo colour active vision system, an industrial robot arm, and a robotic hand. In total the robotic setup has 25 DOF (see Figure 7). Most of the work has been performed to improve the sensorimotor capabilities of the robotic hand. The tendon driven robot hand (see Figure 8a) is partly built from elastic, flexible and deformable materials. For example, the tendons are elastic, the fingertips are deformable and between the fingers there is also deformable material. It has 13 degrees of freedom that are driven by 13 servomotors, a bending sensor is placed on each finger as a measure of the position, and a set of pressure sensors based on conductive rubber cover the hand (e.g., on the fingertips, on the back and on the palm).



a b

Figure 8: Robotic setup. (a) Robot head (Active vision system with 4 DOF + neck with 2 DOF), robot arm (6 DOF) and robotic hand (13 DOF) with tendon driven system, bending and pressure sensors. (b) Grasping an object.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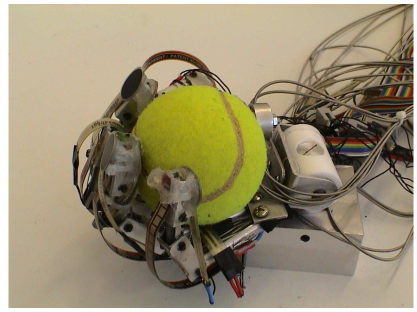

b

Figure 9: Robotic hand. (a) Tendon driven system, bending and pressure sensors. (b) Grasping an object.

UNIZH Published Papers

1. Gomez, G., Hernandez, A., Eggenberger Hotz, P., and Pfeifer, R. (Submitted). An adaptive learning mechanism for teaching an anthropomorphic robot hand to grasp.
2. Hernandez, A., Yokoi, H., Arai, T., Yu, W. (In press). "FES as Biofeedback for an EMG Controlled Prosthetic Hand". Proceedings Tencon05 . Melbourne Australia. Nov 21-24, 2005.
3. Gomez, G., Hernandez, A., Eggenberger Hotz, P., and Pfeifer, R. (In press). An adaptive learning mechanism for teaching a robot to grasp. To appear in Proc. of AMAM 2005.
4. Pfeifer, R. and Gomez, G. (2005). Interacting with the real world: design principles for intelligent systems. Artificial life and Robotics. Vol9. Issue 1. pp. 1-6.
5. Gomez, G. Lungarella, M., Eggenberger, P., Matsushita, K., and Pfeifer, R. (2004). Simulating Development in a Real Robot. Poster in ICDL04 in San Diego.

4.2.4 University of Uppsala (UNIUP)

UNIUP worked on the cognitive roadmap and on experiments on the perception of gaze direction, event perception in autistic children, gaze tracking, reaching for moving objects, and object manipulation. We have begun collaboration with UNFE on the development of mirror movements. A meeting was held in January in Ferrara to plan this research

UNIUP Major Achievements

UNIUP contribution to WP2 - Cognitive development
The cognitive roadmap. Version 1 of the cognitive roadmap has been completed during this period. It has been a collaborative effort to which several members of the consortium have contributed including UNIUP, UGDIST, UNIZH, and UNIFER have contributed. Progress reports were delivered at the Lisbon meeting in March and at the Genova meeting in July. The work by UNIUP has focused on the principles of development: the biological foundation of action, core abilities, motivational factors and the principles of predictive control. Four different areas of cognitive development was identified and discussed. 1. Developing posture and locomotion. 2. Developing looking and other modes of exploration. 3. Development of reaching and manipulation. 4. Developing of social skills.
Developmental architecture. Experiments have been conducted on children's ability to manipulate objects and understand events in the surrounding. In these experiments, measurements of gaze direction and reaching activity have been used to investigate the development of the cognitive function.

UNIUP contribution to WP3 - Sensorimotor Coordination
In this work package, we have conducted research on human infants to investigate the ontogenesis of gaze control and reaching. **First**, we have studied the development of horizontal-vertical gaze tracking, the process by which infants learn rules by which they predict the motion of objects, and the development of infants' ability to catch moving objects. **Secondly**, we have started research on the development of infants' ability to perceive the goals of actions and on the development of mirror neurons. This research is partly done in collaboration with UNIFE. In January this year, a meeting was held in January in Ferrara to plan this research. Three kinds of experiments are being conducted. We have measured infants' looking patterns when observing the experimenter move an object from A to B and when they themselves perform the same action. These experiments show that both when they perform a goal-directed action themselves and when they observe someone else perform the same thing, infants look at the goal of action. In another set of experiments, we have shown that fixating the destination of motions only occur when they motions are part of goal directed actions. We have finally begun EEG experiments find out what kinds of cortical activations are associated with the observation of actions.

UNIUP contribution to WP4 - Object's Affordance
A series of experiments are being conducted where toddlers' understanding of the affordances related to object manipulation is investigated. We study how children go

about when trying to fit objects into each other, how they learn to pile objects on the top of each other, and how they learn to fit lids on pans. Such activities reflect children's ability to mentally move and rotate objects, their understanding of form and size relationships and their understanding of physical laws such as gravity and inertia. How infants learn to handle objects in such situations, is crucial for their understanding of spatial relationships between objects, their ability to mentally rotate objects, and the ability to formulate distant goals.

UNIUP Published Papers

1. von Hofsten, C., Dahlström, E., & Fredriksson, Y. (2005) 12-month–old infants' perception of attention direction in static video images. Infancy, 8, 217-231.
2. Gredebäck, G., von Hofsten, C., Karlsson,J., and Aus, K. (2005) The development of two-dimensional tracking: A longitudinal study of circular visual pursuit. Experimental Brain Research, 163, 204 – 213.
3. Ornkloo, H & von Hofsten, C. (2005) Fitting objects into holes: Development of spatial cognition skills. Submitted manuscript.
4. Gronqvist, H., Gredeback, G. & von Hofsten, C (2005) Developmental asymmetries between horizontal and vertical tracking. Submitted manuscript.
5. von Hofsten, C. (2005) The development of prospective control in looking. In J. Lockman and J. Rieser (Eds.) Action as an Organizer of Perception and Cognition during Learning and Development. Minnesota symposium on Child Psychology. Vol 33.
6. von Hofsten, C. (2005) Development of prehension. In B. Hopkins (Ed.) Cambridge Encyclopedia of Child Development. In press.

4.2.5 University of Ferrara (UNIFE)

UNIFE is doing experiments on the development of the capability to plan and recognize actions. It is currently is involved in monkey electrophysiology of hand-related premotor cortex during action execution/observation, in the study of predictive capabilities of the motor system during execution of grasping and during observation of similar actions of others, in the study of the mechanisms at the basis of human communication (gestural as well as verbal). We started collaboration with UNIUP and with other RobotCub teams on the development of mirror neuron system. A meeting was held in January in Ferrara to plan these researches. Moreover, in the frame of the European Science Foundation Collaborative Research (EUROCORES) Program, the Origin of Man, Language and Languages (OMLL), UNIFE participated to the organization in Ferrara of the Workshop "Phylogeny and Ontogeny of Human Communication", from 2 to 4 June 2005. Nine students coming from different European countries were funded by UNIFE Robot-Cub grant to allow their participation to the Workshop.

UNIFE Major Achievements

In addition to the experiments mentioned in WP3 section of this deliverable, we projected and realized a multielectrode amplifier (36 channels) to study motor representations in rats, we are developing a non invasive system to record transcranially brain activity in infants (NIRS), we are investigating the possibility to extract metabolic signals from the brain as an index of localized neural activity. We coordinated WP3 planning by involving also non-neuroscience teams. Among our most recent results, an fMRI experiment on gesture recognition demonstrating the involvement of a speech premotor area (Broca's) in action understanding (WP2), some new techniques of fMRI analysis based on new statistical ideas on the correction for multiple comparisons, the finding that many motor neurons recorded in monkey's area F5 are sensitive to the vision of monkey's own hand during grasping (WP3 and WP4). Finally, during the last Lisbon meeting, we planned a series of experiments in collaboration with 1) EPFL, aiming at characterizing the kinematics parameters of arm reaching during execution and imitation of observed actions and with 2) UNISAL, to build a prototype of a device to record hand movements based on the measurement of pulsating electromagnetic fields. During the last Genova Meeting (July 2005), we discussed together with UGDIST and TLR how to implement the crawling strategy. Some solutions, based upon the measure of crawling kinematics in babies and monkeys, have been taken into consideration.

In the framework of WP5, we started the experiments in collaboration with EPFL, in order to replicate some experiments done by this partner on the kinematics during imitation of movements. The aim of the experiments is to verify if the position of articulations influences the way in which the same action is imitated. We investigated a group of subjects observing and subsequently imitating a real model seated in front of him/her executing different actions. Possible movements to be imitated were:

- transitive actions: grasping of an object 1) in a natural way, 2) in an unnatural way (the movement is modified only in its proximal part -elbow elevation) and 3) with a velocity increased with respect to the natural way.- intransitive actions: the hand is placed at different positions on the table 1) in a natural way, 2) in an unnatural way (the movement is modified only in its proximal part -elbow elevation) and 3) with a velocity increased with respect to the natural way.

UNIFE Published Papers

1. Rizzolatti G. Craighero L., The mirror neuron system, Ann. Rev. Neurosci. 27:169-192 (2004)
2. Fadiga L, Craighero L, Olivier E. Human motor cortex excitability during the perception of others' action. Curr Opin Neurobiol. 15:213-8 (2005)
3. Fadiga L., Craighero L. (in press) Hand actions and speech representation in Broca's area. Cortex
4. Fadiga L., Craighero L., Roy A. Broca's Region: a Speech Area?, in Grodzinky Y and Amunts K (Eds) The Broca's Area, Oxford University Press, (in press)
5. Fadiga L., Craighero L., Fabbri Destro M., Finos L., Cotillon-Williams N., Smith A.T., Castiello U., Language in shadow, submitted.

4.2.6 University of Hertfordshire (UNIHER)

Research activity has been devoted to the following topics related to WP6 under direction of K. Dautenhahn, C. L. Nehaniv, and/or R. te Boekhorst:

1. Investigation of information theoretic methods applied to characterizing and identifying experience (Assif Mirza)
2. Mapping sensor space and learning motor capabilities using information theoretic measures. (Lars Olsson).
3. Pilot studies of Robot-Child interactions in a series of experiments using a semi-autonomous Aibo robot toward mapping interaction space; analysis of requirements for engagement (Ben Robins).
4. Work on defining a structure for research into developmental levels in robot interactions with humans (Dorotée Francois).
5. Mechanical/interaction design and construction on interactive minimal expressive robotic face/head, jaw/mouth, eyes, eyelids, neck (Andrew Appleby and Marc Blow).

UNIHER Major Achievements

- Completed preliminary study of space of robot-child interaction and analysis of requirements for sustaining interaction (published in IEEE ROMAN 2005).
- Developed concept of Average Information Distance plots for robot self-characterization of interactions along with software for Aibo.
- Organized (along with Giorgio Metta) a special workshop on Ontogenetic Robotics at the IEEE CIRA 2005 conference in June to support RobotCub research and dissemination, and promote scientific interest in the area.
- Completed first prototype minimal expressive head/face, providing feedback to IST Lisbon on expressive requirements for Cub (conference paper submitted).
- Extended sensorimotor learning work using information-theoretic methods, and developed new metrics for experience and broader temporal horizon (8 published conference papers and 1 technical report).
- Specific collaborations ongoing:
    - UNIHER and IST Lisbon: UNIHER integrated discussions arising from the studies on facial gestures into IST design of the robot head for WP2.
    - UNIHER and UNIFE: Discussions have begun on the informational geometry of sensorimotor maps and neural cortex somatosensory structure possibly leading to a new foundation of the understanding of the role of information in cortical development.
    - UNIHER and EPFL: Discussions with EPFL have begun discussions on using technology for determining head-orientation by tracking the nose to help the interaction studies being conducted at UNIHER.

UNIHER published papers

1. N. A. Mirza, C. Nehaniv, R. te Boekhorst, and K. Dautenhahn. Robot self-characterisation of experience using trajectories in sensory-motor phase space. In Proc. of Fifth International Workshop on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems (EpiRob2005), pages 143-144. Lund University Cognitive Studies, 2005.

2. N. A. Mirza, C. L. Nehaniv, K. Dautenhahn, and R. te Boekhorst. Using sensory-motor phaseplots to characterise robot-environment interactions. In Proc. of 6th IEEE International Symposium on Computational Intelligence in Robotics and Automation, 2005.
3. N. A. Mirza, C. L. Nehaniv, K. Dautenhahn, and R. te Boekhorst. Using temporal information distance to locate sensorimotor experience in a metric space. In Proc. of 2005 IEEE Congress on Evolutionary Computation, volume 1, pages 150-157, 2005.
4. C. L. Nehaniv, N. A. Mirza, K. Dautenhahn, and R. te Boekhorst. Extending the temporal horizon of autonomous robots. In Proc. of the 3rd International Symposium on Autonomous Minirobots for Research and Edutainment (In Press), 2005.
5. C. L. Nehaniv. Sensorimotor experience and its metrics. In Proc. of 2005 IEEE Congress on Evolutionary Computation, 2005.
6. L. Olsson, C. L. Nehaniv, and D. Polani. Discovering motion flow by temporal-informational correlations in sensors. In L. Berthouze, H. Kozima, C. G. Prince, G. Sandini, G. Stojanov, G. Metta, and C Balkenius, editors,Proceedings of the Fifth International Workshop on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems, pages 117-120. Lund University Cognitive Studies, 2005.
7. L. Olsson, C. L. Nehaniv, and D. Polani. From unknown sensors and actuators to visually guided movement. In Proceedings the of International Conference on Development and Learning (ICDL 2005), pages 1-6. IEEE Computer Society Press, 2005.
8. L. Olsson, C. L. Nehaniv, and D. Polani. Measuring information distances between sensors and sensor integration. Technical Report 431, University of Hertfordshire, School of Computer Science, 2005.
9. L. Olsson, C. L. Nehaniv, and D. Polani. Sensor adaptation and development in robots by entropy maximization of sensory data. In Proceedings of the 6th IEEE International Symposium on Computational Intelligence in Robotics and Automation (CIRA-2005), pages 587-592. IEEE Computer Society Press, 2005.
10. B. Robins, K. Dautenhahn, C. L. Nehaniv, N. A. Mirza, D. Francois, and L. Olsson, Sustaining interaction dynamics and engagement in dyadic child-robot interaction kinesics: Lessons learnt from an exploratory study. In Proc. of the 14th IEEE International Workshop on Robot and Human Interactive Communication, RO-MAN2005, pages 716-722, 2005.
11. M. Blow, K. Dautenhahn, A. Appleby, C. L. Nehaniv, D. Lee, The Art of Designing Robot Faces - Dimensions for Human-Robot Interaction, Human-Robot Interaction 2006, Assoc. for Computing Machinery Press, (submitted).

In April 2005, another conference paper on the pilot studies mapping the space of robot-child interaction and requirements will be submitted to IEEE RO-MAN 2005, also further papers on information-theoretic interaction history learning from sensorimotor experience will be submitted to IEEE CEC 2005.

UNIHER Demonstration to general public

Demos of University of Hertfordshire Robot-Cub work have been prepared for the Artificial Intelligence and Simulation of Behaviour Convention (AISB'05) in the U.K. April 2005. Journalists are expected to attend with possible follow-up media coverage.

4.2.7 Instituto Superiore Tecnico (IST)

The activity at IST during the year of the project is described in correspondence to each Workpackage. In addition to the work on the design of the I-Cub head, IST has developed methodologies and performed experiments with its current anthropomorphic arm-and-torso-head system, Baltazar (see photo on the right hand side).

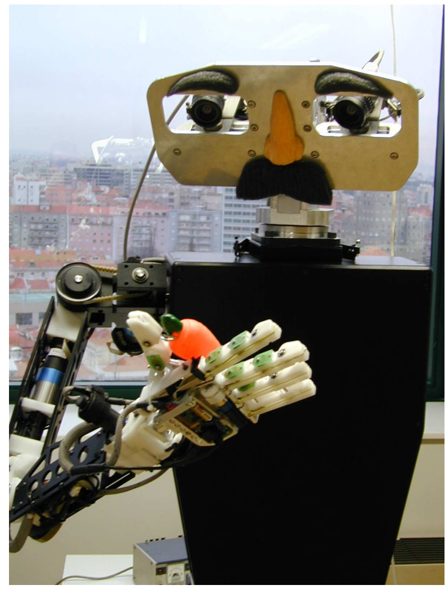


Figure 10: The robotic platform Baltazar

IST Contribution to WP1 - Management
In addition to participating in all project meetings, IST hosted the 3rd Robot-Cub General Meeting, in Estoril, March 17-19th, 2005. The meeting included a visit to the laboratories at IST/ISR where the first prototype of the head was demonstrated.

IST Contribution to WP2 - Cognitive Development
A developmental approach was partly implemented and tested in Baltazar following the main three stages:

a) Learning about the self
b) Learning about objects (grasping and affordances)
c) Learning about others (imitation)

During phase i), the robot executes “random” arm movements while observing the images of its own arm/hand. Since both proprioceptive and visual information are simultaneously available, it is then possible to learn a Visuo-Motor Map (VMM). This map works in two ways. It allows the robot to predict the visual consequence of its motor activity (excluding object interaction) and it also allows the robot to compute the motor commands required to reach a certain configuration (direct and inverse models).

Once this map has been learned, the robot can position the wrist in a reference position specified in visual terms. This developmental milestone triggers the second phase, where the robot reaches for objects of interest (usually colour based saliency). As suggested in studies in psychology, this reaching phase is essentially open-loop, from the visual point of view, and relies on the learned VMMs. The final part of the grasp is visually controlled. For that purpose, during this phase, the robot learns jacobians relating arm joints to image speeds. The jacobians are used in a visual servoing strategy, during the final approach to the goal.

Once the robot is able to grasp, attention will be drawn towards other people/robots in the scene. Here we have focused on the recognition of (grasping) gestures and gesture imitation. In some cases, the robot computes the View-Point Transformation” to align its own body coordinate system and that of the demonstrator. The VMM is used for final production of the gestures. Current work addresses the question of segmenting the observed gesture (simple action) in meaningful segments, as well as the use of different metrics for imitation.

Most of this work is described in a paper presented at the AISB 2005 Symposium on Imitation in Animals and Artifacts, 2005. It is worth saying that this work is intimately related to Workpackages WP3, WP4 and WP5.

IST Contribution to WP3 - Sensorimotor Coordination

Part of the work mentioned in WP2, IST worked on methods to build visuomotor maps from self- observation. These maps include both static and velocity (jacobians) maps. While the static visuomotor maps are used for the first phase of grasping, the visuomotor jacobians are used for visual servoing.

In the context of visuomotor jacobians (or, in other words, visuomotor dynamic maps), the issue of redundancy has been addressed. In fact humanoid robots are often redundant, when a specific task is considered. Then, most learning methods rely on the use of additional criteria to "freeze" the redundant degrees of freedom during learning. Instead, we have considered the situation where those additional degrees of freedom remain available until execution time and can thus be used for secondary tasks.

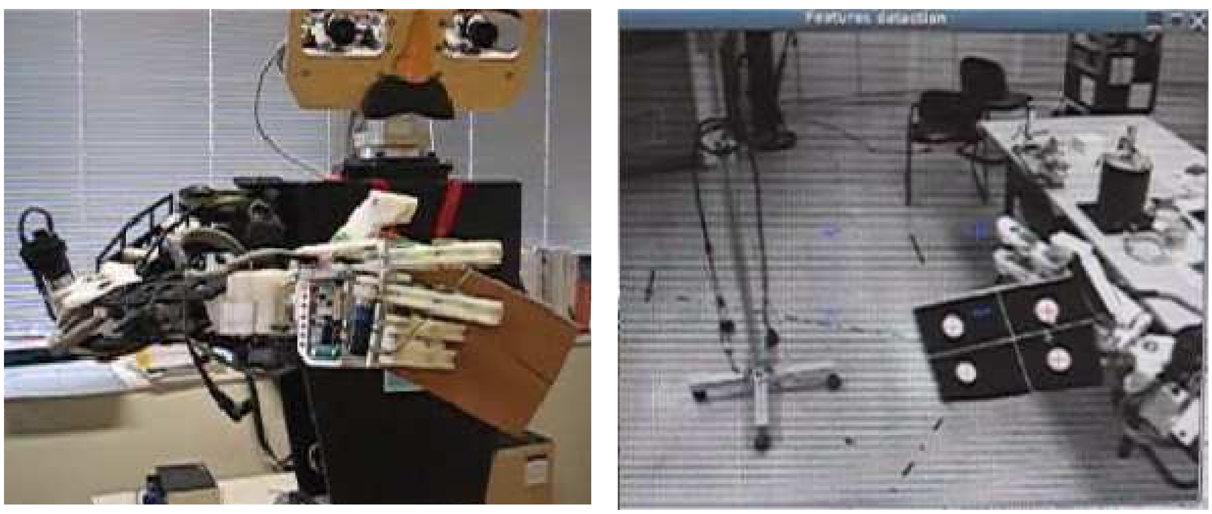


Figure 11: Left: Baltazar grasping an object using the learned VMM (both static and dynamic). Right: the view from one of Baltazar's cameras.

IST Contribution to WP4 - Object's Affordances

Preliminary work of using object affordances in gesture (manipulation) recognition was done. Basically, it involves a relationship between an object's identity (shape, colour) and the probability of different grasp actions acting upon this object. This is used for recognizing grasping gestures, since most of the time, the image of the hand can be significantly ambiguous.

Part of the work done for WP4 addresses, in a joint manner, the interdependencies between objects affordances and gesture recognition. The developed models allow the recognition of particular types of gestures, given a preliminary training phase. This capability is an important component of cognition for gesture communication.

IST Contribution to WP5 - Imitation

Low-level imitation was tested in the Baltazar platform. At this level the imitation metric is mainly the exact reproduction of the observed gesture, while the imitation of goal-directed action is the focus of current work. In particular, we have developed methods where an image sequence is "summarized", resulting on a short set of images that describe the most relevant instants of the sequence.

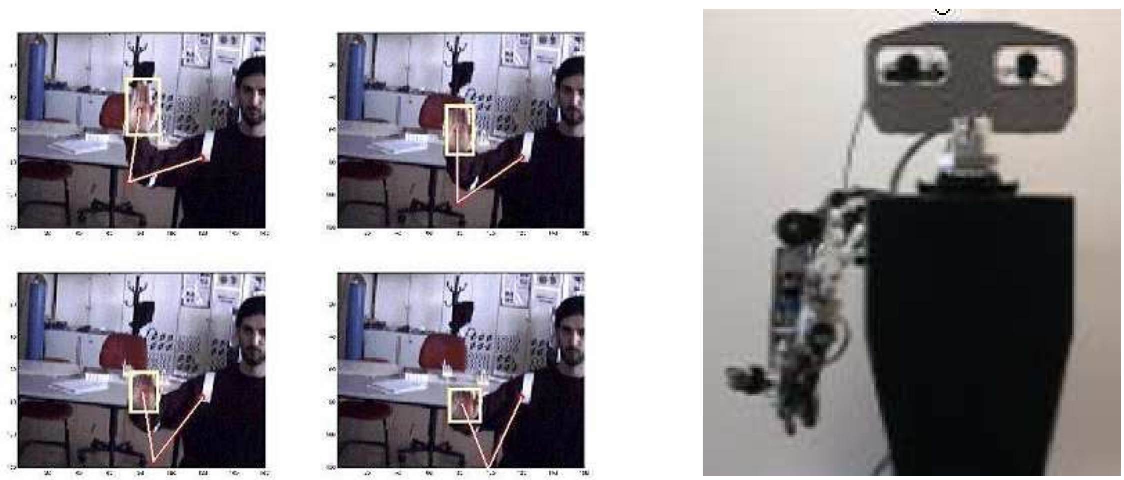
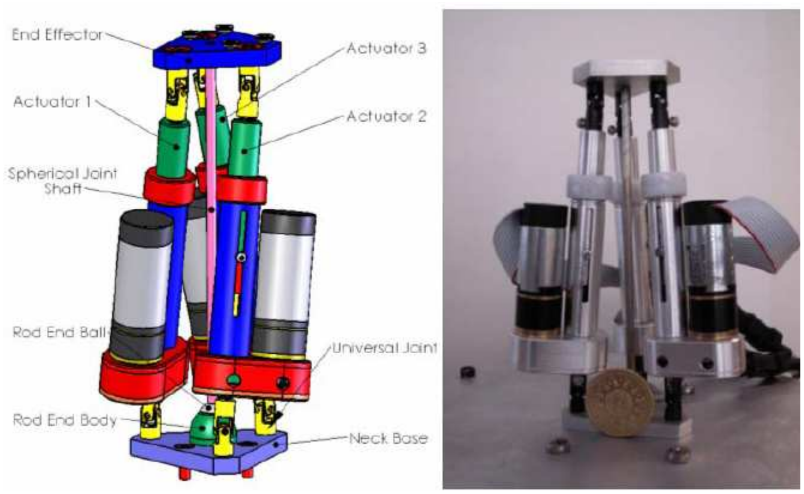


Figure 12: Left: Tracked arm gestures produced by a demonstrator. Right: Baltazar imitating (action-level imitation) the same gesture, after performing detection and the View-Point Transformation.

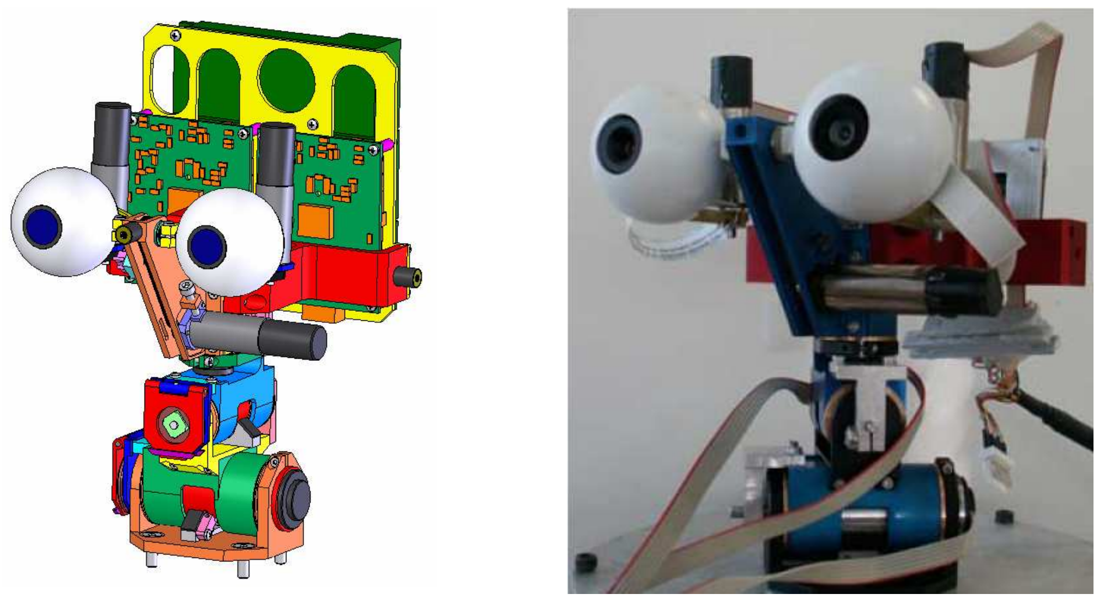
IST Contribution to WP7 - Mechatronics of the Cub

During the first year, IST has studied and proposed a set of specifications of the head as well as various design alternatives meeting those specs. This step was very important since the definition of an adequate set of specifications has a critical impact on the developed solution, size, weight, motors, etc.

The proposed head design consists of two modules: the neck and the eyes. For the neck several solutions were studied, designed and prototyped. These included a serial neck structure, a parallel neck and a study with a cable driven mechanism. Several prototypes were built and demonstrated in a light tracking experiment during the RobotCub General Meeting in Lisbon. The serial mechanism was the final choice and is currently being improved mechanical robustness.

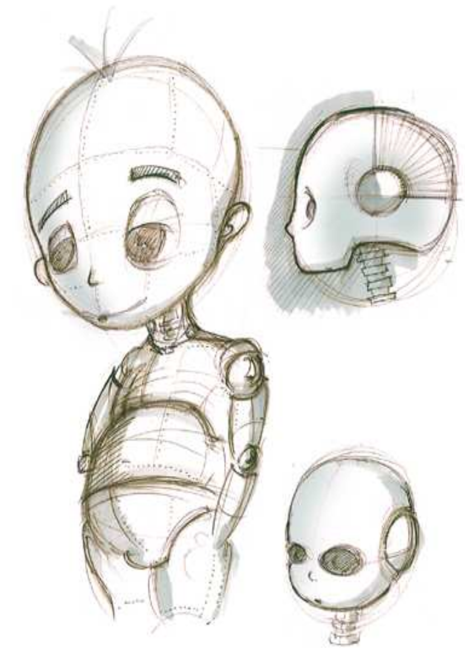


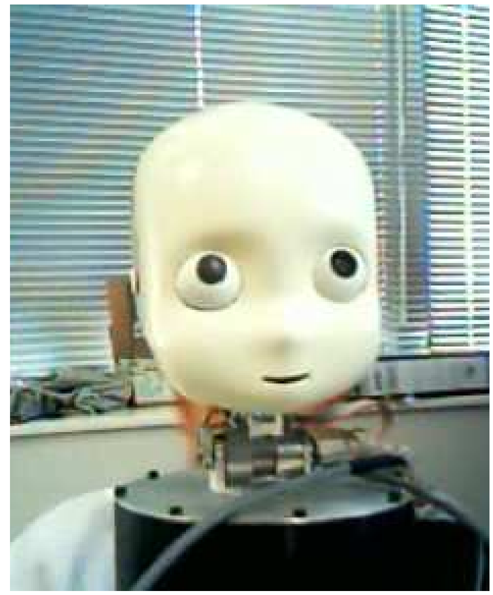
CAD Model and Prototype of the head neck actuated by a miniature parallel robot.



CAD model and prototype of the most advanced head design. The design is modular, highly integrated.

Although not initially planned, IST has pursued work on the design of the iCub face. For this particular issue IST has worked with several arts and architecture schools in Portugal as well as discussed with UNIHER regarding specific features of the face design. Several design concepts were studied and a first prototype built.





Concept designs for the iCub body and face. On the right hand side, we show the face first prototype mounted on the head mechanism.

IST Contribution to WP8 - Open System

As the developers of the iCub head, IST has contributed to the definition of the documentation standards, mechanical design and components.

IST Contribution to WP9 - Community Building and Self-Assessment

IST has organized a competition for high school, Art and Design students for the design of the iCub face and expressions. This procedure had an enthusiastic response from the students and results were shown during the RobotCub Meeting in Lisbon.

Concept designs for the iCub face as seen by high school arts students at the Escola António Arroio, Lisbon, Portugal

IST Major Achievements

1. Definition of the specifications of the iCub Head.
2. Head design, including eye system and neck mechanisms. Three alternative designs studied for the neck: serial, parallel and parallel + cable actuation. The cable driven had the disadvantage of having the motors inside the robot chest.
3. Prototype of the iCub head with the serial neck. Demonstrated in Lisbon on March 18th, 2005. The parallel version will be assembled shortly.
4. New version of improved neck-eye system for the iCub head.
5. Work on sensory motor coordination, learning and cognitive development using the anthropomorphic humanoid-type platform, Baltazar.
6. Work on Jacobian estimation and learning in redundant manipulators.
7. Organization of the 3rd RobotCub general meeting in Lisbon, March 17-19 2005

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IST Published Papers

1. M. Lopes, A. Bernardino and J. Santos-Victor, A Developmental Roadmap for Task Learning by Imitation in Humanoid Robots: Baltazar's Story, AISB 2005 Symposium on Imitation in Animals and Artifacts, University of Hertfordshire, UK, 12-14 April 2005
2. M. Lopes, R. Beira, M. Praça, J. Santos-Victor, An anthropomorphic robot torso for imitation: design and experiments, IROS - IEEE/RSJ International Conference on Intelligent Robots and Systems, Sendai, Japan, September 28 - October 2, 2004
3. Nicolas Mansard, Manuel Lopes, François Chaumette and Jose' Santos-Victor, Jacobian Learning Methods for Visual Servoing Sequencing, submitted to ICRA06, Orlando, USA
4. Manuel Lopes Jose' Santos-Victor, Sensory-Motor Coordination for Redundant Robots, submitted to ICRA06, Orlando, USA
5. R. Beira, M. Lopes, J. Santos-Victor, A. Bernardino, G. Metta, F. Becchi, R. Saltaren, Design of the Robot-Cub (iCub) Head, submitted to ICRA06, Orlando, USA.

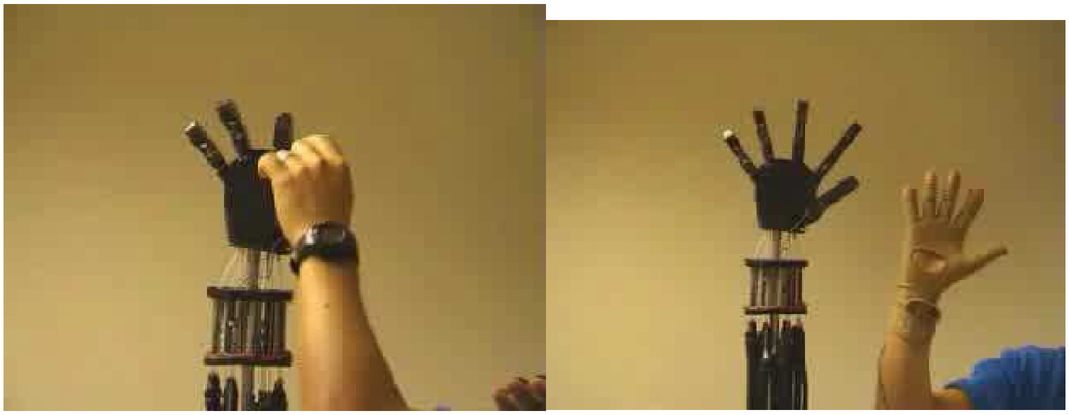
4.2.8 University of Salford (UNISAL)

The work at UNISAL has involved input across 6 of the workpackages, with the major efforts in WP3 and particularly WP7. In addition to specific development with regard to the spine, hips, legs and feet, UNISAL has developed work in connection with experiments on our current hand, arm and leg systems with particular reference to the actuation and sensory requirements that will inform the future development of iCub.

UNISAL contribution to Workpackage 1: Management
Participation in project meetings and co-ordination of the day to day management of the local efforts.

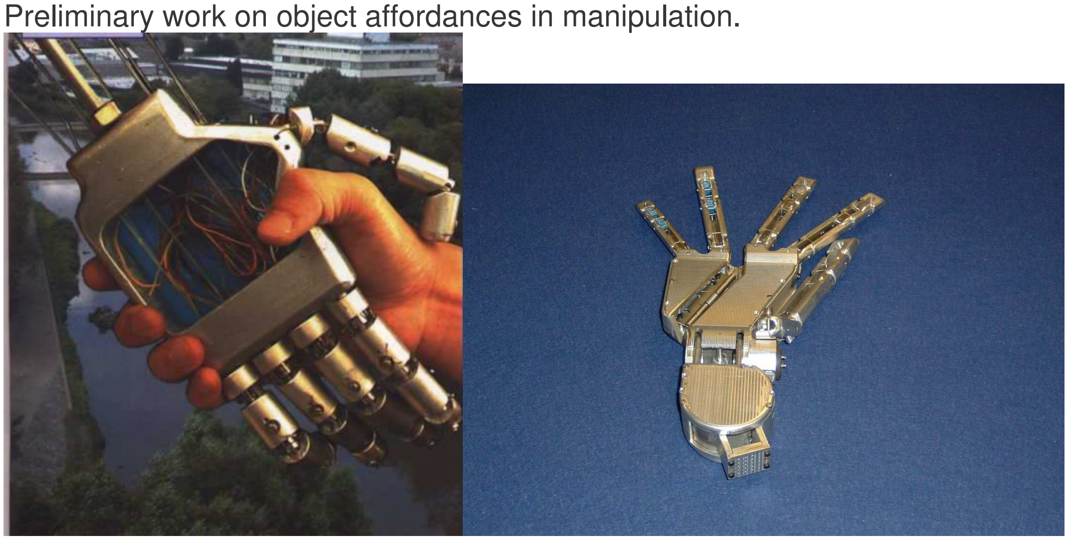
UNISAL contribution to Workpackage 3: Sensorimotor Coordination
Development of an initial understanding of links between sensory systems for legs, hips, feet and the sensory requirements of the iCub. Some outline work on grasping to support activities of other partners. Work in conjunction with UNIUP looking at the development of technology to accurately track hand actions in infants up to 24 months. This work has produced a new miniaturised wireless sensory glove able to track the motions of the all finger and the thumb. The system is Bluetooth enabled and powered from lithium batteries giving free motion of greater than 4hrs. This is more than adequate for the testing required. Current technical work is improving the ease with which this glove can be fitted to a child.

Finger Tracker – Miniaturised version used in Child motion Testing

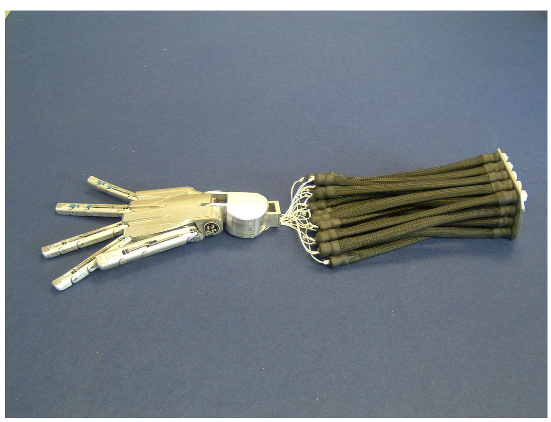


Hand hand /Robot Hand Control and Interaction Studies

UNISAL contribution to Workpackage 4: Object's Affordance
Preliminary work on object affordances in manipulation.



Dexterous Robotic Hands

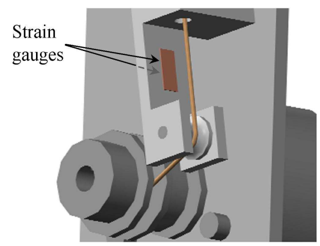


pneumatic Muscle Actuation for Robotic Hands

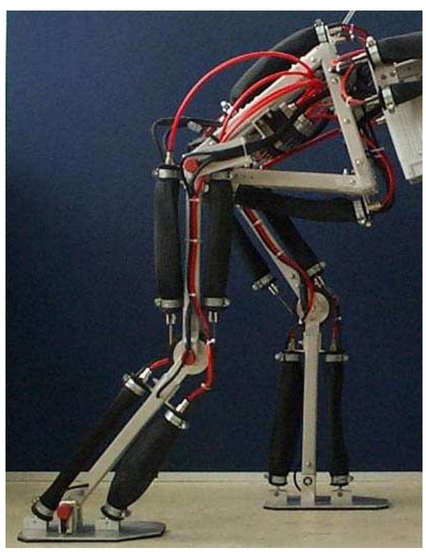
UNISAL contribution to Workpackage 7: Mechatronics

Specification of performance criteria for the lower body of the iCub. Extensive design and design revision for the spine, hips, legs and feet. This has involved mainly mechanical design although physical models have been made. Designs for motor control and drive circuitry have also been developed.

Spine, Hips and Legs



Strain gauges mounted on for force measurement



Hip, Legs and Foot of a pneumatically power robot

UNISAL contribution to Workpackage 8: Open System
Work in support of lead partners on the development of an open system.

UNISAL contribution to Workpackage 9: Community Building and Self Assessment

Work in promoting the project to the community and in particularly forming links with psychologists to permit insights into the needs of cross-disciplinary work in the area of cognition, child psychology and robotics.

UNISAL Major Achievement

1. Development of a VR simulation of the iCub to provide a discussion perspective for the development of the iCub leg and spine functionality during, crawling, sitting and transition phases.
2. Development of a MATLAB simulation of the control efforts for the lower limbs. This provides basic data needed on the control efforts and has been used in the development of the design specification.
3. Survey of mechanisms in spines and lower limbs in anthropomorphic robots.
4. Definition of the specification of the iCub spine, hips, leg and foot performance in collaboration with the other partners in the mechatronic design workpackage (UGDIST, SSSA, IST, TRL and EPFL). This work has developed through a series of design phases looking at the required performance and structure. This work has ensured effective integration of the components for the version 1 prototype to be produced later this year.
5. Stage design for the spine ensuring compact integrated fit with the shoulder and head designs. 2 designs for the hip ensuring integration with the spine, and 1 leg/foot design.
6. Design of a fully integrated lower body mechanical system.
7. Design, construction and initial testing on motor drive boards. In conjunction with UGDIST we have been considering electronic design options for the primary drive and control boards. A specification for the electronic system performance has been developed to address the full integration issues within the iCub
8. Design, construction and initial testing of torque sensing systems for the joints
9. Development of a new hand tracking mechanism for babies, in conjunction with UNIUP. It was noted that a system to track the motion of infant hands was a key need for the study of child behaviour, however, no effective methods achieving this tracking particularly for the fingers is available. Within the ROBOTCUB group a new hand and finger tracking systems (Project ANDRIANA) is developing systems specifically for applications with small children. It is believed that it may be possible to extend this to the primate studies at UNIFE.
10. Collaborated in a survey of actuators and sensing technologies.
11. Report on the design, development and application of pneumatic Muscle Actuators (pMAs).
12. Outline collaboration with UGDIST on haptic control and feedback for a dextrous robotic hand.

UNISAL Published Papers

1. D.G.Caldwell, “Biomimetics in the development of Humanoid Robotics”, IARP Workshop on Dependable Robots in Human Environments, Salford, UK, 7-9 Sept. 2005.

2. N.G. Tsagarakis and D.G.Caldwell, “A Compliant exoskeleton for multi-planar upper limb physiotherapy and training”, Advanced Robotics, Invited Paper, (submitted)
3. V.Tsachouridis, N.G.Tsagarakis, and D.G.Caldwell “Control System Design for a Compliant Actuated Joint using On/Off Solenoid Valves”, IEE Control Theory and Application (submitted).
4. S.Davis and D.G.Caldwell “Braid Effects on Contractile Range and Friction Modelling in pneumatic Muscle Actuators”, Int. J. Robotics Research, (submitted).
5. S.Davis, J.O.Gray and D G Caldwell, “Bimimetric Design for Bipedal/Quadrupedal Motion in a Robotic Primate”, Journal of Intelligent and Robotic Systems (submitted).

UNISAL Appearance on press

“Ciao l’ambasciatore”, Manchester Evening News, June 2004.

“”, 60 sec segment on North West Tonight, Regional Television programme, 15th April 2005

UINISAL Major Equipments

No major equipment purchased.

UNISAL Deviation from Planned Activity

No major deviations from the planned activities.

4.2.9 Ecole Polytechnique Federale de Lausanne (EPFL)

EPFL Major Achievements

The ASL3 laboratory at EPFL contributed principally to WP5 and WP6, through the development of ANN-based algorithms for recognition and reproduction of arbitrary gestures, as well as for a robust imitation of goal-directed reaching motions. It also worked towards neural modelling of the brain mechanisms underlying human ability to imitate. The BIRG laboratory at EPFL contributed principally to WP7 through the development of algorithms for locomotion (crawling), as well as through precise requirements for the CUB.

EPFL Published Papers

The following papers were submitted as part of RobotCub:

1. A. Maurer, M. Hersch & A. Billard, Extended Hopfield Network for Learning Sequences: Application to Gesture Recognition,, International Conference on Artificial Neural Networks, International Conference on Artificial Neural Networks, Warshaw, Sept. 12-14 2005.
2. L. Righetti & A-J. Ijspeert, Dynamical systems study of locomotor patterns, Physica D (In Press), 2005.
3. E. Sauser & A. Billard, Neural Selectivity and Interference in Self versus Others-Representation of Motions, Conference on Development, MarateaBrain Development and Cognition in Human Infants: From Action to Cognition, Maratea, Italy, October 1-6 2005.
4. E. Sauser & A. Billard, Parallel and Distributed Neural Models of the Ideomotor Principle, Neural Networks (submitted), Aug. 2005.
5. J. Buchli, L. Righetti, and A.J. Ijspeert. A dynamical systems approach to learning: a frequency-adaptive hopper robot. In /Proceedings of the VIIIth European Conference on Artificial Life ECAL 2005/, Lecture Notes in Artificial Intelligence. Springer Verlag, 2005. in press.
6. L. Righetti, J. Buchli, and A.J. Ijspeert. From Dynamic Hebbian Learning for Oscillators to Adaptive Central Pattern Generators. In Proceedings of the Third International Symposium on Adaptive Motion in Animals and Machines (AMAM2005), 2005 (in press).
7. B. Petreska & A. Billard, Computational Model of Apraxia, Conference on Development, MarateaBrain Development and Cognition in Human Infants: From Action to Cognition, Maratea, Italy, October 1-6 2005.
8. Hersch, M. & Billard, A.G. (2005), An internal multimodal model for imitating 3D reaching movements, Poster presented at the AISB Symposium: Imitation in Animals and Artifacts, 12-15 April 2005.
9. Righetti, L., Buchli, J. & Ijspeert, A.J., Dynamic Hebbian learning for adaptive frequency oscillators, Physica D (Submitted), 2005.

4.2.10 Telerobot S.r.l. (TLR)

TLR Major Achievements

The main activities done in this first period are:

- Definition of a common model to be used as base for the design of the iCub.
- Definition of the coding standard for the mechanical design and documentation.
- Realization of the DWG (Autocad) templates for the iCub.
- Definition of first approximation weight goal of each iCub group.
- Realization and successful test of new tubing for tendon drive based on PTFE thin wall inner pipe and external stainless steel spiral spring.
- Design and realization of high power density rotary actuator based on frameless Harmonic drive gearbox and houseless brushless motor.
- Main axis upper body design (shoulder+ elbow) with the new servomotor.
- Integration of the mechanical design and contribution to the design issued raised by the other groups in the consortium.
- Mechanical design activities coordination.

4.2.11 European Brain Research Institute (EBRI)

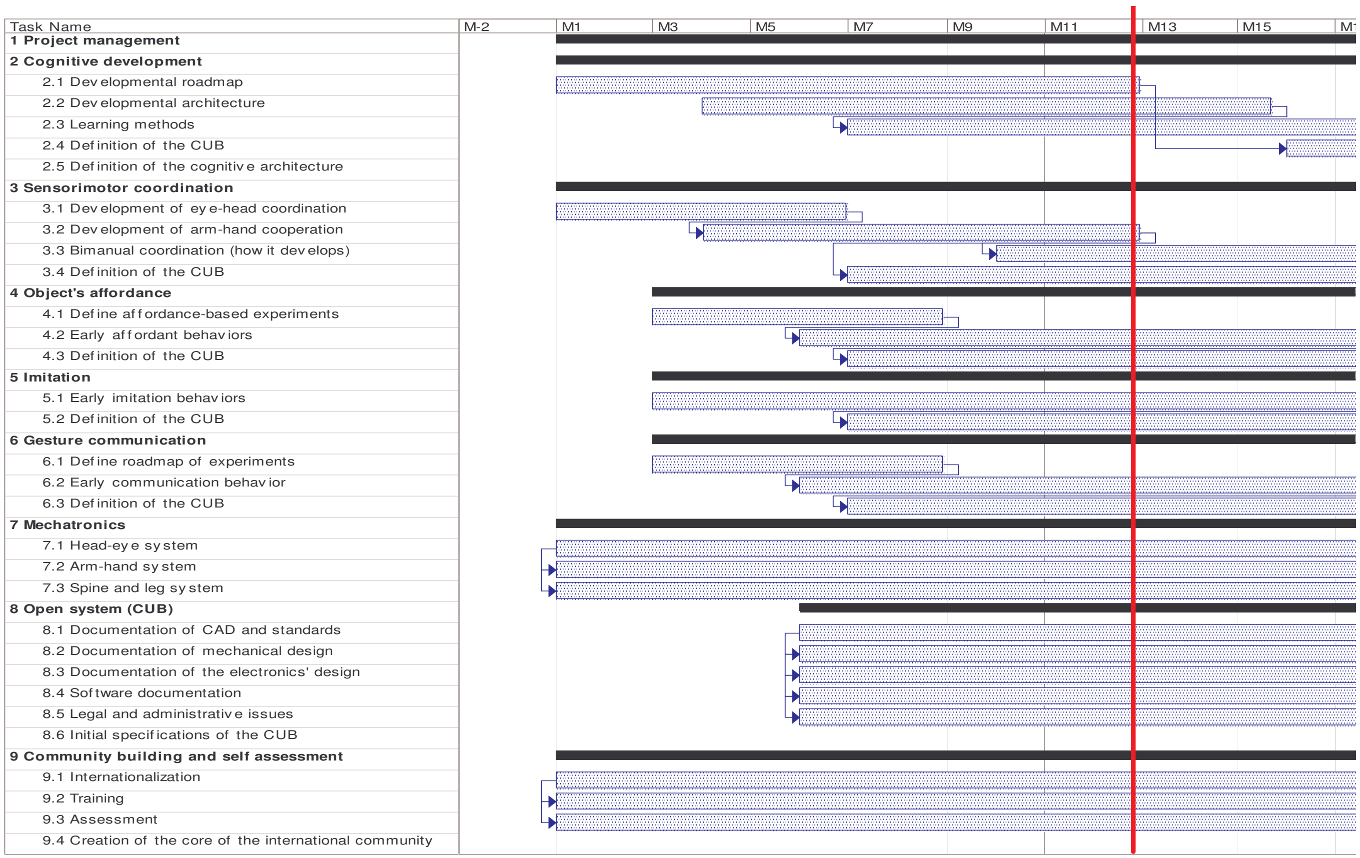
EBRI participation to the project is essentially to contribute knowledge about sensorimotor coordination in humans and suggesting biologically interesting solutions of the control algorithms. The budgeted financial participation is, accordingly, quite limited.

EBRI Deviation from planned activity

In this initial part of the project EBRI's participation has been mostly through meetings between the coordinator and Prof. Bizzi to discuss the overall experimental plan of the projects. The participation of EBRI to the project's activities during the first year of the project has been much smaller than planned because of Prof. Bizzi's unforeseen engagements at MIT.

It is expected that EBRI participation will become more active and continuous during the second year because of the full-time presence of Prof. Bizzi at EBRI in Rome.

4.3 Project timetable and status



The time table indicated above is still valid in its general structure.
A few deviations and changes are reported below:

1. T2.1: Developmental Roadmap. During the first year it was decided to change the duration of activity described by T2.1. This activity was aimed at the preparation of a document describing the roadmap of human development. The consortium has decided to extend the scope of this document by including also a description of a possible implementation of such roadmap in an artificial system. This activity will continue for the first three years of the project and will be reported as an on-going document whose initial basis is in deliverable D2.1.
2. T3.1 Bimanual Coordination. This activity has not started yet but will be maintained as an important component of the project.

5 Other issues

Nothing to mention

6 ANNEX 1 – Plan for using and disseminating the knowledge

6.1 Exploitable knowledge and its use.

Considering that this is the first year of the project there are no results with potential for industrial and commercial application in research or for developing, creating or marketing a product or process or for creating or providing a service. On the other hand several actions were undertaken to firmly establish the "open" licensing strategy of the project including the definition and signing of the consortium agreement, the rules for dissemination of the iCub design documents and manuals, the protection of the trademarks of the project (logos and main names).

6.2 Dissemination of knowledge

The dissemination activities of the consortium are reported in the section of this document describing the activities of WP9 (Community Building and Self Assessment). The following table summarizes the activities carried out during the first year.

Type	Audience
Project's Press Release	General Public
No. 18 Press appearances (see section 3.9.5 for details list)	General Public and Industry
No. 56 Scientific Publication	Research
July 2005 - Organization of 1st Open Day (see section 3.9.2 for details)	Research
Participation to kick-off meeting of other projects and scientific events (see section 3.9.2 for details)	Research
Participation in organization of conferences and workshops as part of training activities (see section 3.9.3 for details)	Research
Preparation and maintenance of project's website page: www.robotcub.org	Research, General Public and Industry
Preparation of RobotCub Poster	Research

6.3 Publishable results

Most of the papers and publications coming from the RobotCub projects as well as all the working documents produced can be found in the RobotCub's web site http://www.robotcub.org

A list of all papers published or in the press is presented in alphabetical order.

1. Beira R., M. Lopes, J. Santos-Victor, A. Bernardino, G. Metta, F. Becchi, R. Saltaren, Design of the Robot-Cub (iCub) Head, submitted to ICRA06, Orlando, USA
2. Blow M., K. Dautenhahn, A. Appleby, C. L. Nehaniv, D. Lee, The Art of Designing Robot Faces - Dimensions for Human-Robot Interaction, Human-Robot Interaction 2006, Assoc. for Computing Machinery Press, (submitted).
3. Buchli J., L. Righetti, and A.J. Ijspeert. A dynamical systems approach to learning: a frequency-adaptive hopper robot. In /Proceedings of the VIIIth European Conference on Artificial Life ECAL 2005/, Lecture Notes in Artificial Intelligence. Springer Verlag, 2005. in press.
4. Caldwell D.G., "Biomimetics in the development of Humanoid Robotics", IARP Workshop on Dependable Robots in Human Environments, Salford, UK, 7-9 Sept. 2005.
5. Carrozza , G. M.C., Cappiello, G.Stellin, F. Zaccone, F. Vecchi, S. Micera, P.Dario, "A cosmetic prosthetic hand with tendon driver underactuated mechanism, compliant joints and EMG control: ongoing research and preliminary results", International Conference on Robotics and Automation, ICRA 2005 Barcelona, Spain, April 16-22. 2005.
6. Davis S. and D.G.Caldwell "Braid Effects on Contractile Range and Friction Modelling in pneumatic Muscle Actuators", Int. J. Robotics Research, (submitted).
7. Davis S., J.O.Gray and D G Caldwell, "Bimimetric Design for Bipedal/Quadrupedal Motion in a Robotic Primate", Journal of Intelligent and Robotic Systems (submitted).
8. Fadiga L, Craighero L, Olivier E. Human motor cortex excitability during the perception of others' action. Curr Opin Neurobiol. 15:213-8 (2005)
9. Fadiga L., Craighero L. (in press) Hand actions and speech representation in Broca's area. Cortex
10. Fadiga L., Craighero L., Roy A. Broca's Region: a Speech Area?, in Grodzinky Y and Amunts K (Eds) The Broca's Area, Oxford University Press, (in press)
11. Fadiga L., Craighero L., Fabbri Destro M., Finos L., Cotillon-Williams N., Smith A.T., Castiello U., Language in shadow, submitted.
12. Gomez, G., Hernandez, A., Eggenberger Hotz, P., and Pfeifer, R. (Submitted). An adaptive learning mechanism for teaching an anthropomorphic robot hand to grasp.
13. Gomez, G., Hernandez, A., Eggenberger Hotz, P., and Pfeifer, R. (In press). An adaptive learning mechanism for teaching a robot to grasp. To appear in Proc. of AMAM 2005.
14. Gomez, G. Lungarella, M., Eggenberger, P., Matsushita, K., and Pfeifer, R. (2004). Simulating Development in a Real Robot. Poster in ICDL04 in San Diego.

15. Gredebäck, G., von Hofsten, C., Karlsson,J., and Aus, K. (2005) The development of two-dimensional tracking: A longitudinal study of circular visual pursuit. Experimental Brain Research, 163, 204 – 213.
16. Gronqvist, H., Gredeback, G. & von Hofsten, C (2005) Developmental asymmetries between horizontal and vertical tracking. Submitted manuscript.
17. Hernandez, A., Yokoi, H., Arai, T., Yu, W. (In press). "FES as Biofeedback for an EMG Controlled Prosthetic Hand". Proceedings Tencon05 . Melbourne Australia. Nov 21-24, 2005.
18. Hersch, M. & Billard, A.G. (2005), An internal multimodal model for imitating 3D reaching movements, Poster presented at the AISB Symposium: Imitation in Animals and Artifacts, 12-15 April 2005.
19. von Hofsten, C., Dahlström, E., & Fredriksson, Y. (2005) 12-month–old infants' perception of attention direction in static video images. Infancy, 8, 217-231.
20. von Hofsten, C. (2005) The development of prospective control in looking. In J. Lockman and J. Rieser (Eds.) Action as an Organizer of Perception and Cognition during Learning and Development. Minnesota symposium on Child Psychology. Vol 33.
21. von Hofsten, C. (2005) Development of prehension. In B. Hopkins (Ed.) Cambridge Encyclopedia of Child Development. Pp.
22. Lopes M., A. Bernardino and J. Santos-Victor, A Developmental Roadmap for Task Learning by Imitation in Humanoid Robots: Baltazar's Story, AISB 2005 Symposium on Imitation in Animals and Artifacts, University of Hertfordshire, UK, 12-14 April 2005
23. Lopes M., R. Beira, M. Praça, J. Santos-Victor, An anthropomorphic robot torso for imitation: design and experiments, IROS - IEEE/RSJ International Conference on Intelligent Robots and Systems, Sendai, Japan, September 28 - October 2, 2004
24. Lopes M., Jose' Santos-Victor, Sensory-Motor Coordination for Redundant Robots, submitted to ICRA06, Orlando, USA
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26. Maurer A., M. Hersch & A. Billard, Extended Hopfield Network for Learning Sequences: Application to Gesture Recognition,, International Conference on Artificial Neural Networks, International Conference on Artificial Neural Networks, Warshaw, Sept. 12-14 2005.
27. Metta, G., D. Vernon, G. Sandini. The RobotCub Approach to the Development of Cognition: Implications of Emergent Systems for a Common Research Agenda in Epigenetic Robotics. In Epigenetic Robotics workshop, Nara Japan, July 2005.
28. Mirza N. A., C. Nehaniv, R. te Boekhorst, and K. Dautenhahn. Robot self-characterisation of experience using trajectories in sensory-motor phase space. In Proc. of Fifth International Workshop on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems (EpiRob2005), pages 143-144. Lund University Cognitive Studies, 2005.
29. Mirza N. A., C. L. Nehaniv, K. Dautenhahn, and R. te Boekhorst. Using sensory-motor phaseplots to characterise robot-environment interactions. In Proc. of 6th IEEE International Symposium on Computational Intelligence in Robotics and Automation, 2005.

30. Mirza N. A., C. L. Nehaniv, K. Dautenhahn, and R. te Boekhorst. Using temporal information distance to locate sensorimotor experience in a metric space. In Proc. of 2005 IEEE Congress on Evolutionary Computation, volume 1, pages 150-157, 2005.
31. Natale L., F. Orabona, F. Berton, G. Metta, G. Sandini. From sensorimotor development to object perception. Accepted to the International Conference of Humanoids Robotics. 2005.
32. Natale L., F. Orabona, G. Metta, G. Sandini. Exploring the world through grasping: a developmental approach. In the 6th CIRA Symposium, Espoo, Finland, June 27-30, 2005.
33. Natale L., G. Metta, G. Sandini. Learning haptic representation of objects. In International Conference on Intelligent Manipulation and Grasping. Genoa - Italy July 1-2, 2004.
34. Natale L., G. Metta, G. Sandini. A Developmental Approach to Grasping. In Developmental Robotics. A 2005 AAAI Spring Symposium. March 21-23rd, 2005. Stanford University, Stanford, CA, USA.
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36. Nehaniv C. L.. Sensorimotor experience and its metrics. In Proc. of 2005 IEEE Congress on Evolutionary Computation, 2005.
37. Olsson L., C. L. Nehaniv, and D. Polani. Discovering motion flow by temporal-informational correlations in sensors. In L. Berthouze, H. Kozima, C. G. Prince, G. Sandini, G. Stojanov, G. Metta, and C Balkenius, editors, Proceedings of the Fifth International Workshop on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems, pages 117-120. Lund University Cognitive Studies, 2005.
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