

# The RobotCub project

## an open framework for research in embodied cognition\*

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### Abstract

This paper presents a research initiative on embodied cognition called RobotCub. RobotCub is an EU-funded project that aims at developing an open humanoid robotic platform and, simultaneously, following an original research path in synthetic cognition. We report on the motivations behind the realization of our humanoid robotic platform and the current status of the design just before the construction of the first full prototype.

### Keywords

Development, cognition, manipulation, design of a humanoid robotic platform

### 1. Introduction

The RobotCub project is a research initiative dedicated to the realization of embodied cognitive systems [1, 2]. It has the twin goals of 1) creating an open humanoid robotic platform for research in embodied cognition – the iCub – and 2) advancing our understanding of cognitive systems by exploiting this platform in the study of the development of cognitive capabilities in humanoid robots.

The iCub will have a physical size and form similar to that of a two and a half year-old child and will achieve its cognitive capabilities through development and learning in its environment: by interactive exploration, manipulation, imitation, and gestural communication. The iCub will be a freely-

available open system which can be used by scientists in all cognate disciplines from developmental psychology to epigenetic robotics. The iCub will be open both in software but more importantly in all aspects of the hardware and mechanical design.

One of the tenets of the RobotCub stance on cognition is that manipulation plays a key role in the development of cognitive capability. Consequently, the design is aimed at maximizing the number of degrees of freedom of the upper part of the body (head, torso, arms, and hands). The lower body (legs) will support crawling on arms and legs and sitting on the ground in a stable position with smooth autonomous transition from crawling to sitting. This will allow the robot to explore the environment and to grasp and manipulate objects on the floor. The total height is estimated to be around 90cm. The total number of degrees of freedom for the upper body will be 41 (7 for each arm, 9 for each hand, 6 for the head and 3 for the torso and spine). Each leg will have a further 6 degrees of freedom. The sensory system will include binocular vision and haptic, cutaneous, aural, and vestibular sensors. Functionally, the system will be able to coordinate the movement of the eyes and hands, grasp and manipulate lightweight objects of reasonable size and appearance, crawl using its arms and legs, and sit up. This will allow the system to explore and interact with the environment

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not only by manipulating objects but also through locomotion.

The mechanics, electronics and software components of the iCub are being developed by the RobotCub's team in parallel and synergistically. We aim at a global optimization process of these three components. Our goal is to produce an integrated design, of an open platform, apt to support various behaviors, and of the most general use possible. Complementary to this requirement, the robot platform has to incorporate manipulation by providing sophisticated hands, a flexible oculomotor system, and a reasonable bi-manual workspace. Finally, on top of this, we need to support, global body movements such as crawling, sitting, etc. These many constraints had to be considered in preparing the specifications of the robot and later on during the whole design process.

## 2. Rationale of the specifications

The behaviors we set forward for representing the robot's skills at the end of the RobotCub project can be summarized into two types of constraints:

- Kinematics: about the geometrical construction of the robot
- Dynamics: about the forces and torques we require from the robot

The possibility of achieving certain tasks is favored by a suitable kinematics, and in particular this translates into the determination of the range of movement and the number of controllable joints (where clearly replicating the human body in detail is fairly impossible with current technology). Kinematics is also influenced by the overall size of the robot. We decided *a priori* to target the size of a two and a half year old child (approximately 90cm high). Actual dimensions were taken from books of ergonomics and x-ray images [3]. This size can be achieved with current technology. QRIO [4] is an example of a robot with similar size although with less degrees of freedom. In particular, our specifications have to consider at least the same degrees of freedom found in QRIO plus hands and moving eyes. Also, we wanted to consider the workspace and dexterity of the arms and thus a three degree of freedom shoulder is required. Later, we will elaborate these considerations into a proper list of joints, ranges, and sensory requirements at the joint level.

Considering dynamics, the most demanding requirements clearly appear in interacting with the environment. Impact forces, for instance, have to be considered for the crawling behavior, but also and more importantly, developing cognitive behaviors such as manipulation might require exploring the environment very erratically. As a consequence, it is

likely that impact forces are generated in various elements of the robot structure. These turns out to require strong joints, gearboxes, and more in general powerful actuators. In order to evaluate the scale (order of magnitude) of the required forces we decided to run simulations of various behaviors in a reasonable model of the robot. These dynamic simulations provided data for starting the design of the robot.

At a more general level we had then to evaluate the available technology, compared to the experience of the consortium and the targeted size of the robot: it was decided that electric motors represent the most suitable technology for our platform, given also that the iCub has to be ready according to the very tight schedule of the overall RobotCub project. Other technologies (e.g. hydraulic) are left for a "technology watch" activity and they are not considered further at the moment.

In addition, given the size of the robot, and given the power density available, considerations of speed for certain joints lack of significance: i.e. given the power and the torques required, speed is a consequence rather than a design parameter. In certain cases, in comparing to human data, clearly also the power density is much lower than desired (e.g. the wrists cannot possibly stand the weight of the robot).

Finally, the iCub is not only about motors, sensors are equally important. Also in this case, we have to deal with and exploit at best the available technology. The robot will have vision, audition, joint sensors, force sensors, tactile sensors – where possible – and temperature sensors in many of the motors. The robot will also be able to provide feedback to humans through a speaker. iCub will thus include:

- Cameras
- Microphones
- Gyroscopes
- Linear accelerometers
- Encoders (or other positional sensors)
- Temperature sensors, current consumption sensors
- Various tension, force/torque sensors
- Tactile sensors

The choice of these components is clearly related to the robot specifications.

To recapitulate, the constraint of size and available technology determines a good part of the design choices – i.e. our freedom is deciding which components to use. In parallel, we simulated some of the robot's behaviors to determine the required joint torques. These two pieces of information were then used in selecting the best available motors compatible in size, torque, and strength. As we mentioned earlier, speed is a consequence rather than a design

parameters here, although, in simulation we examined the dependency of speed to torque for crawling.

Other design choices are related to the embedded electronics and the structure of the software. The iCub will have many sensors and actuators working in parallel. We would like to exploit this parallelism also at the computational level and, consequently, the iCub API will be multi-process and will be amenable to be run on multiple machines with full-blown parallelism.

The remainder of this paper is organized as follows: section 2.1 describes the kinematic constraints and design choices; section 2.2 deals with dynamics and section 3 wraps this up into the current design choices and result of the CAD design activity. Section 3.1 describes the elements of the controlling electronics required to drive the robot and acquire its sensors; the list of sensors currently included into the design is reported in section 3.2 and, finally, section 3.3 deals with the software architecture that is being planned for the iCub. A concluding section summarizes the content of the paper and points to future directions.

## 2.1 Kinematics

The gross kinematic features of the iCub are the number of degrees of freedom (dof) and the overall size. The latter was determined by approximate technological evaluation: the iCub will have the approximate size of a two and a half year old child. The number and allocation of the degrees of freedom reflect the use of the robot for manipulative tasks and the general resemblance with human form. The main decision is how many degrees of freedom to allocate for the hands. Clearly, the most part of the hand's actuators can only be located in the forearm for evident reasons of space. By analyzing the requirements for grasping and manipulation and drawing on our past experience we estimated that 9 degrees of freedom in the hand will be optimal – always given the size and technological constraints. The hand of the iCub will be underactuated: i.e. the 9 motors will in fact move 17 joints coupled in various ways. The thumb, index, and middle finger will be independent; the last two fingers will act as a simple one dof device. The thumb will have three degrees of freedom, one of which will be actuated from a small motor inside the palm (the opposition movement). The last two degrees of freedom will move the remaining three joints, the last two of which being coupled together through a small rotational spring. It remains to be decided whether the actuator will provide both agonistic and antagonistic forces (a loop wire). The index finger will have the same number of joints of the thumb with a similar arrangement and

actuation. The abduction/adduction movement will be driven together with the ring and little finger, by keeping the middle finger fixed with respect to the palm. The middle finger will thus have only three joints and two controlled dofs. Finally, the ring and little finger will be connected together, coupled by means of springs and actuated by a single motor. The abduction/adduction movement will be driven by a little motor inside the palm. It has been shown [5] that 9 dofs distributed on three fingers allow full manipulability (e.g. rotation and translation) by allowing the positioning of three points of contact onto the object (the fingertips). The iCub hand, if analyzed according to [5] will lack one dof since the middle finger is fixed with respect to the palm. Given the targeted size we believe nothing more can be done at the moment.

Next we analyzed the requirements for the oculomotor system. The simplest and yet flexible configuration has to have three degrees of freedom for moving the eyes, allowing for independent panning (and thus vergence control) and a common tilt. The neck complements this module with three additional degrees of freedom. We did not consider additional degrees of freedom in the neck as in some existing robot heads to save in complexity. The remaining 47 dof of the iCub are quite a feat anyway.

The minimum number of dofs for the arm is seven. While theoretically six would already allow reaching any point in the workspace with every attainable orientation, in practice, the seventh dof provides a means to reach without interfering with vision. This additional flexibility is very much desired if we have to deal with grasping and the interaction with objects in front of the robot while maintaining sight of the action. It is worth mentioning that the full range of motion for the shoulder can only be obtained by a double joint mechanism similar to the human clavicle and collar bones. Since it is difficult to include also this additional dof, we might expect a limitation of the final range of movement. This will be verified and the range of bi-manual manipulation considered as a parameter to optimize.

Legs are supposed to support crawling but we discovered that, in practice, the requirements for crawling are not very different from walking. It is thus possible, although not fully verified because outside the domain of RobotCub, that the iCub could be made to stand and walk. This aspect although not covered by RobotCub, it is clearly advantageous with respect to the promotion of the iCub openness, since it can eventually stimulate other groups, outside the present consortium, to invest in the iCub platform and develop walking, balance, etc. Each leg will consist of 6 degrees of freedom: the hip will contain three joints, the knee one, and the remaining two will

be allocated in the ankle. The foot yaw rotation will not be implemented.

For each joint we have to simultaneously consider the available sensors. Encoders or potentiometers will provide position feedback. Absolute sensors will be preferred and they are, in fact, a requirement for all the major joints (shoulders, hips, elbows, etc.). Tension sensors will be integrated in each joint controlling the fingers, especially if a single tendon solution is chosen (in which case they are mandatory). Temperature sensors are useful as a safety measure for the most mechanically stressed actuators. We will consider the incorporation of these sensors within the motor housing.

Finally, for each joint we have to consider the type of actuation (DC or brushless DC) taking into consideration the complexity of the driving electronics, speed, torque, etc. The range of movement is specified for each joint according to the two previous tables. The column to be considered as requirements is the first from the left. Next to it, comparison values are reported (including human values where available).

## 2.2 Dynamics

The next step of the design of the iCub requires taking into account masses, forces & torques, and starting to consider the dynamics of the robot in action. The dimensioning of the motors will follow from this activity. The first set of numbers we need is the distribution of the mass of the robot. It has been defined starting from our experience with previous designs. A reasonable estimate of what can be achieved with current actuation technology and materials falls in the range of the 20Kg. The maximum weight which we then used in computing force and torque was estimated in 23Kg divided as per the next table (which includes the length of the body segments as used in the simulation).

**Table 1:** Mass distribution and main body segments size.

Body part	Mass (Kg)	Length (m)
Arm	1.15	0.15
Forearm (includes thehand)	1.25	0.13
Tight	1.5	0.17
Leg (lower part)	1.5	0.17
Ankle – foot	0.5	
Upper torso	3.75	0.12
Lower torso	6.5	0.12
Head	1.5	

We then performed a simulation of crawling using the Webots platform [6], which in turn uses ODE – a dynamical simulator. The aim of the simulation is to obtain values of the torques at the joints both in static and dynamic situations. The static values were also cross checked through more traditional calculations and they were in agreement with the results of the simulation. Clearly, many factors impact on the torque values including the crawling strategy, and the simulation might not be guaranteed to be perfect. Nonetheless, these numbers, and their verification in the static case, are a good basis to start the design of the robot.

For the simulation, as ODE does not implement a PID controller but uses some approximation to control motors, we had to implement our own PID to control the simulated motors of the iCub. We made some basic experiments with simple movements to make sure the torque values were consistent with theoretical values. Subsequently, we measured the torque generated by the PID during crawling and also while doing some simple push-up like movements on the arms.

The last experiment was about crawling: we measured the torques at each joint, for a 1Hz and 0.5Hz crawling. In this crawling motion, only the front-back dofs of the arms and legs, the knees and the elbows have sinusoidal reference trajectories. The other dofs just have to maintain the initial angle. The period and phase of the reference trajectories was manually tuned to actually generate a suitable crawling behavior. Results are collected in the tables below for the 0.5Hz crawling.

**Table 2:** Speed and acceleration while crawling.

Joint name	0.5Hz crawling		1Hz crawling	
	Max speed (rad.s-1)	Max acceler (rad.s-2)	Max speed (rad.s-1)	Max acceler (rad.s-2)
Right leg 1	1.25	3.94	2.51	15.79
Right knee	0.72	2.27	1.44	9.08
Right arm 1	1.25	3.94	2.51	15.79
Right elbow	1.57	4.93	3.14	19.73

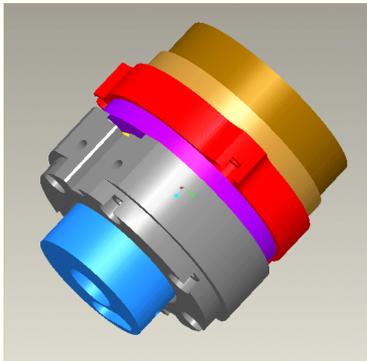
The maximum errors of angle are of the order of 3 degrees, except for the torso, where errors can reach 5 degrees. It is to be noted that these numbers are specific to the crawling control/strategy adopted, while it seems plausible that the optimization of the

controller would reduce the requirements at least for dynamic tasks. On the other hand, the static case still requires torques at the shoulder in the order of 40Nm, which we are taking as a reference in the following.

**Table 3:** Torques for the simulated crawling at 0.5Hz.

Joint	Maximum torque (Nm)
Left arm 1	40.4
Left arm 2	18.1
Left arm 3	7.9
Left elbow	18.6
Torso 1	34.3
Torso 2	26.5
Torso 3	13.7
Left leg 1	38.5
Left leg 2	15.1
Left leg 3	23.2
Left knee	28.0
Left ankle	11.3

Armed with these numbers, we can look at the best possible motors that can guarantee the required torques, given the speed for crawling at, let's say, 0.5Hz and that possibly fit within the dimensions provided by the model of the robot (i.e. the two and a half year old child). We proceeded again by drawing from the RobotCub's team experience with designing robots. In particular, we analyzed various brands and gearboxes in combination. The most critical joints are those of the shoulder and hips; the requirement of about 40Nm is very demanding especially for the gearbox. In fact, at the shoulder, the power requirement is in the order of 450W per motor. The issue of the total weight of the robot is also important, since typically, power comes at the cost of bulkier actuators.



**Figure 1:** The Kollmorgen motor and Harmonic Drive gearbox.

Eventually, especially because of the total weight, the choice fell onto the Harmonic Drive gearbox. They are very compact, lightweight, and can be purchased without the enclosure (housing), which can save some additional weight and space. On the actuator side, we compared the most common solutions of DC motors, but eventually we had to resort to the Kollmorgen motors [7], also, without housing. Then, by designing the package, it is possible to mount the motor and the Harmonic Drive gearbox in an approximate cylinder of about 60mm in diameter and 50mm in length (not counting the motor shaft and pulley). This is the basic module, now under testing, on which we are basing the design of the major joints of the iCub.

### 3. Current state of the design

We have already discussed the choice of the motors. The following excerpt from the Kollmorgen catalogue gives an idea of one of the motors we considering in our design:

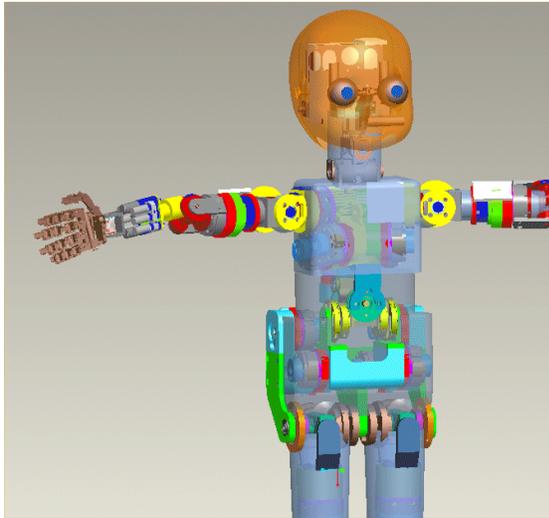
Winding Constants	Symbol	Units	A	B	C	A	B	C	A	B	C	A	B	C
Current at Const. Torque	$I_c$	Amps	5.41	3.89	6.95	5.81	3.63	9.06	5.42	3.38	8.45	5.77	4.00	8.88
Current at Peak Torque	$I_p$	Amps	15.0	10.6	18.9	20.0	10.6	26.8	20.0	10.6	26.8	22.5	13.4	30.1
Torque Sensitivity	$K_t$	oz-in/Amp	3.34	4.64	2.60	5.80	9.30	3.72	8.49	13.6	5.45	10.0	14.5	6.50
		N-m/Amp	0.0236	0.0328	0.0183	0.0410	0.0657	0.0263	0.0600	0.0962	0.0388	0.0707	0.102	0.0459
Back EMF constant	$E_b$	V/ERPM	2.47	3.43	1.92	4.29	6.88	2.75	6.28	10.1	4.03	7.41	10.7	4.81
Motor Resistance	$R_m$	Ohms	0.698	1.38	0.431	0.664	1.75	0.276	0.803	2.11	0.334	0.733	1.55	0.307
Motor Inductance	$L_m$	mH	0.280	0.54	0.17	0.32	0.83	0.13	0.44	1.1	0.18	0.47	0.97	0.20

\*Rth assumes a housed motor mounted to a 4.0" x 3.75" x 0.25" aluminum heatsink or equivalent

In particular, note the current consumption of the second motor type RBE01211 which for the winding type B gives currents in the order of 10.6A, in our case with 48V supply and a maximum torque of about 0.4Nm at a maximum speed of 4000rpm. Coupled with the Harmonic Drive, which provides a reduction ratio of 1:100, we obtain the 40Nm required by the dynamic/static analysis on the crawling behavior. It is worth noting again that crawling seems to be the worst case scenario for the iCub, involving in fact a strong interaction with the environment and possibly high impact forces. The Kollmorgen motors are brushless DC thus requiring tri-phase control signals which are going to be generated by a suitable DSP based microcontroller. The packaging we have chosen does not leave much room for an encoder. Fortunately, the brushless motor is already equipped with digital Hall-effect sensors that are used by the controller for driving the commutation of the phases. The same signals can be used as an incremental encoder. The resolution for the motor we consider is of 24 impulses per turn which gives a resolution of 0.15 degrees on the position feedback only slightly higher than the required precision (0.1 according to the specifications). It is still to be determined whether electronic 2X or 4X circuits could be applied in this

case. For the brushless motors we are planning to include the temperature sensors as discussed earlier. The sensor will be directly mounted inside the enclosure.

For smaller joints, such as the wrist and the fingers, the brushless motors are out of question because of their size and the complexity of the control electronics. We chose instead to employ the Faulhaber/Minimotor with their standard gearbox and encoders. The Faulhaber motors are very standard DC micro-motors and the RobotCub's team has a very long experience in developing solutions using them. Motors here range from the 8mm for the thumb opposition and abduction/adduction, to the 17mm in the neck. The controller in this case is also much simpler (single phase), which helps in fitting several of them inside the robot.



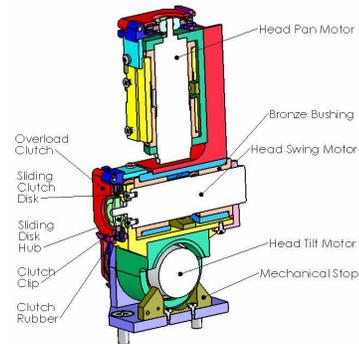
**Figure 2:** CAD drawing of the latest iCub.

The current design uses 23 brushless motors in the arms, legs, and the waist joints. The remaining 30 degrees of freedom are controlled by the Faulhaber DC motors. Most of the joints are tendon driven, some are direct, according to the placement of the actuators which is heavily constrained by the shape of the body. A comprehensive picture of the latest design is shown in Figure 2.

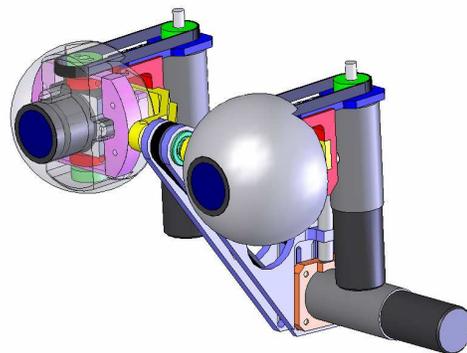
The head is based completely on the Faulhaber motors. The neck (3 dofs) consists of a serial chain of rotations, with the three degrees of freedom placed in a configuration that best represents human movements. For driving this mechanism, DC micro-motors (Faulhaber) with planetary gearheads have been used. An initial prototype is already built, tested, and demonstrated in a light tracking experiment. It is important to say that, in spite its simplicity, the mechanism is very robust, easy to control and has high performances, meeting all the desired

specifications. Each joint uses an overload clutch system (Figure 3) that increases the robustness of the mechanism, by absorbing (by sliding) different kind of impacts and efforts during its interaction with the external world.

The eyes mechanism (Figure 4) has also a total of three degrees of freedom. Both eyes can pan (independently) and tilt (simultaneously). The pan movement is driven by a belt system, with the motor behind the eye ball. The eyes (common) tilt movement is actuated by a belt system placed in the middle of the two eyes. Each belt subsystem has a tension adjustment mechanism. The calculation of the actuators characteristics was based on the desired specifications and the moment of inertia, as well as the various components weight, given by the CAD software.



**Figure 3:** The neck mechanism (a section).

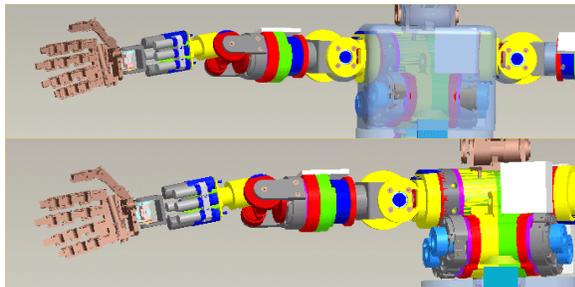


**Figure 4:** The eye assembly.

The shoulders were designed from the Kollmorgen motor assembly described earlier. A single aluminum block contains the three motors required for each shoulder. The joint is tendon driven; the motors do not move with respect to each other. The following pictures (Figure 5) show the arrangement of this module. The shoulder is a roll-pitch-roll configuration. The motor group and the orientation of the joints have been designed at an angle with respect

to the front-back midline to position the range of motion as frontal as possible which clearly enhances the manipulation workspace of the arms.

The elbow is driven by another Kollmorgen motor occupying almost the entirety of the upper arm link. The forearm attachment is shifted from the rotational axis to allow the maximum possible range of movement (estimated in 120 degrees in this realization). The space along the axis of the elbow is empty which allows a nice routing of the cables coming from the forearm motors. The forearm consists of 10 Faulhaber motors and their relative support structure. The wrist is hollow so that it can house the tendons actuating the fingers. Finally two motors are mounted inside the palm.

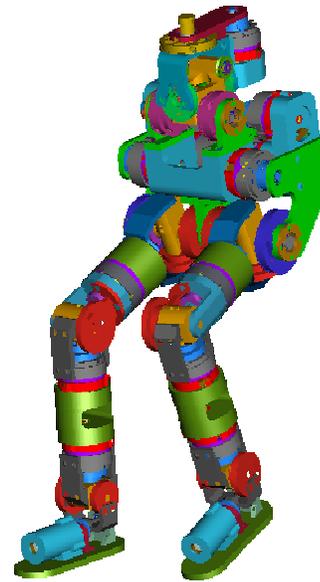


**Figure 5:** One of the latest design of the arm subsystem with (top) and without the external shell (bottom).

The waist joint (3 degrees of freedom) and the legs are designed with the Kollmorgen actuators which make the whole design very uniform. In fact, only two brands of motors are employed: the Kollmorgen in the brushless version and the Faulhaber in the DC version. The following Figure 6 shows the waist and legs design.

The design strategy seems to be converging at this stage of the project. The legs are conceptually similar to the shoulders and arms (apart from the evident simplification). The legs are 6 dofs each. The first 3 dofs are allocated at the hip joint, 2 motors per leg are placed in the lower body; the third motor is located inside the thigh. The knee and ankle motors are, at the moment, located both in the lower leg. The foot design is still to be completed (1 dof).

This section in practice contains all the information required for drawing the kinematics of the robot. We are planning to improve the simulation of section 2.2 by including kinematic constraints and singularity to make sure the planned skills are not hampered by an incorrect placement of the axes of rotation. Also, the range of movement and especially the manipulation workspace will be checked carefully. It is to be reminded that the overall size of the robot, in many respects, does not leave options available to the designer.



**Figure 6:** Latest design of the legs and waist.

Although not yet included in the design, we are evaluating the inclusion of weak points and clutches where possible to protect the robot from over-shocks that might damage either the gearboxes or the sensors. Given the available space, the solution to be preferred seems to be that of the weak points. The neck includes a first prototype of a clutch system. The possibility of reducing the gear ratio of the Harmonic Drive gearboxes is being considered. In particular, since the performance of the brushless motors can be increased by improving the cooling system, in a next release of the robot we could increase the driving voltage and pull more torque out of the Kollmorgen, bringing simultaneously the gear ratio down to 50 or 33 (now it is foreseen to be 100). This will increase backdriveability of the main joints of the iCub. The drawback is the requirement of voltages higher than 48V, which require a different set of specifications and standards. Also, safety of operation would need to be considered.

### 3.1 Electronics

The electronics of the iCub will be mostly embedded for the generation of the control signals and the sensory data acquisition. The interface between the iCub and the outside controller will happen through a Gbit Ethernet cable and a power cable. The robot will contain the amplifiers, a set of DSP controllers, a PC104 acquisition card based on a Pentium processor, and the sensors' acquisition and control electronics. Sensory data and motor commands will eventually travel on the Ethernet connection. The low level control contains two types

of card for the brushless and the DC motors respectively. Both are likely to be based on the same CPU (a DSP). Other cards might be employed to digitize sensory data locally to be subsequently sent to the PC104 relay station. In the latest evaluation, the relay station is going to be a PC104 processor card with some additional custom hardware for data acquisition. The PC104 processor will take care of preparing the IP packets for communicating bi-directionally with the external world. We imagine that a cluster of PCs will be employed for the implementation of the RobotCub cognitive architecture.

The controller for the brushless motors will take most of the empty space of the robot because of the high currents required (10A, 48V). A heat sink is likely to be required and will probably be incorporated on the iCub chassis. The Faulhaber motors employed so far are all with maximum current below 0.5A, 12/24V which is very convenient to contain the size of the amplifiers. Capacitors will be included where needed to allow the rapid transients that might be required by the robot. In addition, AD cards are foreseen in various places, for example in the hand, to read the position and tactile sensors. These cards will be connected to the iCub multiple CAN bus structure.

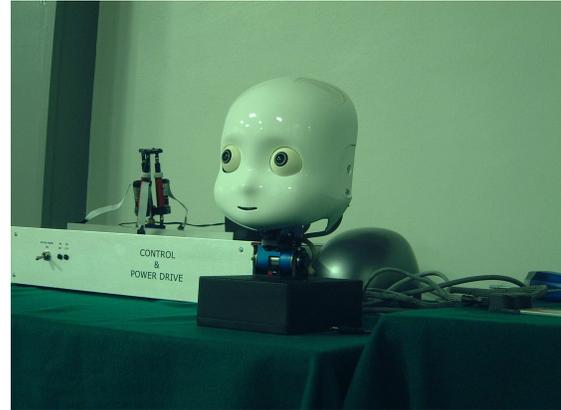
### 3.2 Sensors

Given the size of the iCub, sensors are being evaluated for performance but also weight, easiness of interface, etc. The following table contains a list of possible components that, at the moment of writing, are under evaluation for inclusion in the iCub final design. We are considering several alternatives when available.

Component	Model/type
Cameras	PointGrey Dragonfly 640x480 30fps version with remote head
Microphones	Shure – Model MX183
Inertial sensors	XSense MTi
Force/torque sensor	ATI Mini-45
Tactile sensors	Not defined yet
Absolute encoders	Austria Microsystems AS5043
Cable tension measurement	Not defined yet
Temperature sensors	Not defined yet
Hall-effect	Honeywell SS495 series

For the skin and tactile sensing technology we are starting the evaluation at the moment of writing. The

problem of sensorizing the skin will be investigated independently from the realization of the skeleton and the mechanics. This will simplify the design of the robot and leave different options open to evaluation for a technology that is not yet mature. An example of the face of the iCub under developed in shown in Figure 7.



**Figure 7:** The prototype of the head including the protective shell and face.

### 3.3 Software

The iCub software is potentially parallel and distributed. Apart from the interface API that speaks directly to the hardware, the upper layers might require further support libraries. These libraries are known as middleware. We analyzed various alternatives [8] and eventually decided to try following our own version of the middleware called YARP [9]. YARP is open-source and thus suitable for inclusion with the newly developed iCub code. The rationale of this choice lays in the fact that having the source code available and especially well understood could potentially simplify the software integration activity.

To facilitate the integration of code clearly the simplest way would be to lay out a set of standards and ask developers to strictly follow them. In a large research project we should also allow for a certain freedom to developers so that ideas can be tested quickly. These two requirements are somehow conflicting. Especially, they are conflicting when different behaviors are to be integrated into a single system and the integrator is not the first developer.

To allow developers to build upon the already developed behaviors, we plan to layer the software and release packaged behaviors in the form of APIs. The idea is to produce behaviors that can be used without necessarily getting into the details of the middleware code employed. While for lower levels there is no much alternative than following a

common middleware approach, higher levels and user-level code can be developed by considering a less demanding scenario. In the latter case, we will distribute modules with interfaces specified in an API (possibly a C++ class hierarchy). Internally, each module will unleash a set of YARP processes and threads whose complexity will be hidden within the module. We foresee various configurations: in one case, the given module would be capable of running on a single processor machine. This is a tricky and difficult choice since in many cases the behavior of the robot relies explicitly on timing, synchronization, and performances of its sub-modules. Considering that eventually each module is a very specialized controller, issues of real-time and performances have to be carefully evaluated. The modules' APIs will include tests and indications on the computational timing and additional requirements in this respect to facilitate the proper configuration and use.

The lowest level of the software architecture consists of the level-0 API which provides the basic control of the iCub hardware by formatting and un-formatting IP packets into appropriate classes and data structures. IP packets are sent to the robot via the Gbit Ethernet connection. For software to be compliant to the iCub the only requirement is to use this and only this API. The API will be provided for both Linux and Windows operating systems. It is then possible to consider multiple levels of software development and level-n APIs that re-use the underlying levels to create even more sophisticated modules. The same rationale of level-0 APIs clearly applies to higher levels.

#### 4. Conclusion

We presented the description of the design process of the iCub, the humanoid robotic platform being realized as part of the EU-funded project RobotCub. The rationale of the design has been introduced and the current set of choices analyzed to some details. We will provide this platform with an FDL and GPL licenses. Also, RobotCub will include the realization of copies of the robot in an attempt to maximize the success of this open source initiative in the hope this, in turn, will help in building a community of users with a common interest in robotics and cognitive sciences altogether. The first prototype is expected to be ready in the spring of year 2007.

Although we might have given the impression that RobotCub is only about building and promoting a robotic platform, it is worth mentioning that this is not the case. The realization of the robot represents only one third of the activities of RobotCub. A relatively large effort is, on the other hand, allocated to the implementation of several cognitive skills into this newly developed humanoid robot.

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