Project IST-004370

RobotCub

Development of the iCub Cognitive Humanoid Robot

Instrument: Integrated Project
Thematic Priority: IST – Cognitive Systems

Fourth Periodic Activity Report

Months 37-48

Period covered from **01/09/2007** to **31/8/2008**

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Start date of project: **01/09/2004**

Duration: **60 months**

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

Revision: **1.0**

Executive Summary

Project Summary

RobotCub is an Integrated Project funded by European Commission through its Cognitive Systems and Robotics Unit (E5) under the Information Society Technologies component of the Sixth Framework Programme (FP6). The project was launched on the 1st of September 2004 and will run for a total of 60 months. The consortium is composed of 10 European research centres and is complemented by three research centres in the USA and three in Japan, all specialists in robotics, neuroscience, and developmental psychology.

The project has two main goals: (1) to create a new advanced humanoid robot – the iCub[1] – to support Community research on embodied cognition, and (2) to advance our understanding of several key issues in cognition by exploiting this platform in the investigation of cognitive capabilities.

RobotCub is a highly interdisciplinary teamwork-driven project: it depends crucially on the many inputs of all ten of its partners: from neuroscience and developmental psychology, through dynamical modelling, computer science, and robotics, to human-robot interaction. The total funding for the project is €8.5 million, a significant component of which (approx. 25%) is targeted at providing up to eight [2]copies of the iCub cognitive humanoid robot for the research community at large.

The iCub itself is a 53 degree-of-freedom humanoid robot of the same size as a three/four year-old child. It can crawl on all fours and sit up. Its hands allow dexterous manipulation and its head and eyes are fully articulated. It has visual, vestibular, auditory, and haptic[3] sensory capabilities. The iCub is an open systems platform: researchers can use it and customize it freely[4]. It is intended to become the research platform of choice, with people being able to exploit it quickly and easily, share results, and benefit from the work of other users.

Over the past twelve months, the principal objectives for the period have been substantially achieved:

SO-1. The preparation and update of a roadmap of human cognitive development, with scenarios (e.g. reaching, grasping) and empirical investigations (ways to demonstrate the behavior of the robot in the various scenarios).

SO-2. The complete fabrication of the iCub. Although amenable to improvements, the iCub is in a state whereby multiple copies have been built and are actively used in at least two different institutions (together with several components: e.g. heads).

SO-3. The initial results of the implementation of cognitive abilities. Although there's some slippage here in the timing with respect to the original plan, all WPs have now ported their work on the iCub following the iCub software standards.

[1] Cub stand for *Cognitive Universal Body*.
[2] Six platforms were finally awarded to research institutions in Europe, one delivered at the moment of writing.
[3] Under development.
[4] The iCub is freely licensed under the GNU General Public Licence.

SO-4. New tests and technology evaluation is continuing. While this cannot influence the current realization of the iCub's, it is possible to start planning a second iteration with some technological improvements: e.g. joint-level torque control, smoother trajectory generation.

SO-5. Community building has continued at a good pace. The iCub software architecture for example is being used to develop robot control software or in general to support cognitive systems work in several laboratory outside the RobotCub consortium.

SO-6. The possibility of commercializing the iCub is still under consideration and a specific deliverable has been prepared summarizing the discussion. So far, the new partner, IIT, is taking care of proving the know-how and manufacturing abilities when a new robot is required. In this respect, at the moment of writing 14 copies of the iCub are foreseen (plus the prototype in Genoa).

Progress and Results

Although the overall timing of the project is very tight, the project remains on schedule to meet most of its major milestones, with some slippage on the development of the cognitive architecture (as from last period) but some compensating advances on the development of the complementary software architecture.

The following are a selection of highlight of the results achieved by the project over the past 12 months. Many more achievements are detailed in Section 2.

1. More than 70 papers have been published (or are currently submitted or accepted) during last 12 months (compare to 40 last year). A full list is provided in Section 3.
2. The duplication in 6 copies of the iCub prototype. Current design has been frozen in "version 1" and duplication started. A few missing components that for practical reasons were not delivered at the first batch of the Open Call will be delivered before the end of the project.
3. New documentation structure on the RobotCub Wiki in the form of a manual. This will include all necessary documentation required to duplicate, assemble, install and run the iCub both hardware and software (D8.5).
4. Porting of all subsystems developed in the various WPs into the iCub making all software fully compatible. This is a major advancement into the integration of the software into the "cognitive spine" mentioned in the previous report.
5. The Open Call was completed (UGDIST).
6. The iCub was made to crawl. More work is required but the robot successfully endured the test.
7. The rhythmic and discrete controller has been ported and used extensively on the iCub (EPFL-UGDIST-IIT).
8. The body-schema learning was run on the iCub and used to reach for a visually identified target (EPFL-UGDIST-IIT).
9. The affordance learning has been ported to the iCub (IST-UGDIST-IIT).
10. Integration of the information distance and interaction histories modules into the iCub (HERTS-UGDIST-IIT).
11. Several neurophysiology experiments were completed (UNIFE, UNIUP)

Publications

A full list of all publications can be found in Section 3: Consortium Management. Approximately 70 papers have been published in the past year. PDF copies of publications can be found both on the project website (http://www.robotcub.org/misc/papers/papers.html) and on the accompanying CD.

Dissemination activities

Our primary vehicle for dissemination is through publication of journal and conference papers. In addition, we have issued a call for proposals and we have engaged in a variety of more informal dissemination activities. These are catalogued in Annex I, Section 2 below.

Use of the knowledge generated by the project

As noted last year, the knowledge being generated by the project is not yet at the point where it can be used, in the sense of being taken up by third parties in a transparent manner. As stated in Annex I, Section 1 below, the RobotCub project is dedicated to the production of free-available open source results license under the GNU General Public Licence. Consequently, direct commercial exploitation is precluded. However, our explicit goal is to make the iCub humanoid robot the platform of choice for empirical research in embodied cognition and, to that end, our focus is on producing industrial grade designs and software, and making them freely available to the community on the RobotCub CVS repository.

In spite of the restrictions of the GPL, several other research projects started using components of our software, in many cases unnoticed by the RobotCub consortium. For example, FP7 projects ITALK adopted the iCub as standard platform and is now actively contributing with an open source simulator. The project URUS used Yarp (the iCub software architecture) and developed further on it (in particular an XML layer that formally describes applications). The project CHRIS (also FP7) is planning to adopt Yarp as the basic control structure. The project SEARISE is planning to use a good subset of Yarp for controlling a trinocular head. On the hardware side, collaboration with the University of Karlsruhe has now led to the development of a pair of legs loosely based on the iCub design.

Diagrams & photos of the work

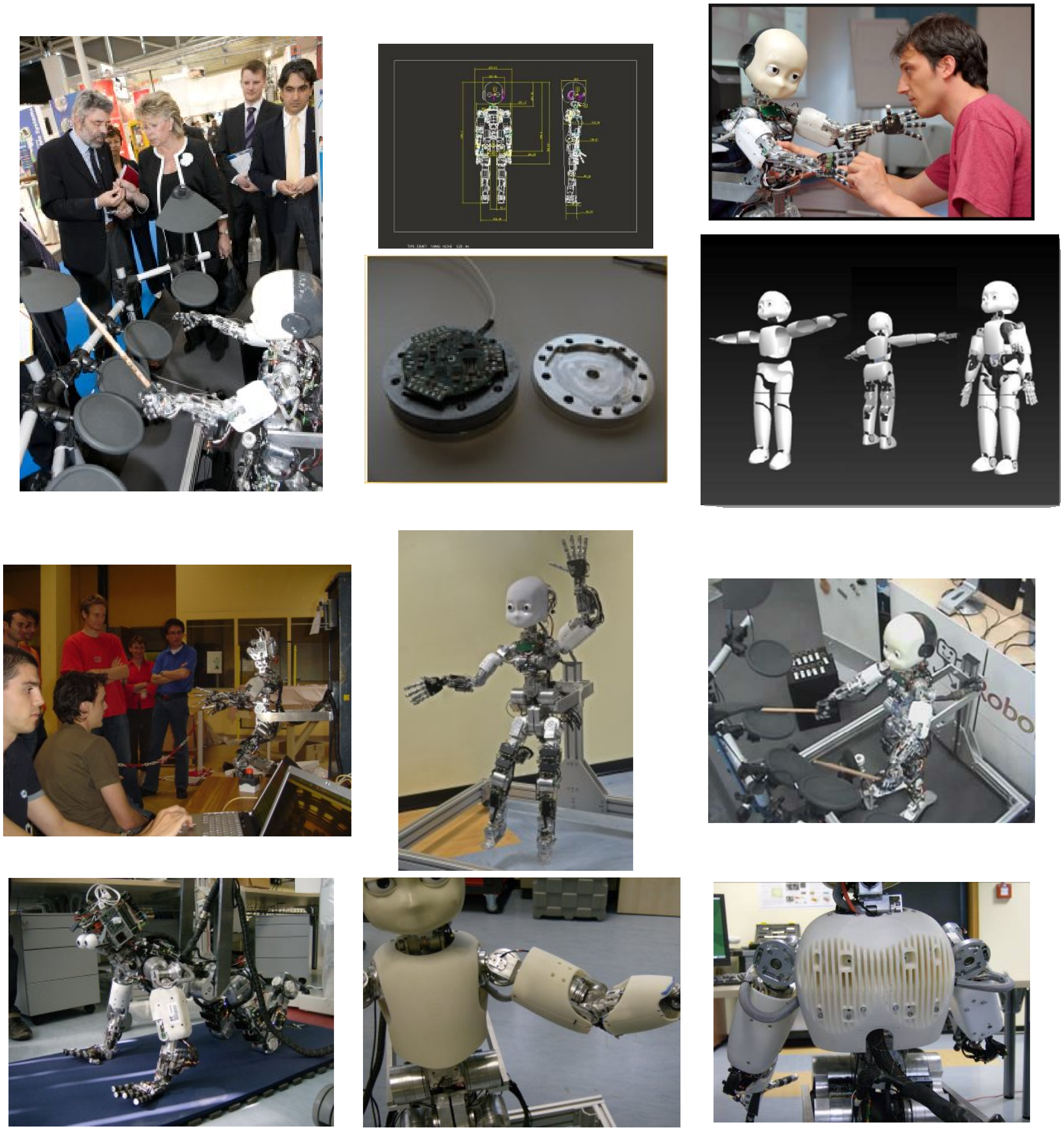


Table 1: From left to right, from top to bottom: the visit of EU Commissioner Ms. Reading at the RobotCub stand at Automatica 2008; iCub 2D chart showing dimensions and the miniaturization of force/torque sensor electronics; the design of the iCub cover (new); the iCub in Paris at UPMC (first delivery of the Open Call); a picture of the iCub at IIT; the iCub playing drums at Automatica 2008; the iCub crawling; part of the cover has been realized in rapid prototyping material (SLS); particular of the back of the cover made in SLS.

Section 1 – Project objectives and major achievements during the reporting period

Relation to the Current State-of-the-Art

To the best of our knowledge, the iCub cognitive humanoid robot is beyond the current state-of-the-art in developmental robotics. The empirical work on cognitive neuroscience that is being carried out by the partners is leading edge research. Together, these research efforts have led to approximately 70 publications in the past year.

Review Recommendations and Consequent Actions

The Report on Review 3 made three recommendations. The following revisits those recommendations and sets out the actions that were taken as a result.

1. Some of last year's recommendations, being only partially met, still require attention (see JB's recommendation 1 and PFD's recommendation 4)
    a. JB's recommendation 1.

       The full text is reported below:

       "1. Meet last year's recommendations. Before you give out robots! Certainly before the summer school. To summarise (focusing on what is still left undone), these were:

       (a) The 'spine' . . . should be demonstrated by at least prototype versions of the D2.1:16 scenarios, to be accessible from boot on the distributed iCub. We wanted to see one such prototype scenario at the 36 month review (but only saw robot yoga!), and at least skeletons of all five for the 42 month release.

       (b) Coordinators for the computer vision, the cognitive architecture, and the phylogenetic / behaviour module library — someone(s) to moderate progress and the module-selection process for distribution.

       (c) Dissemination of the component technologies.

       (d) Safety statement: This is pretty good, but what do you mean by "accompany"? Will it be pasted to the robot itself? Also, you only mention the mechanical danger, but there is electrical danger as well. You may want to specifically mention not being suitable for children or pets, since it will probably engage the interest of both.

       (e) The call is done.

       (f) We would like you to consider marketing — at least keep a list of people who approach you (if anyone does) so that this issue can be addressed later."

       This recommendation was well made and well taken: we agree on all points. Let's summarize here what actions have been started and/or carried out to comply with this recommendation:

        a. The spine is in much better shape this year. All modules from the different WP have been ported to the iCub. This required not less than ten visits of various groups from all partners to Genoa. Each visit was approximately one week long. All partners have now a much better knowledge about the details of the iCub. The design of the architecture is basically the same of last year since it included already attention and reaching which are the aspects that have been mostly covered so far.

b. Coordinators for "vision" and "software" have been appointed in the persons of Alexandre Bernardino (IST) and Lorenzo Natale (UGDIST/IIT).

c. As mentioned earlier, the software architecture (Yarp) is being already used outside the consortium (one of the technologies developed by RobotCub). On the hardware side, the controller cards and structure of the iCub has been used into the new legs being developed together with the University of Karlsruhe.

d. The safety statements and disclaimer are now into the contract and people have been trained both at the summer school and specifically as part of the Open Call activities (technicians from the "winners" visited Genoa for one month).

e. The call is done and construction is progressing. Robot number six is under construction and the first Open Call robot (called 3 or iCub-paris-01) has been delivered.

f. We considered marketing seriously and an initial investigation on the possible forms of a spin-off company has been considered. IIT is acting at the moment as the recipient of the iCub requests. Currently there are plans to build up to iCub number 15. 3 more copies are under negotiation as part of a new FP7 project. One has been officially requested very recently and one more might be awarded as the seventh robot of the Open Call. The count would then be 20 (including the prototype in Genoa)

b. PFD's recommendation: "*I made a comment last year on risk management, recommending that the project make tables identifying the links between functions identified in the scenarios and the implementation of these functions in distinct WPs. There was a response indicating that this has now been done via a different method. The recommendation stands (and it is fine if it can be addressed by a different method) to clearly identify how defined and required behavioral capabilities are allocated to WPs (i.e. defining responsibility).*"

   a. The same procedure of last year has been maintained. The risk of integration has been well considered by finally appointing two responsible persons for vision and software integration respectively (Alexandre Bernardino and Lorenzo Natale) and by proceeding with a strong plan of direct integration on the iCub prototype which was used as the reference against which testing the actual software development. We still maintain the table of responsibilities as mentioned in the last period.

2. To set up complete demo scenarios based on partner interaction within and across work packages (see in particular PFD's suggestions) and implement them in time for delivery to the Call winners, of the iCubs (see AB's recommendations and also PFD's recommendation 2(?) and JB's recommendations 3 and 4).

   a. PFD's recommendation 2: *"We recommended that for the next review every WP should have something running on the iCub, and that there should be interaction within and across WPs, in the form of interesting scenarios. Here are some more specific ideas:…"*

b. AB's recommendation: *"The cognitive manipulation scenarios described in "Annex 1 – 'Description of Work', Year 3 Revision of Section 8 - Detailed Implementation Plan Months 37-54" should be made more specific and turned into concrete demonstrator scenarios for each of the WP 3 to 6."*
    a. Certainly these comments are also well taken since the risk of integration in a project like RobotCub is very high: this has been mitigated by defining a solid software architecture (from the beginning, thus giving time to the developers to learn and contribute to it) with reasonable specifications for modules (being these mapped one to one on the Yarp modules), defining appropriate documentation, and finally by proceeding with a tight schedule of "development" meetings in Genoa to port the software directly on the iCub. We cannot claim that the work is finished but we can certainly say that the system is in a better shape this year.

3. Work on the iCub documentation (D8.5) should commence as soon as possible.
    a. This has been started and the deliverable is available in full as a Wiki (http://eris.liralab.it/wiki/Manual). The manual contains all details that have been turned into some written format so far. It includes chapters for the hardware structure, data sheets, for the robot calibration procedures, details of the protocols (e.g. CAN bus), definition of standards for coding the kinematics and dynamics of the iCub, instructions on how to install the software and use it, on the iCub specific software, and will contain chapters on standardization of programming styles. The documentation standards are also included. Clearly, there is still much to do in this respect, but now the documentation of the iCub has a clear single entry point and an almost linear manual.

To summarize, the requirements of integration are captured by two aspects of the iCub development process:

- The Cognitive Architecture: still available at http://eris.liralab.it/wiki/ICub_software_architecture which is available from the manual (D8.5).
- The full documentation of integrated modules defined as "applications". These "applications" instantiate full behaviors (from the cognitive spine) which consist in turn of several Yarp modules. This documentation is available from: http://eris.liralab.it/iCub/dox/html/group__icub__applications.html

Objectives for the Current Period

We had many individual objectives for the current period, all of which are well-documented in the individual work packages, but two overarching goals of our work for the year stand out clearly. These are:

1. The completion of the Open Call and the manufacturing of several copies of the iCub.
2. The porting/integration of individual WPs work onto the iCub.

As will be evident from the results listed in the Executive Summary, all of these two objectives have been achieved.

Section 1 – Workpackage progress of the period

WP1 – Management

The activity and results of this Workpackage are reported in Section 3 of this report.

WP2 – Cognitive Development

Workpackage objectives

In this workpackage, we will 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 will 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). We will study and model how young children learn procedures to accomplish goals, how they learn new concepts, and how they learn to improve plans of actions. This research will be strongly driven by studies of developmental psychology and cognitive neuroscience and it will result in a physical implementation on an artificial system.

This work-package then will develop a conceptual framework that forms the foundation of the RobotCub project. It 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. It will explore neuro-physiological 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. It will present a roadmap that uses the phylogeny and ontogeny of natural systems to define the innate skills with which iCub must be equipped so that it is capable of ontogenic development, to define the ontogenic process itself, and to show exactly how the iCub should be trained or to what environments it should be exposed to accomplish this ontogenic development (this would be an extension of the six-stage development plan above). Finally, it will address the creation and implementation of an architecture for cognition: a computational framework for the operational integration of the distinct capabilities and cognitive skills developed in WP3-6, and it will investigate the (very challenging) issue of theoretical unification of distinct models.

Progress towards objectives

Considerable effort has been expended in the past year in developing Deliverable D2.1. A Roadmap for the Development of Cognitive Capabilities in Humanoid Robots. However, less has been achieved on the cognitive architecture per se than might have been desired but this is due to a more pragmatic refocusing of our efforts in line with the reviewers' recommendations regarding the need to establish a sound working software environment centred initially on the phylogenetic capabilities. This effort has already been summarized in this report in the response to Recommendation 1 so we won't repeat it here. Instead we will highlight specific instances of scientific progress in this workpackage.

Note that this is the same wording used last year but in fact the recommendations still apply and we have devoted considerable effort in the implementation of the first version of the cognitive architecture on the iCub. Although we haven't refined the architecture we aim at transforming it from a "paper" architecture into a proper implementation running on the iCub.

UNIUP

Revision of the Cognitive Road Map. Substantial additions are available directly on the D2.1 and have been fully integrated into this new release of the deliverable.

UNIFE

Task 2.2: Explore neurophysiological and psychological models of these capabilities, noting where appropriate architectural considerations such as sub-system interdependencies that might shed light o the overall system organization.

We decided to study the development of a predictive behaviour during action observation in developing infants (UNIUP) and in children affected by Autism Spectrum Disorders (ASD) (both UNIUP and UNIFE). The predictive behaviour refers to eye movements during action observation and execution. The pattern of gazing 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 behaviour during action observation supports the direct matching hypothesis for action recognition. We have tracked the gaze of 8 high functioning autistic children while they were performing a modification of the Flanagan and Johansson paradigm (Nature, 424:769-771, 2003) by using a version of the TOBII system that allows the recordings also during a real action (i.e. not presented by a video clip). We have tested also 5 normal children as a control group. Moreover, we recorded also the kinematics parameters by using the QUALYSIS system (Qualysis, Sweden) in order to accurately correlate the movements of the eyes and of the arms, and to verify the presence of differences between ASD patients and normal control subjects. Results on eye movements are reported in Deliverable 3.1. Here are some new data arising from kinematics analysis:

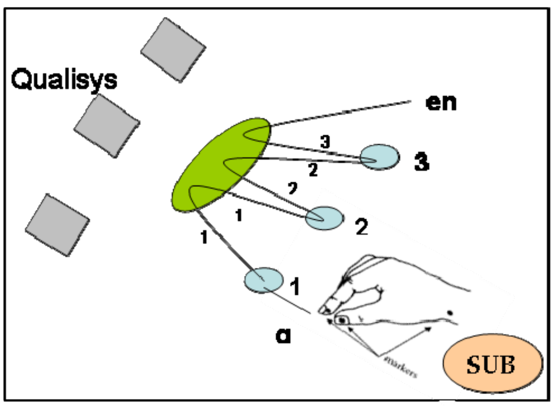


Fig. 1: Schematic representation of the experimental setting. The child sat with the right hand resting on the starting position. The session starts when the subjects grasps the first object and put it into a container. The action was repeated for each object.

Children were requested to grasp with their right hand some toys placed on the table and to put them into a container located in front of them (Fig. 1). At the beginning of each trial, participants' right hand was placed on the table in correspondence of the starting point. The hand/arm kinematics of the action performed by the subjects was recorded during the whole experiment. Three infrared-reflecting markers were fixed on the wrist, and on the tips of index finger and thumb. While the marker on the wrist provided the transport component of the hand reaching movement, the distance between the two markers positioned on fingertips was used to measure fingers aperture during grasping. Data were acquired by a high-speed kinematics tracking system (Qualisys, Sweden) providing the 3D position of each marker at a temporal resolution of 1 KHz.

The difficulty to keep the markers on the fingers and the incapacity to respect setting's requests, did not allow us to verify the pattern of hand grasping actions in ASD individuals. However, data on reaching were available and are summarized as follows:

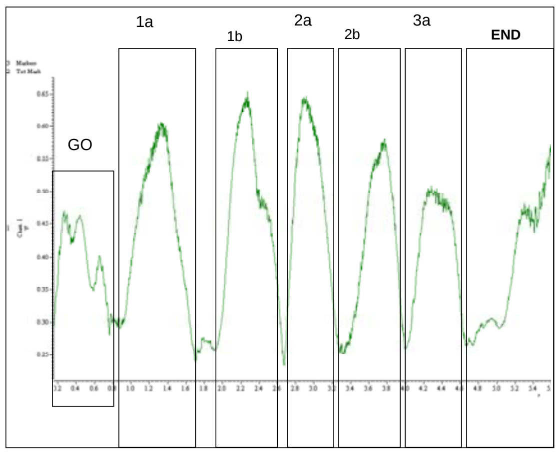


Fig. 2: Reaching velocity profiles during a typical trial. Numbers and letters as in Fig. 1.

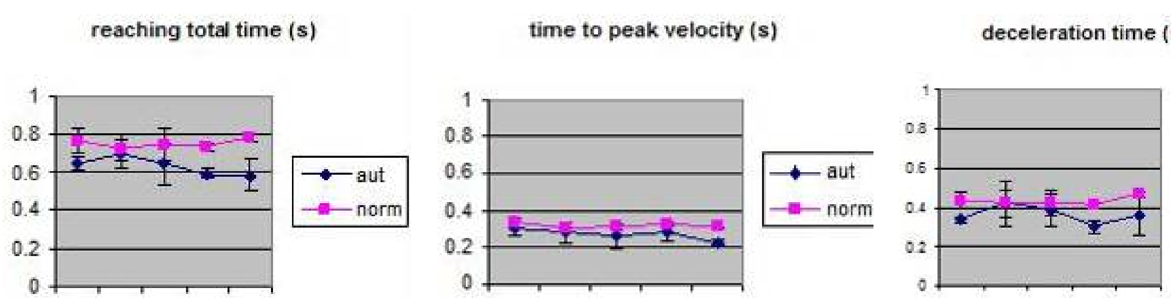


Fig. 3: Reaching time, time to peak and deceleration time as recorded from autistic children and from normal controls during the task depicted in Fig. 1. The sequence on abscissa is the same described in Fig. 2 (1a, 1b, 2a, 2b, 3a). Note that autistic children are faster than controls and that their performance trend improves with the progression of the task.

Future plans involve the replication of the experiment with another group of children in a simpler experimental setting. The setup we have in mind is placing task in which a wooden block is grasped from the table and placed on a support. During this task we aim at recording the kinematics by using an electromagnetic device that measures the 3D location of very small coils (diameter about 1 mm) fixed on the fingertips and on the wrist (Ascension Technology, USA).

Another contribution to WP2 is represented by the work we published recently on Current Biology in collaboration with the University of Parma. The amount of time spent in observing stimuli presented in different experimental conditions is an index which provides information on the mental state of subjects that are not able to verbally communicate, such as infants and non-human primates. We have used this approach to study action recognition in behaving monkeys.

We carried out three preferential looking-time experiments on macaques, modeled on previous work on human infants, to test whether macaques are sensitive to the functional efficacy of familiar goal-related hand motor acts performed by an experimenter in a given context and to examine to which extent this sensitivity also is present when observing non-goal-related or unusual goal-related motor acts. We demonstrate that macaque monkeys, similar to human infants, do indeed detect action efficacy by gazing longer at less efficient actions. However, they do so only when the observed behavior is directed to a perceptible and familiar goal. Our results show that the direct detection of the functional fitness of action, in relation to goals that have become familiar through previous experience, is the phylogenetic precursor of intentional understanding.

Task 2.4: Create a cognitive architecture: a computational framework for the operational integration of the distinct capabilities and cognitive skills developed in WP3-6; also investigate the issue of theoretical unification of distinct models.

We actively contributed to make a computational model of visuo-spatial attention to be integrated in the i-Cub cognitive architecture. The model is biologically plausible and gives a substantial contribute to Milestones **M1.2** and **M3.1**. Indeed, Visuospatial attention is one of the crucial aspects in visual perception and it allows the individual to select specific stimuli among the multiplicity of possible targets populating the environment.

UGDIST

Evolutionary Optimization of Kernel Machines

A variety of problems in robotics can be approached using machine learning techniques. Examples include creating kinematic and dynamic models of the robot, which are proven to be very hard to model analytically. A difficulty in applying machine learning techniques, however, is that their performance is usually critically dependent on the configuration parameters. The traditional way to optimize these is using a costly grid search, i.e. a 'trial-and-error' approach on a large set of configurations.

We applied evolutionary optimization methods for the optimization of the parameters and kernel function for the Least-Squares Support Vector Machine (LS-SVM). Empirical validation suggests that evolutionary methods are more efficient for this parameter optimization problem than grid search.

The current work is to make this viable to robotics by several structural modifications:

- Full online settings (all previous experiments were batch)
- Reasonable computational cost (training is typically time consuming)

Validation will be carried out on the iCub on the problem of learning the limbs dynamics from the force/torque sensor readings and measurements of the joint angles. We have already analyzed the problem from a parametric learning point of view as described in Deliverable 3.1.

IST

The work in this WP continued within the framework presented during the previous years of the project. As before, the main development stages were roughly organized as:

i) Learning about the self (sensory-motor coordination)
ii) Automatic attention
iii) Learning about objects (grasping and affordances)
iv) Learning about others (imitation)

The work on sensory-motor coordination has proceeded in the direction of learning sensorimotor maps. Amongst other aspects, effort has been devoted to: auto-calibration of the robot head from exploratory motion, learning techniques applied to continuous variables, predictive control based on vision.

The effort to design an automatic attention system for the iCub continued from last year and it consisted of joint work with the University of Zurich (UZ). This work was developed under YARP and integrated in the iCub SW repository.

The current version of the system is able to represent the perceived visual and auditory information in the so-called ego-sphere and attend to salient regions in the perceptual space. A mechanism of inhibition of return was also implemented.

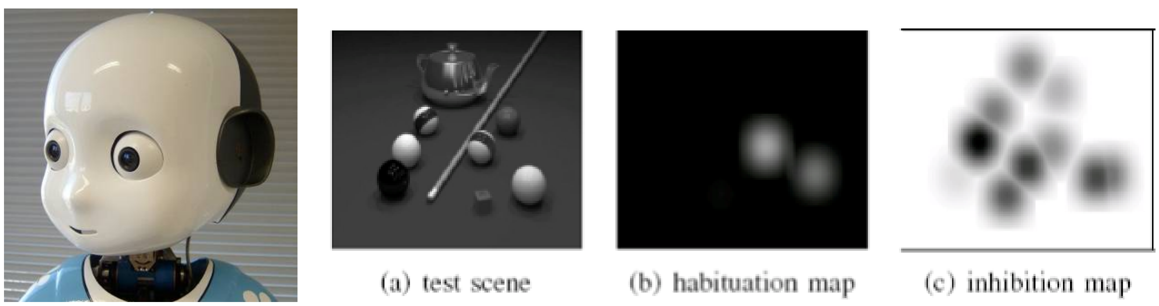


Fig. 4: Left: Experimental platform used for the development of the attention system. Right Input images, habituation (memory decay) and inhibition maps that contribute to the final saliency value.

During the fourth year we have improved this work and we extended it in two directions: the addition of top-down object representations and memory.

In our previous work, the egosphere included only saliency information, i.e. short term salient stimuli. During the fourth year, we included spatial memory of objects that can last for longer periods. The objects are learned by having a caregiver showing them to the robot. After this learning stage, the robot includes these salient objects in the representation that can be used later on, whenever the robot encounters similar objects in its explorations. This model will be used to switch the robot attention focus automatically between objects, independently of the robots field of vision or the visibility conditions of objects.

During the fourth year of the project, a substantial effort was directed to learning about object affordances (WP4), in particular the redesign and integration of almost all software modules. The basic idea is that the physics of the world can be modeled as the interplay between three entities: actions, objects and action outcomes. While these relations are not known a priori, they can be learned through observation and/or self-exploration. Once this interplay has been learned, it can be used in multiple ways: recognizing actions of others, predicting outcomes of actions, recognizing objects, planning, etc.

Deviations from the project work-programme

None.

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	2	M42/M48	M42/M48	UGDIST
D2.2	Software Implementation of the iCub Cognitive Architecture (version 1.0)	2	M48	M48	UGDIST

List of milestones

Milestone. No.	Milestone name	Workpackage no.	Date due
M3.1	Release of version 1.0 of the iCub software	2	M42[5]

[5] There's perhaps a typo in the detailed implementation plan since the milestone is set earlier than the corresponding deliverable D2.2.

WP3 – Sensorimotor Coordination

Workpackage objectives

In this work package, we will study and model the development of sensorimotor coordination and sensorimotor mapping. We will identify in what ways the sensorimotor system is determined by biology, how this is expressed in development, and how experience enters into the process in forming reliable and sophisticated tools for exploring and manipulating the outside world. Sensory information (visual, proprioceptive, auditory) necessary to organize goal-directed actions will be considered. These aspects will be investigated in humans and transferred into the cognitive architecture of the artificial system. There are two main objectives of WP3:

1. Model how sensorimotor systems evolve from sets of relatively independent mechanisms to unified functional systems. In particular, we will study and model the ontogenesis of looking and reaching for example by asking the following questions: How does gaze control evolve from the saccadic behavior of newborns to the precise and dynamic mode of control that takes into account both the movement of the actor and the motion of objects in the surrounding? How does reaching evolve from the crude coordination in newborns to the sophisticated and skillful manipulation in older children?

In addition, we will model how different sensorimotor maps (for gaze/head orienting, for reaching, for grasping, etc.) can be fused to form a subjectively unitary perception/action system. Among our investigations, the way by which the brain coordinates the different effectors, to form a pragmatic representation of the external world will be modeled by using neurophysiological, psychophysical, and robotics techniques.

2. Investigate and model the role of motor representation as tools serving not only action but also perception. This topic, partially covered by WP4, WP5 and WP6, clearly benefits from a unifying vision based on the idea that the motor system (at least at its representational level) forms the “active filter” carving out the passively perceived stimuli by means of attentional or “active perception” processes.

The contribution of WP3 to the implementation of sensorimotor coupling in the artificial system concerns, in more detail, (i) the ability of learning and exploiting object affordances in order to correctly grasp objects on the basis of their use; (ii) the ability of understanding and exploiting simple gestures to interact socially; (iii) the ability of learning new manipulation skills and new communicative gestures; (iv) the ability of correctly interpreting and imitating the gestures of a human demonstrator; (v) the ability to allocate attention and to predict own and others’ action outcomes. These objectives will be demonstrated through neurophysiological experiments in animal models, through psychophysics and neuroimaging in humans, through the testing of the robot’s cognitive abilities in realistic situations, such as the interactions with humans. Note that WP3 is only concerned about the sensorimotor bases of these behaviors while the details of affordances are explored in WP4, imitation in WP5 and gestural communication in WP6.

A focus of the effort in months 37-54 is the implementation of these phylogenetic abilities specifically for the iCub (refer to Deliverable D2.1, Section 15.6.1 for details).

Progress towards objectives

UNIFE

Task 3.1: Modeling the ontogenesis of gaze control and eye-head coordination, for example to study and model oculomotor involvement in orienting of visuospatial attention and visuomotor priming in object-directed actions.

The classic Posner paradigm was used, a very simple experimental design that allows to verify the efficiency of orienting of attention towards one visual hemifield, according to a central cue preceding the appearance of the to-be-responded target. The classical result is that reaction times to a target appearing in the cued hemifield are faster than those to a target appearing in the not cued one.

A particular type of cue that became recently investigated is gaze direction. It has been demonstrated that it is very efficient in directing attention, even if the probability of occurrence of the target in the cued hemifield is at chance level.

UNIFE and IST decided to investigate the efficiency of directing attention determined by the robot gaze in comparison to real human gaze, to face drawing gaze, and to arrow pointing. Moreover, differently from what previously done in literature, the to-be-responded target was an LED not lying on the same plane as the cue, but in the space between the cue and the subject (see Fig. 5). Two are the main goals of the experiment. The first one concerns the comparison of effectiveness in orienting of attention between the drawing of a schematic face apparently moving its eyes, and the real face of an experimenter seated in front of the subject and directing his gaze. In literature, only schematic drawings, or static face pictures have been used. The second goal addresses the way in which individuals consider the i-Cub: is it considered more similar to the drawing of a schematic face or to a real human face? In other words, is the effectiveness in orienting of attention determined by the direction of the i-Cub gaze, more similar to that obtained by observing gaze direction in a schematic face or in a human face?

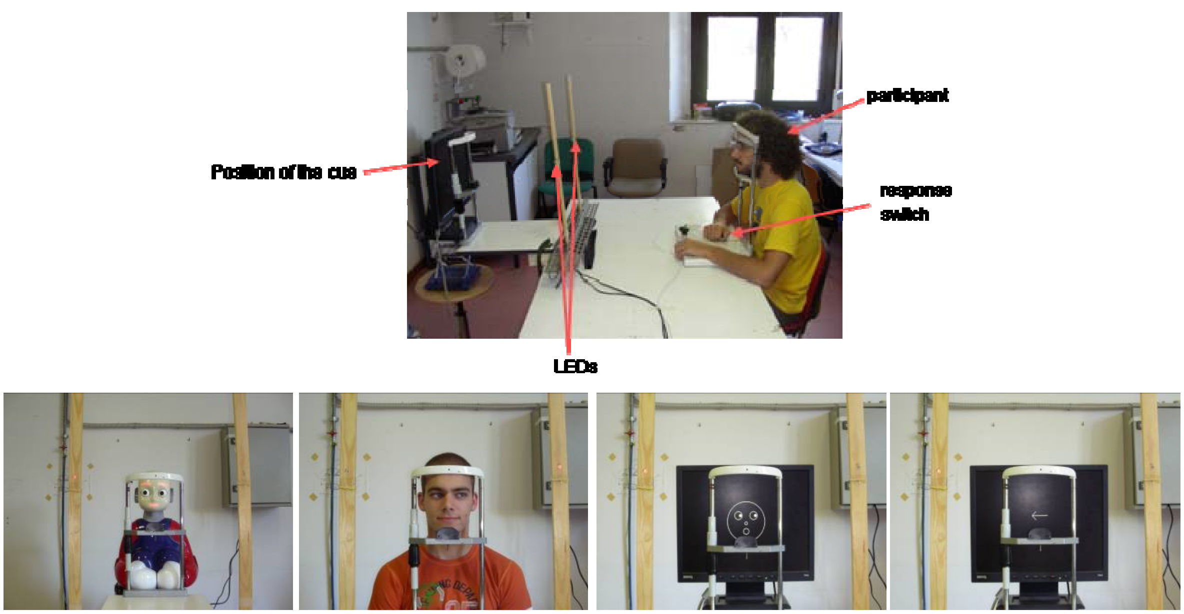


Fig. 5: Upper panel (see previous page), experimental set-up illustrating the position of the participant with respect the position of the to-be-responded target (LEDs) and the position of the cue. Lower panels, different possible cues: robot gaze, real human gaze, face drawing gaze, arrow pointing.

In a preliminary experiment we have submitted twelve subjects to an experimental design considering two intervals between cue and target presentation (short SOA, 200 ms; long SOA, 1000 ms) and two types of cues: non informative (probability of target occurrence at the cued position at chance level) and informative (80% of probability of target occurrence at the cued position) (see Fig 5). The results were somehow unclear and we attributed this to two factors. The first one was that the target was visible only by the participant and not by the experimenter/robot (in other words it was not shared). The second one was that too many variables were considered. Therefore, we decided to slightly modify the experimental set-up in order to simplify it and to really focus our study on the sharing of attention on the target position between participant and experimenter/robot.

Fig. 6: New experimental set-up in which the to-be-responded target (LEDs) is visible by both the participant (on the left) and the experimenter (on the right).

Consequently, we changed the position of the target (see Fig. 6) and we considered only the short SOA. Finally, we introduced catch trials (cue present, target absent: the participant has to refrain from responding) to ensure that responses are based on target detection and not triggered by cue appearance. At the present we are finishing to collect data. The future plans are to complete the experiment and to analyze the data.

Task 3.2: Modeling the ontogenesis of functional reaching and grasping of arm-hand cooperation (Grasping - haptic) to study aspects such as how to predict reaching/grasping outcomes and how to code action goals.

The aim of the present work was to test the ability to predict the instant at which a grasping hand touches an object. Our hypothesis was that, because of the activation of the mirror-neuron system, the same predictive process necessary for action execution should be active during observation. Experimental evidence indicates, however, that not only observed actions but also observed objects automatically activate observer’s motor repertoire. What happens, therefore, if the observed action is different from the one automatically evoked by the vision of the object? To answer this question we presented subjects with two different grasping actions: the one most suitable for the presented object and a less appropriate one. Subjects were required to detect the instant at which the demonstrator’s hand touched the object. In a further condition, subjects were required to detect the outcome of an action performed by a robotic arm moving with constant kinematics. Results showed that while in the case of robot grasping subjects responded before the touch instant, in the case of human grasping the response followed the touch instant, but occurred much earlier than simple reaction times. This demonstrates that subjects were able to predict the outcome of the seen action. The predictive capability was specifically enhanced during observation of the "suitable" grasping. We interpret these results as an indication of the synergic contribution of both object-related (canonical) and action-related (mirror) neurons during observation of actions directed towards graspable objects.

Task 3.5: Neuroscience and robotic experiments on the functional development of cortical representations (i.e. sensorimotor synergies and somatotopy).

a) Single neuron recordings in rats:

during the fourth year of the project we significantly advanced in exploring the possibility that a mirror-neuron system exist not only in primates but also in simpler animals such as rats. After design and realization of a multi-electrode amplifier (32 channels) we finished the experiments of intracortical microstimulation in the rat premotor/motor cortex, in collaboration with the University of Parma (Italy) and the University of Odessa (Ukraine). A new description of this experimental protocol is given in Deliverable 3.1. As stated in the previous report, we have been able to obtain the first neural recordings from a chronic implant. The detailed results and the state of the art of the project are now widely described in the new version of Deliverable 3.1.

Future plans foresee to start the action-observation experiment by showing observer rats with other animals performing various type of food retrieval/manipulation. The feasibility of training has been already assessed in our laboratory and the training procedure is described in Deliverable 3.1.

b) Single neuron recordings in monkeys:

visual responses in the monkey ventral premotor cortex have been explored since long time. Area F5 has been shown to contain grasping neurons that visually discharge either to 3D-object presentation (canonical neurons) or to the observation of actions performed by other individuals (mirror neurons). It has been suggested that the mirror response results from the progressive generalization to others' actions of a visuomotor link which, during action execution, associates the vision of the own acting effector with the motor program selected for the ongoing action. To start tackling this hypothesis, we specifically asked whether area F5 contains neurons responding to the observation of one's own grasping movement. A specially-designed experimental apparatus was used to test F5 neuronal discharge while monkeys were engaged in a reach-to-grasp task and either continuous or transient visual information on the ongoing movement was made available. Single-unit activity was additionally recorded from the hand region of the primary motor cortex (area F1). Neuronal responses evoked by the vision of the own entire grasping action or of brief meaningful phases of it were detected in both areas. However, F5 modulation was overall more strong and specific. The finding that neurons in area F5 exhibit discharge properties that are common to both purely motor and mirror neurons allows the formulation of important assumptions about the critical role of online visual information during grasping and the nature of the mirror discharge.

UNIUP

Task 3.6 and 3.7: We completed a report on crawling (Reference: Righetti, L., Nylén, A., Rosander, K., and Auke Ijspeert, A. (submitted) Are crawling human infants different from other quadruped mammals?).

Task 3.1: Alexandre Bernandino, Kerstin Rosander & Claes von Hofsten conducted a series of experiment in Uppsala with the icub in June, 2008. We tested predictive eye-head tracking both when the icub moved and when the icub was stationary and the object moved. Alex was going to write a report on these experiments.

Task 3.1: We accomplished studies of infants' ability to use global motion to control smooth pursuit. Ref: Kochukhova, O., Rosander, K. (2008)Integrated global motion influences smooth pursuit in infants. *Journal of Vision, 8 (11)*, 1-12.

EPFL

Task 3.6: Modeling of locomotion and transitions between locomotion and rest (sitting) states; including simulation and robotic experiments on the autonomous exercise of locomotive behaviour.

Characteristic features of crawling in infants have been brought to light, based on detailed kinematic data collected by the team in the University of Uppsala. The data is used to improve the model of crawling. A journal article on this subject has been submitted to Experimental Brain Research Journal.

We have finished the development of the close-loop control of crawling. It was successfully tested in a physically realistic simulation of the iCub. Moreover, since this controller is sufficiently general it was also used to control two other robots in simulation and one real robot designed in our lab (Cheetah). It is based on insight we got from crawling infants and knowledge on mammalian locomotion. This work was presented at ICRA08 in Pasadena.

The open-loop version of the controller was successfully implemented on the real robot.

Task 3.7: Superposition of rhythmic and discrete movements.

Development of a three-layered, bio-inspired architecture suitable for the superimposition of discrete and rhythmic movements (see Deliverable 3.4).

As a first test of this architecture, drumming with the four limbs has been implemented on the robot iCub. Online modulations of parameters such as the frequency or the phase shift between the limbs have been tested, as well as the integration of feedback information. This demonstration has been shown at CogSys08 in Karlsruhe and at Automatica08 in Munich. This work will be presented at BIOROB08.

UGDIST and IIT

Task 3.8: Energy Efficiency in Humanoid Robots A preliminary study on a humanoid torso

This work is about the energy analysis of a humanoid robotic arm, seen as complex energy chain. We developed a simulation platform suitable for modelling the kinematics, dynamics, and energy balances of a real humanoid robotic arm. The model was validated by an accurate comparison with the real robot. Then, we performed a first compared study of the motion dynamics of the simulated robot arm and the energy flowing across its energy converters, with respect to a set of different motion control strategies. Moreover, we conducted a preliminary investigation on the possibility of saving and recovering energy during robot motion.

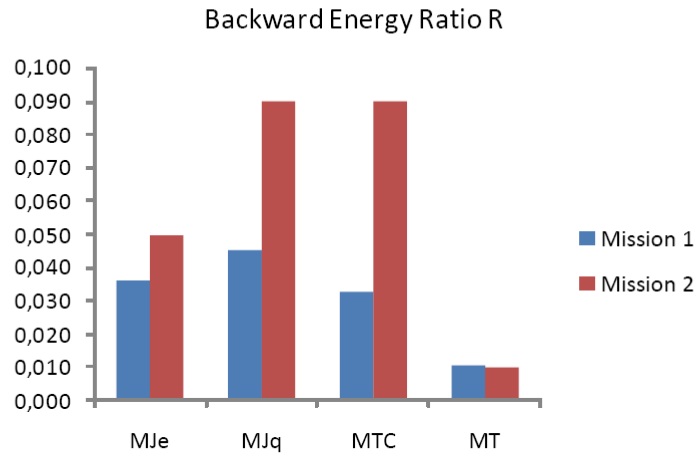


Fig 7: the comparison of various optimization criteria with respect to two different missions (sets of positions to reach).

According to the simulation results we conducted within this framework, the control strategy currently implemented on the real robot James and iCub (i.e. minimum jerk in joint space, MJq) seems to be poorly efficient. Moreover, the average backward energy ratio of MJq (Fig. 7) calculated for two different missions (e.g. different sets of targets), is maximum for minimum jerk. Thus, at least in principle, minimum jerk may assure the largest amount of energy recovery, provided that appropriate accumulators and hardware adaptations are added to the real robot. This first study is aimed at exploring a possible approach for helping the understanding of the energy balance of robots in correlation with their motion controls and their mechanical constraints. Further studies on this topic might, for example, conduct to the design of energy recovery systems and to the exploration of energy efficient motion strategies. For comparison MT is the minimum torque criterion.

More information can be found in:
De Michieli, L., Nori, F., Pini Prato, A., Sandini, G., "*Study on Humanoid Robot Systems: an Energy Approach*", proc. Humanoids 2008, Daejeon, Korea (accepted for publication), 2008.

Task 3.5: Gravity models in humans

Many are the circumstances in which action–perception dissociations have been observed. Among the best known cases there are the pictorial illusions which induce errors in perception but cannot deceive a motor act. We wanted to investigate whether action-perception dissociations affect also prediction. We performed an experiment to evaluate whether prediction is differently realized when it's aimed at driving a motor act and when instead its purpose is "perceptual-only". In particular we focused on how dynamical information of target motion is used depending on prediction goal. In a previous experiment (an interception task) we observed that predictive performances where significantly better when the target maintained unvaried its dynamic features (i.e. the force field that drove its motion). Furthermore, when the target was driven by a force field similar to gravity interception resulted easier. We wanted to check if the same results could be found in a predictive task in which no motion was involved.

Results showed that for a motor task the conditions and difficulty with respect to the gravitational force field influence performance of the subjects significantly. On the contrary for purely perceptual tasks, the judgment of interception does not change as a function of the manipulation of the difficulty and/or conditions of the task with respect to gravity.

Details of these experiments are reported in D3.1.

Task 3.8: learning kinematics and dynamics of the arm

Parametric and non-parametric acquisition of the arm kinematics and dynamics has been considered. For the iCub given the unconventional placement of the force/torque sensor, additional modeling is required to map the measurements into the equivalent joint torques. A proof-of-principle has been implemented and tested on a twin robotic arm available at UGDIST. This has not been ported yet on the iCub. It is described in details in Deliverable 3.1 and thus we do not report it here.

Task 3.8: inverse kinematics

The inverse kinematics of the iCub limbs has been obtained by using the Interior point optimization method. This has been used both for position and velocity control. This module has been just completed and it is only available in software with an initial documentation (there's no report proper). It allows:

- Robust calculation of the inverse kinematics taking into account limits and other constraints.
- Inverse Jacobians for velocity control.
- It merges the joint-cartesian space VITE model of EPFL for trajectory generation

Additional details can be found at:
http://eris.liralab.it/iCub/dox/html/group__icub__armCartesianController.html

Task 3.1: Control of the head using self-organizing dynamical systems

We tested a new approach for the creation of real autonomy in artificial systems based on the use of nonlinear dynamical systems. The purpose of this research is to demonstrate the feasibility of using coupled chaotic systems within the area of cognitive developmental robotics. Using the iCub head, we demonstrate that the visual input coming into the head's eyes is enough for the self-organization of the axes controlling the motion of eyes and neck. No specific coding of the task is needed, which results in a very fast adaptation and robustness to perturbations. Another equally important goal of this research is the possibility of having new insights about how the coordination of multiple degrees of freedom emerges in human infants. We show that the interaction between body and environment modifies the inner connections of the controlling network resulting in the emergence of a tracking behavior.

More details can be found in:
Durán, B., Kuniyoshi, Y., Sandini, G., *Eyes-neck coordination using chaos,* Springer Tracts in Advanced Robotics, vol. 44, pp. 83 – 92 2008.

Task 3.6: Bipedal locomotion

Although the humanoid iCub was initially designed for crawling, in this study the bipedal locomotion of iCub is studied. It fits in a bigger framework to study the use of advanced actuators for dynamic locomotion.

The intended control architecture consists of a trajectory generator which sends desired joint trajectories to the low level motor controllers. Afterwards stabilizers will be added in the control architecture to use the force/torque sensor information of the feet to modify the generated trajectories in order to be able to handle disturbances.

The trajectory generator is based on the preview control method for the ZMP developed by Kajita et al. 2003, which has been successfully used in the humanoid robot HRP-2, Lucy and different other robots. The goal is to have the ZMP follow a predefined trajectory. This is not as straightforward as calculating the ZMP out of the joint trajectories. The main idea is to plan the motion of the COG in function of desired ZMP trajectories determined by the foothold sequence. The problem is regarded as a ZMP servo control implementation, trying to track the ZMP by controlling the horizontal jerk. Because the hip has to move before the ZMP path changes, information about desired position of the ZMP in the future is needed, hence the use of a preview control method. The dynamics are simplified to a cart-table model, a cart that represents the global COG of the robot moving on a horizontally positioned pedestal table with negligible mass. Since the true robot is a multibody system the real and desired position of the ZMP will differ. In order to solve this issue, Kajita et al. 2003 proposed a re-feeding of the complete multibody calculated ZMP trajectory into a second stage of the preview control with the same cart-table model by means of taking the error between the multibody calculated ZMP and the desired ZMP trajectory. This results in deviations of the horizontal motion of the COG. By implementing this method it is observed that the real ZMP tracks the imposed trajectory well, so a more stable walking motion is obtained also at higher walking speeds.

Fig. 8 and 9 show some preliminary results of tracking performance when the robot replays the walking motion with both legs in the air. The low-level controller uses the difference between the desired and real angular joint position to calculate a command speed with a PD controller. The command is sent to the motor controllers at a sampling rate of 100Hz. The absolute magnetic encoder at joint side has 12 bit resolution, so a resolution of 4096 per revolution or 0.088°. This causes that the velocity signal, obtained by taking the discrete derivative, contains a large portion of noise and consequently the PD gains have to be kept low, jeopardizing the tracking performances. Also the communication delay of about 20ms will probably become a problem when force/torque sensory information will be implemented in the control loop. Further research is necessary to improve the tracking performances.

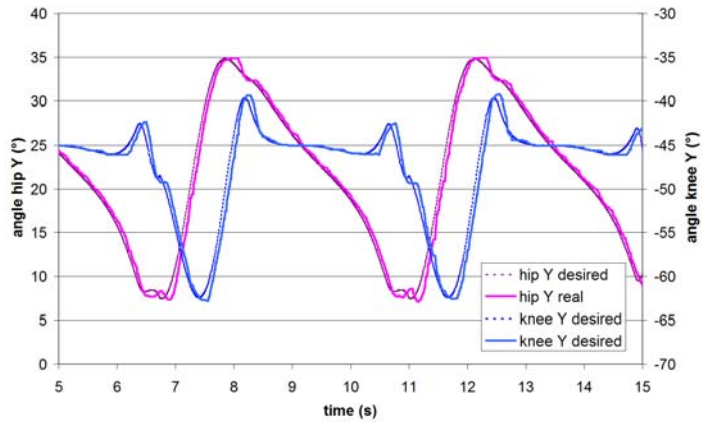


Fig. 8: Real and desired angular position of Hip (Y – pitch) and Knee (Y).

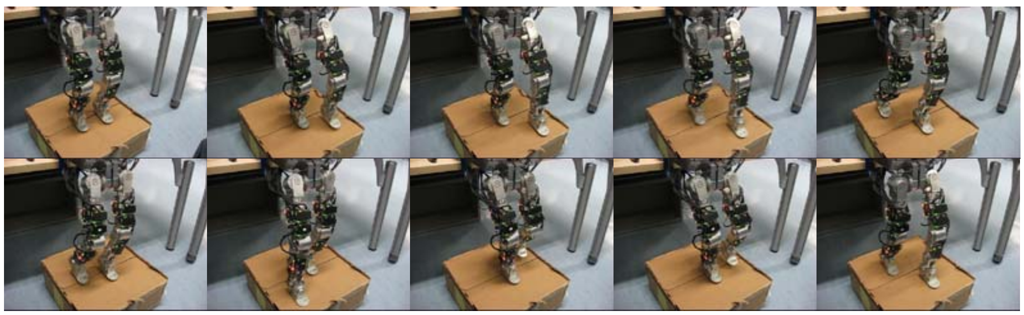


Fig. 9: Exemplar postures of the sequence plotted in Fig. 8.

UNIZH

The attention system serves as a front gate to select from an abundance of streaming sensory input and thus is an important prerequisite for the ontogenesis of sensory-motor coordinated behaviors such as reaching and grasping. We summarize here a biologically-inspired stochastic attention selection mechanism and its integration in the iCub's multimodal attention framework. Based on existing results that demonstrate that human eye saccades can be modeled as a super-diffusive process, we conjectured that the incorporation of a Levy-flight random walk strategy in the attention selection mechanism, would lead to an increase of the performance of the robot's in terms of: (a) speed of the visual exploration process, and (b) the related energy consumption. Using manually generated images, we performed a systematic parameter selection for the Levy-flight-based attention selection algorithm. We conducted an experiment in order to evaluate the Levy Flight-based attention selection algorithm while embedded in the iCub's multi-modal attention and sensory-motor framework. We also compared the performance against the iCub's existing winner-take-all saliency-driven attention selection mechanism. In this experiment, the robot performed a visual exploration task, which integrates the low-level sensory processing, multi-modal sensory integration, bottom-up saliency, and attention selection mechanism. The results demonstrate that the stochastic Levy Flight-based attention selection mechanism enables the robot to explore its environment up to three times faster compared to the standard winner-take-all saliency-driven attention mechanism.

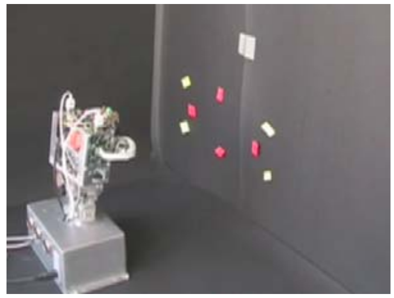


Fig: 10. The experimental setup consists of the iCub head and a set of colored targets. The targets can be placed by the experimenters and repetitive testing can be performed without external disturbances (apart the intrinsic imaging noise).

The results obtained demonstrate that the robot conducts a qualitatively faster exploration when using the stochastic Levy Flight-based attention selection mechanism compared to the standard winner-take-all saliency-driven attention mechanism, while keeping similar behavior in terms of the similarity with the saliency map and mean power consumption. This research presents a novel approach to drive the attention of the robot using the Levy fly random walk restricted to the saliency map, implemented on the iCub head that runs in real-time. This enforces the exploration of the environment but also keeps the attention of the robot in the salient points in the environment, without having to keep track of what has been looked at by the robot. This is one of the major differences between the novel approach and the standard algorithm employed to drive the attention of the attention systems.

For future work, it would be interesting to explore how the attention system can be exploited to provide relevant information for an specific task like grasping. Furthermore, because the attention system in itself only delivers retino-centric coordinates, and therefore does not provide any 3D position information, we have begun the development of a real-time depth perception algorithm for the iCub. Depth information is required for efficient reaching and grasping. The implementation relies on a vergence-based real-time stereo-vision algorithm which includes an on-line calibration scheme. We expect that compared to a static stereo-vision setup, our approach will lead to higher precision in depth estimation.

IST

The work developed by IST in this workpackage was concentrated the following main directions: (i) autocalibration of the robot head from self motion; (ii) experiments on the head-eye control system and (iii) learning of continuous maps.

(i) Head autocalibration: with the increasing miniaturization of robotic devices not all actuators are provided with absolute position sensing, thus making the state of the system unknown at startup. At IST, we developed methods for vision based automatic calibration of serial pan-tilt kinematic structures with a perspective camera on the end-effector. Examples of such systems are surveillance cameras and humanoid robot heads. The method is based on prospective motions of one joint in the kinematic chain to induce image motion in the camera.

Bartosz Tworek, Alexandre Bernardino, José Santos-Victor, *Visual Self-Calibration of Pan-Tilt Kinematic Structures*, Robotica 2008, 8th Conference on Autonomous Robot Systems and Competitions, Aveiro, Portugal, April 2008.

(ii) Model based visual tracking and pose estimation: visual tracking of objects is an enabling functionality for many distinct behaviours. We have worked on model based tracking techniques that can handle partial occlusions and 3D rotations of the tracked object. In addition, for reaching or manipulation we have developed a methodology for binocular pose estimation of objects (subject to an ellipsoid approximation) that can provide the necessary information for initial reaching.

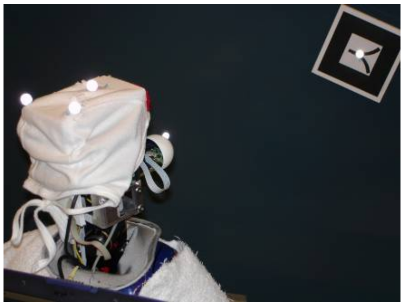
Giovanni Saponaro, Alexandre Bernardino, Pose Estimation for Grasping Preparation from Stereo Ellipses, Proc. of the Workshop on Humanoid Robotics at CLAWAR 2008, Coimbra, Portugal, 8-10 Sept. 2008.

Matteo Taiana, Jacinto Nascimento, José Gaspar and Alexandre Bernardino, *Sample-Based 3D Tracking of Colored Objects: A Flexible Architecture,* British Machine Vision Conference, BMVC2008, Leeds, UK, 1-4 Sept. 2008.

(iii) Reinforcement learning control algorithms in continuous spaces: to learn how to approach and grasp objects through experience. We propose a new algorithm, natural actor-critic (FNAC), that extends the work in [Peters er al, ECML 2005] to allow for general function approximation and data reuse. We combine the natural actor-critic architecture] with a variant of value iteration using importance sampling. The method thus obtained combines the appealing features of both approaches while overcoming their main weaknesses: the use of a gradient-based actor readily overcomes the difficulties found in regression methods with policy optimization in continuous action-spaces; in turn, the use of a regression-based critic allows for efficient use of data and avoids convergence problems that TD-based critics often exhibit.

Francisco S. Melo and Manuel Lopes, Fitted natural actor-critic: A new algorithm for continuous state-action MDPs, European Conference on Machine Learning (ECML/PKDD) Antwerp, Belgium, September 2008.

Eye-head coordination: IST designed and implemented in Yarp the software for the head controller. In collaboration with the University of Upsala (Uniups), we have tested the iCub-head using the Uniups experimental facilities to provide a benchmark of future research on this topic. On-going research addresses the issues of learning how to adequately acquire movement coordination across the multiple head joints (as opposed to being programmed a priori), represent space and track objects in azimuth-elevation coordinates (the egosphere), and develop motion-based, multi-model predictive tracking algorithms.



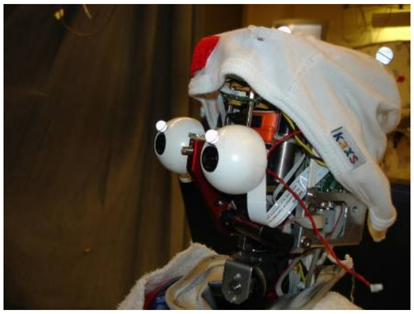


Fig. 11: The iCub head following targets while the head-eye motion is being recorded (joint work IST – Uppsala).

SSSA

SSSA is concerned with the development of two complementary modules: a vision module, for object localization, and a visual servoing module for the arm control.

We implemented an image processing algorithm that recognizes a convex object that will be defined as the target for the reaching task. The camera images are first filtered by using a color histogram, and then the resultant objects boundary are processed by a new pattern recognition in order to derive the object features. Moreover, we implemented a velocity control algorithm for controlling the head joints, in order to track the object in realtime mode. Then, we used the forward kinematics of the head to get a 3D spatial localization of the targe within the surrounding environment. Finally, we provided also the implementation of a color histogram gonorator, in order to make the user able to create the color database that serves as imput for the tracker. For further information refer to the deliverable D 3.5 month 42, and to the attached publication (Nicola Greggio , Luigi Manfredi, Cecilia Laschi , Paolo Dario , Maria Chiara Carrozza. 'RobotCub Implementation of Real-Time Least-Square Fitting of Ellipses', Simulation, Modelling and Programming for autonomous robots (SIMPAR), November 3-7, 2008, Venice -Italy).

The visual servoing module uses an on-line image jacobian estimation for the reaching task. The servoing algorithm uses an image jacobian initialized from the internal model that associates the vision and the joints of the robot manipulator. The internal model has been previously built by an ANFIS neural network. For further information refer to the deliverable D 3.5 month 42, and to the attached publications.

During the next months we will apply our modules to the iCub platform, ad we will publish our test about their performances.

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
D3.4	An architecture for the superimposition of discrete and rhythmic movements	3	42	42	EPFL
D3.5	Robotic implementation of models of sensory-motor coordination for reaching and grasping tasks.	3	42	42	SSSA
3.6	Software implementation of the phylogenetic abilities specifically for the iCub & integration in the iCub Cognitive Architecture.	3	42	42	UGDIST
3.1	Initial implementation of models of sensorimotor coordination primitives (report and demo)	3	48	48	UNIFE

List of milestones

Milestone. no.	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
		3			

WP4 – Object Affordances

Workpackage objectives

The goal of this WP is that of exploring and modeling 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 behaviors 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.

Progress towards objectives

UNIFE

Task 4.2: Early affordant behaviors. Initial experiments will focus on self-exploration, to understand the development of the "basic" repertoire upon which an imitation system can develop.

(i) Cortico-spinal (CS) excitability during interception with precision grip.

Interception in humans is a complex visuo-motor task that requires in few hundreds of milliseconds to detect and process visual motion information, to estimate future position of object in space and time, to transform visual information into an appropriate motor action and to trigger this action in advance to compensate for physiological and mechanical delays. Despite this complexity, humans demonstrate rather good performance in interceptive actions.

The main objective of the present experiment was to investigate this issue by studying corticospinal excitability during motor imagery of an interceptive task. We decided to use this task because the preparatory phase is intrinsically well separated from the executive one. While intercepting a moving object, one must prepare to grasp it and then not trigger the action as soon as the object starts to move but rather wait for the right time to trigger the action (internal "Go" signal), using as a countdown an estimate of time remaining before impact (Time To Contact, TTC) (see Tresilian, 1993 for a review). This time-related preparatory phase should be present also during the motor imagery of the interception of a moving object, when clear cues regarding the virtual TTC are given. Thus, to test if during motor imagery of motor preparation a modulation of the corticospinal system is present, we delivered single pulse TMS over the motor cortex at different time during the preparatory phase in subjects required to imagine to catch a falling object. We completed a series of experiments to investigate the excitability of the cortico-spinal (CS) system in humans during the interception of a falling object and its relationship to the target parameters. The hypothesis is that CS excitability should increase as the estimate of time-to-contact is updated until it reaches the threshold value at which the muscular activity is triggered.

The second goal of the project was to determine if a similar modulations of the CS excitability could be seen also during observation and simulation of an interceptive action. In addition to these experiments we measured spinal motoneurons excitability during the same experimental conditions by means of the H-reflex techniques.

(ii) It is assumed that action observation elicits the motor representation that is evoked during execution of the same action on the basis of data indicating the sharing of muscle specificity and temporal pattern during both observation and execution tasks (Fadiga et al., 1995; Kilner et al., 2004 ; Borroni et al., 2005 ; Montagna et al., 2005). There is now some indication (Pobric et al., 2006) that force required to execute the action is also coded during observation. What information is used by the observers to code force? Hamilton et al. (2007) reported that kinematics cues could be used to estimate the weight of an object during observation of its lifting. However it is not known if these information is sufficient or if it requires visual cues and if it can be modulated by explicit cognitive cues.
Using single pulse Transcranial Magnetic Stimulation (TMS), we tested the following questions :
1) Is motor cortex facilitation during action observation modulated by the amount of force required to accomplish the action even when no explicit visual weight-related cues are present?
2) Is this modulation influenced by explicit cognitive information?

(iii) Mirror neurons in the monkey premotor cortex have been shown to respond similarly for grasping action observation and execution (di Pellegrino et al., 1992). In humans similar mechanisms have been demonstrated with different techniques (Rizzolatti, Craighero, 2004). Primary motor cortex was shown to be facilitated by observation of goal-directed and non-goal-directed actions and this effect was specific for muscles involved in the observed movement (Fadiga et al., 1995). We studied if this facilitation is scaled according to the amount of muscle activity and resulting different kinematics in the observed movement. Moreover we verified if explicit contextual cues could modulate such effect. Motor Evoked Potentials (MEP) elicited by TMS stimulation of M1 representation of First Dorsal Interosseous (FDI) muscle were measured during the observation of reach-grasp-lift actions upon 6 different objects: 1) transparent empty bottle (VisLight); 2) transparent full bottle (VisHeavy); 3) opaque empty bottle (HidLight); 4) opaque full bottle (HidHeavy); 5) opaque full bottle labelled light (LabLight); 6) opaque full bottle labelled heavy (LabHeavy). Light objects were 50g and heavy were 500g. This difference of weight induced clear different patterns of muscle contraction and kinematics. TMS was applied when this difference was found to be maximal, in a 100 ms window after the beginning of lifting. Condition 1 and 2 afforded full knowledge of weight differences and kinematics information, 3 and 4 only kinematics, 5 and 6 no kinematics but hi-level cues (labels). We found significant difference in MEPs amplitude in the 1-2 and 3-4 comparisons but no difference in 5-6, 1-3 and 2-4. Therefore, our results show that the motor cortex does scale for the amount of muscle activity present in the observed action by analysing movement kinematics. Moreover all subjects reported the presence of only 5 objects (they recognised only one opaque instead of two) arguing for an implicit processing carried out by the motor system.

UNIUP

(i) Studies on fitting objects into holes. In Dec. 2007, Helena Örnkloo's disstertation "**Fitting objects into holes: On the development of spatial cognition skills** " was approved for PhD in Psychology at

Uppsala University. Part of this work had been done within Robotcub. The dissertation consists of 3 articles:

I Örnkloo, H., & von Hofsten, C. (2007). Fitting Objects into Holes: On the development of Spatial Cognition Skills. *Developmental Psychology*, **43**(2): 404-416.

II Örnkloo, H. & von Hofsten, C. (2008). Young Children's Ability to Solve Spatial Choice Problems. *European journal of Developmental Psychology*.

III Shutts, K., Örnkloo, H., Spelke, E. S., Keen, R. & von Hofsten, C. (Submitted). Young Children's Representations of Spatial and Functional Relationships between Objects.

(ii) Studies on reaching for moving objects. A series of experiments have been conducted on infants with objects that move on elliptical paths. The are perceived as having constant velocity when the velocity is modulated according to a sinusoidal function and as having changing velocity when the celocity is constant (Viviani and Stucchi, 1992). Both kinds of motion are found in nature. The significance of the sinusoidally changing motion is that movements produced by biological creatures have these properties. It is also the case that if the energy invested in the production of a sinusoidal motion is constant, its velocity will be sinusoidally modulated. Thus, Viviani & Schneider (1991) showed that when subjects were asked to trace an elliptical path with constant velocity hand-movements, the movements produced were sinusoidally modulated. Thus, it seems that both the perception and production of velocity of sinusoidal motion is determined by the effort in producing the motion rather than the physical velocity itself. When the effort is constant, the perceived velocity is constant and when subjects try to produce a constant velocity of elliptical motions, they rather produce sinusoidally modulated motions. In the present study, we inquired about the ontogeny of this perceptuo-motor adaptation. If infants perceive the velocity of sinusoidally changing motion as constant, how will that affect their ability to organize reaches towards objects moving in this way? Biological motion might look simple and uniform because the effort in producing it is uniform, while actions on them might be difficult because the perceived constant velocity does not correspond to the physical motion. The idea of dissociation between perception and action has recently received much support (Milner & Goodale, 1995, Milner, 1998, Goodale & Westwood, 2004). It has also been found that different visual pathways are devoted to perception and to action. Visual information used for identification and evaluation of objects and events follow a ventral pathway to the inferior temporal area and visual information used for preparing actions follow a dorsal pathway over the parietal area (Atkinson, 2000).

Another set of questions has to do with the emergence of this perceptuo-motor system. If perception as well as action is tuned to sinusoidal motion, what is the origin of this sensitivity? Are children endowed with ability to perceive sinusoidal motion in this way or does it develop from frequent encounters with sinusoidal motion. In order to investigate these questions, we studied infants at 3 different ages. If sensitivity to sinusoidal motion develops with age, then we should expect infants who have less reaching experience to have more difficulties in catching objects moving sinusoidally than objects moving with constant velocity. These studies are ongoing.

UGDIST-IIT

Certain work in WP3 can be as well part of WP4. In particular, work related to objects is part of both the sensorimotor foundations and the interaction with objects. Similarly, the analysis of optic flow in terms of the time to contact is a fundamental building block of the determination of the behavior of objects that was exploited in the past by Metta et al. in learning object affordances. Optic flow is particularly important in a developmental scenario where it can cue approximate reaching behaviors and thus drive the exploration of eye-head-arm coordination spaces. Our work contributes to D4.1.

In particular, as part of a software module aimed at extracting optic flow cues while moving and reaching we are porting on the iCub a set of modules described in:
http://eris.liralab.it/iCub/dox/html/group__primateVision.html

This work is described in:
Andrew Dankers, Nick Barnes, Walter F. Bischof, and Alexander Zelinsky. *"Humanoid Vision Resembles Primate Archetype"* - Springer Tracts in Advanced Robotics.

IST

The work in this package has focused on the development of a general methodology to acquire affordances in an unsupervised manner. The rationale is that the robot has already developed some elementary actions (sensorimotor coordination in WP3) that allow it to explore the environment and understand the interplay between actions, objects and action outcomes.

We use a Bayesian network to model the relation between actions, object properties and effects. In such a probabilistic framework, many of the quantities of interest are a function of the marginal probabilities of the Bayesian network. The model can be used for prediction, action selection or object selection. In addition to this, the use of Bayesian networks provides a generic and sound model that allows addressing learning and inference within the same framework. Furthermore, it is possible to model different learning contexts such as self-exploration, imitation or reinforcement learning.

The learned model is then used to predict the effects of actions, recognize actions performed by a human and to play simple imitation games. These imitation games are driven by the observed effects of the human action, and exploit knowledge contained in the affordance network to obtain the same effects (emulation). In this sense, imitation is not limited to mimicking the detailed human actions. Rather, it is used in a goal directed manner, as the robot may choose a very different action (when compared to that of the demonstrator) provided that its experience indicates that the desired effect can be met.

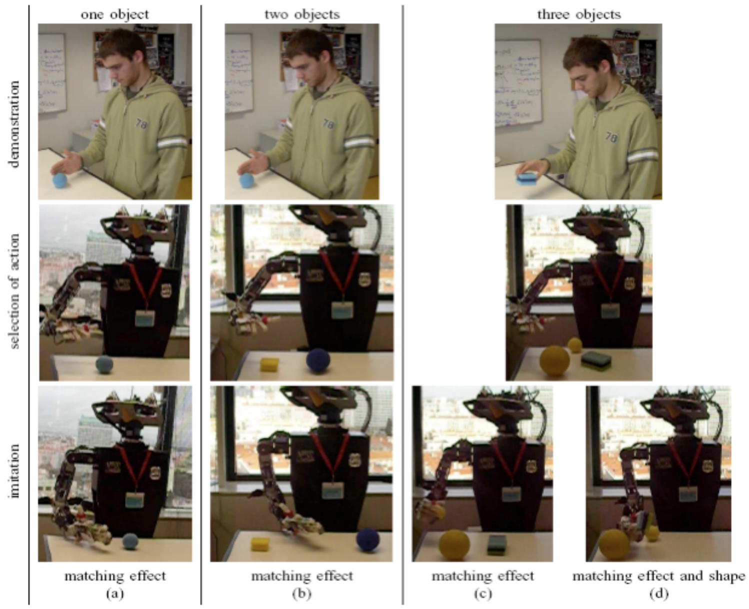


Fig. 12: Imitation games using affordance knowledge.

The work developed so far under this Workpackage has been published as:
Luis Montesano, Manuel Lopes, Alexandre Bernardino, and José Santos-Victor, "Learning Object Affordances: From Sensory Motor Maps to Imitation, "IEEE Transactions on Robotics, vol. 24(1), February 2008.

During the fourth year of the project we have carried on this work in two directions: (i) investigating methods for learning grasping points from experiments, (ii) adding speech information to the affordance model and (iii) extensive software redesign and integration for allowing running a demo on the iCub platform.

(i) Learning visual descriptions of grasping points from experience - Determining where and how to grasp an object is the first step towards fine manipulation. Actually, an object affords certain types of grasping and not others. For instance, grasp and grip actions will select different grasping points for the same objects. We are currently developing non parametric learning algorithms to estimate the probability of success of different grasps according to the visual input features. The procedure is the following. The examples are based on the robot's own experience on different objects. Based on this example, we compute a map between visual features and the probability of grasps using kernel based smoothed beta distributions. The picture below illustrates the prediction of grasping probability for novel objects.

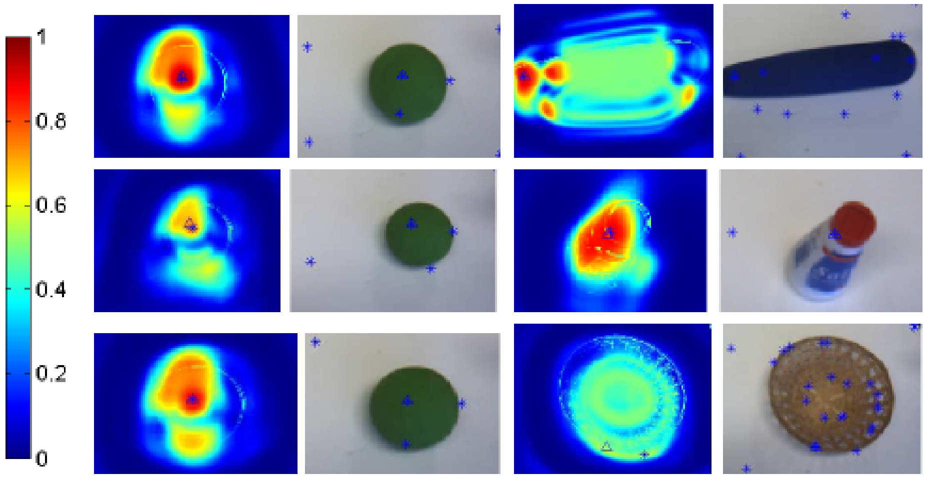


Fig. 13: Examples of the acquisition of grasping points from experience (see text for details).

(ii) The demo shown during the Y3 review through videos illustrates how this affordance model can be used to bridge the gap between sensorimotor development and higher cognitive skills like imitation and interaction. The robot is able to observe an action and then, after looking at two available objects, it is able to choose one to replicate the observed effects in the best possible way.

The software necessary to conduct this demo, was redesigned and integrated in the iCub software architecture. The following modules/libraries were developed:

- *artoolkittracker* - a generic module to track markers based on ARToolKit
- *camshiftplus* - the opencv camshift tracker method that also gives information about the contour of objects
- *affordances* - library that generates the affordances, based on the PNL library
- *affdemo* - main module for the demo

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
4.2	Software implementation for the iCub & integration in the iCub Cognitive Architecture.	4	42	42	IST

List of milestones

Milestone no.	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
		4			

WP5 - Imitation

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 behavior:

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.

Progress towards objectives

UNIHER

Task 5.1: UNIHER carried out Task 5.1 which is reported in D5.8. T5.1 concerns the design, experimental study and analysis of aspects of mirroring, timing, body expression and communicative aspects of imitation, using computational models of imitative interaction games. UNIHER developed a novel technique to detect similarity in movements in human-humanoid interaction, using KASPAR as a testbed. The method was verified with simulated as well as real interaction data and resulted in an accepted paper at the workshop "From motor to interaction learning in robots" at IEEE IROS 2008 in Nice.

This work contributes to our understanding of the synchronization and mirroring interaction aspects in human-humanoid teaching and collaborative scenarios. Specifically, the work covers (a) the development of a new method for identifying similarity and synchronous behaviour in human-humanoid imitative interaction, (b) dynamical system modulation for robot skill acquisition from kinesthetic demonstrations, and (c) the relationship between the quality of imitation and attention behaviour in experiments where subjects imitate simple arm movements. The method in (a) is directly relevant for autonomously detecting synchronization and mirroring, the method in (b) for the matching of kinesics in humanoid imitation of humans, and (c) for the understanding of the role of kinesics in human-human imitation and lessons for ontogenetic humanoid robotics.

UNIFE

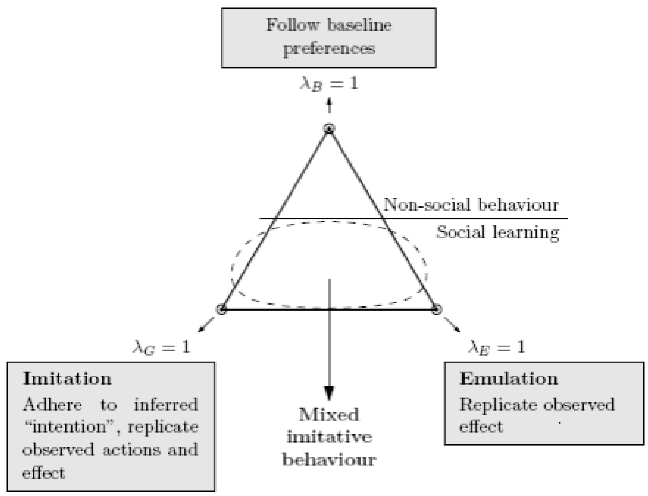
Task 5.4: Experimental investigation on the role of gaze in imitation of hand movements.

In the framework of WP5, we have conducted an experiment 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 experiment was to verify if the position of articulations influences the way in which the same action is imitated. EPFL has done the first part of the analysis and we are now planning a new set of experiment which will involve the participation of EPFL people working at the UNIFE lab before the end of the year.

IST

In addition to the use of the affordance model for imitation tasks, the work we developed in WP5 together with the University of Uppsala has been focused on modeling social learning behaviors with reinforcement learning.

We analyzed several such social learning behaviors and developed a common formalism design to model all such behaviours. This formalism borrows the fundamental concepts and methods from the reinforcement learning framework. By considering different ways by which an expert can provide information to the learner, we consider different types of learning from observation and formalize each of the aforementioned behaviors in a reinforcement learning (RL) context.



We showed that different behavior like: emulation, stimulus enhancement, contextual learning and response facilitation, can be modeled under the same unifying formalism. We also studied the specific advantages/disadvantages of each one.

Manuel Lopes, Francisco S. Melo,Ben Kenward and José Santos-Victor, A computational model for social learning mechanisms, IROS-2008 Workshop - From motor to interaction learning in robots, Nice, France, September 2008.

SSSA

Implemented a gaze tracker module that utilizes a human's gaze behavior, in particular gaze shifts and gaze fixation, to make task prediction that can be used as part of a robotic control system. Real-time gaze data is obtained from faceLab. This work is based on neuroscientific findings of human gaze behavior during manipulation tasks. Initial results have been presented in BIOROB 2008.

UNIUP

Studies of brain activity in young infants. In Sept. 2008, Pär Nyström's dissertation "From motion to movements – revelations by the infant EEG" was approved for PhD in Psychology at Uppsala University. Part of the work was done within Robotcub. The dissertation consists of 3 articles.

I. Rosander K., Nyström P., Gredebäck G., von Hofsten C. (2007) Cortical processing of visual motion in young infants. *Vision Research, 47*, 2007, Pp. 1614-1623.
II. Nyström P. (in press, 2008)). The infant mirror neuron system studied by high density EEG. *Journal of Social Neuroscience*.
Nyström P., Ljunghammar T., Rosander K., von Hofsten C. (submitted) Using mu rhythm perturbations to measure mirror neuron activity in infants.

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
5.6	Results of the robotic implementation of anthropomorphic gaze behaviour in imitation of hand manipulative actions.	5	42	42	SSSA
5.7	Software implementation for the iCub & integration in the iCub Cognitive Architecture.	5	42	42	UGDIST
5.8	Synchronization and mirroring in imitative interaction games	5	48	48	HERTS

List of milestones

Mileston e. no.	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
-	-	-	-	-	-

WP6 – Gesture Communication

Workpackage objectives

This WP focuses on the regulation of interaction dynamics of social interaction during human-robot play. The pre-requisites for interactive and communicative behaviour grounded in sensorimotor experience and interaction histories will be investigated and developed with specific consideration of interaction kinesics (including gestures, synchronization and rhythms of movements etc.). This work includes, *inter alia*, information theoretic methods applied to characterizing and identifying experience, mapping sensor space and learning motor capabilities.
The objectives of this WP are four-fold:

- Development of the pre-requisites for (non-verbal) interactive and communicative behaviour grounded in sensorimotor experience and interaction histories
- To research mechanisms for an autonomous robotic agent (both humanoid or other as appropriate) to engage in non-verbal gestural communication with humans, and to ontogenetically develop such capabilities through various kinds of social interactions including play.
- Investigation of turn-taking kinesics (the study of the rhythm and timing of non-verbal communicative behaviour) in play-based interactions between a humanoid robot and humans.
- To investigate how a robot can recognize the types of interaction it is engaged in and adjust its behaviour accordingly in order to regulate the interactions towards an appropriate level of complexity of interaction

Progress towards objectives

UNIHER

UNIHER carried out Tasks 6.1, 6.2, 6.3, 6.4 which are all related to the Interaction History Architecture that formed part of Assif Mirza's PhD thesis and the results relevant to the tasks are reported in D6.4 This worked involved playful gestural human-humanoid interaction games using information-theoretic based interaction histories. We also used further sensor modalities to enrich the robot's experience, and incorporated this into the interaction history. Lastly, we addressed issues of scalability in terms of time by collapsing and deleting experiences in an interaction history ("forgetting"). This was related to such modified experiential spaces to driving concepts of novelty, familiarity and mastery as well as to aspects of episodic memory.

UNIHER completed Task 6.7 which concerned the implementation of software for action and gesture communication generation based on interaction histories demonstrable on a humanoid robot, and release in the iCub software repository. This is reported in D6.3.

UNIHER investigated mechanisms to adjust levels of play in real time as a response to styles and levels of interaction of a robot with people. This work contributed to Task 6.5 and is reported in D6.5. This deliverable brings together three areas of complementary research work relevant to gesture communication carried out by UNIHER:

1. Timing and Non-verbal Cues in Interaction with a Humanoid Robot.
2. Ontogeny of Humanoid-Human Interaction Capability.
3. Robot-Mediated Play.

Work (1) describes the Drum-mate work with the usage of gestures and turn-taking models in a call-and-response imitation based interaction game. Work (2) describes our work on Interaction Histories and the development of Peekaboo interaction games, and their implementation on humanoid robots. Finally Work (3) describes research on Robot-Mediated Play.

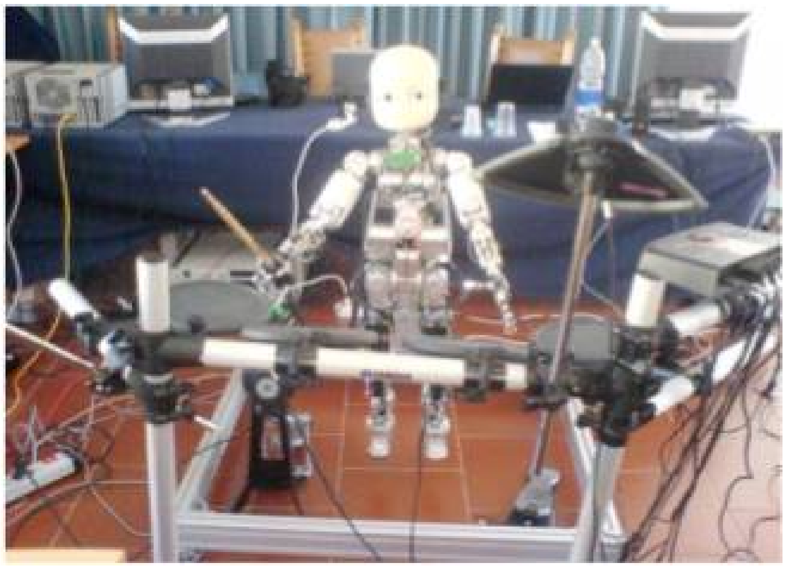


Fig 14: iCub playing with an electronic drum set

Fig. 15: iCub grasping the drumstick, and hitting the drum pads

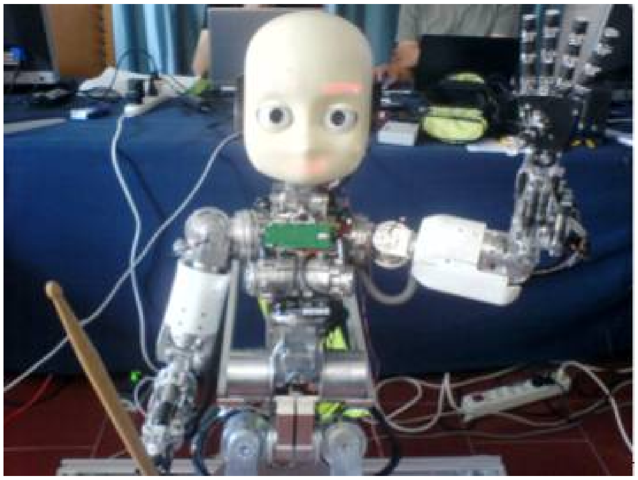


Fig. 16: iCub smiling and waving its left hand at the end of the game. It uses the left hand to hit the drum pads with the drum stick.

Fig.17: Human participant playing *drum-mate* with humanoid KASPAR

IST

We have applied the affordances model to link perception to language. During self-exploration of the environment, the robot may listen to verbal descriptions of the executed actions, objects and effects. By exploiting the co-occurrence of words with perceptual stimuli and motor commands, the robot is able to learn to associate words to the world symbols. Embedded in the affordances network, this knowledge can be used for planning robot actions from verbal instructions and improving speech perception skills using the scene context.

Verica Krunic, Giampiero Salvi, Alexandre Bernardino, Luis Montesano, José Santos-Victor, "Associating word descriptions to learned manipulation task models," IROS-2008 WORKSHOP on Grasp and Task Learning by Imitation, Nice, France, September 2008.

UNIFE

Task 6.6: Investigate eye-contact capability for the iCub

Sympathy is the ability of the observer to reproduce the internal states of others, either when observing an external event or the display of a reaction, motor or affective. We test the hypothesis that sympathy is used as an information extracting device: the reproduction of the neural activity of the observed subject provides a signal on the information available to the observed subject. An implication of the theory is that a subject has very little to know on his own internal states, so brain activity related to sympathy should be smaller than it is when a different subject is involved. We test this hypothesis using the simplest form of interpersonal communication: the exchange of gazes among human subjects, including the subject looking at himself. Five different conditions have been used. The key comparisons are between the brain activity of a subject when he is looking at a different person and when he is looking at his own eyes. In other conditions, subjects are looking at an observer who is not looking, or they are looked at as they are not looking. A group of 29 subjects has been observed in an fMRI study. The results support the hypothesis of sympathy ax an information acquisition. For example, BA 44 is involved specifically when two subjects exchange gazes. Anterior Insula is activated when subjects are being looked at and are not looking.In addition to this study (preliminary data were presented in, Fadiga, L. Craighero, L., Lungu, O, and Rustichini, A. Eye-to-eye communication, 2005, Society for Neuroscience Meeting, Washington DC), we more recently carried out a behavioral experiment aiming at investigating the gaze behavior of two human subjects while they look each other into the eyes. The parameters we acquired where: eye position (60 Hz), pupil diameter (as an index of attention) and blinking. The basic experimental condition was contrasted with two control conditions. In the first, subjects were looking at themselves through a mirror, in the second, they were looking at a photograph of two eyes*. During the fourth year of the project, gaze data have been analyzed and, as expected, they show no difference between the various looking conditions. We are now writing a paper describing together fMRI and behavioral results.*

Task 6.3: Investigate multi-modal experience with respect to turn-taking and interaction

The brain areas involved in gestural communication.

Broca's area has been considered for over a century the brain center for speech production. Growing evidence however shows that its role goes far beyond that. Neuroimaging and neuropsychological studies of left brain-damaged human patients indicate that Broca's area is also involved in speech comprehension, linguistic or musical syntactic processing and even mathematical calculation. More recently it has been further shown that Broca's area belongs to the human mirror-neuron system, becoming significantly active when one observes hand or mouth actions of other individuals. This discovery, together with the cytoarchitectonic homology between Broca's area and the monkey premotor area where mirror neurons have been found, prompts the idea that speech and action understanding may share a common functional substrate. Here we tested this hypothesis by selecting frontal aphasic patients without apraxia and by testing their ability to pragmatically understand visually presented actions. Patients, as well as matched control subjects, were shown with movies of human actions and of physical events and were requested to correctly sequence four pictures taken from each movie presented at random. Patients performance showed a specific dissociation in their ability to reorder human actions with respect to physical events. This finding provides the first demonstration that the lesion of Broca's area specifically impairs the capability to correctly represent observed human actions, in a task devoid of any verbal content.

Task 6.1: Explore simple playful gestural interaction games

The behavioral study of cooperation and competition during human interaction.

We studied the behavior of 12 pairs of (normal, right-handed) undergraduate students while they were involved in a simple coordination game requiring motor interaction. Three experimental conditions were defined according to whether a monetary prize was given to both or only one player, if the couple was

successfully completing the required assignment. Electromyographic potentials (EMG) were recorded from the right first dorsal interosseus (FDI) muscle, a muscle critically involved in the motor task. We also collected written answers from standard questionnaires from which we constructed individual measures based on organized group interaction, social involvement and altruism. These measures of 'Altruism' were collected to estimate individual pro-social or altruistic attitudes and behavior. Consistently with a simple behavioral model, by which EMG signals may reveal subjects' personal concern (utility) associated to the given task, experimental evidence shows that individual average EMG signal was increasing when the players where expecting a monetary reward. When we split the subject pool into two sub samples (according to the measures of Altruism obtained from the questionnaire), we found that monetary incentives explain the level of subjects' EMG signal only in the sub sample characterized by low SC or Altruism. These findings seem to support the possibility that an electrophysiological measure, such as EMG recording, could reveal the most profound attitudes and believes that guide social interaction.
More in detail, below are some additional information**.** *We have in program to finish writing the paper soon and to submit it before the end of the year***.**

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
6.3	Software implementation for action and gesture communication generation based on interaction histories for the iCub platform, and integration into the iCub cognitive architecture.	6	42	42	UNIHER
6.4	Interaction histories for robot ontogeny through playful interaction	6	42	42	UNIHER
6.5	Studies on human-humanoid interaction kinesics	6	48	48	UNIHER

List of milestones

Milestone no.	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
-	-	-	-	-	-

WP7 – Mechatronics of the iCub

Workpackage objectives

- To define the functional specifications for the initial design of the mechatronic components of the iCub, 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 iCub subsystems, both from a hardware and a software point of view.
- To manage the development of the iCub and support the fabrication of multiple copies for the Open Call.
- To identify problems and debug hardware/software problems and improve the iCub.

Progress towards objectives

Despite some delays, all the current objectives have been achieved.

TLR, IIT and UGDIST

Design of some mechanical upgrades starting form input generated by tests run at IIT/UGDIST in order to increase robustness and dexterity of upper limbs:

- Review of 3rd and 4th finger coupled flexion group eliminating the coupling slider and redesigning consequently the forearm motor group;
- Thumb and index flexion motor layout review for enhanced tendon routing;
- Wrist actuation with crimped end tendons for easier backlash tuning;
- Head eye group redesign to accommodate new Dargonfly2 camera (bigger).

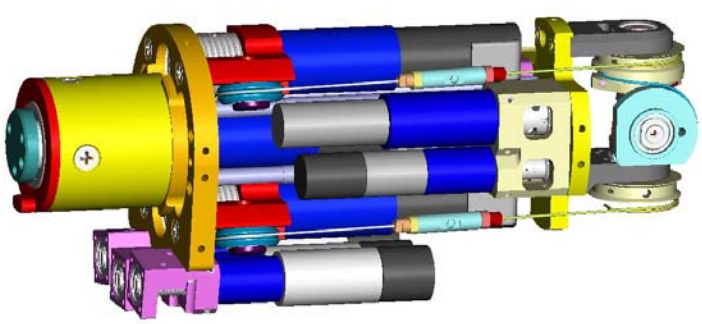


Fig. 18: Example of the modifications to remove the slider mechanism that proved to be problematic. The new arrangement is more standard using a wider capstan to route the tendon.

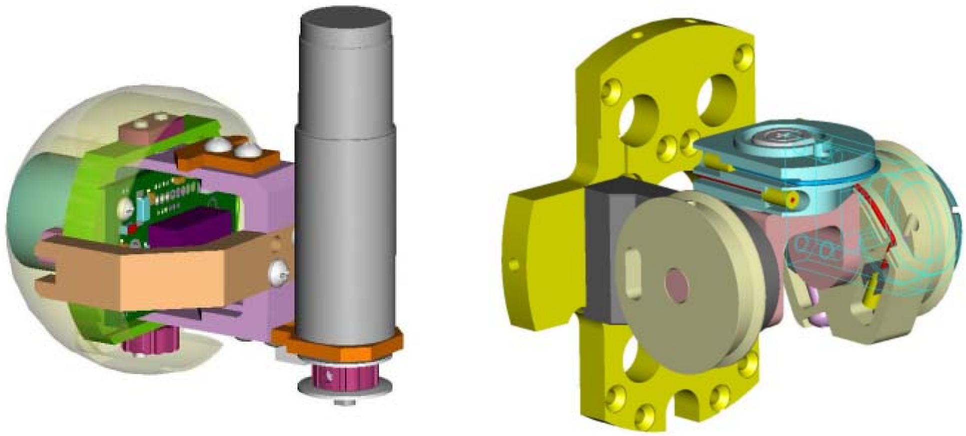
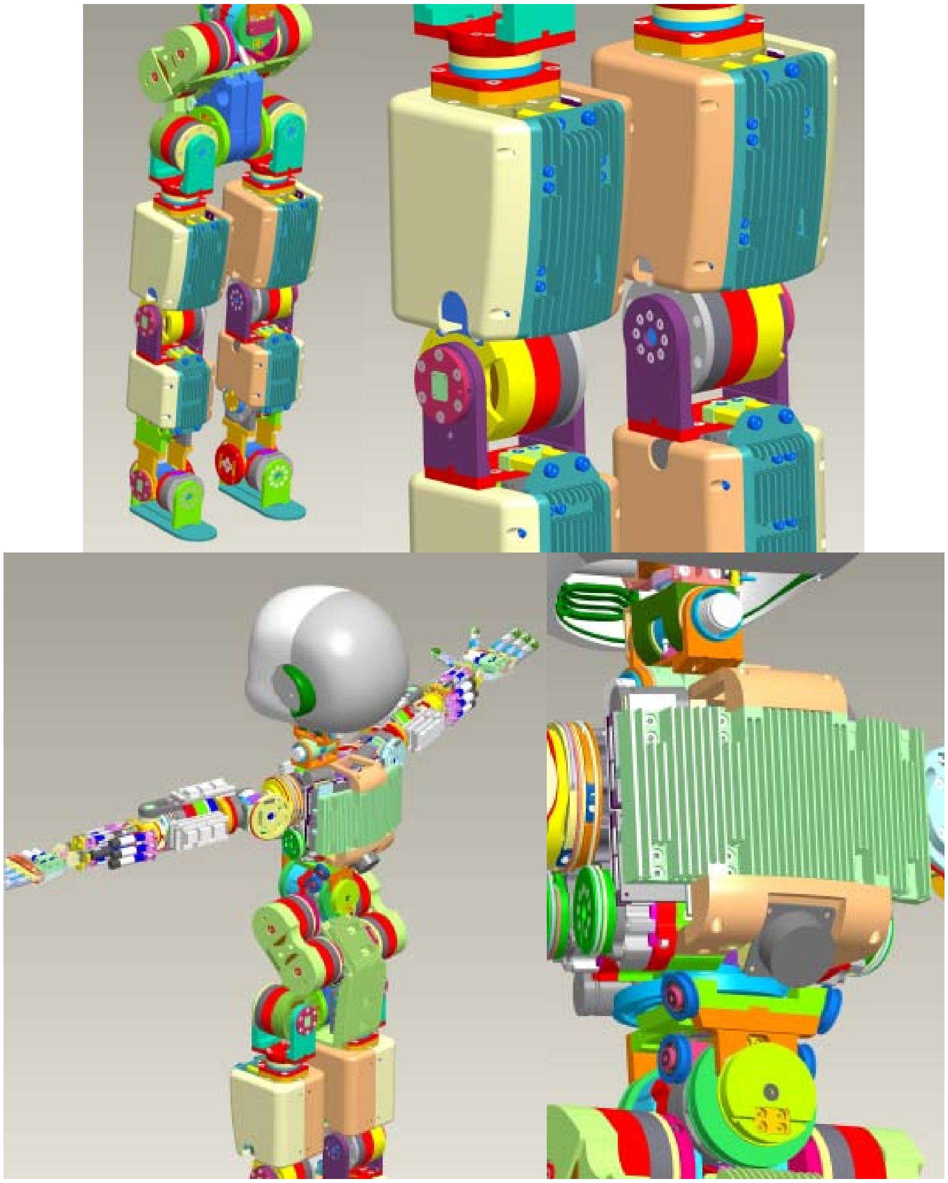
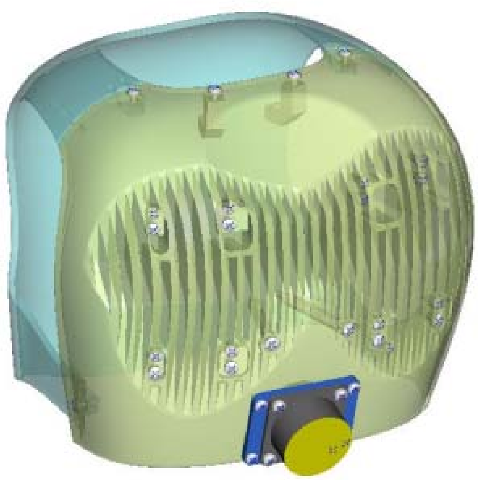


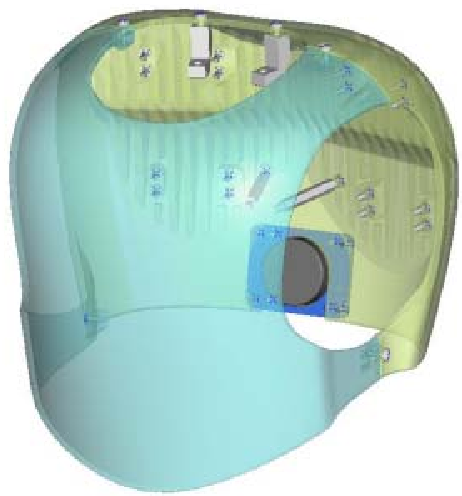
Fig. 19: New camera placement and new wrist parts to allow automatic crimping of tendons on the wrist.

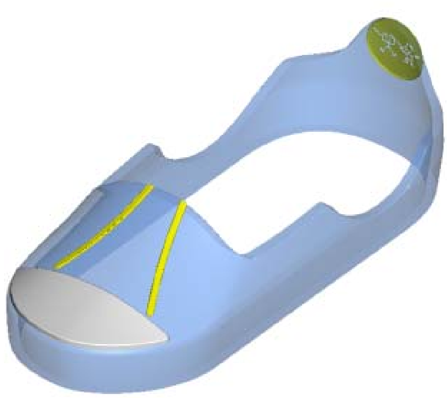
After a first functional cover design with heatsink integration taking into account both heat dissipation and cable routing along the robot body (some views of the leg cover are below reported). A second cover design that matches exactly the study done by IST is now being designed and immediately prototyped and tested at IIT using a RP resin machine and one of the platforms availables as testbed (detailed covers views are reported below).



After solving the problems outlined in this first check a final set of covers, built using plastic laser sintering and Selective metal aluminium alloy laser melting, will be integrated on the iCub.







Mechanical integration

Four iCub's were completely assembled before July 2008 in Telerobot and IIT: two of them are for the Open Call winners (the first batch), another one for IST and the fourth is for the integration and test site of IIT (this was built completely on IIT funding).

The legs designed by the University of Karlsruhe were also assembled between June and September.

Two more iCub's for the Open Call (second batch) and a third robot are under assembly. The third robot will be delivered to EPFL.

Assembly procedures and a mechanical integration manual were developed in close cooperation with Telerobot, IIT and UGDIST and are integrated now in the assembly documentation and into the iCub manual (http://eris.liralab.it/wiki/Manual).

UGDIST/IIT

IIT and UGDIST contributed to WP7 by mainly:

- Debugging activities. A comprehensive testing of the platform was carried out. For example the robot was run at the Summer School for 10 consecutive days without failures and at Automatica 2008 for 4 consecutive days with only one broken tendon. An intensive optimization of the forearm allowed reducing the wearing of the tendons. A stress test on one of the fingers allowed up to 40000 cycles before showing some wearing. This result depends on the actual bending and routing of the steel cable and tube across the wrist and forearm.
- Electronics: the PC104 quad-can card was fully integrated and it is being delivered together with the robots. Further development of the force-torque and hall-effect position sensors was carried

out although we eventually decided not to release these cards in the first batch of the Open Call. Debugging and testing is still on-going and we aim at releasing a set of plug-ins for the robots once we have certainty about the quality and software/hardware integration. We plan to full support this activity. A Linux driver has also been developed.

- Electronics: a feasibility study of a new PC104 10-CAN card with improved bandwidth, DMA and full buffering has been carried out. The idea is to improve on this crucial piece of hardware (especially bandwidth). Actual design starts now.
- UGDIST and IIT was active in supporting the iCub duplication and assembly by defining the procedures for calibration and testing, developing software tools and debugging electric/wiring problems (e.g. disturbances).

This effort has been large.

Fig. 21: The CFW (quad-can, firewire, sound) interface card that is installed in the head of the iCub. This card together with a standard Pentium-duo CPU makes the interface of the robot hardware with the external world by reading sensors and sending commands to the actuators.

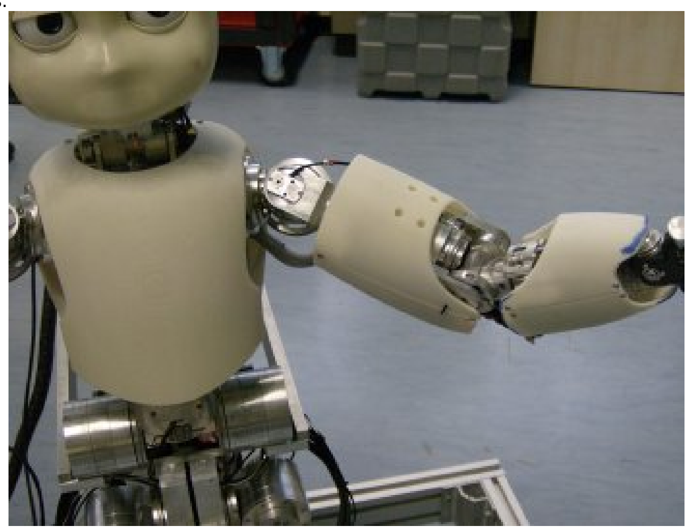


Fig. 22: The iCub prototype with a test of the cover made with a RP machine. This work is a contribution of IST (initial design), Telerobot (engineering), IIT (testing and debugging).

IIT

This work is about the development of a new compact soft actuation unit intended to be used in the iCub or in similar multi degree of freedom and small scale robotic systems. Compared to the other existing series elastic linear or rotary implementations the proposed design shows high integration density and wider passive deflection. The miniaturization of the newly developed high performance unit was achieved with a use of a new rotary spring module based on a novel arrangement of linear springs. The model and the control scheme of the actuator are analysed. The proposed control scheme is a velocity based controller that generates velocity commands signals as a function of the desired simulated stiffness using the spring deflection state. The overall system is evaluated with experimental trials performed using a prototype unit. Preliminary results are presented to show that the unit and the proposed control scheme are capable of replicating simulated impedances within a wide range and with good fidelity.

Further reporting of this solution is being held until verification of possible patenting issues is solved.

UGDIST/IIT

We designed and realized (the prototype of) a fingertip which includes a capacitive pressure sensor with 12 sensitive zones. It is naturally shaped and its size is small enough so that it can be mounted on the fingers of the iCub. As a result it is 14.5 mm long and 13 mm wide. The PCB with the electronics is included in the fingertip. It connects all the electrodes of the capacitive pressure transducer to an off-the-shelf capacitance to digital converter. The fingertip is made of silicone, which makes its surface and inner structure compliant and flexible. The transducer of the capacitive pressure consists of two conductive layers separated by a soft insulator made of silicone foam. The inner conductive layer is separated into 12 areas (see Figure 7), forming the taxels, acting as electrodes. The silicone layer, which compression is measured, is overall only 2mm thick in order to maintain a good spatial resolution. We use the silicone foam because it compresses easily after the first contact. This makes the sensor very sensitive to light touch. The foam is filled with bubbles that when compressed enough make the whole structure somewhat stiffer. A stronger force is then necessary to compress the silicone even more. This non-linearity is useful to enhance the range of measurable forces. Special focus has been paid on the production the 12 electrodes, as there production was intricate because of their small size. Also the support of the transducer can be flexible, which maximizes the compliance of the fingertip. We performed preliminary experiments with the first prototype showing the sensitivity of the sensor.

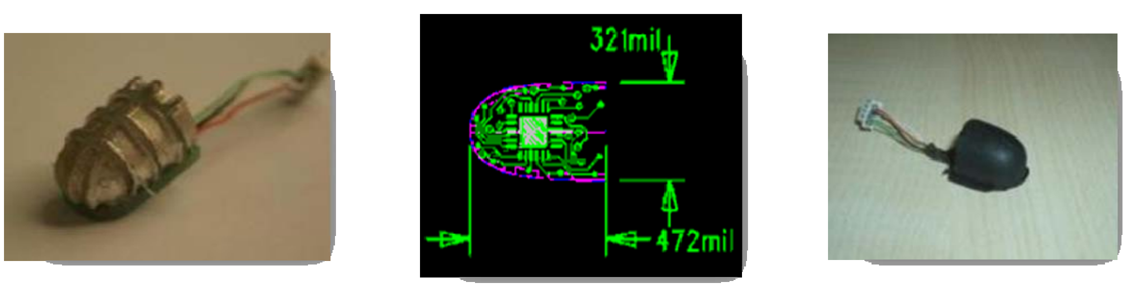


Fig. 23: From left to right: the electrodes painted on solid plastic, the PCB layout (earlier version) and the fully coated fingertip (initial prototype).

Alexander Schmitz, Marco Maggiali, Marco Randazzo, Lorenzo Natale and Giorgio Metta. (2008) A Prototype Fingertip with High Spatial Resolution Pressure Sensing for the Robot iCub. Proceedings of the 8th IEEE International Conference on Humanoid Robots (Humanoids08), in press.

IST

During the fourth year of the project, the contribution of IST to WP7 was centered in the final adjustments on the head/face cover/expressions mechanisms and corresponding software. In addition, in collaboration with the company ALMA Design, IST was provided an updated version of the iCub body cover, redesigned to meet the constraints arising from modifications in the body mechanical design.

In addition IST contributed to the effort of duplication of the iCub platforms with two engineers working for one month at the IIT in the mechanical assembly, integration of electronics and testing of the platforms.

SSSA

A novel bio-inspired sensory system for the open-loop to closed-loop transition in manipulation tasks has been developed. Moreover, a robotic platform (composed by upper torso, right shoulder, right arm and hand) was assembled and cabled for testing and developing software. As, in the development of a local low level control for a dextrous manipulation of objects, both proprioception and exteroception are mandatory, a further investigation of dedicated sensors was made to avoid the risk of a not closed-loop or limited capabilities available in the iCub final version. This work is two-folded: the first part is dedicated to the hardware (concluded), while the second one concerns the consequent tests on the SSSA iCub hand-arm-shoulder system.

For further details, please refer to "Giovanni Stellin, Christian Cipriani, Franco Zaccone, M. Chiara Carrozza, Paolo Dario, 'Design of an Anthropomorphic Dexterous Hand for a 2-years-old Humanoid: Ongoing Work', RoManSy 2008, July 5-8, 2008, Tokyo (Japan)" and to D7.4 "Development of a novel bio-inspired sensory system for the open-loop to closed-loop transition in manipulation tasks"

Deviations from the project work-programme

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
7.4	Novel bio-inspired sensory system for the open-loop to closed-loop transition in manipulation tasks.	7	42	42	SSSA
7.5	Status of the platform: major changes, debugging activities, problem report	7	48	48	TLR

List of milestones

Milestone no.	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M3.2	Release of the iCub kit	7	42	42	UGDIST

WP8 – Open System: iCub

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.

Progress towards objectives

UGDIST, IIT

UGDIST and IIT allocated considerable effort into the software development, debugging and support, effectively making the iCub software architecture a viable alternative for robotics projects not necessarily related to RobotCub. UGDIST and IIT have developed further the standardization of the basic modules, interfaces and documentation of software development. As part of this activity the first draft of the iCub manual has been produced which includes a new set of files documenting both the mechanics, the protocols and the entire software architecture ideally down to the very low level details.

Further, UGDIST has supported the development of low-level software updates, firmware releases and debugging tools for the iCub. For example new versions of the firmware resolved subtle timing problems with the Brushless motors commutation and new debugging tools allow printing status information over the CAN bus to screen. Finally, GUIs have been developed for testing the entire robot and for loading and checking control card status.

At the general software architecture level, UGDIST was active in the following:

- Managed regular releases of YARP containing new features and bug-fixes.
- Rewrote compilation mechanism for device "plugins":
  - Complete rewrite of "plugin" mechanism for devices in YARP and ICUB. The rewrite concerned how these devices got compiled, as opposed to the software API (which was

stable). Now it is easier for a contributor to develop and test plugins step-by-step, with better localization of any problems that might occur along the way..
    - Ported all existing devices to compile using the new mechanism, and developed documentation and a tutorial for it.
- Improved name server protocol and performance:
    - The YARP nameserver represents a potential single point of failure in a YARP network, which is otherwise peer-to-peer. YARP "namespaces" were improved to simplify the creation of non-interacting sub-networks of a single physical network.
    - The nameserver was made fully multi-threaded so that slow or buggy clients could no longer impact performance.
    - The nameserver protocol was unified with the regular port-to-port connection protocol. It was "special" only for historic reasons. Eliminating this specialness let the nameserver inherit the robustness of regular ports.
    - Wrote "yarpfs" as a test of nameserver performance. Yarpfs is a virtual file system for linux that maps ports onto files so that they can be read or written using regular file I/O.
- Improved YARP Port protocol:
    - Added an administrative interface for ports that is compatible with the standard YARP network data format. This will simplify add-on tools for controlling a YARP network.
    - Added "fast_tcp" carrier, a variant of the "tcp" carrier with no flow control. Useful in specific cases where flow control is known experimentally to be unnecessary and causes undesired latency.
    - Improved "local" carrier, which avoids unnecessary data copies when communicating between ports in the same memory space.
    - Improved YARP Port API:
    - Added notifications for port connections/disconnections.
    - Added greater user control over object lifetimes in buffered ports, through an "acquire/release" interface that lets YARP know which objects the user wants to hold on to.
    - Added callback for thread-safe finalization of objects just before they get written.
    - Continued to add more support for command line interaction with YARP, so that users can determine the state of port and connections from scripts.
- Improved ICUB ODE Simulator (within the ITALK project):
    - Worked with Vadim Tikhanoff (hosted at IIT) on improving the ODE-based iCub simulator. Improvements included making virtual cameras in the eyes, and inserting visual data from external scenes onto surfaces in the simulator.
    - Worked to release the simulator in pre-compiled form, since there was a lot of interest in the simulator from people who didn't necessarily have the capacity to compile it.
- ICUB release preparation:
    - Improved "make install" target of ICUB to better isolate future packagers from needing to understand the details of ICUB modules.

- o Developed a ResourceFinder class for managing configuration files and other resources in a flexible enough way to be able to remap ICUB modules onto various different organizations for different release platforms.
- o Modified three selected applications (the robot simulator, the iCubDemoY3 demonstration program, and a GUI for controlling individual joints) so that they were "releasable"

External code contributions to YARP in the last year (the following is just meant to show the overall enthusiasm around Yarp and the iCub in general):

- Giacomo Spigler: CUDA device driver, initial version and maintenance. RC servo motor device driver.
- Lorenz Mösenlechner: developed Allegro Lisp bindings for YARP via SWIG.
- Stefan Freyr Stefansson: patch for a new image type, patch to support camera index in opencv image source device driver.
- Freyr Magnusson: contributed a class for testing connections.

YARP bug reports, fixes, from external sources:

- Andreu Corominas Murta: reported an important bug that had been appearing for others sporadically but never consistently enough to track down. Andreu granted remote access to his environment, where he had a scenario that triggered the bug consistently. This finally let us track down and eliminate the problem for everyone.
- Philipp Robbel: noted a problem with the "local" carrier for connections.
- "johndoe32102002" (sourceforge username): reported a build problem on OpenSUSE.
- "dantard" (sourceforge username): reported several issues with the Bottle class.

Robotcub-hackers mailing list external activity:

- Federico Ruiz Ugalde: with Jonathan Kleinehellefort, released "roboview.py" for visualizing kinematic chains. This is independent to RobotCub, but was very useful at the last summer school.
- Pierre Griffault (imelavi.fr): questions about compiling simulator, connecting to the simulator from matlab.
- Stéphane Lallée (soon-to-be student of Peter Ford Dominey): compiling the simulator.
- Baris Atkun (ceng.meta.edu.tr, open-call): contributed KDL description of the hand; noted problem with touch port on simulator.
- Tahir Bilal (ceng.meta.edu.tr, open-call): questions about communicating with simulator.
- Dario Figueira: basic port questions.
- Kaijen Hsiao, Huan Liu (MIT): YARP with Xenomai.
- Ernesto Homar (iri.upc.edu): problems with autoconf build of YARP.
- Irene Markelic (bccn-goettingen.de): YARP with RTAI.
- Giovanni Saponaro: OpenCV device driver
- Nelson Gonçalves (isr.ist.utl.pt): OpenCV device driver

- Cristina Aleixo: OpenCV device driver
- “christln@tiscali.it”: Compiling YARP
- Marco Barbosa (isr.ist.utl.pt): notifications of connections.
- Miguel Vaz (dei.uminho.pt): YARP on MacOSX intel.

IST

During the fourth year of the project, IST has again allocated a substantial effort to software development, according to the Yarp architecture. The implemented software (mostly related to vision and head control functions and affordances) has been made available in the repository and used during integration meetings in Genova and during the the RobotCub summer school. The main contributed software was:

- head control
- affordances demo
- attention system
- tracking modules

Deviations from the project work-programme

Deliverable D8.1 (Version 2 of the iCub Specification) is delayed until M42 because design refinements are on-going and it seems to be sensible to defer the creation of a final specification until the robot design is finalized.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
8.1	Initial Specification of the CUB Open System.	8	42	42	UGDIST
8.5	Robot manual	8	48	48	UGDIST

List of milestones

Milestone no.	Milestone name	Workpackage no.	Date due
3.3	Launch of third party research projects (open call)	8	48

WP9 – Community Building and Self Assessment

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 fulfillment 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.

Progress towards objectives

UGDIST

The internationalization of RobotCub happened through a set of targeted activities, mostly recently due to the availability of the platform (or part of it) which provided a natural means of advertising the project. In particular:

- Live demonstrations of the iCub
- Presentations about RobotCub and the I-Cub at international conferences, workshops or other public events
- The RobotCub Open Call
- The RobotCub summer school: latest edition http://www.robotcub.org/summerschool
- New FP7 EU projects (under negotiation) with explicit links to RobotCub

Details of these activities are reported in Deliverable 9.3.

In particular, we would like to highlight two events where the iCub was demonstrated live:

- the Cogsys conference in Karlsruhe;
- the Automatica 2008 show in Munich. In Munich, the EU Commissioner Viviane Reading visited our stand and could see the robot in a live demo.

We believe that "live demonstrations" are good for dissemination but also to show to a wider audience that the technology of iCub is solid enough to allow research and long demonstrations without substantial failures. The iCub will be also demonstrated at the next ICT2008 in Lyon in November in two copies. In ICT2008 we will have two events:

- A stand with two robots on show: http://ec.europa.eu/information_society/events/ict/2008/index_en.htm
- A networking session called "iCub and friends forum" where representative from various projects using the iCub or part of it will be invited to share their experiences

For publications see list at the end of this document.

Task 9.6: RTS functions

The RTS was started and as first activities contributed to:

- Software maintenance: specifically low-level driver debugging, testing scenarios for the software architecture (performance test) and continuous support to the robotcub-hackers mailing list.
- Training: we organized training sessions on the mechanics (assembly) and the electronics (cabling of the robot) for the Open Call winners and for RobotCub partners receiving the iCub.
- Integration: we supported the visits of RobotCub partners researchers as well as from other projects. This activity will continue soon.

Although described in a few lines of text, the RTS activity required a considerable effort (provided by IIT at no cost).

IST

Major Achievements:

- Demonstration of the iCub attention system during the Y3 review
- Final revision of the iCub face, facial expressions and electronics.
- Development of a model for affordances learning and usage, including the integration into the Robotcub SW architecture.
- Work on learning sensory-motor maps,
- Software development for the iCub platform under Yarp.
- Collaboration in the duplication of the platform.

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
9.2	Material produced for the training activities (Wiki document)	9	48	48	UGDIST
9.3	Progress report on internationalization activities (Wiki document)	9	48	48	UGDIST

List of milestones

Milestone no.	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
-	-	-	-	-	-

Section 2 – Consortium management

New Contractor

On August 2008, on behalf of the RobotCub consortium, the Coordinator sent a formal request to the Commission, asking for the addition of the University of Sheffield to the project Consortium and the termination of the University of Salford participation to the project. The main role of University of Sheffield is to contribute to the development of the iCub Mechatronics and the realization of the sensorimotor skills, activities and abilities, with particular focus on generation of walking gates and balance coordination.

IIT

IIT has received budget (changing the original plan) to manage some of the Open Call acquisition of mechanical and electronics parts more efficiently. The budget transfer happened from UGDIST.

Delays

The full integration of the Cognitive Architecture had some slippage. Nonetheless, we have a solid plan now of integration into a single platform happening mostly through targeted visits to IIT in Genoa where we maintain a reference implementation of the iCub devoted to integration activities.

RobotCub

RobotCub list of published papers

Last update is 18.October.2008

2007-2008 in alphabetical order

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Section 3 – Other issues

None.

ANNEX – Plan for using and disseminating knowledge

Section 1 – Exploitable Knowledge and its Use

The RobotCub project is dedicated to the production of free-available open source results license under the GNU General Public Licence. Consequently, direct commercial exploitation is precluded.

Section 2 – Dissemination of Knowledge

Publications

See Section 3.

Dissemination Activities

See section on WP9 and especially the online deliverable 9.3 which contains details of the dissemination activities of RobotCub.

Press (selected)

1. National Television: Falar Global – Science dissemination program (July 2008)
2. Science exhibition visited by the Portuguese minister for Science, Technology and Higher education.

Fig. 24: The iCub head demonstrated for the Vice-Rector of the Beijing Institute of Technology on December 2007, during a visit to IST.

Fig. 25: The iCub head demonstrated a an elementary school during a seminar introducing the topic of robotics and information technologies., Lisbon, Portugal, April 2008.

3. British Satellite News including interview with Hatice Kose-Bagci on her work in Robotcub (related to her work reported in D6.5)

4. STRI Showcase event 5-7 March 2008: Hatice Kose-Bagci's work on human-humanoid drumming in Robotcub was identified as one of the highlights of the event (related to the work reported in D6.5):

5. Interview with Prof. C. L. Nehaniv on Anglia TV referring to Dr. Kose-Bagci's work reported in D6.5:

6. Dorothee Francois work (reported in D6.5) has been reported on German Television 3SAT broadcasted on 25th August and 26th August on 3SAT, repetitions later on SF, RBB, BRAlpha

7. Article on Wired, Getting a Grip: Building the Ultimate Robotic Hand, December 2007: http://www.wired.com/science/discoveries/magazine/15-12/mf_robothand

8. Article on EE-Times, Research bots leverage open-source for child-like intelligence: http://www.eetimes.com/news/latest/showArticle.jhtml?articleID=208808365

9. "Caro robot, fai una carezza" - Tutto Scienze (in Italian), Sept. 3rd 2008.

10. Robotino, Omnibus La7 (Italian, national coverage).

11. La pelle hi-tech, ora il robot ha anche il tatto, La Repubblica, July 23rd, 2008 page 30.

12. La sfida del Robot Intelligente, Il Secolo XIX, July 24th, 2008 first page.

Section 3 – Publishable Results

None to report.