RobotCub.org

ROBotic Open-architecture Technology for Cognition, Understanding and Behavior

Cogsys Cognitive Systems

Project IST-004370

RobotCub

Development of the iCub Cognitive Humanoid Robot

Instrument: Integrated Project
Thematic Priority: IST – Cognitive Systems

Third Periodic Activity Report

Months 25-36

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

Revision: **1.0**

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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 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 two year-old child. It will be able to crawl on all fours and sit up. Its hands will allow dexterous manipulation and its head and eyes are fully articulated. It has visual, vestibular, auditory, and haptic sensory capabilities. The iCub is an open systems platform: researchers can use it and customize it freely[2]. 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 three principal objectives for the period have been substantially achieved:

1. The construction of the first complete prototype of iCub;
2. Achievement of significant progress on YARP-integrated software development for the iCub, specifically in the implementation of the new scenario-derived software architecture ('cognitive spine').
3. Launch the Open Call for Research Projects on 1st September 2007 seeking research projects which will make use of the iCub.

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[1] Cub stand for *Cognitive Universal Body*.
[2] The iCub is freely licensed under the GNU General Public Licence.

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 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 year.

Many more achievements are detailed in Section 2.

1. Over 140 papers have been published or accepted for publication, with more that 40 having been produced in the last year. A full list is provided in Section 3 and PDF copies of these papers are available on the accompanying CD and on the RobotCub website.

2. The completion of the first prototype of iCub, head, face, upper body, arms, hands, lower body, legs, wiring, and documentation. This is major milestone and represents the culmination of a very intensive year's work on many fronts (DIST, TLR, IST, UNISAL).

3. Complete integration of the mechanical documentation of the platform (TLR)

4. Organization of the manufacture of additional copies of the iCub (TLR)

5. Realization of the development scenarios as a scripted set of empirical investigations.

6. Design of a new software architecture ('cognitive spine')' that represents a neuroscientifically-plausible (at least in terms of the inter-module feedback and feedforward connections) model of how attention, gaze control, and reaching are effected.

7. Significant progress on software development for the iCub software architecture based on YARP; modules are now available on the CVS repository (DIST, IST, UNIZH, EPFL)

8. The RTS has been started at the Italian Institute of Technology, with three people having been hired for the positions of Software integrator and maintainer, Mechanical documentation manager, Component and purchase manager.

9. The Open Call for Proposals was launched and, in preparation for the commissioning of the iCub copies: manufacturing procedures were organized with four machine shops in Italy after extensive validation of their ability to work to strict RobotCub standards (DIST)

10. Analysis of crawling of real infants in order to improve the model of crawling, notably by closing the loop. To the best of our knowledge, this is the first detailed quantitative study of infant crawling (EPFL & UNIUP)

11. A general controller has been developed for combining discrete and rhythmic movement during locomotion (EPFL)

12. An algorithm for learning the body schema, its convergence properties have been mathematically proved, and it has been implemented on a humanoid robot, enabling it to adapt to tool use, or to bad camera calibration (EPFL)

13. A reinforcement learning algorithm has been implemented to enable a robot to imitate a simple goal directed tasks, despite different initial conditions even when there are obstacles on the way (EPFL)

14. A number of advances on learning sensory-motor maps, particularly for redundant systems and manifold estimation (IST).

15. Developed of a model for learning and using affordances (IST)

16. Development of a drummer module for both Kaspar and iCub, which works together with a newly-developed audio analyser tool, takes the played pattern information and causes the robot to imitate the human drumming (UNIHER).

17. Simple non-verbal gestures were included in the drumming modules described above, and imitation based human-humanoid interaction games were performed (UNIHER).

18. Interaction games were performed with 12 adult participants, to study imitation, deterministic turn-taking, non-verbal social interaction, gestures, and affect of gender differences. The interaction games performed in this study are not using a wizard-of-oz (remote control) approach, but the humanoid robot functions fully autonomously (UNIHER).

19. Integration of the Information Distance work into the Yarp system was carried out (UNIHER)

20. Porting of interaction history architecture to C++ YARP. Includes calculation of experience distance, placing of sensorimotor experiences in a metric space and maintaining multiple metric spaces with communication between processes via YARP so allowing for distribution of computation load (UNIHER)

21. Mass Manufacture of the Force/Torque sensor (UNISAL)

Publications

A full list of all publications can be found in Section 3: Consortium Management. Approximately 40 papers have been published in the past year. PDF copies of publications can be found both on the project website and on the accompanying CD.

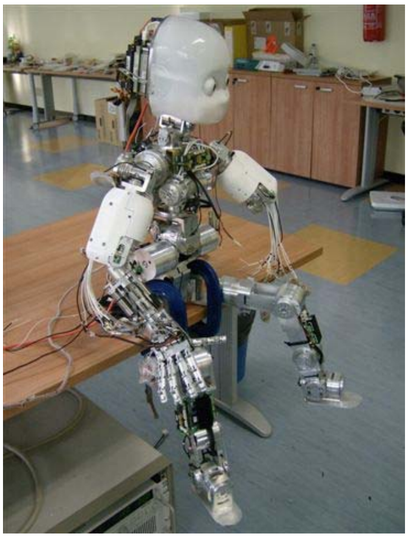
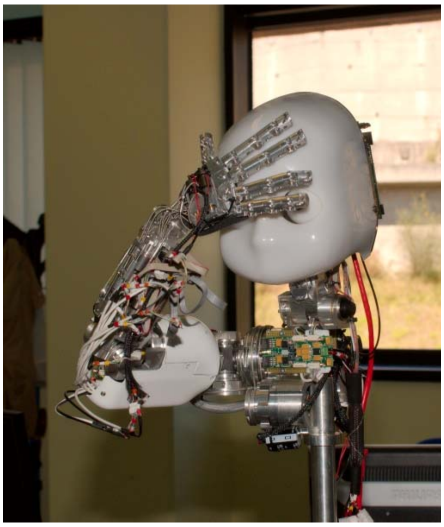
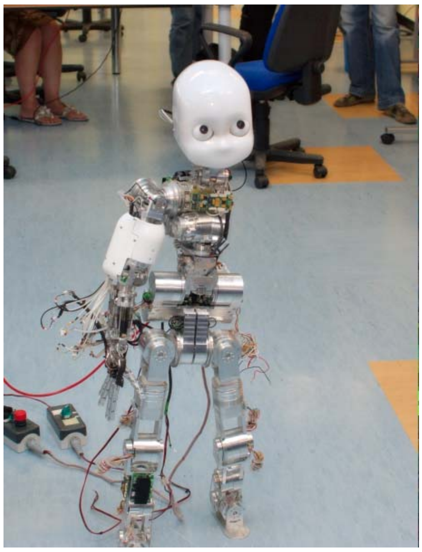
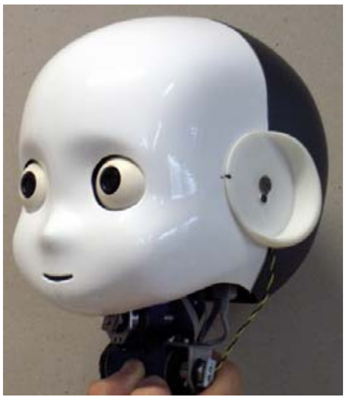
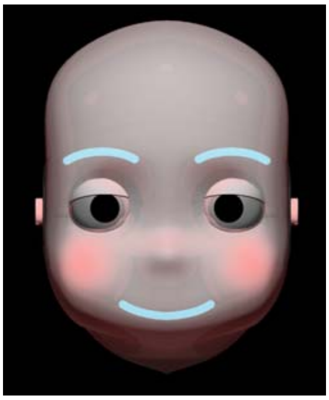
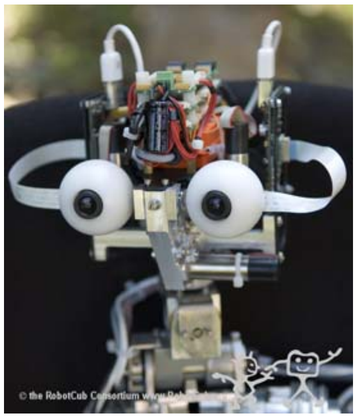
Dissemination activities

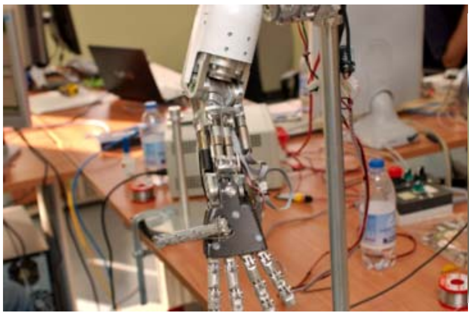
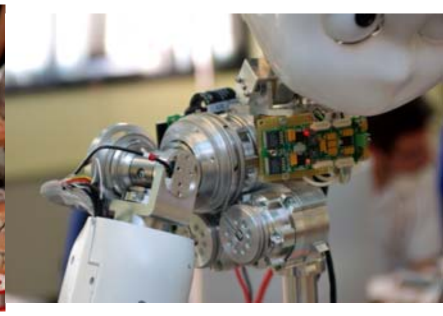
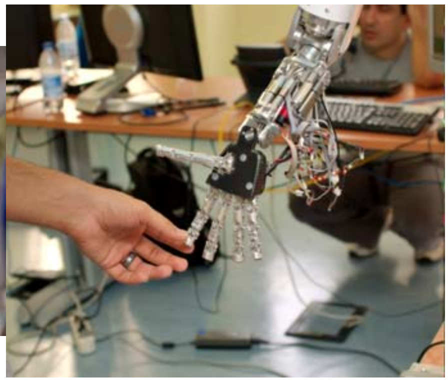
Our primary vehicle for dissemination is through publication of journal and conference papers. In addition, we have issued a call for proposals and we have engaged in a variety of more informal dissemination activities. These are catalogued in Annex I, Section 2 below.

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.

Diagrams & photos of the work

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 forty publications in the past year.

Review Recommendations and Consequent Actions

The Report on Review 2 made six recommendations. The following revisits those recommendations and sets out the actions that were taken as a result.

Recommendation 1: There needs to be some sort of framework for the cognitive architecture — a 'spine' for enabling the expression of the phylogenetic capabilities. More than one approach could be envisaged.

This recommendation was well made and well taken: it is clear that there is a huge gap between the outline 'in principle' paper design of a cognitive architecture that was presented at the review last year and a working system, even one with extremely modest cognitive capabilities. Bridging this gap presented us with a great challenge and it one that we attempted to address over a series of four dedicated workshops[3] at which we endeavoured to identify this cognitive 'spine'. These workshops culminated in the 2nd RobotCub Summer School (VVV '07)[4]

Since this is such a major aspect of our work during the past year, it is worth spending some time setting out what we attempted to achieve, what we actually ended up in achieving, and how it allows us to move forward.

[3] 19th January 2007, Munich; 2nd March, Munich; 17th April, Ferrara; 10th July, Herfortshire.
[4] The 2nd RobotCub Summer School: see http://eris.liralab.it/wiki/VVV07

Our strategy throughout the year was to focus on the end result, specifically equipping the iCub for Experimental Scenario 1, as detailed in Section 16 of Deliverable D2.1. Initially, we sought to identify

- The minimal cognitive architecture
- The minimal set of phylogenetic abilities
- A top-level and lower level data-flow architecture
- A standard set of interfaces (APIs, class access methods, data acquisition and device control protocols, etc).

Unfortunately, we made little progress until it was decided that a more prescriptive task specification was required than is encapsulated in the Scenario descriptions. This led to the development of a specification for a set of empirical investigations. These investigations, developed by the University of Uppsala, are a scripted version of the manner in which a psychologist would interact with a young infant during a series of typical sessions and they set out the behaviour that she or he would expect that infant to exhibit. They are set out in full in Section 17 of the latest version of Deliverable D2.1. These scripted investigations allowed us to cross-reference the phylogenetic and cognitive skills that had already been specified specified in D2.1 with our functional requirements and thereby identify those phylogenetic skills that had not been catered for so far. This minimal set of phylogenetic and cognitive skills is documented in the latest version of D2.1 (Section 15.6.1). Each capability corresponds to one or more communicating YARP modules (executables). It was decided that all YARP modules should be designed to be re-usable and interoperable since, in the interests of comparison and research diversity, there may eventually be more than one YARP module with the same functionality. The agreement of the appropriate level of granularity for these modules and the interface protocols was in itself a major challenge and one that took many hours of discussion to resolve.[5]

Of course, this was only the beginning and it remained to bring these functional capabilities together in a way that would facilitate the empirical investigations. The trap that confronted us in this process was the temptation to adopt a position of engineering expediency: to get it to work for the review demo! It is inevitable that we would have fallen into this trap had it not been for the repeated warnings and remonstrations of our partners from the neurosciences and psychology who insisted at every turn that whatever we did must have some biological plausibility and should not be an ad hoc engineering kludge.

Further discussions and consequent delay naturally ensued but during the second two workshops there was a break-through and we agreed – after four generations of revision – a new ‘software architecture’ that represents a neuroscientifically-plausible (at least in terms of the inter-module feedback and

[5] For example, see http://eris.liralab.it/wiki/ICub_joints for a definition of the joint naming convention and control interfaces.

feedforward connections) model of how attention, gaze control, and reaching are effected (which is the purpose of the first scenario and associated empirical investigations; the target functionality for the 3rd review). Apart from the software architecture design exercise, this involved a very considerable amount to software engineering to achieve this minimal functioning system. We refer to this initial system configuration as the software architecture, an architecture that will allow us to create a working system that is neuroscientifically and psychologically viable but which is biased towards the very early phylogenetically-derived behaviours and is nevertheless supportive of subsequent developmental ontogeny. This is our 'spine': a core software infrastructure for the iCub so that it will be able to exhibit a set of target behaviours for the first set of empirical investigations. This software architecture[6] (cognitive spine) is described in Section 15.6.6. of Deliverable D2.1 and is more fully documented on the RobotCub wiki:

- The evolution of this design is recorded on the RobotCub wiki at http://eris.liralab.it/wiki/ICub_software_architecture.
- The iCub capabilities are set out on the wiki at http://eris.liralab.it/wiki/ICub_capabilities.
- The YARP modules themselves are documented on the wiki at http://eris.liralab.it/wiki/ICub_YARP_module_specifications.
- The overall status of the iCub software is set out on the wiki at http://eris.liralab.it/wiki/RobotCubSoftware.

Our plan is for the software architecture to evolve so that it is compatible with what is known about the neuroscience of action, perception, and cognition. Ideally, it should also evolve in a manner that is also compatible with the iCub cognitive architecture and, vice versa, the cognitive architecture should evolve to be compatible with the software architecture. Ultimately, they should be the same thing. The software architecture page on the wiki contains a working summary of the issues that affect this evolution.

Two challenges now face the project. First, we need to consolidate the software architecture and complete its implementation (so far, just the gaze and attentional system is working; we need to finish the reaching system and integrate the two as specified by the architecture). Second, we need to then add on more ontogenetically-motivated functionality to facilitate learning and development, *i.e.* more cognitive behaviour. The goal is to have both software and cognitive architecture co-evolve in mutual specification: in the end, we plan to end up with a neuro-scientifically and psychologically plausible cognitive architecture that is grounded in a fully-functioning robust phylogeny which in turn facilitates self-development through interactive exploration of the iCub's environment and interaction with other agents.

[6] Henceforth, when we refer to the software architecture we mean this minimal phylogenetic system – the cognitive spine – and not YARP which had been referred to in the past as the iCub software architecture. YARP of course remains and is the indispensable middle-ware upon which all iCub software is built.

Recommendation 2: It is advisable to have coordinators for key areas (e.g., computer vision, the cognitive architecture, and the phylogenetic / behaviour module library), to moderate and coordinate the progress in these areas and to moderate the process of selection for what alternative mechanisms are kept in the main software distribution.

We agree fully with this recommendation. Unfortunately, the appointment of such coordinators really only makes sense once the overall design of the minimal system is complete and responsibility can be parcelled out. As will be evident from the preceding text, our efforts in the past year on the software side were focussed completely on achieving this milestone and we have not yet assigned specific coordinating responsibilities. We are now at the point where we can do this and will intend to implement this recommendation forthwith.

Recommendation 3: Dissemination of the iCub component technologies should be considered. While not necessarily requiring full support they could be incorporated in other research by people not needing entire Cubs.

This recommendation is well taken and will certainly be worth implementing. However, in the intervening year since it was made, all the consortium's time and effort has been taken up in keeping to the schedule for the completion of the full integrated iCub, the complexity of which continues to pose a very significant challenge for logistics (sourcing, ordering, etc.), design, fabrication, assembly, test and debug, and engineering revisions. We simply have not had sufficient resources to divert effort to the dissemination of individual components or sub-systems up until now. Once the first complete prototype is debugged and the design is complete, with the fabrication of the copies for the Open Call underway, we intend to return to this recommendation and implement it.

Recommendation 4: Safety issues should be taken into consideration and addressed in a statement to be distributed with all iCubs.

A new deliverable has been produced to this effect: D8.4: Safety Notice and Liability Disclaimer.

Recommendation 5: The planned competitive call needs to be fleshed out along the lines of Annex III.2 (Competitive calls) to the contract. A pertinent document should be listed under Deliverables.

A new deliverable has been produced to this effect: D9. Text of Call for Research Proposals.

Recommendation 6: Early consideration of marketing (of marketable results of this project) is encouraged.

Again, this recommendation is well made and it is certainly well taken by the consortium. However, in much the same vein as Recommendation 3, we felt that until the first complete prototype is debugged and the design is complete, with the fabrication of the copies for the Open Call underway, it would not be appropriate to implement it. Again, we intend to return to this recommendation and implement it once the new research proposals have been launched and the iCub copies have been fabricated.

In addition to these six recommendations, the Report on Review 2 also made the point that

“all comments (including comments and suggestions that have not explicitly been marked as ‘recommentations’) should be given due consideration. This concerns in particular:

- JB’s comments on remaining challenges
- PFD’s comments on risk management
- RR’s comments on the iCub hardware”.

In the following, we will attempt to present the essence of the concerns of the three reviewers and our consequent actions.

JB’s comments on remaining challenges

Dissemination: the consortium should also be publishing in leading mainstream conferences and leading journals, as well as niche ‘new AI’ conferences and journals. In other words, we should not just be talking to our own community but engaging with the full scientific community.

This is a fair criticism and, one year on, we have had some success. In the past year, the consortium has submitted too, or had accept for publication in, the following journals and conferences: Progress in Brain Research, ICRA, Phil. Trans. Royal Soc. B., Neuroimage, HRI 07, Advanced Robotics, IROS 07, IEEE Trans. System, Man, and Cybernetics, IEEE Trans. Robotics, BMVC, Behvioural Brain Research, Neurophysologica, Vision Research, Journal of Neurophysiology, among others (notably those in the developmental or new AI forums). Clearly we can do more to broaden our dissemination, such as targeting NIPS, IJCAI, TICS, and AIJ, etc. and we will strive to do so over the coming year.

Integrated Behaviour: the consortium should redouble its efforts to ensure that all its work is capable of being integrated in one system.

Again, this is fair comment. We are in full agreement and this has been the focus of our work in the new ‘software architecture’ described above in response to Recommendation 1. It is worth mentioning again here that it is not straightforward to achieve this in a research project such as this one, both because of the absolute effort required and the apparent unattractiveness (or invisibility on some occasions) of the necessary commitment of resources to a software engineering enterprise that doesn't pay obvious dividends in terms of published research. Nonetheless, it is crucial for the success of the project and we now have a sound foundation of integrated functionality upon which to build.

Capture of methodological contributions.: the consortium should publish an account of their methodology in realizing the iCub, focusing on the processes that have enabled innovation and development in our highly heterogeneous multi-disciplinary consortium.

Unfortunately, this suggestion, though well taken and extremely valuable, has not yet been acted upon. This is not out of any disinterest in writing a methodology paper but because of the strain our time and resources have been under for the past year. We could & should do better, and we will.

PFD's comments on risk management

Introduce a new item in Deliverable D8.3: a compatibility table of software components vs. workpackages, with each cell identifying the responsible laboratory and a flag to indicate integration compatibility.

We made some progress towards this but did not make it a formal deliverable. In fact, we developed and used on several occasions a variant of this table to identify the components of the minimal system (i.e. the new software architecture discussed above and set out in Deliverable D2.1) required to carry out the empirical investigations derived from scenario 1. This variant identifies the components (grouped under three heading; see Section 15.6.1, Deliverable D2.1 and the wiki at http://eris.liralab.it/wiki/ICub_capabilities) versus each responsible laboratory. This table went through four generations of evolution before it was finalized (we can make all four generations available for inspection by the reviewers, if required.) The issue of integration compatibility didn't arise in this case as all modules identified have to be integrated as YARP modules or as groups of YARP modules (again, please refer to D2.1). With that said, there is considerable merit in the creation of the table as suggested as an exercise in auditing the current development work in the project and consideration will have to be given to doing this in the coming months.

Introduce a new item in Deliverable D8.3: a table of phylogenetic capabilities vs. workpackages 3-6, with each cell identifying the status of the contribution.

We decided to drive the identification of the phylogenetic capabilities from the newly-introduced scripted empirical investigations (Section 17 of D2.1) rather than on the basis of the work-packages. However, there is clear merit in creating the table as suggested as an exercise in auditing the current development work in the project and hopefully more time becoming available and greater consolidation in the software architecture, this is something that we need to attend to.

Introduce a new item in Deliverable D8.3: a table of scenario capabilities vs. work-packages 3-6, with each cell identifying the status of the contribution.

The same observation as above applies here too: such a table would no doubt be very useful but within the time constraints available (and the urgency of specifying and implementing the ‘cognitive spine’ software architecture), we chose to expend our energy in developing the four generations of the table mentioned above.

In summary: the three suggested tables would be very useful and, all things being equal, they will be created over the coming months.

RR’s comments on the iCub hardware

Address safety issues, with the implementation of an emergency cut-off switch and hardware-based velocity limiters for the actuators.

At present, the emergency cut-off switch has been implemented but velocity limits are handled by the DSP chips, rather than by dedicated hardware limiters. Velocity can be also limited by lowering the power voltage. The control electronics work fine down to 12V (instead of 48V).

Since communication latency and associated delays will cause control problem in an off-board distributed control system, define which control loops will be effected on-board and which will be off-board.

To date, we have not distinguished between the different control loops, mainly because they weren’t identified until we reached the current (fourth) generation of the software architecture design at the Summer School in July. However, we feel that this issue won’t pose a problem because we can elect to run the control loops either on the robot-side of the Ethernet interface (i.e. on the on-board PC104 computer) or on the host-side of the Ethernet interface (i.e. on the distributed system) because the location of the control modules is transparent to the YARP middleware. For reference, the delay times are as follows.

1. DSP level, on-board, 1ms or less latency (depending on the implementation)
2. PC104 level, on-board, over the CAN bus, 4ms or less latency (depending on the implementation and bus traffic)
3. Ethernet level, outside the robot, 10ms over the GBit Ethernet connection (typically 30ms camera frame rate)

To maximize the spread of technology, either provide some of the components to other laboratories or identify a company that will be able to act as a second source of complete assembies.

This will be a priority action once we have completed the design, implementation, and test of the complete integrated iCub; our primary focus at present in on getting over this critical hurdle. Once that is done, we will take up these suggestions and implement them: our having neglected to do it to date is not due to any questioning of their validity, it has been to do with scarce human resources and limited available time.

Lower the barrier to entry by reducing the cost of the iCub.

We want to do this but, as the reviewer notes, it is difficult to do it until the first system has been completed. Nonetheless, we have conducted several budgeting exercises over the past twelve months to see where economies of scale can be achieved and where cost-savings can be leveraged by adopting alternative vendors and sub-contracting to different machine shops. These budgets can be made available to the reviewers should they wish to study them. Ultimately, the best cost reductions will probably be achieved by lowering the very high component specifications we adopted at the outset to minimize though judicious over-engineering risk of failure because of insufficient performance. Once again, this can only be done when the first few prototypes are in operation and we are in a position to establish empirically the latitude for relaxing specifications.

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 first prototype of iCub, head, face, upper body, arms, hands, lower body, legs, wiring, and documentation.

2. Achieve significant progress on YARP-integrated software development for the iCub; specifically the new scenario-derived software architecture (cognitive spine).

3. Launch the Open Call for Research Projects.

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

Section 2 – 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 study the development of early cognition and how to model the relevant aspects of such process within the boundaries of an artificial system. In particular, we investigate the timeframe of a developmental process that begins to guide action by internal representations of upcoming events, by the knowledge of the rules and regularities of the world, and by the ability to separate means and end (or cause and effect). This research is strongly driven by studies of developmental psychology and cognitive neuroscience and it will result in a physical implementation on an artificial system.

Biologically plausible models of how early cognition evolves are being investigated, taking into account both the brain mechanisms underlying the modeled cognitive processes and the learning procedures used by the child to accommodate new concepts and assimilate already acquired ones to better fit the outside world. These models will be validated against behavioral studies of how young children solve problems of various kinds and how they use internal representations of objects and events to plan actions.

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.

UNIUP

Cognitive Roadmap: During this period UNUP worked on the scenarios that the robot should be trained at (pp. 84-88 in D2.1)and on the design of subsequent experiments (pp.88-91 D2.1). A substantial part of the meetings in Munich and Ferrara this year were devoted to this problem. UNIUP also investigated how motion analysis could help solving the object segregation problem. This analysis was presented at the meeting in Hatfield.

Developmental Architecture: Experiments have been conducted on children's ability to manipulate objects and understand events in the surrounding. In these experiments, measurements of gaze direction and reaching activity have been used to investigate the development of the cognitive function. Together with IST, we investigated the ability of the robot to track an object with its head and eyes. For this purpose, the upper part of the robot was brought to Uppsala and we tested it in two situations. First, we used the large 2-D object display developed at UNIUP to study gaze tracking and reaching in human infants. The object moves on a vertical plane (1 X 1 m) in any arbitrary way define in advance. We tested how well the robot could track this target in space and time. Secondly, we put the robot in a cylinder in which the robot and an object on the inside of the cylinder could be independently moved. This apparatus has been used in Uppsala since 15 years to test the visual-vestibular coordination in infants (see e.g. Rosander & von Hofsten, 2000). The results show that the robot still has problems with the predictive control of the head and eyes.

UNIFE

Task 2.2: Explore neuro-physiological 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.

a) The pattern of eye movements during action observation is the same as that recorded during action execution. In both cases, the eyes anticipate the hand and reach the target well before the arrival of the fingers. Thus, saccadic behaviour during action observation supports the direct matching hypothesis for action recognition. We decided to study the development of this predictive behaviour during action observation in developing infants (UNIUP) and in children affected by Autism Spectrum Disorders (ASD) (both UNIUP and UNIFE, see D3.1). 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. Now we are finishing the analysis of the kinematics data.

b) The amount of time spent in observing stimuli presented in different experimental conditions is a dependent variable which gives 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. The experiment has been carried out in collaboration with the University of Parma. Indeed, the origins of the supposedly unique human ability to understand and predict the behaviour of others by ascribing them inner mental states is matter of controversy in both comparative and developmental perspectives. Recent studies suggest that the human infants’ early capacity for understanding and predicting others’ goal-directed actions relies on non-mentalistic strategies. However, there is no consensus about the nature of the mechanisms underpinning these strategies. Behavioural studies on macaques’ capacity to evaluate the goal-relatedness of movements performed by others can shed light on these mechanisms, and therefore on the basis of the evolution of humans’ intentional understanding. We carried out two preferential looking-time experiments on macaques, modeled on previous work on human infants, to test whether macaques recognize means-ends adequacy while observing goal-related and non goal-related movements performed by an experimenter. The preliminary results demonstrate that macaques monkeys are sensitive to means-ends adequacy while observing goal-directed motor acts, but only when others’ behaviour matched their own motor experience in a given context. Thus, the direct detection of the intrinsic intentionality of action, based on previous motor experience, seems one key element for the evolution 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. This task will also address the mapping of this computational framework for cognitive processing onto the software architecture being developed in Task 8.6.

As far as Task 2.4 is concerned, 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.

Experimental evidence from brain imaging, behavioral, neurophysiological and neurological studies suggests that covert orienting of spatial attention and planning eye movements are strictly linked both at the functional and anatomical levels. The existence of such a link was firstly predicted by the premotor theory of attention, proposed, among others, by the UNIFE key persons. Premotor theory claims that orienting of attention toward a spatial location is a consequence of an eye movement preparation toward that location. According to this theory, movement preparation determines an enhancement in the detection of stimuli presented in the location target of the prepared saccade, even if the movement is not subsequently executed. The idea that the motor system plays a crucial role in one of the highest cognitive functions, such as attention orienting, is in line with the issue of the embodied cognition pursued by the Robot-cub project and, when implemented in the i-Cub, will allow to obtain a biologically-based highly cognitive behavior without any necessity of separate cognitive modules (for further details see Deliverable D2.1, Section 15.6.6).

UGDIST

Evolutionary Optimization of Kernel Machines

The performance of Kernel Machines is critically dependent on both hyperparameter optimization and sometimes on the kernel function. We explored hyperparameter optimization using Evolution Strategies and kernel tuning using Genetic Programming. The approach was validated by using the Least Square Support Vector Machine (regularized least square). Future work will be devoted to the online formulation of the approach and possibly modularization to improve speed to compute the solution (which is required for motor control applications).

Online independent Support Vector Machine

In a developmental scenario (where data arrives on a continuous basis) online learning seems the main way out, thanks to the possibility of adapting to changes in a smart and flexible way. Nevertheless, standard machine learning approaches usually suffer when confronted with massive amounts of data and when asked to work online. Online learning requires a high training and testing speed, all the more in certain robotics scenarios, where a continuous flow of data comes from one or more cameras, from tactile, sound or force sensors. We followed the Support Vector Machines-based approach, proposing an improvement that we call Online Independent Support Vector Machines. This technique exploits linear independence in the image feature space to incrementally keep the size of the learning machine remarkably small while retaining the accuracy of a standard machine. Since the training and testing time crucially depend on the size of the machine, this solves the above stated problems. Our experimental results prove the effectiveness of the approach.

IST

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

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

While the work during the first two years of the project focused on sensory-motor coordination (WP3) and imitation (WP5), in the third year there was considerable effort dedicated to the aspect of learning about object affordances (WP4).

For that purpose, IST developed an approach for learning object affordances through experimentation and observation. The affordances model learned in this way allows the system to predict or plan its own actions as well as to interpret the actions executed by others. As a result, the model allows the system to reproduce (imitate) such observed actions in its own way, bridging the gap from sensory-motor maps to imitation.

Most of this work is described in a journal paper accepted for publication at the IEEE Transactions on Robotics on a special issue o Bio-robotics. The work on the different aspects of sensory-motor coordination will be presented at the IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS2007. This work is also closely related to that of Workpackages WP3, WP4 and WP5.

In addition, a substantial effort was initiated in the design of the attention system for the iCub. This work was developed together with the University of Zurich (UZ).

Jointly with U.Zurich several YARP modules were developed to be the support of such integrated attentional system. For that purpose, we developed an integrated representation of multi-modal sensory information. The current version of the system is able to represent the perceived visual and auditory information in the so-called ego-sphere.

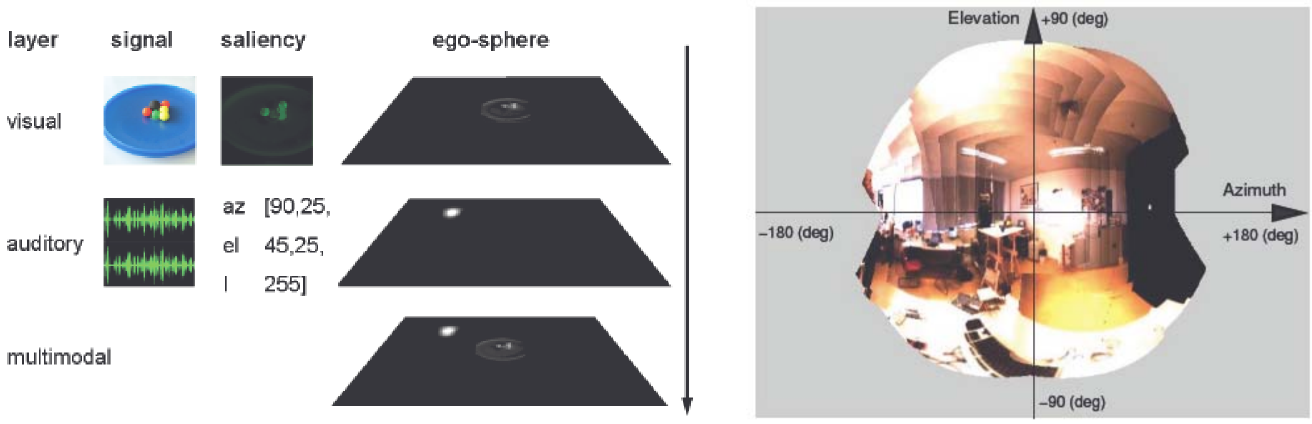
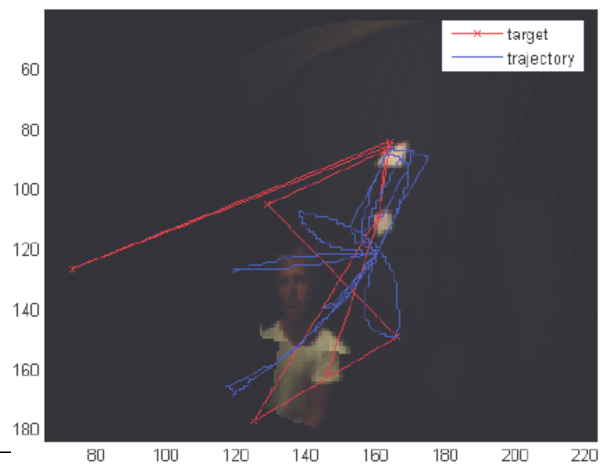


Figure 1 - Visual representation of the space around the robot.

Having this joint multi-modal representation allows the system to keep short-term memory of the sensory space. The ego-spherical stimuli map is used for saliency computation which drives the exploration of the surrounding space of the robot. A process of inhibition-of-return is included in this attentional module.

The figure shows the gaze pattern of this exploratory behaviour.



UNIZH

The University of Zurich contributed significantly to the software implementation of the iCub software architecture. Specifically, the following software modules have been developed (partly in collaboration with IST/Vislab):

- CamCalib: undistortion of camera images.
- Salience: visual saliency filters (motion, face, directional, intensity).
- Ego-sphere: aggregation of multimodal sensory stimuli in a egocentric frame of reference.
- AttentionSelection: gaze point determination based on a multimodal saliency map.
- AttentionLogger: recording and debugging module for the attention system.
- Visual blobs: calculation of connected regions.
- EMD / fastFilt library: optical flow implementation (elementary motion detection).

Deviations from the project work-programme

None.

List of deliverables

Del. No.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
D 2.1	A Roadmap for the Development of Cognitive Capabilities in Humanoid Robots	2	30, 36	30, 36	DIST

List of milestones

Milestone. No.	Milestone name	Workpackage no.	Date due
M1.5	Definition of the cognitive architecture	2	36

WP3 – Sensorimotor Coordination

Workpackage objectives

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

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

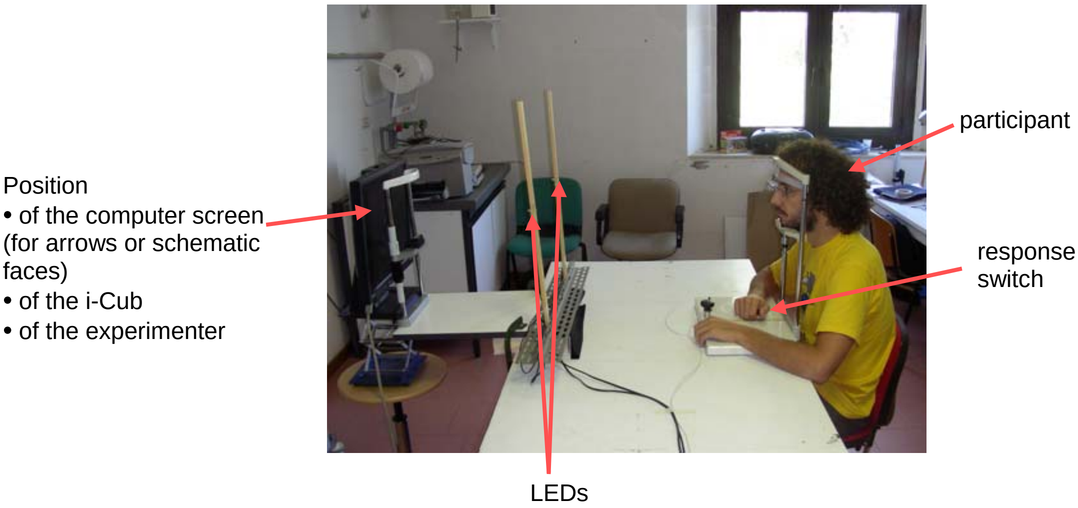
Progress towards objectives

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

In order to study and model oculomotor involvement in orienting of visuospatial attention, UNIFE and IST collaborated to perform an experiment based on recent behavioral data indicating that gaze direction triggers reflexive shifts of attention toward the gazed-at location. 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?

In order to answer these questions we performed an experiment in which participants were required to press a button as soon as an LED placed on their right or on their left was switched on (see the figure below).



Before the appearance of the imperative stimulus, four different experimental situations, each of them presented separately in different experimental sessions, could be presented: (1) a central horizontal arrow pointing either towards the left or towards the right; (2) a schematic face with its eyes deviated either towards the left or towards the right; (3) the i-Cub directing its gaze towards the left or towards the right; (4) the experimenter directing his gaze towards the left or towards the right.

Preliminary results of the experiment indicate, firstly, that the orienting of attention determined by the schematic face is more similar to that determined by an arrow than to that determined by a real human face. Thus, a schematic face can't be considered a "biological stimulus" as it is often defined in literature. Secondly, the performance of the participants in the i-Cub session is statistically more similar to the performance in the experimenter session than to the one in the other two sessions. Consequently, from this preliminary experiment, we can suggest that the i-Cub is perceived to be "more biological" than the drawings of schematic faces.

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 paper Craighero L., Bonetti F., Massarenti L., Canto R., Fabbri Destro M., Fadiga L. "Temporal prediction of touch instant during grasping observation" has been accepted for publication in Brain Research Bulletin. We attach a draft of this paper, describing an experiment in which subjects were required to detect, both in monocular and binocular vision, the instant at which a demonstrator's hand firstly touched an object while grasping it. Grasping movements were performed with two different orientation of the fingers. Results showed that, to accomplish the task, subjects implicitly use an internal model of the seen action, especially when the visual information is partially lacking.

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.

As stated last year, we are exploring the possibility that a mirror-neuron system exist not only in primates but also in simpler animals such as rats, characterized by an intense social interaction. To this purpose, we projected and realized a multi-electrode amplifier (32 channels) and we started experiments of intracortical microstimulation in the rat, in collaboration with the University of Parma (Italy) and the University of Odessa (Ukraine). A detailed description of this experimental protocol is given in Deliverable 3.1. During the third year of the project we completed the mapping of the rat premotor cortex by microstimulating various frontal regions, we set up the experimental framework in Odessa (A. Oleynik was sent there for two months for this purpose), we started an alternative design for the recording array. We plan to have the first neural recordings during the first months of 2008.

b) Single neuron recordings in monkeys.

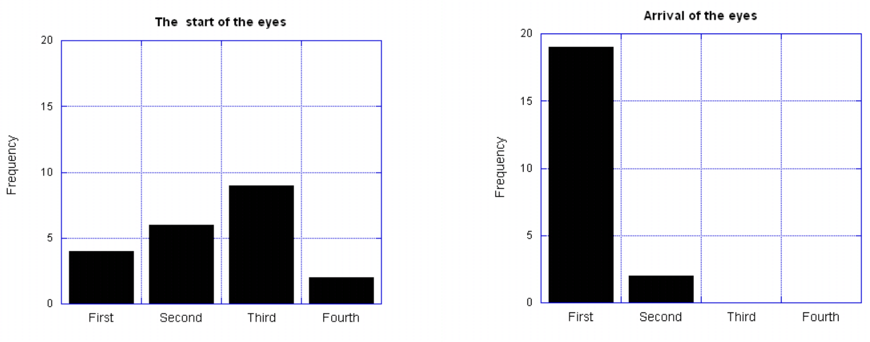
The experiment is aiming at investigating the role of visual feedback in hand action planning and execution, and we are now finishing the analysis. We have recorded three hemispheres from two monkeys. A preliminary report concerning a new method for virtual stereotaxis in monkeys is attached to this report (Gesierich et al.). Preliminary results of single neuron recordings indicate that many motor neurons recorded in monkey's premotor area F5 are sensitive to the vision of monkey's own hand during grasping (WP3 and WP4, see Deliverable 3.1). As far as this part of the project is concerned, we must report some delay, mainly due to two reasons. The first reason is the discovery of a procedural error in the analysis that forced us to repeat the spike sorting procedure. Moreover, in March 2007, the person involved in this analysis decided to leave our lab because he was offered with a long-term position in Rome. Now we have solved this unexpected situation by increasing our own efforts and we are writing two papers on this experiment that will be submitted soon. The second reason is that we spent a lot of energy to set up electrophysiological recordings in humans. We have indeed now the possibility to record single neurons from awake neurosurgery patients in the framework of a collaboration with Udine Neurosurgery Department and the Italian Institute of Technology of Genova. This is an ambitious and promising project which associates fMRI on individual patients, electrophysiology and neuropsychological testing. The preliminary data are so encouraging that we will propose to create a new task within WP 3.

UNIUP

Integration of different modes of actions in the accomplishment of a complex manual task

It is known from studies of adults that they are consistently predictive when looking at their own actions (Land & Hayhoe, 2001; Johansson, Westling, Bäckström, & Flanagan, 2001), that is, they move gaze to the goal of their actions before the hand arrives there. It has also been found that both adults and 12-month-old infants look at the goal of actions performed by other individuals before their hand arrives there (Flanagan & Johansson, 2003; Falck-Ytter, Gredeback & Von Hofsten, 2006). It is not known, however, whether infants look predictively at the goal of their own actions. Neither is it known how they coordinate eye, head, and hand movements during the executions of these manual actions. We studied 10 to 11-month old infants while they carried out complex manual movements consisting of, at least, two sequential actions, for instance grasping and displacing an object, grasping and inserting an object into a container, or grasping and handing the object to another person. While the infants carried out these actions, head and hand movements were recorded with a passive reflective marker system (Qualisys AB, Proreflex). Eye movements were recorded with EOG. All data were synchroniously recorded at 120 Hz. For more detailed information about the EOG setup, see Rosander and von Hofsten (2000, 2002, 2004) and von Hofsten and Rosander (1996, 1997).

The analysis show that the head often leads at the beginning of the movement and sometimes the hand. However, the eyes always arrive first at the goal followed by the head and the hand arrived last. This is depicted in Figure 1. The results suggest that action plans are formulated ahead of time and based on information gathered earlier. Looking becomes important towards the end of actions as the spatial demands increase. The movement time for the head was ~860 ms, the hand ~700 ms, and the eyes ~600 ms. Comparing these durations with the corresponding ones for a reach shows that the hand movements are similar, but the times for head and eyes are shorter for the reach. On the average, 1.5 movement units were obtained for the hand.



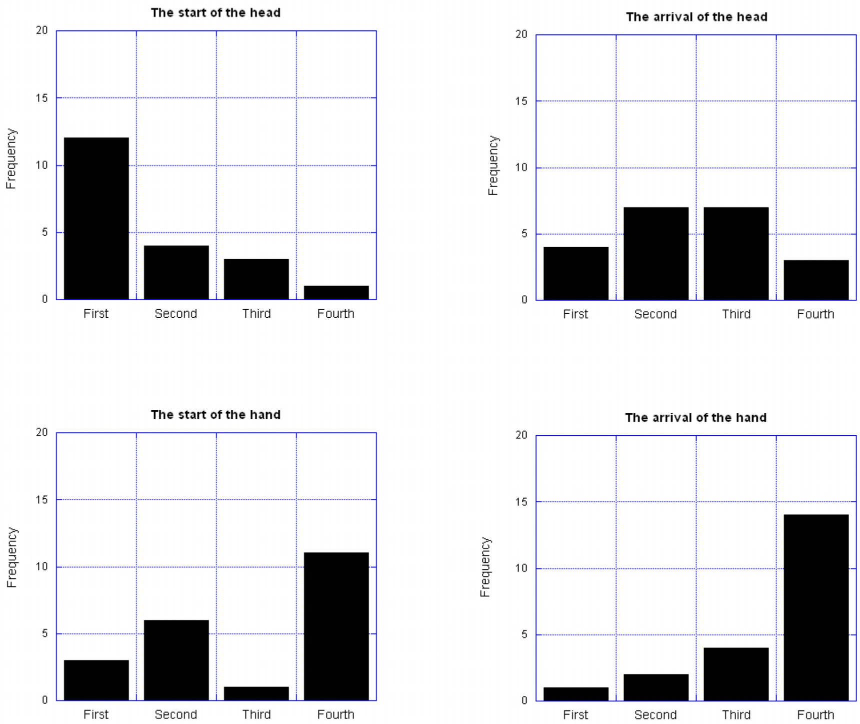


Figure 1. The order of the start and arrival of the head, hand, and eyes

Studies on the development of complex object manipulation

The ability to manipulate objects is the end-point of several important developments; perceptual, cognitive and motor. We have conducted two kinds of studies on this topic, building towers of blocks and fitting blocks into apertures. Three studies were conducted on the object fitting problem. In Study I, 14- 26-month-old infants were presented with one object and one fitting aperture. A number of object forms were included in the experiment. In Study II, they were given a choice task; two different objects were either presented together with an aperture that fitted one of the objects or one object and two apertures, one of which the object fitted into. Finally, in Study III, the subjects were presented with two objects with different sizes and/or different forms and an aperture that matched one of the objects.

All the studies show that young children are fascinated by the fitting problem but that their ability to solve the problems change drastically with age. Study I showed that 14-18-month-old children were rather unsuccessful in getting the object through the aperture but that the the 22- and 26-month-olds succeeded very well. The analysis of the results showed that successful insertions were associated with pre-adjustments of the orientation before the object arrived at the aperture. Such an idea can only arise if the infants can mentally rotate the manipulated object into the fitting position before moving it there. The ability to imagine objects at different positions greatly improves the child’s action capabilities. It enables them to relate objects to each other, and plan actions that involve more than one object more efficiently.

The solution of the choice problems is not just a question of choosing one alternative, but also to inhibit the choice of the other one. This made the problem much more difficult. Fifteen-month-old children were neither able to use size or shape to select the matching object. 20 months were able to choose between differently sized objects but not between different forms. 30 months managed to choose between blocks of simpler forms, but not even by 40 months children could make a choice between objects of different triangular cross sections. The children might have thought that any of these triangular blocks would fit any triangular aperture.

In the tower building studies, that we conducted together with Rachel Keen and Yupin Chen, toddlers strategies in building towers were examined. We found that reaching slows when the hand approaches to pick up an object that will subsequently be used in a precision task, compared to an imprecise task. We tested 35 toddlers using blocks to build a tower (precise task) or to "clean up" by throwing them into a container (imprecise task). We hypothesized that toddlers who were able to build tall towers (4+ blocks) would have more mature kinematic characteristics than toddlers who only built low towers (2-3 blocks). Thirty-five toddlers between 18 and 21 months of age were tested. Reaches during the approach phase and the placing phase were recorded using motion analysis systems. When the hand approached the block for pickup in the tower task, there was greater deceleration than for the imprecise task. The approach phase did not differ depending on the toddler's ability to build a tower. For the placement phase the reaches of the tower task, as expected, were significantly slower, less forceful, with a longer deceleration phase and lower speed at releasing, compared to the imprecise task for all children. Here ability mattered: toddlers who could build tall towers had a longer deceleration phase in their reaches than toddlers who built low towers.

Investigations on the Mirror Neuron System in human infants

We have investigated the development of the Mirror Neuron System (MNS) in infants. The mirror neuron system has been suggested to play a role in many social capabilities such as action understanding, imitation, language and empathy. These are all capabilities that develop during infancy and childhood, but only very few studies have been devoted to the development of the human MNS. We have approached this problem in a situation where subjects are shown human movements. A high density EEG net was used to measure cortical activity of infants and adults with the aim of identifying mirror neuron activity. The subjects viewed both goal directed movements and non goal directed movements. An independent component analysis was used to extract the sources of cognitive processes. To guide the selection of mirror neuron related activity sources, Mu rhythm de-synchronization was used. This frequency band in the EEG shows a high peak when subjects view static stimuli and passive relaxed individuals. When human movements are shown, however, this frequency band desynchronizes. The desynchronization of the mu rhythm in adults has been shown to be a marker for activation of the mirror neuron system and in our studies was used as a criterion to categorize independent components between subjects. In the first study, video recorded goal-directed movements, non-goal-directed movements, a moving object and a stationary object were shown to 6-month-olds and adults. The results showed significant mu desynchronization in the adult group and significantly higher ERP activation in both adults and 6 months for the goal directed action observation condition. This study demonstrate that infants as young as 6 months display mirror neuron activity and is the first to present a direct ERP measure of the mirror neuron system in infants. In a subsequent study, 8-month-old infants saw a live model demonstrate goal-directed and non-goal-directed movements or being at rest. Sources were selected that showed the highest difference between movements and rest. These sources were then compared with respect to how much the mu rhythm was desynchronized when the subjects saw the goal-directed and the non-goal-directed movements. A significantly stronger desynchronization was found when the infants saw the goal-directed movement compared to the non-goal-directed one. We thereby provide direct evidence that the mirror neuron system (MNS) is functioning at this age level. This will help delineating the maturing MNS and could be used to establish the significance of mirror neurons in social development.

EPFL

Task 3.6: Modelling 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 the American Journal of Physical Anthropology.

A feedback loop has been added in the Webots model so that the robot autonomously switches from swing to stance phase depending on sensory information. This offers more robust locomotion in unknown environments. An article presenting this model has been submitted to ICRA2008 (see also the paper published at RSS06). We are also developing a controller for the transition from crawling to sitting.

A module for crawling in Yarp has been developed and is currently being improved. We also updated the physic simulation of the iCub using Webots with the last information from the current hardware design and we developed a Yarp interface for Webots to have the same code running both on the simulator and the real robot. The Webots model and all the code are available in the iCub repository.

Task 3.7: Superposition of rhythmic and discrete movements.
An architecture for hand placement during locomotion has been developed. In this model, adaptive locomotion is seen as discrete, sensory driven corrections of the basic, rhythmic pattern for crawling. An article on this subject has been accepted for the IEEE IROS conference this year.

A Yarp module has been developed for a drumming task, as this task involves superimposition of discrete and rhythmic movements without requiring a high control of the stability of the robot.

A review on the generation of discrete and rhythmic movements (deliverable 3.3), focusing in bridging the gap between neurobiological and mathematical models, has been performed.

Task 3.8: Robotic implementation of models of sensory-motor coordination for reaching and grasping tasks: Body schema learning and peripersonal space representation

A general framework for adaptive peripersonal space representation has been developed, based on principles drawn from neurophysiology and psychology. This framework comprises the visual, proprioceptive, tactile and motor modalities. It is adaptive in the sense that it develops as a result of sensorimotor contingencies. This work has been submitted to the International Journal of Humanoid Robotics.

UNIHER

The Month 30 update to deliverable D3.2 (*Initial Results of Experiments on the Functional Organization of Somatotropic Maps and on the Cortical Representation of Movements*) was delivered in March 2007. The update consisted of software for the *sensorimotor reconstruction method* based on Information Distances, and placed in the iCub repository. The software was written in C++ and Yarp. This software takes the data from the robot, and other sources if needed, and calculates the *Information Distances* between these sources. Adaptive binning is achieved using Entropy Maximization which enables different sensory modalities to be directly compared, and so allows a multi-modal space to be constructed. Sensorimotor maps are constructed in lower dimensional space using this distance information and can be updated as the robot experiences its environment.

UGDIST

Task 3.2: Trajectory prediction in human subjects

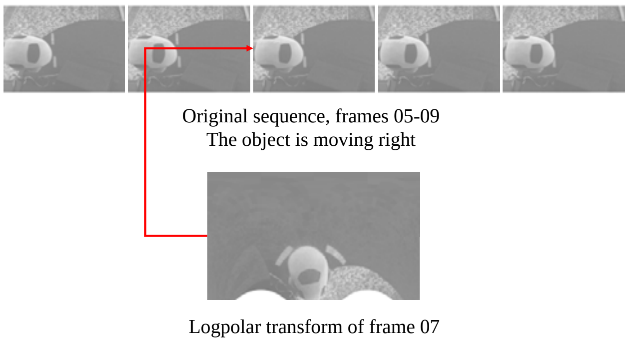
The presence of delays in our central nervous system causes a systematic delay between action instantiation and the corresponding motor act. During interceptive or catching tasks, in particular, these delays prevent the instantaneous adjustment of our movements and force us to use a strategy alternative to feedback control. We have designed an interception experiment with the aim of understanding whether this strategy involves building internal models of the flying object dynamics and whether the motor system plays a role in this modeling phase. Future work is directed at excluding that the effect could be reproduced by vision only (without motor intervention) and to study new force fields that are not necessarily gravitational. The idea is to study object behaviors in different conditions and see how much our prediction of the object behavior is linked to our motor system.

Task 3.2: Prediction of grasping actions

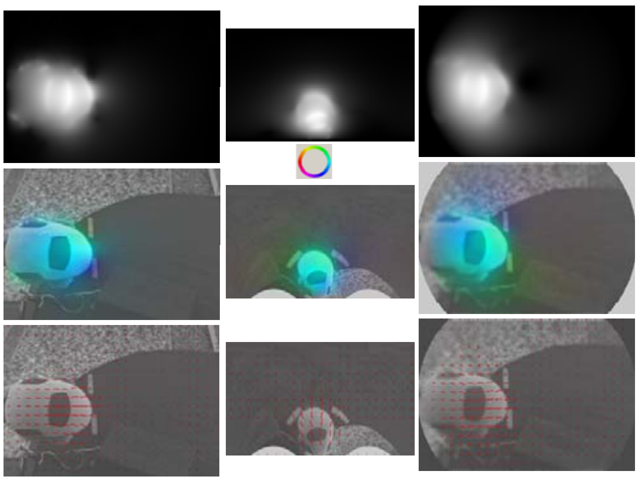
One of the most distinguishing features of cognitive systems is the ability to predict the future course of actions and the results of ongoing behaviors, and in general to plan actions well in advance. Neuroscience has started examining the neural basis of these skills with behavioral or animal studies and it is now relatively well understood that the brain builds models of the physical world through learning. These models are sometimes called ‘internal models’, meaning that they are the internal rehearsal (or simulation) of the world enacted by the brain. In this work we investigate the possibility of building internal models of human behaviors with a learning machine that has access to information in principle similar to that used by the brain when learning similar tasks. In particular, we concentrate on models of reaching and grasping, and we report on an experiment in which biometric data collected from human users during grasping was used to train a support vector machine. We then assess to what degree the models built by the machine are faithful representations of the actual human behaviors. The results indicate that the machine is able to predict reasonably well human reaching and grasping, and that prior knowledge of the object to be grasped improves the performance of the machine, while keeping the same computational cost. More detail can be found in the paper by (Castellini et al., 2007).

Task 3.8: Optic flow computation

Some initial testing of the quality of the recovered optic flow can be seen in the following **Error! Reference source not found.**. Future work will be devoted to making the processing real-time (frame rate, 30fps) and multi-scale to allow for the detection of fast moving objects.



Exemplar sequence where a toy car moves rightward and the corresponding logpolar transform of the frame 7 out of frames 5-9 (shown above).



Comparison of the optic flow estimation between logpolar and standard images (rectangular). The leftmost column shows the optic flow calculated over the original images. Top-left: greyscale representation of the velocity amplitude; middle-left: color coding of the direction of movement; bottom-left : vector field display. The central column shows the same processing applied to logpolar images and the rightmost column the result remapped back into Cartesian coordinates for comparison.

Task 3.8: Estimating Time and Location of Contact

The possible next step after optic flow has been reliably estimated is to detect the time and location of contact. There are various approaches to this problem. The current work aims at verifying the quality of measurements of optic flow, while a more plausible model should probably use machine learning to map optic flow patterns to experienced time to contact (and it would require the tactile sensors and skin described later).

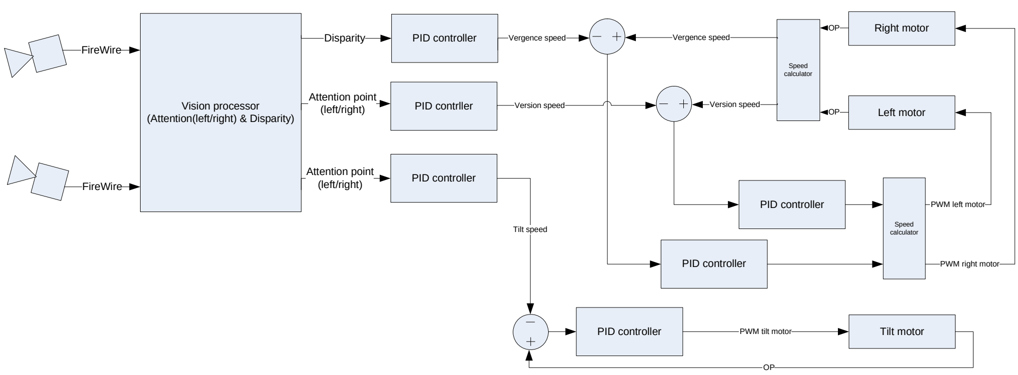
Task 3.1: Biologically inspired visuomotor control of the iCub head

The first problem for the robot system is to move the cameras efficiently. One possible solution to the demand of computational resources by visual processing is to transfer certain functionalities into hardware. It is now becoming efficient and viable to do this on FPGAs. Hardware implementations guarantee real-time frame-rate processing (at the additional cost of extra programming using HDL). Control algorithms can be efficiently carried out by the existing microcontroller cards of the iCub.

Given a stereoscopic vision system, the vergence angle, together with version and tilt angles, describes uniquely the fixation point in space. We interpret vision and motor control, and in particular we focus on developing a biologically inspired control strategy for an active head, by studying the cooperation of vergence and version movements. The following diagram shows the proposed model. The FPGAs implementation will include the interface to the cameras (firewire), logpolar mapping (from rectangular to logpolar), binocular disparity computation, and the attention system.

The FPGA module for the logpolar mapping has been already implemented with the following parameters:

- Cartesian image size: 512X512
- Logpolar image size: 152X252
- Maximum speed of operation: 125 frames/second



The proposed model of visuomotor control for the iCub head : the vision module is implemented by using the FPGA technology.

Task 3.2-3.8: Reaching

We started the implementation of one of the modes of reaching, that is the foveal component of a precise reaching controller. This was done on James, an upper-torso humanoid robot, which is similar to iCub in many respects (number of degrees of freedom, approximate size, and software). The proposed solution is based on a learning strategy which does not rely on a priori models of the kinematics of the arm nor of that of the head. After learning, the robot can reach for visually identified objects in 3-D space by integrating an open loop and a closed loop component; the open loop controller allows ballistic movements, while the closed loop one performs precise positioning of the hand in visual space. Differently from other approaches we handle the critical case of redundancy in the head and the arm and propose a solution that although preliminary possesses some biological relevance.

The method is described in details in (Natale, Nori, Sandini and Metta, 2007). In short, it is based on the construction of a mapping between the description of the fixation point in space (assuming fixation on the target of the reaching movement) and of the posture of the arm to reach that point. For closed loop control, the Jacobian of this mapping is also approximated by machine learning. We take care of building methods that can do all these operations online (via incremental learning) and we make provisions for the redundancy of the robot arm (by learning the forward mapping and building inverses online depending on the task).

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

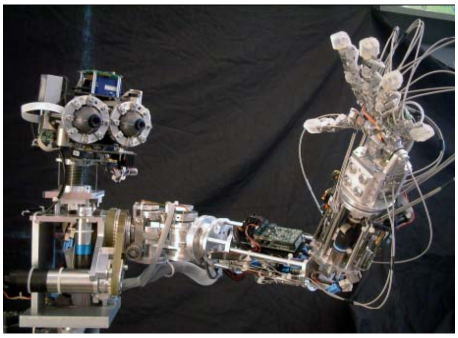
The task of tracking an object has been fully studied and many solutions presented. However, it is a perfect test-bed for the study of a novel model using Coupled Chaotic Systems. Once an object appears in front of a camera, we demonstrated that the visual input is enough for the self-organization of the torques applied to each of the axes controlling the motion of a simulated eye. No learning or specific coding of the task is needed beforehand, which results in a very fast adaptation to perturbations.

In short (more details are in (Duran et al. 2007)) a set of chaotic elements are globally coupled via certain coupling parameters. The coupling determines among other things the degree of synchronization between elements of the chaotic field. The chaotic field can be either completely chaotic (when the coupling is close to zero), completely synchronous (high values of coupling constants) or in between. The in between states are interesting because they can show transitions from meta-stable states into chaos and vice-versa.

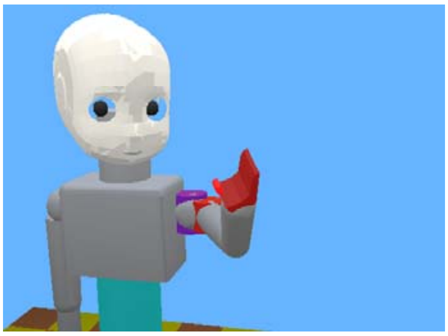
At this point, this is all fairly preliminary work. Future work will be devoted to the implementation of the controller for the head including eye-neck coordination (6 degrees of freedom) including the use of the inertial sensors (VOR). Further, we plan to explore learning of the coupling strength by a simple Hebbian rule (as proposed by Kaneko and Tsuda, 2001).

Task 3.2: Study of a distributed energy system

We are studying the functions of a humanoid robotic system from the energetic point of view which includes energy efficiency with respect to motors control, the specified task, and the design of the robot. To carry out this work, while lacking the real robot (apart from small testing sessions at this stage), we developed a physically accurate simulation tool. Some additional testing was also carried out on James (a robot that is similar to the iCub although simpler and less reliable in many aspects. In this case, 4 DC motors were used for experimentation, controlling the shoulder and elbow. The transmission as for the iCub is obtained by rubber belts, stainless steel tendons and gears. The simulator was based on Webots (as for the iCub), on Matlab and some C code. We needed three different tools because we required an accurate simulation which none of them could easily provide: Webots was used for the simulation of the rigid body mechanics, Matlab to simulate the gear trains using a specific integrator (stiff), and the C code to implement specific components that were not present in the previous tools. The output of the simulation was the energy flow for each motor, the whole system efficiency and the robot and motor dynamics.



A



B

Panel A, the robot James developed at UGDIST; panel B, the simulator output in Webots.

UNIZH

The work of UNIZH focused on 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.

Most of the work carried out during the last 12 months addresses issues related to Task 3.1. The implemented software modules provide a flexible basis for an advanced attention system and enable in a first step bottom-up attention based on multimodal saliency maps. Following a developmental approach to robotics, this implementation is inspired by the reflexive attention found in human babies at birth. The following list gives an overview of implemented capabilites:

- C6 Construct sensorimotor maps & cross-modal maps: Multimodal saliency maps from visual and auditory stimuli are aggregated by the ego-sphere module.
- C8 Exploratory, curiousity-driven, action: By combining saliency based attention selection and a dynamic inhibition of return mechanism, the iCub explores its environment based on preattentive features.
- C4 Attention and action selection by modulation of capabilities: The saliency module provides remote accessible filter weights which enable other modules to adjust and direct attention.
- C11 Saccadic direction of gaze towards salient events (visual, auditory, tactile): Together, the modules salience, ego-sphere, attentionSelection and controlGaze provide this capability. Currently, visual and auditory sensory channels are implemented. Due to the extendable software architecture, it is easy to implement further sensory modalities like tactile information.
- C12 Focus attention and direct gaze on human faces (features, movements, sounds): Besides preattentive filters, the salience module provides an additional filter based on face detection. By applying this filter, human faces are assigned high saliency.
- C13 Ocular modulation of head pose so that head pose is adjusted to centre eye gaze: Working together with the saliency system, the controlGaze module provides this capability (developed at IST).
- C20 Computation of optical flow: The fastFilt library provides an interface for optical flow and includes an implementation of the elementary motion detection algorithm (EMD).
- C1 Object tracking through occlusion (combining smooth pursuit and saccades): A concept for this capability was developed at UZH and tested. It is not yet integrated into the cognitive architecture.

A publication related to C6, C8 and C11 has been submitted to ICRA08: Multimodal saliency-based bottom-up attention, A framework for the iCub platform.

IST

The work developed by IST in this workpackage was concentrated on four main directions: (i) the use of manifold learning for the estimation of sensory motor maps and (ii) experiments on the head-eye control system and (iii) experiments with eye-contact and attention.

1. Manifold learning for the estimation of sensory-motor maps

In the past we have addressed the problem of learning different types of sensory-motor maps and we approached specifically the problems occurring when the map is not well defined because of e.g. redundant degrees of freedom.

To overcome these difficulties, we developed a new algorithm to learn a structure that represents simultaneously both sensory and motor information. This approach provides significant advantages over the traditional map learning techniques and may be used to recover any (partial) map between perception and action. For this we have developed:

- An online algorithm that learns the input-output constraints of a generic smooth map (manifold);
- A method that, given a partial set of input-output variables, provides an estimate of the remaining ones, using the learned constraints (manifold).

The approach consist in representing the sensory-motor capabilities of the system as a manifold and not as a sensory-motor (or motor-sensory) map, thus allowing the representation (retrieval) of multiple solutions that would otherwise lead to non-invertible mappings.

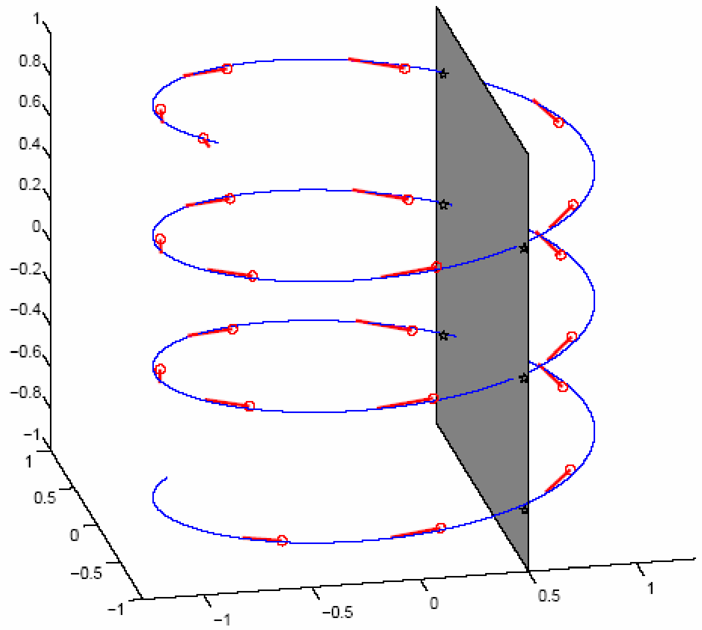
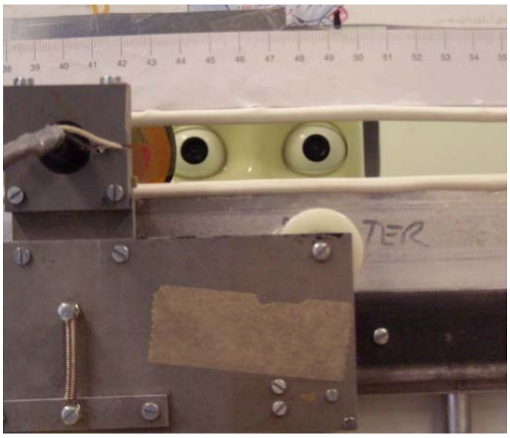


Fig. 4. Recovering the forward model embedded in the manifold. With $x_q = 0.5$ the six possible outcomes are successfully estimated (represented in the figure by black asterisks).

2. Eye-head coordination

IST designed and implemented in Yarp the software for the head controller. When directing the visual attention towards an object of interest the eyes start moving rapidly in the direction of the goal, while the neck lags behind. At the end of the movement, the neck motion compensates for the eye displacement and the eyes look to the target in a frontal manner. This coordination is achieved through optimal control techniques, whereby the inertia or energy consumption of the different degrees of freedom is taken into account,

In collaboration with the University of Upsala (UU), we have tested the iCub-head using the UU experimental facilities to provide a benchmark of future research on this topic. On-going research addresses the issues of learning how to adequately acquire such movement coordination (as opposed to being programmed a priori).



The iCub head following targets while the head-eye motion is being recorded.

3. Visual attention (Posner tasks)

This work was developed in collaboration with the University of Ferrara (Unife). The goal consisted in investigated visual attention, in particular the effect of priming cues in Posner Tasks.

The experiments were conducted in the University of Ferrara using the iCub head. The idea was to compare the difference with respect to priming of the use of a schematic (face) drawing against the robot head or a human head as stimuli.

Discussion is ongoing about the development of an integrated attention system where such aspects might be modeled and taken into account.

UNISAL

Classically robots have had very little autonomous ability to react to the environment. Among the key missing elements is the ability to create control systems that can deal with a large movement repertoire, variable speeds, constraints and most importantly, uncertainty in the real - world environment in a fast, reactive manner. The approach at UNISAL involves learning from experience and creating appropriate adaptive control systems.

Reinforcement learning typically requires an unambiguous representation of states and actions and the existence of a scalar reward function. For a given state, the most traditional of these implementations would take an action, observe a reward, update the value function, and select as the new control output the action with the highest expected value in each state (for a greedy policy evaluation). Updating of value function and controls is repeated until convergence of the value function and/or the policy. This procedure is usually summarized under policy improvement iterations.

Reinforcement learning aims to make an agent learn which actions it should perform in order to maximize the acquisition of rewards. This learning system is interesting as it allows us to “program” agents easily to make them do whatever we want simply by emitting different signals (reinforcement) according to the relevance of their actions. Moreover, animals and humans are very efficient in this task, for example the way dogs can be trained, or that a rat learns to move in a maze in order to find a source of food. Animals can anticipate the reward associated with their actions and it is interesting to know how this is done. However good models for this kind of behaviour are complex to design, the main difficulty is to identify the cues predicting rewards.

Within the past twelve months efforts have been directed towards:

to develop an agent capable to learn an accurate and synchronized gait for performing motion (crawling, walking, etc). This builds on a virtual agent (humanoid robot 3D simulation) and high level programming, to develop, test and validate the proposed learning method.

Work is targeted at 3 main sub goals to achieve:

a) Creation, development and validation of a Fuzzy - Reinforcement learning algorithm to control a simple system as a motor - mass.
b) Research of ways of applying this novel Fuzzy - RL learning algorithm to learn and coordinate several actuators in a limb.
c) Research of ways of applying this novel Fuzzy - RL learning algorithm to learn and coordinate several limbs of a robot.

In addition work continues on ;

a). Development of a input tracker glove in conjunction with UNIUP looking at the development of technology to accurately track hand actions in infants up to 24 months.

b). Development of a high accuracy 6 dof tracker in association with UNIFE.

SSSA

SSSA is using a new bioinspired paradigm called Expected Perception for the grasping and manipulation tasks, which is a paradigm based on predictions of the sensory inputs. 2 PhD students, Nicola Greggio and Fernando Gamarra, are working on designing and developing this paradigm for the iCub platform. First, we will describe the vision algorithm we developed in order to obtain the visual and spatial characteristics of the object to be manipulated. Then, we will describe how we think to implement the Expected Perception in the RobotCub platform.

An image processing algorithm has been implemented to recognize an object that will be defined as the target for the reaching task. This image processing algorithm uses a color filter to recognize the object, finds the centroid of the image in each camera and uses these data as input to a neural network (a Levenberg-Marquardt backpropagation) that gives the position of the object in the head 3D space. Another neural network will be used to classify the object with respect to its position and dimension, so as to identify a grasping type, among a few possible grasps with different hand opening.
The Expected Perception module uses a neurofuzzy neural network to construct an internal model of the world allowing the sensory predictions, i.e. tactile data in this case. This neurofuzzy module is based on a neural network to construct its internal fuzzy rules. A Dynamic Self organizing map has been programmed; this neural network generates its own structure according to the data input. Therefore, we construct a unified matrix that gives us a data representation based on the Kohonen map created for this network. We applied the mean shift algorithm to the unified matrix in order to cluster the data and create the set of fuzzy rules that are necessary for the neurofuzzy controller. Currently, we are working in interfacing the neural network with the fuzzy system.
During the next months the Expected Perception paradigm will be applied with the different modules that are under development for the iCub platform. The Expected perception scheme thought for the iCub is shown in the figure below.

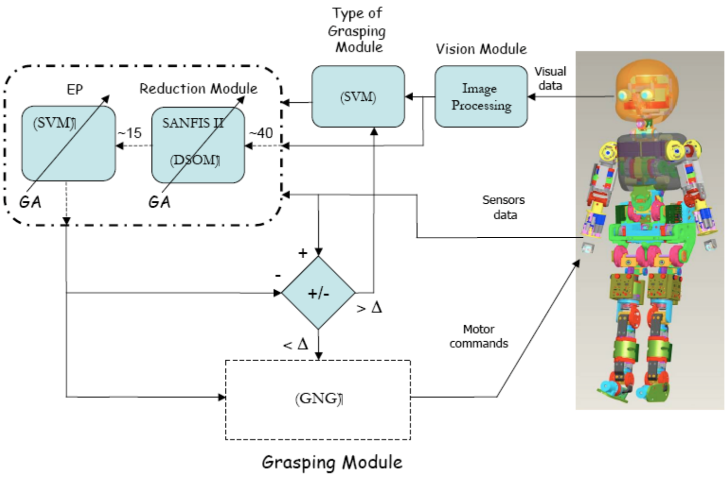


Fig. 1 Application of the Expected Perception paradigm to the iCub

The system is divided into 5 modules:

- Vision Module;
- Type of Grasping Module;
- Expected Perception Module (this is divided into a Reduction Module and a EP Module);
- Grasping Module.

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
D3.1	Initial implementation of models of sensorimotor coordination primitives (report and demo)	3	M24, M30	M36	UNIFE
D3.2	Initial results of experiments on the functional organization of the somatotopic maps and on the cortical representation of movements (report)	3	M18, M30	M30	UNIHER
D3.3	A report reviewing experiments, data, and theories related to the superposition of rhythmic and discrete movement control in animals	3	M36	M36	EPFL

List of milestones

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

W P 4 – O b j e c t A f f o r d a n c e s

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.

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. 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 aspect 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 (for a detailed description see D3.1), during the third year of the project, we measured spinal motoneurons excitability during the same experimental conditions by means of the H-reflex techniques.

The experiment is now finished, the final analysis is ongoing, and we will write and submit the paper within the next few months.

UNIUP

In this work package we have continued the experiments on toddlers' understanding of the affordances related to object manipulation. We have studied how children go about when trying to fit objects into each other, how they learn to pile objects on the top of each other, and how they go about deciding which one of two objects fit into an aperture, or which aperture out of two an object fits into. Such activities reflect children's ability to mentally move and rotate objects, their understanding of form and size relationships and their understanding of physical laws such as gravity and inertia. How infants learn to handle objects in such situations, is crucial for their understanding of spatial relationships between objects, their ability to mentally rotate objects, and the ability to formulate distant goals. The ability to to make choices in these situations also reflect children's executive control and working memory. The results of these experiments are now applied to the training of object manipulation in the robot.

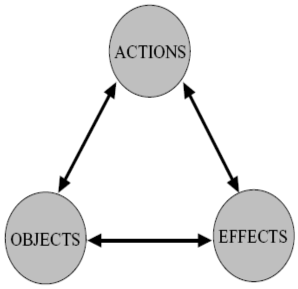
UGDIST

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.

IST

The work in this package has focused on the development of a general methodology to acquire affordances in an unsupervised manner. The robot interacts with the objects using a set of available skills such as the sensory motor maps of WP3. From this interaction, the robot learns the *causal* relations between the actions, the properties of the objects and the resulting effects. Also, the inclusion of affordances and the exploration of the objects allow the robot to discover relevant features associated to each action and to improve and complete the previously learned sensory motor maps.

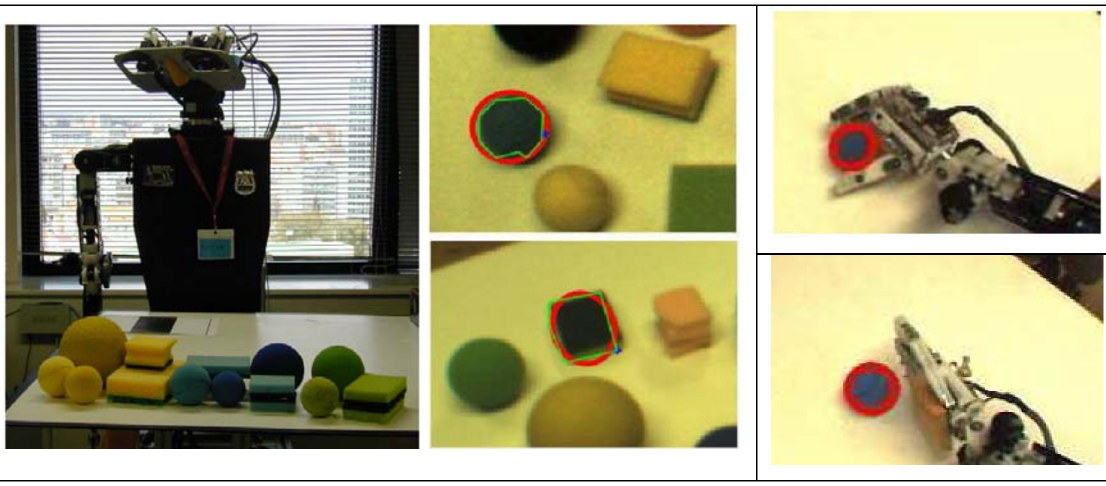
We use a Bayesian network to model the relations between actions, object properties and effects. In such a probabilistic framework, many of the quantities of interest are a function of the marginal probabilities of the Bayesian network. As illustrated by the Table on the left figure, the model can be 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.



inputs	outputs	function
(O, A)	E	Predict Effect
(O, E)	A	Recognize action & Planning
(A, E)	O	Object recognition & selection

Affordances as relations between (A)ctions, (O)bjects and (E)ffects.

So as to cope with the complexity of learning affordances from scratch, we have adopted a developmental perspective, in which we assume the robot has already developed at least coarse actions and perceptual capabilities (see Figure). At this stage, the robot starts to interact with the objects through simple manipulation actions such as tap, touch and grasp.

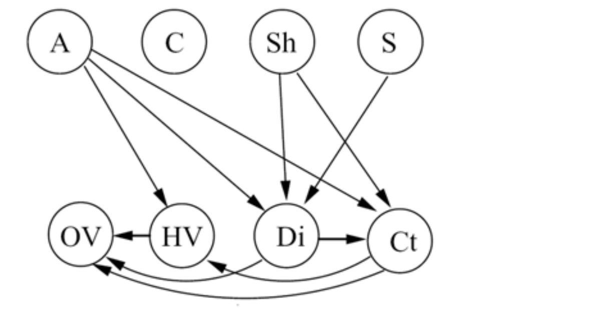


Baltazar humanoid robot and the playground for affordance learning (left). The robot has some simple perceptual skills to recover object properties such as color, shape or size (middle). Action examples: grasp (top right) and tap (bottom left).

So as to validate our approach, we used the humanoid robot Baltazar. We conducted several experiments to illustrate the capability of the system to discover affordances associated with manipulation actions (e.g. grasp, tap and touch), applied to different types of objects. The effects of these actions consist of changes perceived in the sensor measurements, e.g. tactile activation for a grasp, and object motion for a tap. We use unsupervised clustering to group the object properties and the effects into different categories. The tables below list the variables and the values discovered by the clustering process.

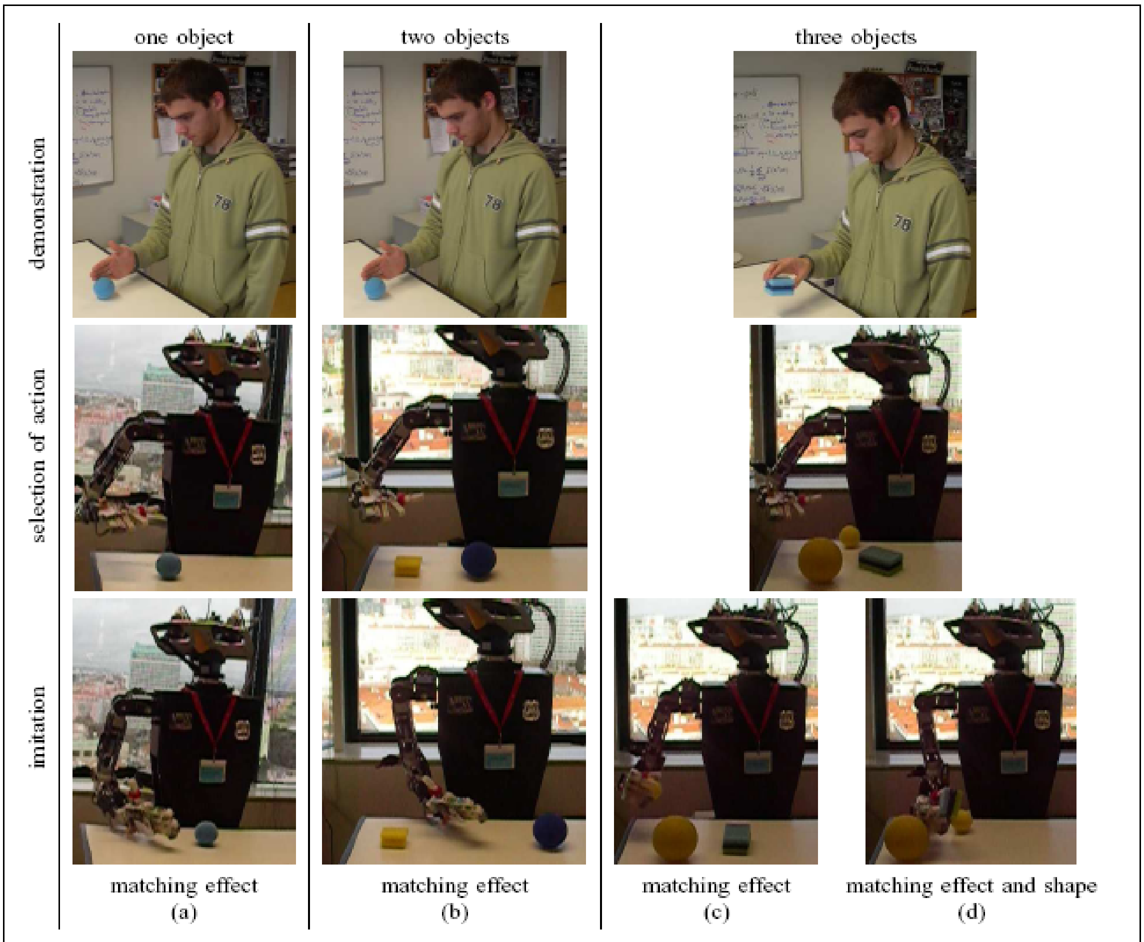
SUMMARY OF VARIABLES AND VALUES.

Symbol	Description	Values
A	Action	*grasp, tap, touch*
H	Height	discretized in 10 values
C	Color	clustered in $green_1$,$green_2$, *yellow, blue*
Sh	Shape	clustered in *ball, box*
S	Size	clustered in *small, medium, big*
V	Object velocity	clustered in *small, medium, big*
Di	Object Hand Distance	clustered in *small, medium, big*
Ct	Contact	clustered in *none, short, long*



Values for action, object properties and effects (left). Affordance network learned by the robot (right).

Our results show how the learned network captures the structural dependencies between actions, object features and effects. The model is able to distinguish the relevant properties of the objects and discard those that do not influence action outcomes, for instance, color. This ‘feature-selection’ aspect of the structure learning method is fundamental in planning because task execution is often linked to object properties and only to a lesser extent to objects themselves.



Imitation games using affordance knowledge.

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.

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
4.1	Results of experiments on affordant behaviors.	4	18, 30	30	IST

List of milestones

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

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

EPFL

Task 5.2 : Imitative learning of simple manipulation tasks

Our framework for imitating goal-directed tasks has been further developed by enabling the robot to learn a dynamical system from kinesthetic demonstrations. This dynamical system is then combined with an attractor dynamical system to reproduce the task despite different initial conditions. The main improvements of this algorithm are that it can deal with external perturbations acting on the robot itself, and that it has additional flexibility to learn more complex tasks. This has been submitted to the IEEE Transactions on Robotics. In addition, a reinforcement learning module has been added to the module, enabling it to deal with unexpected situations like obstacles. A paper describing this has been accepted in Advanced Robotics, in the Special Issue on Imitative Robots.

UNIHER

The M36 deliverable D5.5 (*Results from Interaction Studies on Synchronization, Mirroring and Interaction Kinesics*) was delivered on time. The following paragraphs summarise the research work contained in that deliverable.

Behaviour Delay and Robot Expressiveness in Child-Robot Interactions: A User Study on Interaction Kinesics

This study presents results of a study where 18 children interacted with a humanoid child-sized robot called KASPAR via turn-taking interaction and imitation. Each child took part in six experimental trials involving two games in which the dynamics of interactions played a key part: a body expression imitation game, where the robot imitated expressions demonstrated by the children, and a drumming game where the robot mirrored the children's drumming. In both games KASPAR responded either with or without a delay (2 conditions). Additionally, in the drumming game, KASPAR responded with or without exhibiting facial/gestural expressions. These 6 experimental conditions per child allowed between- and within participant comparisons. Individual case studies as well as statistical analysis of the complete sample are presented. Results highlight individual differences in the children's responses. The statistical analysis of the complete data set showed that a delay of the robot's drumming response lead to larger pauses (with and without robot non-verbal gestural expressions) and longer drumming durations (with non-verbal gestural expressions only). In the imitation game, the robot's delay lead to longer imitation eliciting behaviour with longer pauses for the children. Different possible explanations of these results are discussed. Overall results indicated the impact of timing and gesture on human-robot interaction kinesics via observed changes in human behaviour in the different conditions.

The full work is described in deliverable D5.5 and a modified version has been submitted to a conference.

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. A draft of the experimental procedure is attached to this report (A.Just, Study of Arm Kinematics and Eye Movements during Imitation).

IST

The work developed in WP5 has focused on two main directions: (i) Modeling social learning behaviors wit reinforcement learning and (ii) use the affordances model for imitation.

a) Modeling of social learning behaviors:

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.

b) Affordance based imitation

Using the previous approach and our model of affordances we developed an imitation learning mechanism. We argue that affordances provide sufficient information to learn by imitation. In particular, they combine in a single structure an "action interpreter" and a world transition model. As a result, the previously learned task independent knowledge is used to recover the appropriate information from the observations and elicit a rich imitation behavior. The experimental results using a real humanoid robot platform suggest that the proposed architecture is adequate to implement learning by imitation in real-world tasks.

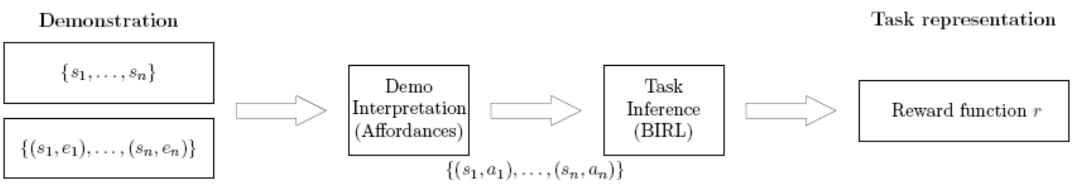
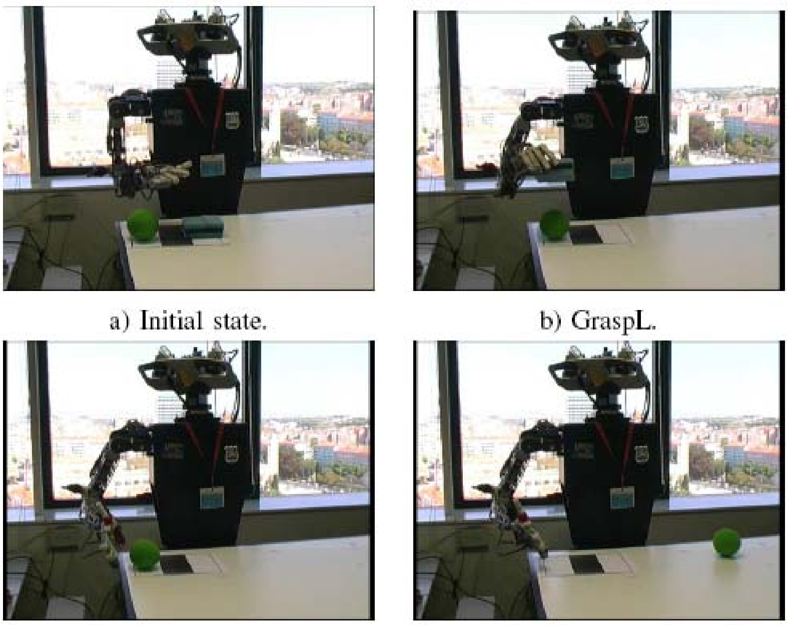


Fig. 3. Representation of the fundamental elements of an imitation learner.

The algorithm was tested in our robot Baltazar.



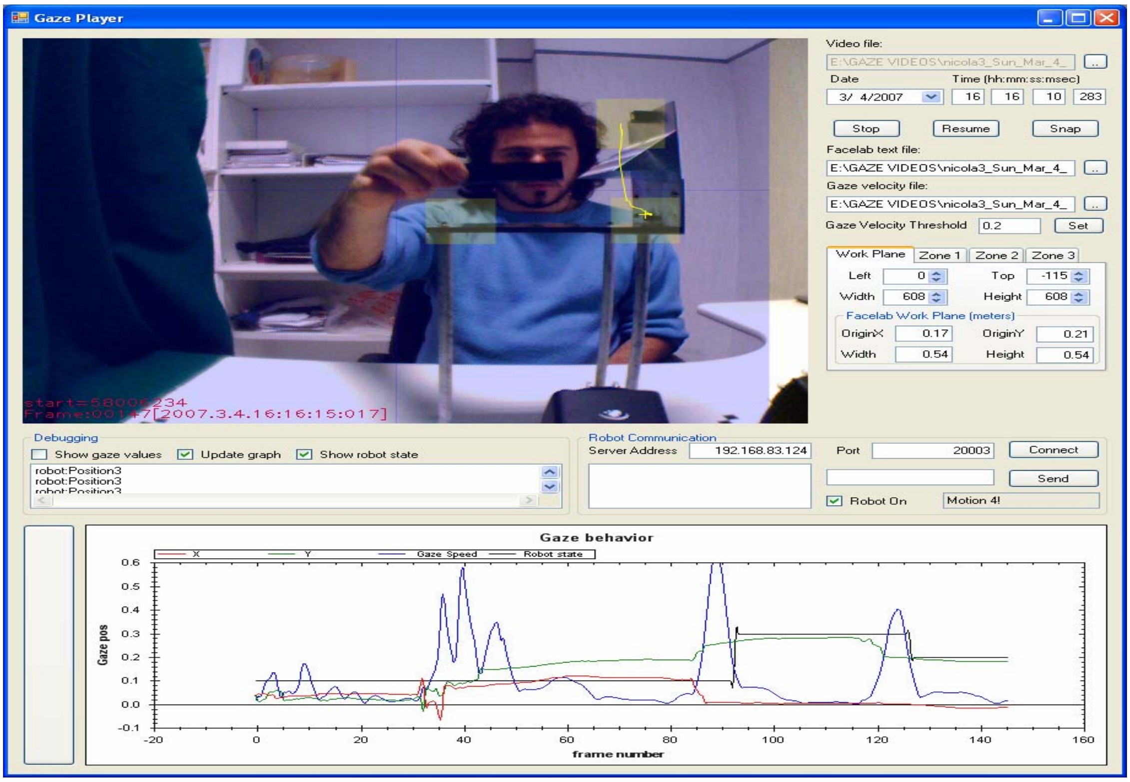
a) Initial state. b) GraspL.

c) TapR. d) Final state.

Fig. 7. Execution of the learned policy in state (Box, SBall).

SSSA

A PhD student (Kenneth Pinpin) is developing a gaze based interface that utilize anticipatory gaze movements to specify movements according to the user's intention and initiate appropriate movement commands of a robot. The current gaze tracking system developed by the latter can help in conducting experiments that will study the role of gaze in the observation of hand movements during learning by imitation. Such experiments will provide insights on how iCub can develop similar gaze behavior.



Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
D 5.1	Evaluation of an algorithm for interpreting the kinematics of arm motion and its relationship to object motion.	5	6	6	EPFL
D 5.2	Implementation of visual recognition and imitation of goal-directed reaching motion.	5	12	12	EPFL
D 5.3	Implementation of goal-directed and functional imitation of simple manipulation of objects.	5	18	18	EPFL
D 5.4	First results of experiments on mirroring and communicative aspects of imitation.	5	24	24	UNIHER
D5.5	Results from interaction studies on synchronization, mirroring and interaction kinesics	5	36	36	UNIHER

List of milestones

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

W P 6 – G e s t u r e C o m m u n i c a t i o n

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

In the 3rd year of the project UNIHER continued investigations into the construction through ontogeny of interaction histories grounded in the sensorimotor experience of robots, and the use of these histories in determining future action based on past experience. Previous work formalized the use of information-based measures in the construction of metric spaces of experience and investigated how a robot can develop the capability to play a limited “peekaboo” type game using actions selected from experiences in this space. During this year the architecture was extended to allow multiple simultaneous horizon spaces and improvements to the action selection mechanism.

Issues of scalability were addressed with the use of forgetting and merging of nearby experiences as well as new techniques for finding the nearest neighbours of new experiences in the growing metric space.

Software was ported to C++ and the YARP framework with view to moving towards the iCub platform.

A simple toy problem in simulation was used to measure the performance of the architecture and compare the information distance measure to other measures of similarity. Finally, new experiments are ongoing on the humanoid platform KASPAR using the peekaboo game with non-verbal audio enriching the interaction between robot and human.

Investigations into the Rhythm and Timing of Gestural Interaction Games

UNIHER explored the impact of simple gestures made by a humanoid robot in the context of a simple interaction scenario with a human partner. This research takes a drumming call-and-response game of the type used in earlier pilot studies, and extends it to include autonomous robot behaviour and interaction while also extending the investigation into the effect of robot gestures on the interaction. KASPAR, a child-sized humanoid robot developed at the University of Hertfordshire imitates a human partner's drumming while making simple fixed head gestures accompanying its drumming (we especially used very simple gestures, not complex ones like smiling or frowning in order not to distract participants too much). Participants of the study played three different games where KASPAR used a different amount of gestures, to study the affect of gestures on the social interaction, and turn-taking. The drumming performance was measured quantitatively. We also assessed participant's subjective opinions on the drumming experiences (using questionnaires). The human partners' in return, perceived these simple expressive behaviours as more complex and meaningful, compared to a no-gesture condition. They seem to have adapted themselves to the system unconsciously. Especially female participants were affected positively by the gestures, and thought the robot performed them on purpose, to motivate them.
In a further series of experiments, we studied emergent turn-taking while regulating the manner in which the robot's actions were produced. In this new work, KASPAR uses different probabilistic models to decide when to start and stop its turn. KASPAR uses the number of beats of human participant and the time duration of its previous play as parameters in the models to decide the start and stop times. Therefore the number of beats and play times are not deterministic but emerge completely from the interaction between the human participant and the humanoid. Based on these facts, during the games, sometimes KASPAR plays the 'leader' role, sometimes it follows the human participant. Results showed an impact of the turn-taking model on the structure of the interaction in terms of duration and complexity of drumming by human participants as well as on their enjoyment of the interaction game; however, individual differences between participants played a strong role. Moreover participants behaviour changed over the course of (order controlled) exposure to the models, indicating that they may have adapted their interaction to perceived capabilities of the robot.

These results sugest that deeper study of human-robot interaction kinesics and recipient design is warranted in the area of ontogenetic robotics where a robot develops by engaging in and sustaining social interaction with human partners.

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Interaction Histories

UNIHER continued investigations into the construction through ontogeny of interaction histories grounded in the sensorimotor experience of robots, and the use of these histories in determining future action based on past experience. Previous work formalized the use of information-based measures in the construction of metric spaces of experience and investigated how a robot can develop the capability to play a limited "peekaboo" type game using actions selected from experiences in this space. During this year the architecture was extended to allow multiple simultaneous horizon spaces and improvements to the action selection mechanism. Issues of scalability were addressed with the use of forgetting and merging of nearby experiences as well as new techniques for finding the nearest neighbours of new experiences in the growing metric space. Software was ported to C++ and the YARP framework with view to moving towards the iCub platform. A simple toy problem in simulation was used to measure the performance of the architecture and compare the information distance measure to other measures of similarity. Finally, new experiments are ongoing on the humanoid platform KASPAR using the peekaboo game with non-verbal audio enriching the interaction between robot and human.

Adjusting Levels of Play in Response to Style and Levels of Interaction

This research focuses on facilitating children's play with a robot in a therapeutic setting by developing further play skills and possibly communicative and social skills. Work on adjusting levels of play in response to style and levels of interaction has continued with first results published (Francois et al. 2007). Recent work reduced delays in the on-line classification of play-style by uilizing an optimized SOM-based algorithm, enabling the recognition of the interaction style with a small delay. Further techniques are being investigated which reduce the requirement for hand-tuning such as Linear Discrimant Analysis, or others based on Kolmogorov complexity, as well as Information Bottleneck. The later gave promising preliminary results and an algorithm based on a cascade of Information bottlenecks was developed in order to extract more information about the sensor data and on the connection between successive segments of the flow of the sensor data. Current work focuses on a novel interaction identification algorithm based on a cascade of regularized information bottlenecks: by adding constraints on the various bottlenecks, we actually aim at freezing degrees of freedom thus enabling to remove the possibility of "learning by heart".

IST

IST has conducted work toward the detection of eyes in images of faces. It is well known the importance of detecting gaze direction in humans, both for shared attention studies and to detect eye contact. A first step toward this objective is the detection of eyes in faces.

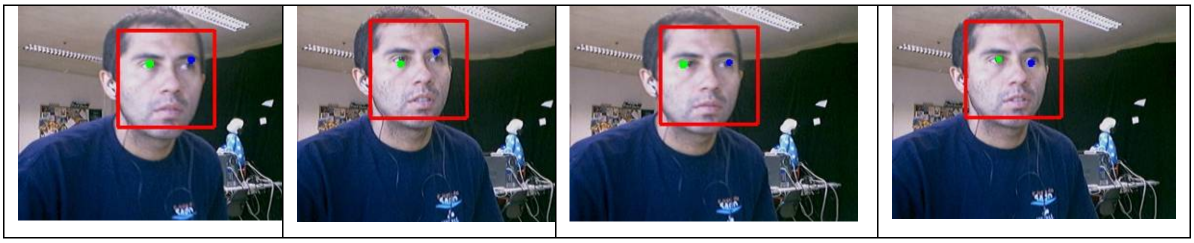
We developed a method based on the work published by Ian Fasel and Bret Fortenberry and Javier Movellan (*"A generative framework for real time object detection and classification,"* Computer Vision and Image Understanding, vol 98(1), pp 182-210, 2005.).

Eyes are modelled by a set of wavelets that best classify eye vs. non-eye examples within faces. The model is estimated in a supervised manner, using the GentleBoost algorithm. To include context information, it is computed the prior probability of eye given location and size with respect to the face region.

After training, we can detect eyes in new images, inside the identified face regions. In every face region, the eye detection comprises:

1. Multi-scale application of the set of wavelets that model the eyes, within a sub-region of the face restricted both in location and scale.
2. Classification of the models at several scales, using the GentleBoost algorithm. The output of the GentleBoost algorithm is the eye versus non-eye log-likelihood ratio.
3. The log-likelihood ratio is combined with the prior for probability of eye given location and size with respect to the face detection window to produce the final log posterior ratio of eye versus non-eye.

The figure below shows some results of the method's application to face images.



The method is able to reliably detect the location of the eyes but the precision may not be sufficient for detecting gaze direction and eye contact. We are studying methods to improve the current implementation toward these goals.

The eye detector code is provided by the MPT project http://sourceforge.net/projects/mptbox/ and was adapted to the iCUb architecture.

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. We are currently analyzing the data and we will soon publish these results together with those of the fMRI experiment described above.

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

The brain areas involved in gestural communication.

The recent finding that Broca's area, the motor center for speech, is activated during action observation lends support to the idea that human language may have evolved from neural substrates already involved in gesture recognition. Although fascinating, this hypothesis has sparse demonstration because while observing actions of others we may evoke some internal, verbal description of the observed scene. Here we present fMRI evidence that the involvement of Broca's area during action observation is genuine. Observation of meaningful hand shadows resembling moving animals induces a bilateral activation of frontal language areas. This activation survives the subtraction of activation by semantically equivalent stimuli, as well as by meaningless hand movements. Our results demonstrate that Broca's area plays a role in interpreting actions of others. It might act as a motor-assembly system, which links and interprets motor sequences for both speech and hand gestures. These results have recently been published in Social Neuroscience Journal (Fadiga, L.; Craighero, L.; Fabbri-Destro, M.; Finos, L.; Cotillon-Williams, N.;

Smith, A.; Castiello, U., Language in Shadow, Social Neuroscience, 1:.77-89, 2006), attached to this report.

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.

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
D 6.1	Implementation of goal-directed and functional imitation of simple manipulation of objects.	6	12, 24	24	UNIHER
D 6.2	Results from interaction studies on gesture communication.	6	36	36	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.

Progress towards objectives

Despite some delays, all the current objectives have been achieved

TLR

The activities developed in this reporting period are briefly described:

- Complete cad documentation is currently available on the web repository for download and is being used as reference for manufacturing the platform copies;
- The first prototype of the icub is now completely integrated and wired. Intensive test on upper limbs were done in the Y3 and consequent debugging with design upgrade of some groups were done.
- Lower limbs as well as waist were tested with more attention to the waist articulation, being the more stressed joint of the body.
- A parallel manufacturing of the icub in EPFL at Lausanne helps in a faster debugging of both the platform and the documentation.
- Eight copies of the platform are now under production. Body groups were divided by tipologies over a set of workshop to optimize the manufacturing process. Delivery of the eight kits is forecasted at beginning of 2008.
- Face with facial features was completed and integrated in the platform and is now under test both in Lisbon and Genova.
- Complete body cover with heatsink integration for brushless amps is under design and some first prototypes are under realization.
- “next release” feasibility design of the main robot motor group in currently under evaluation as well as special “zero play” precision neck for improved tracking and localization purposes.
- Several technologies as alternative to hall effect sensor are under evaluation to develop a new tactile array for the fingertip.

UGDIST

Task 7.1-7.2-7.3 and Task 8.2-8.3: Platform construction progress

The main activity during the last period was on the debugging of the head and upper torso with a complete redesign of the legs starting from the hips. The new version is more solid, compact and efficient. This is in practice a redesign in many respects. The upper torso maintained its earlier structure although many small changes were implemented as resulting from debugging activities.

We have continued integration and testing with particular care to (together with Telerobot):

Documentation: the CAD drawings (3D and 2D) have been integrated with manuals detailing specific aspects, photos (of the assembled robot) and will be complemented soon with assembly instructions for certain difficult parts (hand).

Documentation: the full documentation is and will be available indefinitely from the RobotCub website http://www.robotcub.org/iCubPlatform which corresponds to the CVS module iCubPlatform available also for download from cvs.robotcub.org.

Normalization (database) of components is in progress. This is helpful for duplication.

Debugging: the hand has been modified in the routing of the cable and to solve minor problems related to the wearing of the tendons.

Assembly: the wiring of the iCub has been completed; specific changes were related to the routing of the cables and wires.

Assembly: the covers of the iCub to work in certain cases as heat sinks are under design and/or fabrication (depending on the parts).

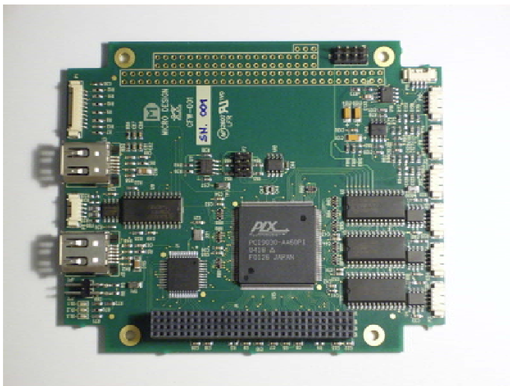
Support: the RTS has been started at the Italian Institute of Technology. We hired three people with the role of:

- Software integrator and maintainer
- Mechanical documentation manager
- Component and purchase manager

Open call: manufacturing procedures were organized with four machine shops in Italy after extensive testing of their ability to work within the RobotCub standards (the fabrication of the prototype was used also as a test of quality).

Debugging: an initial design of a new head with zero-backlash and Harmonic Drive gears has been produced (maintaining the same overall size and specifications).

In particular, we finalized (subcontracting to Microdesign Srl.) the fabrication of the PC104 interface card, which together with a standard PC104 CPU will take care of the low-level synchronization and command definition to the robot. The first set of prototypes were built and tested. We are now working on the implementation of the device drivers. This interface card has two firewire ports (via a standard Texas firewire chip), four CAN bus drivers (one to the head-waist, two for the arms and one for the legs), and a audio amplifier (for the microphones).



The PC104 interface card. Visible the PLX PCI bridge and the 4 CAN bus controller chips.

We also designed (and it is currently under production) the interface card for reading all the position sensors (hall-effect sensors) in the hand. This has been designed custom and it is based on a PIC microcontroller interfacing directly to the CAN bus. It has been fitted to the back of the hand.

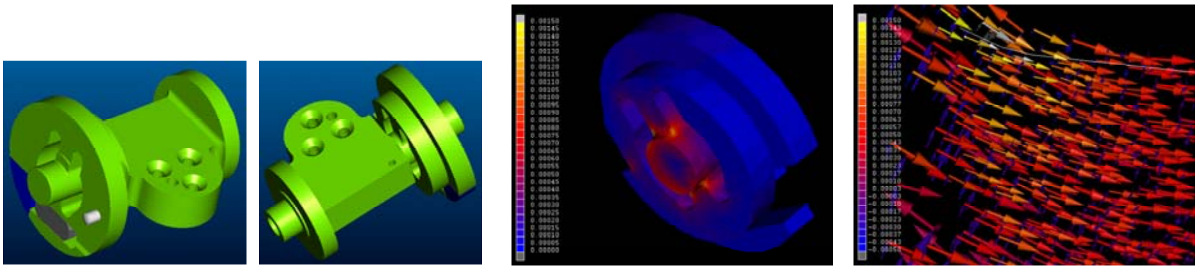
Finally, we developed a microcontroller based card for conditioning, sampling and calibrating the force-torque sensor signals. The force-torque sensor is based on a semiconductor strain gauges technology and requires conditioning, temperature compensation, calibration, etc. We managed to include this additional control card inside the sensor itself. The card is currently under finalization and prototypization. The sensor will thus provide digital output over the CAN bus and/or the serial interface (SPI).

Research/improvement directions

The robot platform, the iCub, is subject to further technology monitoring and improvements. Here is a list of additional work in progress. Certain activities have been started together with IIT.

Task 7.1: Joint-level torque sensing

The possibility of dynamical movement is impeded by the highly reduced gears and electric motors. This choice guarantees the performances required by the project specifications but cancels dynamic effects. One possible solution is to emulate passive/compliant behaviour with force-torque compensation based joint torque sensing. A similar approach was used for example in the series-elastic actuator solution (Williamson 1995). Certain changes are required to implement joint-level torque measurement. We started from the shoulder/elbow group that looks more critical because of the size/space constraints. The mechanical design will be upgraded accordingly. The principle of measurement is by sensing deformations (strain gauges). In the elbow, two symmetric grooves have been added to induce strains to be measured with semiconductor strain gauges. The optimal strain pattern has been obtained by gradually refining the part geometry with the aid of FEM structural simulations.



A B

Figure 2: A. Elbow joint modifications (main pulleys) and B. FEM simulation at the strain gauges mounting site.

The shoulder joint structure is also under modification by improving sensitivity to strain. The following figures show the proposed changes.

A B

Figure 3: Examples of the changes required to two of the pulleys in the shoulder joints.

An experimental torque controlled joint is under development for testing purpose. Fabrication and testing of the changed parts is in progress.

Task 7.1: Polymeric actuators

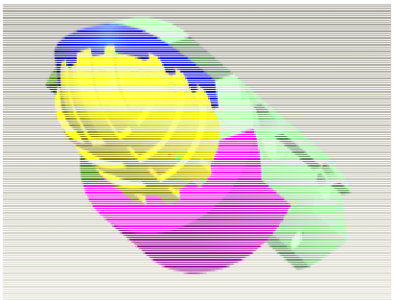
It is relatively clear that in the future humanoid robotics will require different actuation technologies than standard industrial robotics. For example, primary requisites are safety and compliant interaction with the surrounding environment, lightness, low friction, and energy efficiency. As part of the RobotCub technology watch activities, we focus on a particular technology of electro-active polymers (i.e. polymers that exhibit morphological changes function of an applied voltage) called dielectric elastomers (see **Error! Reference source not found.**). Our goal so far was to integrate and test the polymer performance for actuation in a humanoid robotic context (i.e. going beyond the simple demo). To be practically used, many issues still need to be investigated. The greatest challenge consists in finding novel materials, with high dielectric constant, high breakdown strength and low elastic modulus. Moreover the development of new techniques for the fabrication of thinner, micrometric layers of dielectric and their packaging in a macroscopic device is expected to increase the efficiency and lower the high voltages required for actuation.

Task 7.1: Artificial skin

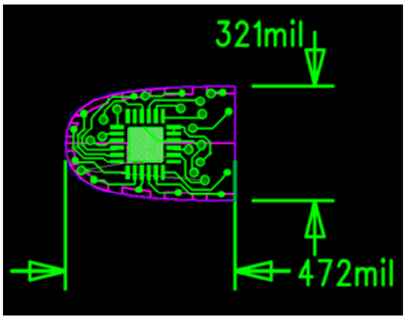
The iCub will include a sensorized artificial skin. This is important and it has been shown by neuroscience (see WP2) how complex behaviors arise from the combination of vision, touch and motor control. This activity is dedicated to the realization of a distributed sensory system that covers almost entirely the body of the iCub. The problems to be addressed beside the sensing technology are related to the connections, routing of the wires, sampling, etc. that is the entire system has to be studied and not only the sensor in isolation. The main idea is to develop a modular and hierarchical structure that allows collecting and grouping information as we move higher up in the hierarchy, while keeping the routing of the wires to an acceptable minimum. This has been identified in a mesh-like structure where N sensing elements connect to a digitizing element (on chip) and M chips then connect to a microcontroller, realizing a modularity of 12x16=192 elements. Mdularity is obtained by grouping 12 sensor pads in a flexible PCB (25 microns) and then connecting many of them in such a way to cover the desired surface.

Task 7.1: Fingertip

The design of a sensorized fingertip for the iCub has been started using the capacitive technology and electronics that has been tested for the skin (see section 0). The plan is to include up to 12 sensitive points into the fingertip and a microphone with complete digital output that can be directly interfaced to the PC104 CPU or to one of the controller cards and/or an additional microcontroller. The microphone can be used to detect texture, time of contact and potentially slip. The PCB with the electronics is included in the fingertip. The electrode structure is made of SLS or silicone (for additional compliance). The electrodes are sprayed conductive silicone; the outer layer (ground) is also sprayed silicone.



A



B

In A, a section of the internal structure of the fingertip: the electrodes support (yellow), the aluminum phalanx (green), the PCB in blue and the cover silicone (purple). In B, the PCB of the sampling and digitizing electronics.

As mentioned, the microphone can be used for sensing material texture, time of contact, and slip. We are testing a preamplified digital microphone (size 2.6x1.6x0.85mm) glued to the fingernail (for extra vibrational properties). One of the problems is that the amount of data to be processes is massive which in turn requires some extra processing chip (e.g. wavelet analysis). We are analyzing at the moment what is really needed for a machine learning algorithm to classify roughness/texture and only this data will be sent upward to the controlling electronics.

Task 7.1: FET-based tactile sensors

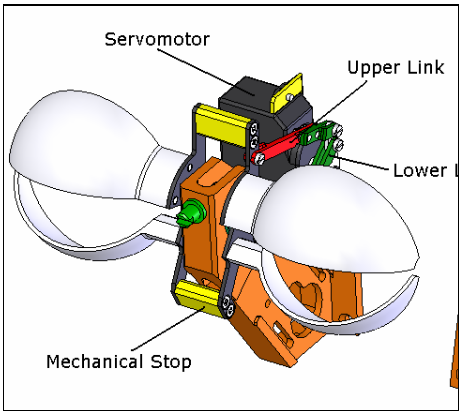
A novel tactile sensing array that comprises of “smart materials” like piezoelectric polymers and Integrated Circuits was developed. These arrays of tactile sensors are intended to be placed on the distal phalange of the iCub. Each tactile element on the array comprises of piezoelectric polymer, PVDF-TrFE, directly deposited on the gate area of a FET device. This direct coupling of the transducer to the gate of FET devices significantly reduces the electrical interference and thus improves the signal to noise ratio. This method presents different characteristics with respect to the capacitive sensing method and, potentially, it bears the possibility of a larger scale of integration. The project develops in three stages: electrode array fabrication (with polymer deposition), FET fabrication with polymer deposition over the gate, and, finally, integration in an ASIC including amplification and conditioning of the sensor signals.

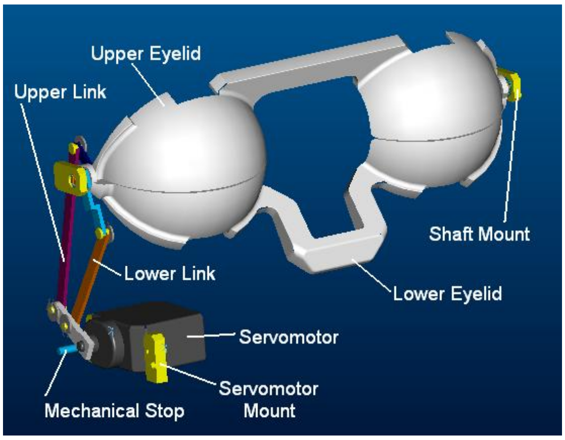
IST

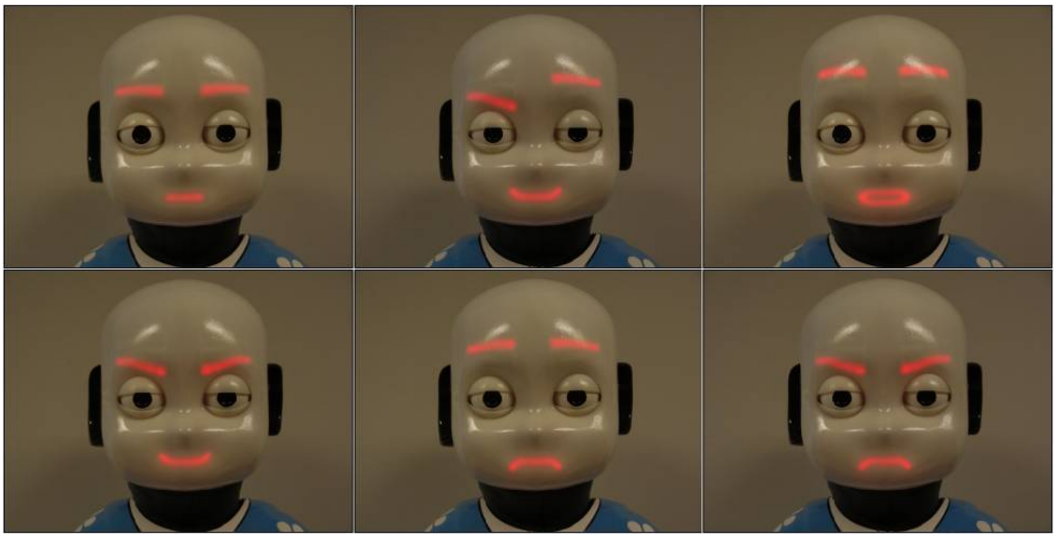
After designing the iCub head, demonstrated during the first year review and the renewed model together with facial expressions shown during the second year review, IST has concentrated its effort in this workpackage to: (i) redesign of the facial expressions and eyelids; (ii) design of the expressions and eyelids control electronics; (iii) start of the duplication of the iCub platform and (iv) re-design of the artificial pinna for sound localization.

i) Redesign of the face and facial expressions

Although the existing model was fully functional and optimized, the face and facial expressions (eyelids included) were changed in order to attach the eyelid mechanism to the face, instead of the keeping the eyelids attached to the head structure mechanism. While this allowed for a larger degree of modularity (a “plug-and-play” face together with eyelids, expressions and control electronics) it lead to a considerable redesign effort that is now concluded.



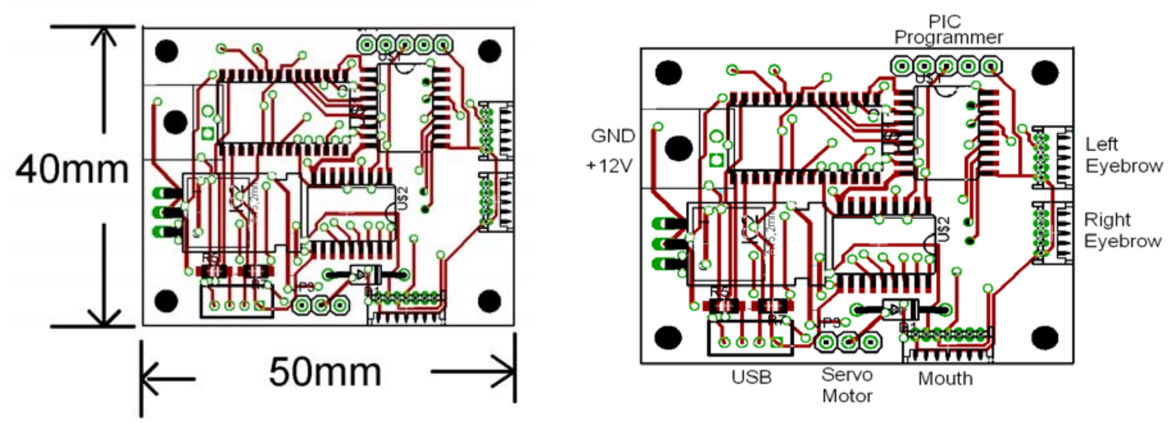




Top Left: Previous eyelid mechanism /head mounted). TopRight: redesigned eyelid mechanism (face mounted). Bottom: iCub facial expressions

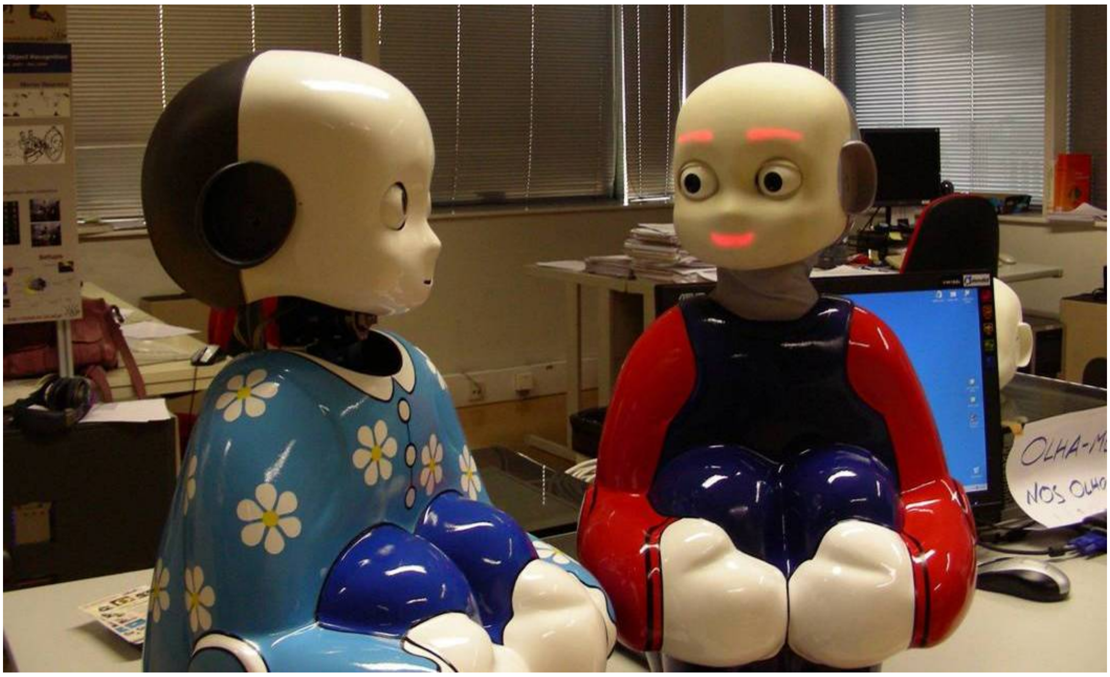
ii) Design of the eyelids and facial expressions control electronics

An electronic board for controlling the iCub eyelids and facial expressions was designed and the firmware developed. Both the circuit design and firmware are available in the iCub CVS repository. The board (shown below) is based on a PIC micro controller and interfaces the iCub via USB.



iii) Duplication of the platform

In the process of verifying the design, documentation as well as testing the assembly and operation of the system IST has started the duplication of the platform. Contacts were established with local machine shops for the production of the mechanical parts.



iv) The algorithm for sound-source localization based on artificial pinnas was also redesigned for improved performance and robustness. Different pinnas were designed and tested.

UNISAL

Significant resources have been devoted to WP7 during the past reporting period and the following results have been achieved.

i). Legs, Hips and Spine Mechanical Design. There has been a full and complete redesign of the lower body to create an iCub v2 lower body. This new design has emphasised design modularity and robustness. The full design of the lower body has been completed and converted to the required drawing format for distribution as Open Source in line with the requirements of the consortium. The design has now been fully constructed and integrated with the upper body in line with the predicted timelines.

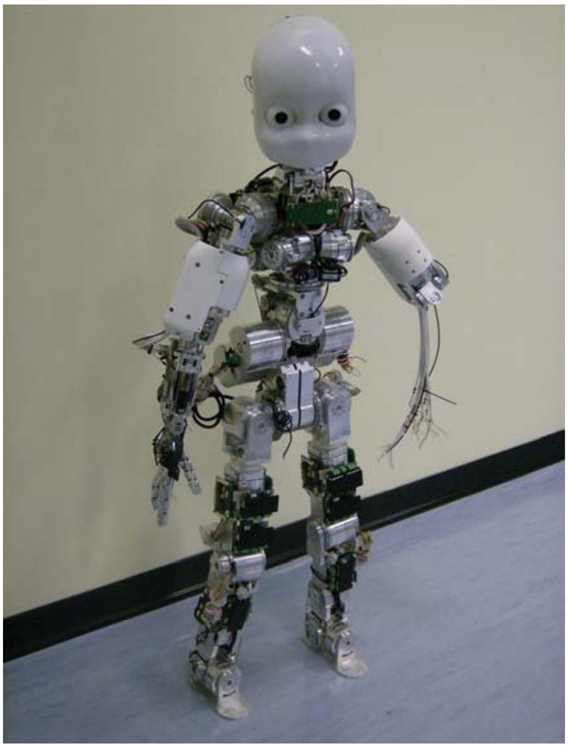
ii). Lower Body Integration and Test. The lower limbs have been fitted with drive unit controller and full single and multi-jpoint motion has been tested. Software has been developed and modified for testing of the motions of the limbs and for later integration in the main iCub software modules.

iii). Force Torque Sensor. Work has continued on the development of a full 6 dof force torque sensor. Testing has been completed and software developed. Several sensors have been developed for integration into the iCub both in the upper and lower limbs.
In addition to the use of this sensor in the major joints there has been collaborative work with UNIGE in the development of a force-torque based finger sensor.

iv). Two tactile senory systems have been designed tested and developed for use in the finger tip. Hese systems have been shown to have very high sensory resolution and spatial resolution comparable with the often quoted 2-point limen limit.

CAD design of a baby hand

vi). An early hip spine assembly has been under test looking at the electronic drive systems and the control strategies. Data obtained in these trials will be used to inform the final hip spine controller.



CAD model and mechanical realisation of the iCub leg.

viii). Integration and initial testing of the lower and upper body sections.

concentrating particularly on the needs and requirement of these activities for the brushless motors that are integral to the actions of the major joints.

SSSA

Beside the tasks 7.1 (complete design) and 7.2 (debugging the existing components), the SSSA-RobotCub team proposed a new task (7.4) at month 24. Hence the main effort has been focused on the development of the final version of the right arm and forearm (see Fig.2) and on the development of a novel bio-inspired sensory system for the open-loop to closed-loop transition in manipulation tasks.

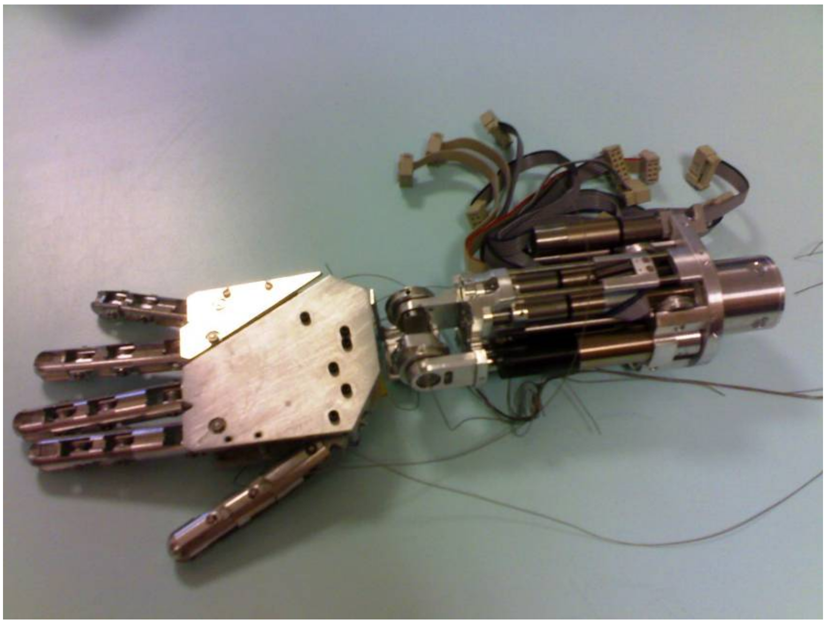


Fig 2: Right forearm and hand system

Several changes in the mechanical design have been performed:

- All the springs in the palm have been changed to a stiffer model
- All the springs for the ab/adduction of the fingers are now pre-loaded
- The structure of the palm has been reinforced
- Changes in the path of the sheats
- Ring/pinky differential moved from the palm to the forearm
- Longer fingers for augmenting grasping capabilities (see table I)

Finger	Length (mm)	Diameter (mm)	Range flection PIP,DIP, MP (°)	Range ab/adduction (°)
Index/Middle/Thumb	68	12	95	30 (only index)
Ring	68	12	95	30
Little	57	11	95	45

Table I: New dimensions and range of movement of the fingers

The hand is equipped with several sensors for control feedback and providing proprioceptive information. In particular it has:

- 12 hall-effect angular sensors. There is one for each flexion joint, except for the MP joint of index, thumb and middle.
- cable tension sensors based on strain gages, one for each finger.

In the development of a local low level control for a dextrous manipulation of objects, both proprioception and exteroception are mandatory. Nevertheless, a further investigation of dedicated sensors is critical to avoid the risk of a not closed-loop or limited capabilities available in the iCub final version. The effort so far has been dedicated to the development of a new set of sensors and their integration in the low level control of this still potentially dextrous hand. Consequent tests on the SSSA iCub hand and forerarm(and eventually on of the iCub complete arm system) will follow.
The final position of Hall Effect sensors has been fixed now. All the motors dedicated to flexion of fingers have their own encoder for position control of the movement of the hand. Consequently, position information may be obtained by means of different sensors, i.e. both motor encoders and hall-effect sensors.

Concerning the control of the angular position in the 2 intrinsic actuation units (thumb opposition and hollowing of the palm with adduction/abduction of the fingers), a change was performed.
Although the good results obtained in developing a compact optical sensor, the fabrication process of the snail showed bad repetitiveness. Hence every sensor had its own angular characteristics. Vibrations (motors) affected the effectiveness. Even if a ‘home-made’ encoder was integrated in the design as replacement, only 10° digital discrimination was obtained. According on these experimental results and on the free room in the palm (no more differential), a more reliable and standard solution has been adopted (the intrinsic motors have been integrated with encoder)

Two new designs of the cable tension sensors were developed and tested. These are the main changes (see Fig. 3)

- New design (slightly thicker cantilever in both versions)
- New material (AISI 630)
- Tension measured up to 320 N
- Lower surface roughness
- New bonding technique for higher repetability

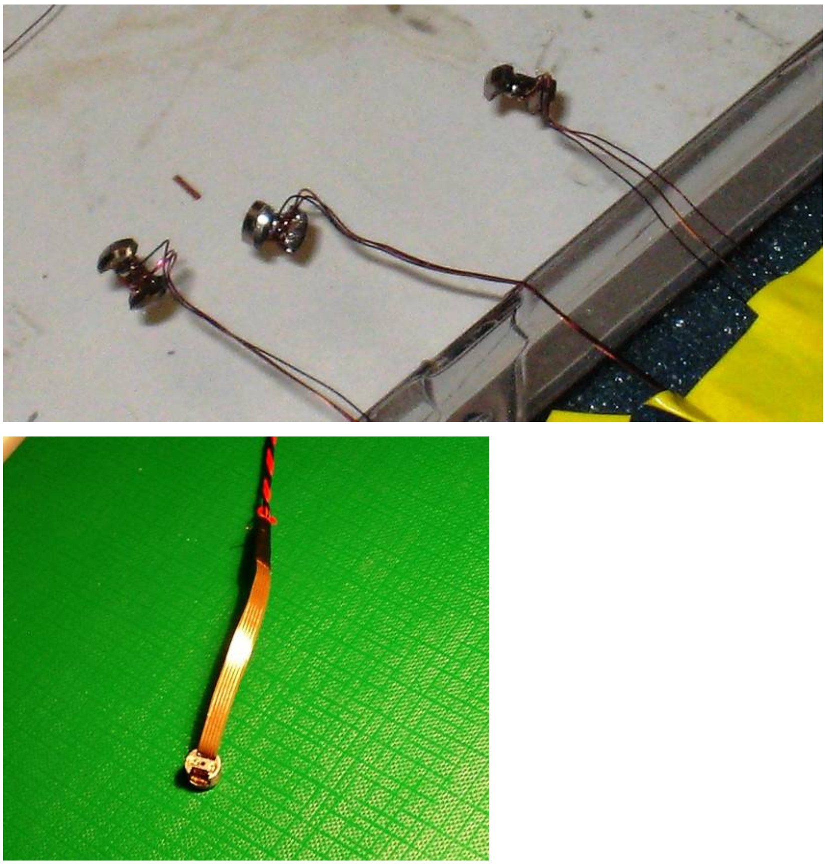


Fig 3: New cable tension sensor design (version 3 and 2)

Concerning the exteroceptive sensors, a new typology of optoelectronic pressure sensors are under development. They have low threshold but this value can be easily changed according to silicone mechanical behavior. Modifying the silicone cover thickness, distance between optoelectronics components and reflection properties changes (see fig. 4). The force range may vary from 2 to 30 N. They are compliant and low cost.

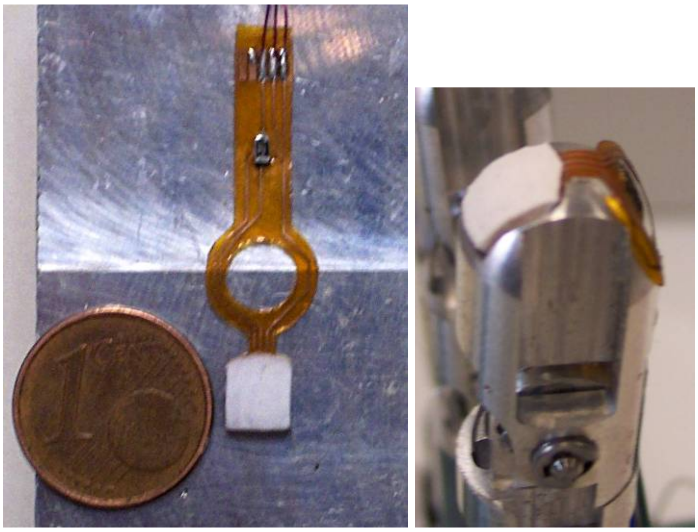


Fig 4: SSSA optoelectronic pressure sensors

Deviations from the project work-programme

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
D 7.1	Specifications of the single components of the mechatronic platform with a preliminary integration compatibility analysis.	7	18, 30	30	TLR
D 7.2	Analysis and pre-selection of the sensor's and actuator's technologies.	7	12	12	SSSA
D 7.3	Experimental results of tests with existing platforms.	7	18, 24	24	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

YARP and related components have been developed further during the reporting period. In particular, communication protocols have been extended/debugged, interoperability has been improved, device modularity increased, and the iCub repository further standardized.

Task 8.4-8.6: Communication

- Introduced “namespaces” to the YARP Network to make it easier to run multiple non-interacting networks of processes over the same LAN. It has always been possible to create such networks, as long as port names did not overlap. Namespaces eliminate that requirement.
- Introduced greater control over the routing of streams carrying multicast packets for systems with multiple physical networks. It has always been possible to choose the routing of streams carrying tcp and udp packets, but multicast packets were not always respecting routing (this is important for RobotCub since images and control data are typically streamed with multicast).
- Introduced control over various protocol-specific parameters via environment variables, in case the defaults need to be overridden.

- Streams carrying shared memory packets have been improved. The previous implementation had various limitations inherited from the ACE library.
- Streams carrying data between ports within the same process have been optimized. Such data can now be shared between threads without any copy operations. Proper interlocking and control of the lifetime of the data is managed transparently without client code change.

Task 8.4-8.6: Interoperability and portability

- Communication with the YARP Name Server was generalized so that it became an ordinary YARP port. This simplified the task of communicating with the YARP Network using just specified protocols, without using any of the YARP library implementations. This is not an important use case within the RobotCub Consortium, but is important for interoperability with other projects.
- An example of interfacing with YARP without using the YARP library implementations was also written.
- Support for C#, Java, Python, and Perl was improved (using SWIG). Matlab support (via Java) was also improved.
- Continued small changes were made for issues reported on various platforms. For YARP, we help with a much broader range of operating systems and compilers than are officially supported in RobotCub.
- Specifically, small fixes were made for 64-bit Linux, Macs (especially Intel Macs), Fedora 6, Sun Solaris.
- Better support for scripting. For example, examining the status of a port from a shell script, or starting/stopping processes on a collection of machines. For portable scripting, we encourage the use of the “bash” shell (available on Windows via cygwin or winbash). Implemented commands such as “yarp run/kill” to work on remote machines.

Task 8.4-8.6: Devices

- Device drivers with closed-source or proprietary components were removed from the YARP repository and moved to project-specific repositories.
- Device compilation made modular, so individual drivers could be compiled separately or bundled with the YARP device library, depending on the user's preferred configuration.
- Improvements to multimedia devices, in particular audio input and output, and interfaces to popular libraries such as PortAudio and FFMPEG.
- Device for using GPUs added (submitted by external author); potentially will provide alternative high speed implementations of common vision filters when the appropriate hardware is available.
- Command-line, text-mode interaction with motor control devices was improved.
- General-purpose serial port driver added (UGDIST/IST collaboration).
- A driver for the JRKERR family of controllers was added (IST). This included code published without explicit licensing by JRKERR which IST persuaded them to release under the 3-clause BSD license. With that license, we (or anyone else) can redistribute customized versions of this code.
- A driver for Dimax control boards was added (from Hertfordshire), and URBTC (from Zurich).

- Better video4linux support via FFMPEG.
- Abstract group device for arbitrary nesting of subdevices was added.

Task 8.4-8.6: Licensing

- Copyright and licensing status of every file in YARP was examined and clarified if necessary. Certain device driver code with ambiguous status was excised.
- Official "tar-ball" releases of YARP now contain a complete statement of the authorship, copyright and licensing of all contained source code. This is generally the GPL version 2, with a small number of included files being under compatible licenses described individually.

Task 8.4-8.6: Miscellaneous

- Added a math library to provide linear algebra and basic operations between matrices and vectors. It requires the GNU Scientific Library (GSL).
- A "Module" abstraction was added to give a standard way of constructing YARP programs, factoring out common patterns we saw in many existing modules.
- Many more examples written, including an integrated "port power" tutorial going beyond the basics already covered.
- Configuration file structure improved.

Task 8.4-8.6: Progress on iCub Repository, compiling

- A uniform, portable method for compiling the ICub repository was introduced based on CMake. This method was documented and applied to all existing, actively used modules in the repository, including both executables and libraries.
- A test server was created that continuously checked out the repository and attempted to compile it. Failure of individual modules to compile is signaled on a status page on the repository website.
- The test server also serves as a mechanism to keep track of the external libraries required by modules.

Task 8.4-8.6: Coding standards

- Basic standards for how modules should operate were developed and documented (for example, the use of configuration files, and the naming of ports). The standards could be met either through use of the YARP "Module" abstraction, or by direct implementation.

Task 8.6: Simulation Software for iCub

We developed an iCub robot prototype simulator using Open Dynamics Engine (ODE). ODE is an open source physics and motor dynamic interface. It enables robotic simulators to consider the role of physical constraints within a simulated environment which can compute and resolve forces that emerge through the interaction of objects/entities. ODE includes an interface to OpenGL that facilitates the rendering or objects (boxes, sphere etc). The simulation model is a replication, using the approximate (but it can be improved) data and inertia matrices, of the actual iCub platform. This simulator has been developed for the users of the RoboCub project, as an alternative to the physical iCub platform for rapid prototyping, fast simulating and testing.

The concept behind it was to make the simulation as faithful as possible to the iCub using the same type of interface. An interface with YARP was created which controls the simulation by the same interfaces that control the robot (same commands and parameters). Therefore the user experiences the same software environment with the additional safety of running in a simulated world, which should improve the user learning curve. Vision has also been implemented, which appears in another graphical window and shows what the simulated robot "sees" in its environment. As for the iCub robot, vision can be retrieved from either the left or the right eye.

Screenshots of the iCub prototype simulator can be seen in Figure 4.

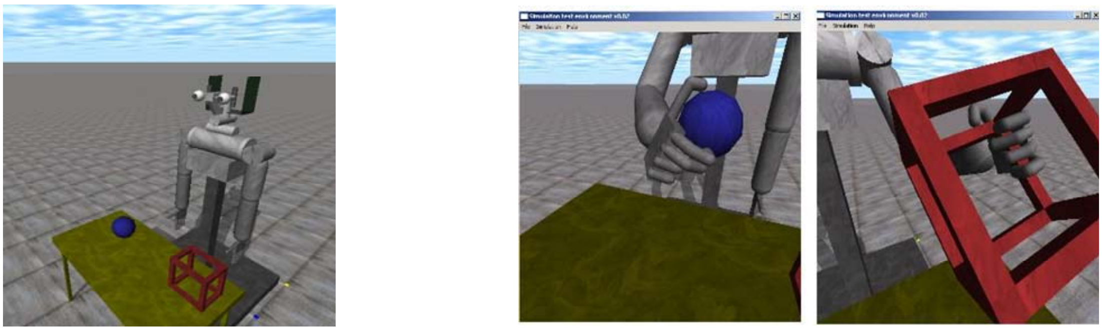


Figure 4: Simulation setup of the iCub (wihtout head cover) and objects. Right arm grasping a ball and left arm holding a cube.

IST

As the developers of the iCUB head, IST has contributed to the definition of the documentation standards, mechanical design and components. The head CAD has been made available in the Robotcub repository.

In addition, during the second year of the project, IST has allocated a substantial effort to software development, according to the Yarp architecture. The implemented software (mostly related to vision and head control functions) has been used during the RobotCub summer school with the use of the IST prototype head.

In addition, IST has contributed to the software repository of the iCub, particularly in relation to the audio acquisition and processing as well as to hea head-eye control modules and attention.

UNISAL

As the developers of the iCub lower body and the force-torque modules, UNISAL has worked in support of lead partners on the development of an open system. The particular activity has contributed to the development of a methodology for ensuring Open forms for the mechanical systems and definition of the documentation standards, mechanical design and components. The lower body CAD has been made available in the Robotcub repository.

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
D 8.1	Initial Specification of the CUB Open System.	8	12, 30	42	UGDIST
D 8.2	Definition of Documentation and Manufacturing Procedures.	8	12, 30	12	UGDIST
D 8.3	Software Architecture	8	18, 30	30	UGDIST
D8.4	Safety notice & disclaimer warning of the hazards of using the iCub and stating that users do so at their own risk	8	36	36	UGDIST

List of milestones

Milestone no.	Milestone name	Workpackage no.	Date due
M2.1	Final design and construction of the first complete validated prototype of the iCub	8	36
M2.2	Launch of call for proposals for 3rd party research projects	8	36
M2.3	Opening of the Research and Training Site (RTS)	8	36

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

Dissemination happened mainly through the usual channels of scientific publication. To be mentioned and crucial during the last period is the summer school (Vidi Vidi Vici 2007) that was held at IIT in Genoa for ten days in July 2007. The format was slightly changed with respect to the 2006 school since the Consortium needed to concentrate on establishing the coding standards required to be productive in the coming two remaining years of the project. We accepted only a small number of external students, while the great majority was from the Consortium. Standardization of methods and interoperability has advanced considerably because of the summer school. The cognitive architecture was refined and detailed during the school. Next year summer school will go back to the more open format. The school website will be available indefinitely on the RobotCub website (http://www.robotcub.org/summerschool) and Wiki (http://eris.liralab.it/wiki/VVV07).

RobotCub also advertised (as of September 1st, 2007) the Open Call.

RobotCub will be the main focus of a Wired feature article to be published on the December issue of the magazine (www.wired.com).

IST

Organization of the 4th International Symposium on Imitation in Animals and Artifacts at the AISB'07 Convention in Newcastle upon Tyne, UK, April 2nd-5th 2007

http://vislab.isr.ist.utl.pt/aisb07_imitation/

Proceedings: http://vislab.isr.ist.utl.pt/aisb07_imitation/aisb07_imitation_web.pdf

Chair: José Santos-Victor (Instituto Superior Técnico, PT)

Co-Chairs: Manuel Lopes (Instituto Superior Técnico, PT)
Alexandre Bernardino (Instituto Superior Técnico, PT)

Steering Committee:
Yiannis Demiris (Imperial College London, UK)
Chrystopher Nehaniv (University Hertfordshire, UK)
Kerstin Dautenhahn (University Hertfordshire, UK)

UNISAL

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

Deviations from the project work-programme

None.

List of deliverables

Del. no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
D 9.1	Proceedings of the Initial Scientific Meeting.	9	6	6	UGDIST
D 9.2	Material produced for the training activities.	9	18, 30	30	UGDIST
D 9.3	Progress report on Internationalization activities.	9	36	36	UGDIST
D9.4	Text of Call for Research Proposals	9	36	36	UGDIST

List of milestones

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

Section 3 – Consortium management

New Contractor

On July 2007, on behalf of the RobotCub consortium, the Coordinator sent a formal request to the Commission, asking for the addition of the Italian Institute of Technology (IIT) to the project Consortium and the termination of the European Brain Institute participation to the project.The main role of IIT in RobotCub will be to effectively contribute to further developing the robot platform, to foster interaction between the different scientific sectors involved in RobotCub, and to help create a more interdisciplinary user basis (IIT is starting an multidisciplinary effort through the department of Robotics, Brain and Cognitive Sciences). IIT will work on improving the design and realization (fabrication procedures) of the iCub platform (for example, IIT will have a fully equipped electronics laboratory, specialized personnel and machine shop); IIT will help further in spreading knowledge about the iCub and will contribute to dissemination/public awareness (IIT has an excellent media office). Further, the RobotCub Research and Training Site (RTS) will be installed at IIT. Figure 5 shows the budget reallocation details after the entrance of IIT and the retirement of EBRI. IIT will participate with own funds only.

1. EBRI budget will be re-allocated to University of Genoa (UGDIST) and to Telerobot S.r.l. (TLR) as follows:

   EBRI budget (Euro)

Pre financing (refunded to the consortium)………………………………	+ 31.790,00
Residual budget ……………………………………………………………	+ 58.210,00
TOTAL **before** re-allocation ……………………………………………	+ **90.000,00**
Assignment to UGDIST ……………………………………………………	- 50.000,00
Assignment to TLR …………………………………………………………	- 40.000,00
TOTAL **after** re-allocation ………………………………………………	**0,00**

2. The **Italian Institute of Technology** will contribute to the project exclusively with its own resources

Figure 5: budget reallocation after the amendment to Annex I.

Delays

The robot debugging is delayed with respect to the initial plan and consequently certain components might not be fully reliable. The plan for recovering the delay involves continuous debugging between now and the time the first two copies of the open call robots will be delivered (approximately March-April 2008). This still allows changing parts on the fly if this were necessary. Effort in WP7 has been bigger than expected.

D8.1 originally due at month 30 has been moved to month 42 when the iCub will have been tested fully. The title should reflect the fact that it will contain the actual specifications of the robot rather than the “initial” ones as specified in the Annex I. Effort in WP8 was lower given also the fact that the platform wasn’t fully available.

Less effort than originally budgeted was allocated to WP9. Most of the extra effort was moved to WP7 to guarantee the completion of the robot that is instrumental to the continuation of the project into the next stage of the Open Call.

List of Conference Papers and Journal Publications

Entries in bold text indicate new papers that have been added since October 2006.

Entries in italic text indicate papers with amended citations or more recent pdf copies.

Arbib, M., Metta, G., Van der Smagt, P. 2006. Handbook of Robotics Chapter 64: Neurorobotics: From Vision to Action, 2008, in press.

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Berthouze, L., and Metta, G. 2005. Epigenetic robotics: modelling cognitive development in robotic systems. In Cognitive Systems Research. Volume 6 Issue 3. September.

Berton, F., Sandini, G., Metta, G. 2005. Anthropomorphic Visual Sensors. In the Encyclopedia of Sensors. Ed. C.A. Grimes, E.C. Dickey, M.V. Pishko, American Scientific Publishers. Volume X, pp 1-16.

Bezdicek, M. and Caldwell, D. G. 2006. "Portable Absolute Position Tracking System For Human Hand Fingertips", Virtual Concept 2006, Cancun , Mexico, Nov. (accepted).

Billard, A., Calinon, S., Dillmann, R., and Schaal, S. "Robot Programming by Demonstration", Handbook of Robotics, B. Siciliano and O. Khatib (Eds.), Chapter 59, 2008, in press.

Blow, M., Dautenhahn, K., Appleby, A., Nehaniv, C. L., and Lee, D. 2006. Perception of robot smiles and dimensions for human-robot interaction design, In Proceedings of the 15th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN 2006), pages 469-474, Hatfield, UK, 6-8 Sept.

Blow, M., Dautenhahn, K., Appleby, A., Nehaniv, C. L., and Lee, D. 2006. The Art of Designing Robot Faces – Dimensions for Human-Robot Interaction. In ACM Proceedings of 1st Annual Conference on Human Robot Interaction (HRI 2006), pages 331-332, Salt Lake City, Utah, USA, 2-3 March.

Caldwell, D.G., Tsagarakis, N.G., Kousidou, S., Costa, N. and Sarakoglou, I. 2007, ""Soft" Exoskeletons For Upper And Lower Body Rehabilitation - Design, Control And Testing", International Journal of Humanoid Robotics, (in print).

Castellini, C., Orabona, F., Metta, G., and Sandini, G. "Internal models of reaching and grasping", to appear in Advanced Robotics, special issue on Imitative Robots, 2007.

Chua, P. Y., Bezdicek, M., Davis, S., Gray, J. O., and Caldwell, D. G. 2006. "Tele-Operated High Speed Anthropomorphic Dextrous Hands with Object Shape and Texture Identification", IROS 2006, Beijing China Oct. pp. 4018-23.

Costa, N. and Brown, M. and Hutchins, S. and Caldwell, D. G. 2005. "Design of Human-Friendly Powered Lower Limb Rehabilitation Orthosis", TDU COE-UK EPSRC Workshop on Human Adaptive Mechatronics (HAM), pp. 69-75, Tokyo , Japan, July.

Costa, N. and Caldwell, D. G. 2006. "Control of a Biomimetic "Soft-actuated" 10 DOF Lower Body Exoskeleton", IEEE BioRob 2006, Pisa, Italy, Feb., 495- 501.

Costa, N. R. S. and Caldwell, D. G. 2006. "Control of a Biomimetic "Soft-actuated" Lower Body 10 DOF Exoskeleton", Syroco, Bologna, Italy, Sept.

Costa, N., Bezdicek,M., Brown, M., Hutchins, S., Gray, J. O., Caldwell, D. G., and Hutchins. 2006. “Joint Motion Control of a Powered Lower Limb Orthosis for Rehabilitation”, International Journal of Automation and Computing , Vol 3, No 3, 271-281.

Craighero L., Bonetti F., Massarenti L., Canto R., Fabbri Destro M., Fadiga L. (in press) Temporal prediction of touch instant during human and robot grasping observation. Brain Research Bulletin.

Craighero L., Bonetti F., Massarenti L., Canto R., Fabbri Destro M., Fadiga L. “Temporal prediction of touch instant during grasping observation”, submitted for publication.

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Dahiya, R. S., Valle, M., Metta, G., Lorenzelli, L., Collini, C. "Tactile sensing arrays for humanoid robot", IEEE- PRIME’07, The 3rd Conference on PhD research on Microelectronics and Electronics, Bordeaux, France, pp. 210-204, July 2007. (Gold Leaf Best paper award).

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Dahiya, R.S., and Valle, M., and Metta, G., and Lorenzelli, L. "Modeling of Lossy Piezoelectric Polymers in SPICE", MRS Fall Meeting, Nov 2007, Boston, USA.

Dahiya, R.S., Valle, M., Metta, G., and Lorenzelli, L. "POSFET Tactile sensor arrays", Accepted for publication in Proc. IEEE- ICECS’07, The 14th International Conference on Electronics, Circuits and Systems, Marrakech, Morocco, 11-14 Dec 2007.

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Davis, S. and Caldwell D.G. 2006, "Pneumatic Muscle Actuators for Humanoid Applications - Sensor and Valve Integration", IEEE 6th Int. Conf. on Humanoid Robots, Humanoids 06, pp.450-55 , Genoa, Italy, Dec.

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Duran, B., Sandini, G., Metta, G. "Emergence of Smooth Pursuit using Chaos", in the First IEEE International Conference on Self-Adaptive and Self-Organizing Systems. Boston, MA, USA, July 9-11, 2007.

Fadiga L, Craighero L, and Olivier E. 2005. Human motor cortex excitability during the perception of others' action. Current Opinion in Neurobiology, 15:213-8.

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Fadiga L. and Craighero L. 2006. Hand actions and speech representation in Broca’s area. Cortex, 42:486-90.

Fadiga L., Craighero L. (2007) Cues on the origin of language. From electrophysiological data on mirror neurons and motor representations In S. Bråten (Ed.), On Being Moved: From mirror neurons to empathy. Amsterdam, John Benjamins.

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Francois, D., Polani, D., and Dautenhahn, K. (2007) On-line behaviour classification and adaptation to human-robot interaction styles, Proc. 2nd ACM/IEEE International Conference on Human-Robot Interaction (HRI07), March 9-11, 2007, Washington DC, USA, pp. 295 – 302.

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Section 4 – 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

Research on the crawling of the iCub was featured on the Swiss national broadcast 10vor10 (the main late evening news show) in October 2006.

National Television: 2010 – Science dissemination program (August 2007)

Science dissemination program produced by the Swedish television.

Science exhibition visited by the Portuguese minister for Science, Technology and Higher education.

The iCub head demonstrated in a Science and Technology Exhibition for by high school students and general public, during the Portuguese Minister for Science, Technology and Higher Education. (April 2007)

UNIHER organised a special session on "Cognitive Architectures for Interaction and Narrative" at IEEE ICDL 2007, 11-13 July 2007, London, UK (Chrystopher L. Nehaniv and Kerstin Dautenhahn)

Invited Keynote Speaker at IEEE ICDL 2007, 6th IEEE International Conference on Development and

Learning, 11-13 July 2007, London, UK (Kerstin Dautenhahn)

UNIHER organized a special session on "Robot assisted play" at IEEE RO-MAN 2007, 26-29 August 2007, Jeju island, Korea (Ben Robins, Kerstin Dautenhahn)

Robot demonstrations, talks and promotion of RobotCub at IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN) "Getting to Know Socially Intelligent Robots", 6-8 September 2006, University of Hertfordshire, Hatfield, United Kingdom.

Hatice Kose-Bagci and Qiming Shen of UNIHER attended the Robotcub VVV 07 summer school, 15-26th of July, in Geneva, Italy.

UNIHER Organised RO-MAN06 The 15th IEEE International Symposium on Robot and Human Interactive Communication: "*Getting to Know Socially Intelligent Robots*") at the University of Hertfordshire. This included a robot demonstration activity where UK press was invited. See below for selected pictures from this event:


University of Hertfordshire
RobotCub

TV4, one of the largest TV channels made a newscast from the lab at UNIUP when IST was there in June. Upsala Nya Tidning (UNT) has made 3 large articles of the research activities at UNIUP. Furthermore, several other Swedish newspapaers, among them Sydsvenska Dagbladet och Aftonbladet made news articles about the activities at UNIUP in the context of Robotcub.

Press (selected)

AATP American Association for Technology in Psychiatry mentioning RobotCub
http://www.techpsych.net/archives/000198.html

A KASPAR article (4 June 2007): http://www.autismvox.com/move-over-pinocchio-and-interact-with-kaspar/ As noted in the weblog of the American Association for Technology in Psychiatry, KASPAR is being developed as part of the European Robot Cup Project with the intent to "build open-source platform for cognitive development research..." [they misspelt RobotCub as Robot Cup]. The article includes a link to the project

BBC2 Northern Ireland programme "Bright Sparks" features Kaspar and
our RobotCub research on drumming/timing delays in human-robot interaction. (Summer 2007) [also mentioned is other work on children with autism - not part of RobotCub]. Can be seen at
http://www.youtube.com/watch?v=AgikQ3rkPwk

Kaspar is also featured on the lunchtime news on BBC 1
http://search.bbc.co.uk/cgi-bin/search/results.pl?scope=all&tab=av&edition=d&q=robots+an+autism&x=8&y=7
29 May 2007

Article in German Newspaper Magazine “Die Zeit (Die Zeit Wissen)” describing research work using the Kaspar robot originally developed for Robotcub. Author: Jens Uehlecke, Date: 5/2007

Section 3 – Publishable Results

None at this point.