ROBotic Open-architecture Technology for
Cognition, Understanding, and Behavior

Project No. 004370

RobotCub

Development of a Cognitive Humanoid Cub

Instrument: Integrated Project
Thematic Priority: IST – Cognitive Systems

D7.5 Status of the platform: major changes, debugging activities, problem report

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Dissemination Level		
PU	Public	**PU**
PP	Restricted to other programme participants (including the Commission Service)	
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1 Introduction

This deliverable resumes the platform current status outlining the initial design limits, the first two years of field-tests and the upgrades already tested or currently being studied.

In the following, iCub versions have been defined as follows:

v1.0: the robot that has been produced for the Open Call;
v1.1: as 1.0 but with the addition of the force/torque sensors, full body covers, improved audio amplifier, position reading from the fingers and a set of small mechanical improvements;
v1.2: as 1.1 but with fingertips and palm tactile sensing (these are the robots for the ImClever project);
v2.0: under design, with full joint level torque control, tension sensors measurements and full-skin, improved electronics.

2 iCub problem report

During the last year the iCub platform was extensively used and has therefore revealed some problems which have been either fixed or scheduled for fixing. Specifically, the observed problems fall within three main categories (new additions in **bold font**):

- Performances of the tendon actuation.
- Robustness of the tendon actuation.
- Reliability of the DSP control boards communication.
- **General reliability of the electronics.**
- **Force/torque sensor calibration.**
- **Fingertip design.**
- **Evaluation of several modifications in the motor group.**
- **Evaluation of modifications on the shoulder/upper torso.**
- **Evaluation of modifications on the head.**

In the following we will describe in details the observed problems and discuss the implemented/schedules solutions.

2.1 Performances of the tendon actuation

Tendon actuation is very effective when the design issues require to have the actuation element (e.g. a dc motor) separated from the actuated joint.

Tendon actuation is widely exploited in the iCub platform and this sometimes poses relevant issues, especially when the tendons display a certain degree of elasticity. More specifically, tendon elasticity represents a problem when trying to precisely position the actuated joint.

2.2 Robustness of the tendon actuation

Extensive use of the hand has revealed an inadequate reliability and robustness of the hand tendons. In particular, it was observed that tendons had a tendency to break pretty easily especially when increasing their tension to enhance precise grasping.

2.3 Reliability of the DSP control boards communication

The final iCub design uses 20 DSP control boards which allow controlling the 53 degrees of freedom. These boards exchange information among them and with the PC104 (mounted on the head) trough 4 different CAN-BUS lines.

The dimensionality of the system reveals the complexity of managing and monitoring all these communications which need to be reliable for a number of reasons, safety included.

A set of monitoring and debugging tools is therefore necessary when dealing with such complex systems but was not planned in the earlier stages of the project.

Moreover, the commercially available communication products (initially employed) revealed inadequate to the goals of the project and required the development of a custom CAN-BUS board.

2.4 General reliability of the electronics (v1.1)

The latest rewiring of the iCub proved to be particularly stable. There are still issues in connection with the CAN bus wiring (small wires and out of tolerances) which will probably be addressed in the future. In the current version, after initial testing the wiring proved to be generally reliable although it shows weakness after repetitive maintenance interventions. In short, it works well but it is not easily maintainable.

Further, because of the addition of a newer CPU (Pentium Duo 2GHz) thermal problems were noted in the head also bringing the power supply outside its nominal specifications.

2.5 Force/torque sensor calibration (v1.1)

The iCub arms and legs mount a 6-axis force/torque sensor (FT sensor), which have been developed as a collaboration between Salford (now IIT) and IIT. There were improvements and debugging on the sensor electronics and mechanics. Issues were detected when we started calibrating the sensor or using it to full scale.

2.6 Fingertip design (v1.2)

We designed and realized several prototypes of a fingertip for the iCub using capacitive technology. We report about the design characteristics of the sensors which are now being integrated on the iCub.

2.7 Evaluation of modifications to the motor group (v2.0)

This work was focused on the design and testing of an updated actuator group module which will form the actuation unit for the future robot upgrades. In particular the existing actuator group was enhanced with additional sensing components and new materials for the module structure were explored. The following sections introduce the details of these developments.

2.8 Shoulder torque sensing (v2.0)

As part of the general improvements towards compliant control, a new activity has been undertaken for the design and integration of joint torque sensors in the upper body. These have been realized at the moment for the first four joints of the shoulder and elbow based on semiconductors strain gauges and by replacing a small number of mechanical parts. Crucial elements of the forearm were also redesigned.

2.9 Improved PC104 I/O card (v2.0)

As joint task between IIT and UGDIST, a new PC104 I/O card interface has been designed and it is now in advanced stage of development.

3 Major changes and debugging activities

In consideration of the aforementioned issues, quite a few debug activities were scheduled and planned in order to solve the arose problems. In this section we discuss in details the current solution. Open issues will be discussed in the next section.

3.1 Improving tendon actuation performances

As discussed earlier the tendon actuation may be problematic when trying to precisely position a joint in presence of elasticity.
The problem can be described as follows. The actuator (dc-motor) can be usually positioned with high precision (by exploiting the associated encoders). In presence of highly stiff transmissions, this precision will directly transfer to the joint positioning because there will be a one to one correspondence between the actuator and joint positions. On the contrary, elasticity introduces a certain degree of uncertainness in predicting the joint position given the actuator position: the more the elasticity the more the uncertainty level.

To improve the position precision in presence of elasticity a viable solution consists in placing a position sensor directly at the joint, thus having a direct measure of the variable to be controlled. This solution was already present on different iCub joints (e.g. soulder roll, hip roll) and up to now only planned for the hand, where the elasticity problem was causing evident positioning errors. In particular, the positioning issue was extremely evident at the level of the hand joints, where the length of the tendons and their reduced diameter (0.63mm) reflect into a sensible elasticity.
Therefore, a total of 17 (Hall effect) position sensors have been placed directly on the hand joints and a suitable custom board (see Figure 1) has been designed in order to collect the data coming from these sensors. At the moment only five1 out of the 17 sensors are used as position sensors for controlling the corresponding joint postures.

All the other joint positions are controlled by exploiting the encoders at the motors (thus resulting in poor position control) but the plan is exploit all the 17 sensors for getting rid of the current positioning limitations.

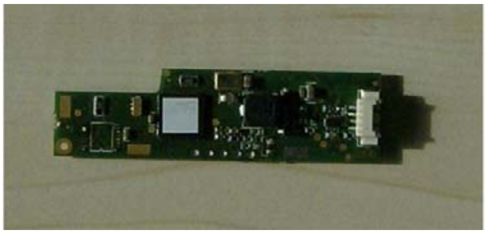

Figure 1: The custom board for reading the hand position sensors.

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[1] Currently only the following joint sensors are used: 1 for the thumb abduction, 1 for the fingers abduction, and 3 for the ring and little finger flexion.

3.2 Improving tendons robustness

Given the goals of the RobotCub project, the reliability of the hand actuation is crucial, especially in terms of robustness.
However, the adopted tendon actuation (mandatory given the dimensions constraints) revealed to be weak in its first design.

Experienced problems were the following:

- Breaking of tendons due to high curvature path;
- Breaking of tendons due to insufficient steel cable tensile strength.

3.2.1 Reducing tendon curvature path

The current hand actuation solution relies on tubes inside which the tendons slide. This solution is very effective because it allows the tendons to follow “arbitrary” paths from the motors to the joints. However, experience revealed that the followed paths should avoid high curvatures in order to avoid high frictions[2] which eventually lead to tendon braking. A set of innovative solutions (see Figure 2) have been introduced in order to optimize the tendon routing thus avoiding high curvatures.

Below are shown two improvements on tendons routing. The pictures show a CAD drawing of mechanical pieces that are used to route tubes and tendons.
Initially (top row) the direction of the tube sockets (highlighted in red) were not optimized. Recent studies (bottom row) have shown that the direction of the sockets can be optimized in order to reduce the stress on the tendons. Specifically, the sockets have been inclined in order to reduce the curvature of the tendons path (compare top and bottom rows).
Moreover, tendon paths have been standardized in order to make them easily reproducible on the different iCub copies and have uniform actuation behaviour across different platforms.

3.2.2 Increasing steel cable tensile strength

The original steel cables (used as tendons) were dimensioned in consideration of their nominal tensile strength. This solution was not taking into account the fact that this nominal strength is reduced when the cable is curved or tied in a knot. In order to increase tendons robustness, all the hand proximal joints tendons were replaced with new cables, increased in their diameter. Specifically, the cable diameter was increased from 0.45mm to 0.63mm.

By eliminating the external cable coating, that increases the overall diameter of about 0.2 mm is assured the compatibility with the pipe that guides the tendon.

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[2] The positions where the path has an high curvature correspond to position of high contact forces between the tube and the tendon. These high forces increase the friction between the tube and the tendon and contribute to easy tendon braking.

Experimental test showed also no relevant friction increase of the tendon inside the pipe related to the coating elimination. The stronger (bigger) cable, more axially rigid than the older respond faster and precisely to the motor control.

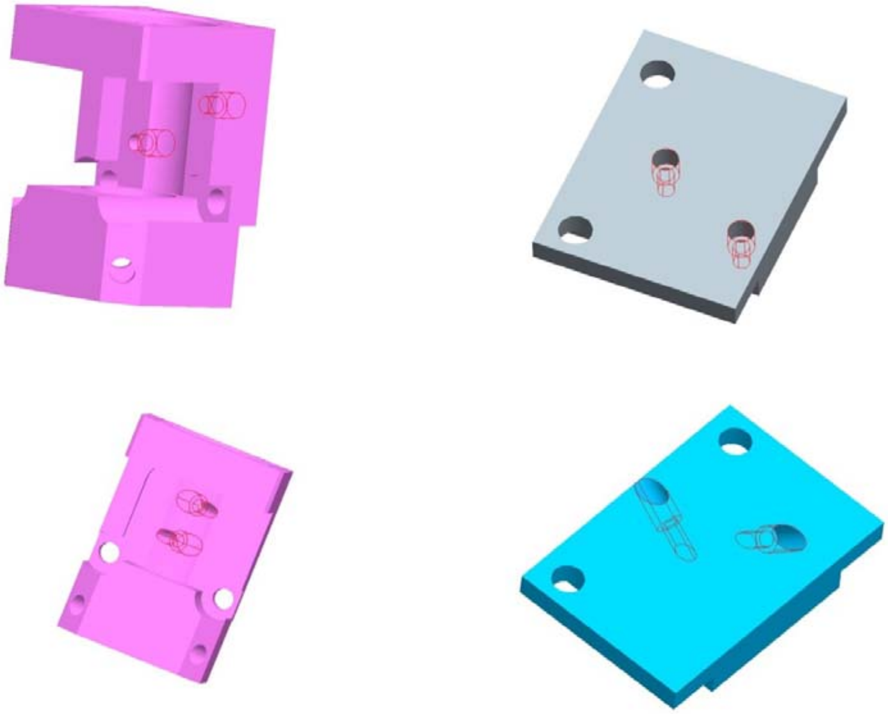
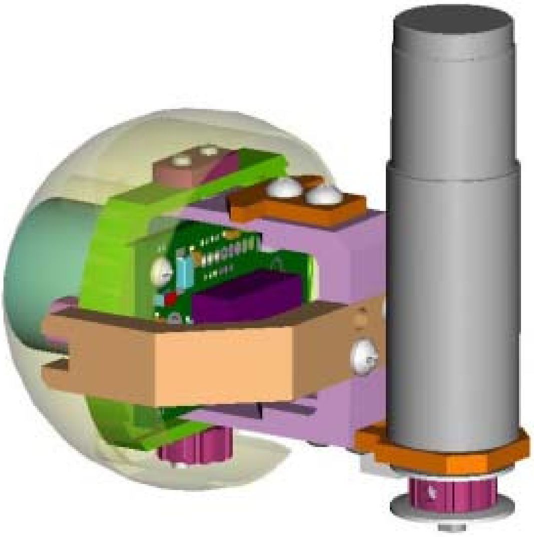


Figure 2: Various modifications to the forearm to improve the tendons' durability.

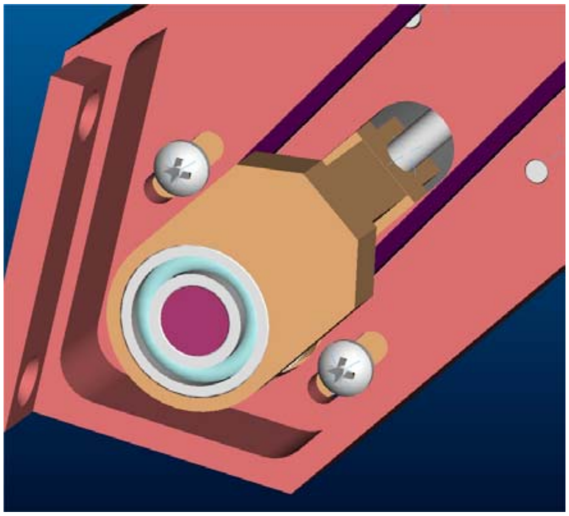
3.3 Head redesign

3.3.1 Eye review



To accommodate the new Dragonfly CE marked camera, significantly bigger that the version used in the first prototype, the eye group was optimized.

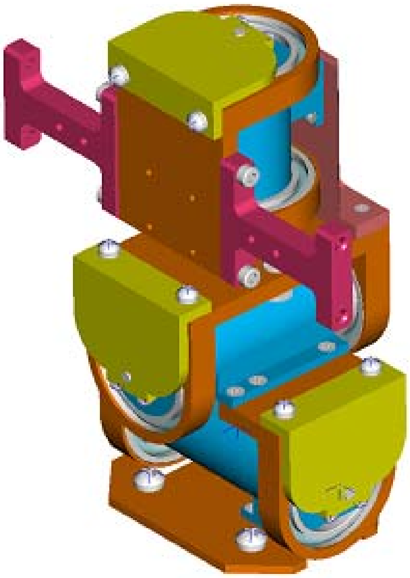
3.3.2 Eye tilt



To reduce the belt driven tilt backlash the dedicate tension group was redesigned to reduce motor shaft flexion, increasing at the same time max belt tension and reducing consequently mechanical play.

3.3.3 Neck redesign

To reduce the tilt and roll neck backlash of the initial design the two standard gearboxes initially used were replaced by GYSIN precision gearboxes with limited play (20’ rather than 3° of the initial solution). A totally reviewed head with zero backlash gearboxes on neck and on eyes actuation is currently under definition. A first attempt was very conservative by replacing only the GYSIN with Harmonic Drive gears.



After reconsidering the total required payload and to enhance the performance of the neck a reviewed kinematic schema of the neck is under design. This new solution merges the advantages of zero backlash transmission, already available with previous design (see above) with higher dynamics and payload. It is based on a differential design (Figure 3).

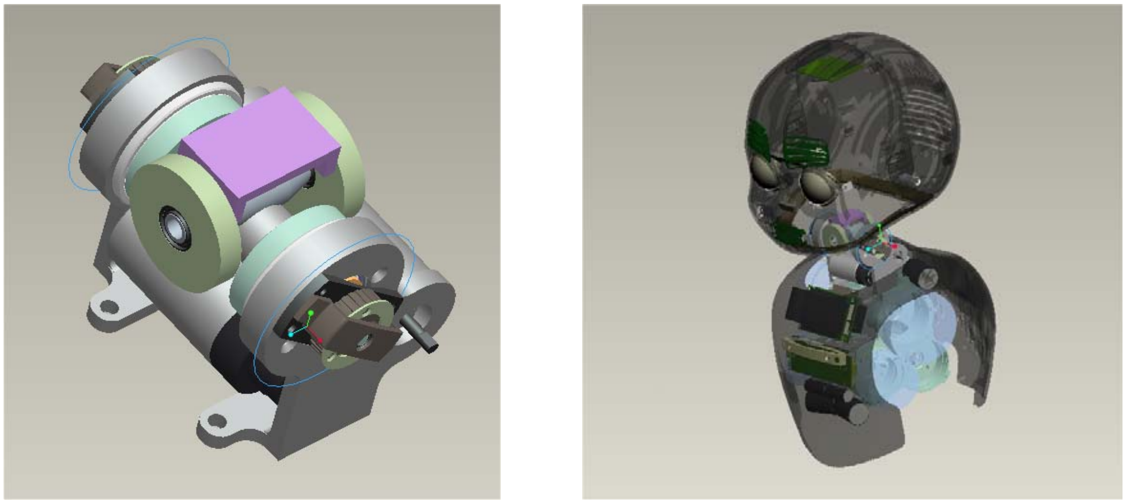


Figure 3: Details of the differential design of the neck (v2.0) and head assembly on the upper body.

3.4 Improving the reliability of the DSP control boards communication

Given the high number of degrees of freedom, the robot is currently equipped with different DSP boards all communicating with the on board PC104 trough four different CAN-BUS lines. In the initial design the communication was inefficient for two main reasons:

- Limited transmission bandwidth (1message/1ms).
- Lack of “sanity check” messages.

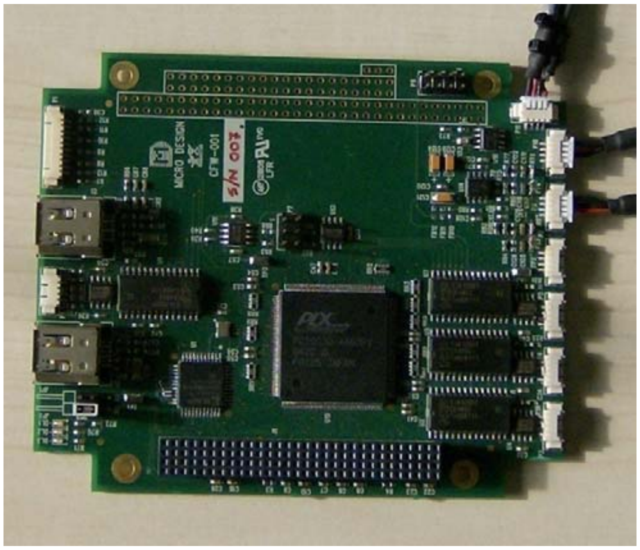


Figure 4: The custom board CFW-01: 4 CAN-BUS (communication with motors), 2 firewire (cameras ports) and 2 microphones.

3.4.1 Custom CAN and FIREWIRE board

In the initial design the communications were managed with the USB-CAN device commercially available from ESD. These devices revealed to be inefficient because of their limited bandwidth during transmission (1message/1ms). A custom board (see Figure 4) was developed. This new board is characterized by a better integration (fits 4 can bus interfaces, 2 firewire ports and 2 microphone signal conditioning on a unique pc104 standard) and faster CAN communication (full send and receive bandwidth: 6-8 messages/1ms).

3.4.2 Improved CAN protocol

The custom CAN protocol used by our DSP boards has been enriched with sanity check messages. Every fixed amount of time (currently 5 seconds) each DSP board is expected to broadcast a message describing its current state (sensors status, external faults, communication failures, overloads etc. etc.) thus allowing the PC104 to have a complete description of the entire motor system. Additionally, when the communication line is completely broken, the DSP (visually) communicate their status with the LEDs mounted directly on the board.

This solves several issues but it was not enough to cope with the increase in bandwidth required by a sensorized skin (e.g. about 2Mbit/s estimate from our current design) or intensive use of force-torque sensors loops (e.g. 1KHz at least). Therefore, a new CAN bus interface (PC104) card was designed. This increases the number of CAN ports to ten and allows partitioning the robot controller on several independent ports (1Mbit/s each). In particular, major improvements are:

- 10 CAN bus ports
- Better sound amplifier with software-controllable gain, stereo
- Better PCI interface including DMA capabilities
- Improved buffering between the CAN drivers/microcontrollers and the PCI bus
- Dual microcontroller for CAN bus management, shared memory, etc.

The code for this new card is CFW-02 (replacing the current CFW-01a). It maintains the Firewire interface as the previous version.

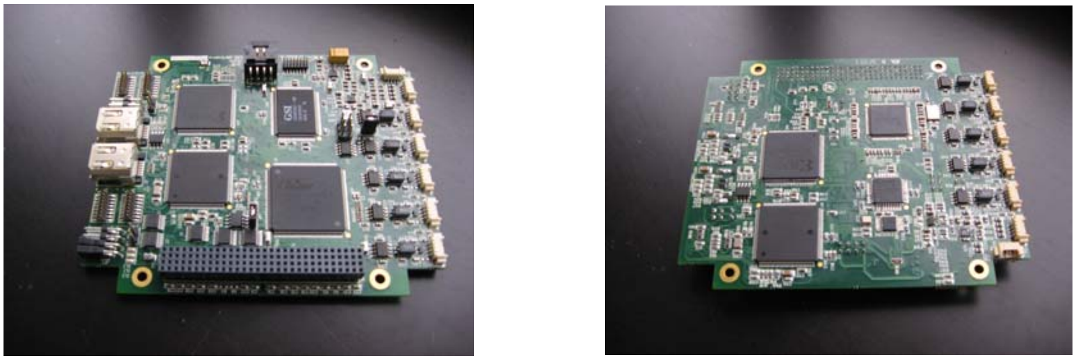


Figure 5: The new PC104 interface card with 10 CAN bus ports (see connectors to the right side of the PCB).

3.5 General reliability of the electronics

3.5.1 Wiring

No action has been taken yet.

3.5.2 Power supply

We redesigned the power supply, added a second fan to the Pentium CPU and are planning to redesign the outer cover to facilitate the air flow/intake. This is still under testing (in oven) since on typical usage the problem was not reported. In addition, The PS_CPU is provided with a 20x20mm FUN in order to dissipate the heat coming from the 5V DC-DC converter. The board has been tested until 55ºC air temperature.

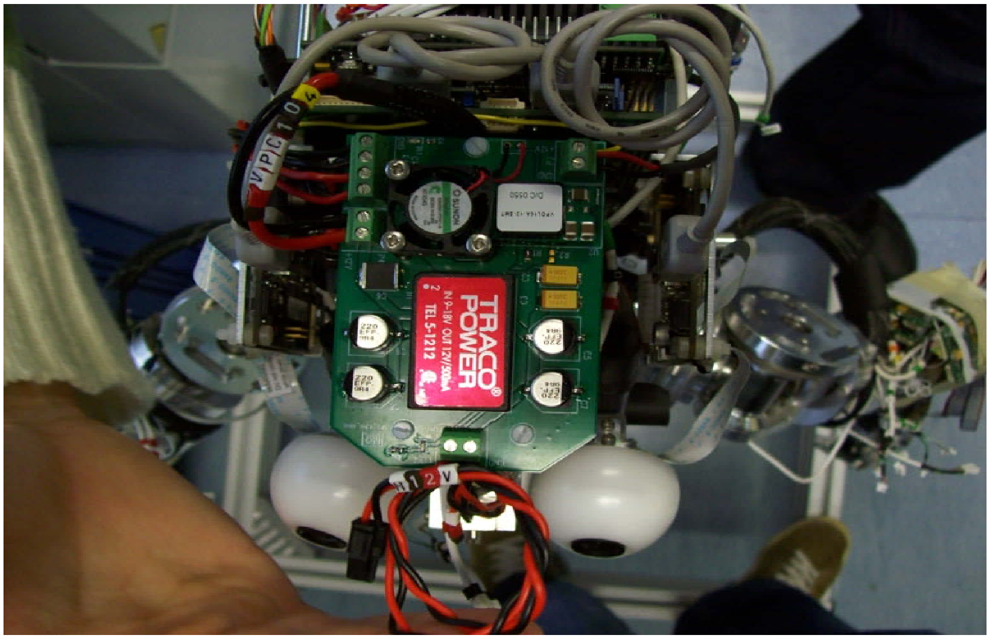
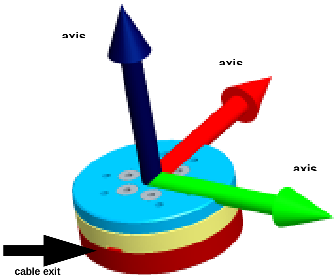


Figure 6: The new power supply mounted on the iCub head.

3.6 Force-torque (FT) sensor

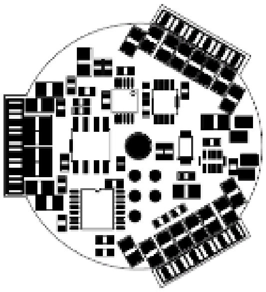
Mechanics

The mechanical solution follows standard rules for the design of the sensors. Three spokes mount two half Wheatstone bridges, each composed of two semiconductor strain gauges (SSG). Note that the sensing element is located between two flanges which link the sensors to the robot. The sensor production does not require any particular machining process, apart from an accurate strain gage bonding (Micron Instruments, USA).



Electronics

A 6 channel data acquisition board (STRAIN A/D board) is embedded into the force/torque sensor. The sensor mounts half of the Wheatstone bridge, while the STRAIN provides for the second half. Sampling of raw voltages is provided using a 16 bit A/D converter with a sample frequency of 1 kHz. Communication with the other boards (motor control boards or PC104) uses CAN bus. On the DSP, a calibration matrix is stored, and the resulting CAN message can be therefore made to contain raw forces and torques values (instead of the stain gauges direct readings).



Calibration

The FT sensor measures 6 independent voltage variations from a Wheatstone bridge. In order to convert the sensor output into the actual forces and torques acting on the FT sensor, calibration is required. The calibration matrix is a 6x6 matrix that accounts for a linear mapping between measured data and forces & torques. The figure to the right shows the reference frames used for force calibration. The calibration procedure consists in the application of known weights in linearly independent force configuration and least square fitting over a series of measurements. Empirical full scale values after calibration are here reported in the following table.

Fx [N]	Fy [N]	Fz [N]	Mx [Nm]	My [Nm]	Mz[Nm]
400	400	800	8	8	8

First use of the sensor is reported in WP3 for zero force control.

Debugging

The sensor electronics had to be revised since last year because of a series of small issue with the power supply and consequently high noise levels. This problem has been solved modifying a few components and the PCB. Additional issues were solved in firmware by synchronizing acquisition (A/D channels) with the multiplexer and the CAN bus receive/transmit function. Further, during calibration, we noted problems in the screw strength which were replaced with higher specs components. They are now ok up to the range specified in the previous table.

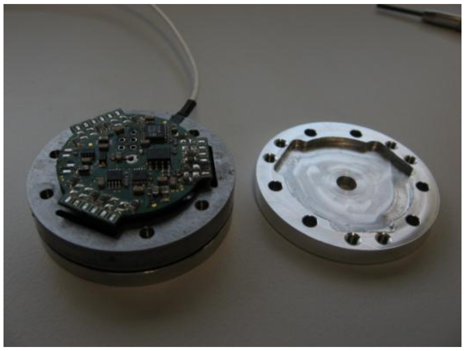


Figure 7: Latest version of the force/torque sensor electronics and mechanics.

3.7 Fingertip sensors

We designed sensorized fingertips to be installed on the iCub, which include a capacitive pressure sensor with 12 sensitive zones (in each finger). It is naturally shaped and its size is small enough so that it can be mounted on the fingers of the iCub. As a result it is 14.5 mm long and 13 mm wide. The PCB with the electronics is included in the fingertip. It connects all the electrodes of the capacitive pressure transducer to an off-the-shelf capacitance to digital converter. The fingertip is made of silicone, which makes its surface and inner structure compliant and flexible. The transducer of the capacitive pressure consists of two conductive layers separated by a soft insulator made of silicone foam. The inner conductive layer is separated into 12 areas (see Figure 8), forming the taxels, and acting as electrodes. The silicone layer, which compression is measured, is overall only 2mm thick in order to maintain a good spatial resolution. We use the silicone foam because it compresses easily after the first contact. This makes the sensor very sensitive to light touch. The foam is filled with bubbles that when compressed enough make the whole structure somewhat stiffer. A stronger force is then necessary to compress the silicone even more. This non-linearity is useful to enhance the range of measurable forces. Special focus has been paid on the production the 12 electrodes, as there production was intricate because of their small size. Also the support of the transducer can be flexible, which maximizes the compliance of the fingertip. We performed preliminary experiments with the first prototype showing the sensitivity of the sensor.

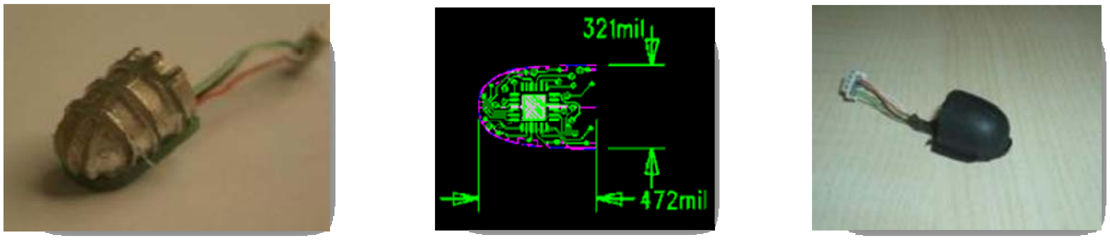


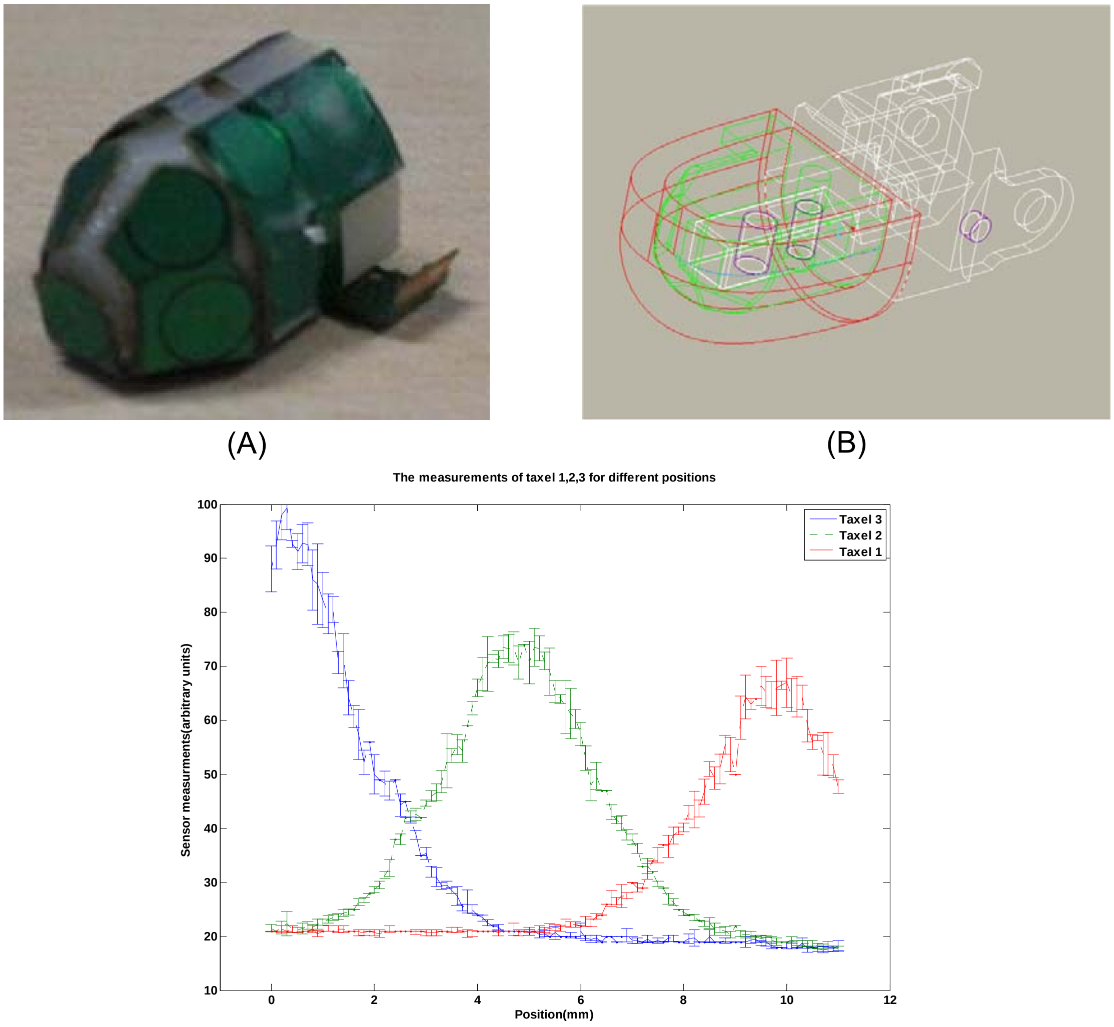
Figure 8: From left to right: the electrodes painted on solid plastic, the PCB layout (earlier version) and the fully coated fingertip (initial prototype).

In the last period, effort was devoted to:

- Practical engineering of the fingertip for production;
- Modifications of the iCub hand for assembling the fingertips;
- Investigations into the materials (silicone) for improvement of dielectric constant;
- Repetitive testing and performance evaluation of the sensors.

The following pictures show the new sensor design using a folded flexible PCB wrapping the fingertip, some initial evaluation of the sensor performance using a robotized setup and the CAD design of the modified finger assembly. This latest version will be delivered in iCub v1.2.

The CAD of the fingertip design, wiring, and mechanical assembly into the iCub hand has been integrated (revision of the fingertips and some minor modifications). Also in this case, this modification will only be available starting from iCub version 1.2 (as under construction for the FP7 ImClever project).



(A) (B)

(C)

Figure 9: (A) The latest implementation of the capacitive fingertip, for production reasons the solution based on conductive dyes was replaced by a flexible PCB; (B) A CAD picture of the new finger accommodating the fingertip sensor; (C) Spatial sensitivity of the fingertip: abscissa is the position of the probe (in mm), ordinates are the output voltages (0-5V) thus representing arbitrary units of pressure (not calibrated).

3.8 Evaluation of a new motor group

Enhanced position sensing

By evaluating walking motions it was found that for dynamic motions the 12-bit resolution (0.088°) of the absolute rotary position sensor (Hall effect sensors of AS5045 from Austria Microsystems) used in the iCub v1.0 (see above for definition of iCub version numbers) and located on the joint after the reduction drive was insufficient. Problems had arisen as the original angular velocity data based on the existing encoder signals is not ideal with the fidelity of the signal affected by the quality of the position sensor and the method used to generate the velocity signal, e.g. pulse counting or pulse timing. With the initial design the smallest detectable angular velocity obtained using the pulse count method is:

$\Delta q/Ts=0.088°/0.001s=88°/s$,
which is too coarse. Although this can be in some degree improved using averaging or filtering techniques a more radical solution is necessary to provide a better resolution velocity signal. To both improve the angular accuracy and velocity signal in the new prototype an additional 11bit incremental encoder is mounted inside the motor housing before the reduction drive (Figure 10).

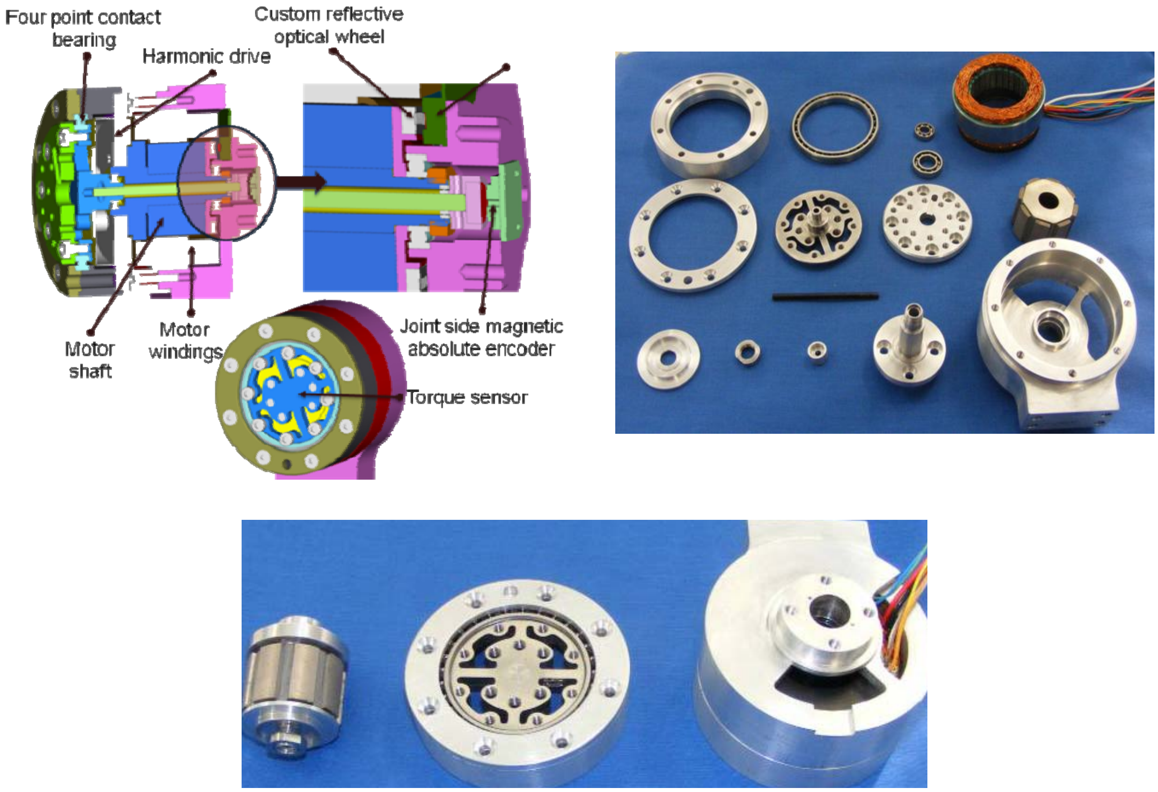


Figure 10: Section of the 3D mechanical assembly and mechanical parts of the updated motor/gearbox group.

In the new design the encoder disk and emitter-receiver with the integrated electronics (micro-e chip encoder) were placed inside the motor housing without the need to increase the size of the motor. Considering the 100:1 gear ratio provided by reduction drive the positional accuracy at the joint side is improved to 0.0017°. The minimum detectable angular velocity using the pulse count method now becomes $\Delta q/Ts=0.0017°/0.001s=1.7°/s$. The absolute encoder at the joint side is retained for calibration purposes. To validate the effect of the joint sensing improvements as discussed above two scenarios were evaluated. In the first case the low level joint control loop is closed on the joint side using the 12bit absolute magnetic encoder (current motor group). In the second scenario the joint control loop is closed using feedback from the incremental encoder which is mounted on the motor side (updated motor group). The tracking performance of one of the joints for a low frequency sinusoidal input (0.3Hz) is illustrated in Figure 11. This low frequency signal was selected to show the inability of the old prototype to accurately track low velocity profiles. The upper panel of Figure 11 shows significant fluctuations in the output trajectory both in the line and peak regions which were even visually evident when the robot was performing air walking trajectories. The main cause of these fluctuations is the friction in the harmonic drive gear which cannot be removed by increasing the damping gains due to the low quality of the velocity signal. In the second case (new motor prototype), Figure 11 lower panel shows that the output trajectory is much smoother without any obvious fluctuations due to the increased damping permitted by the higher resolution sensing.

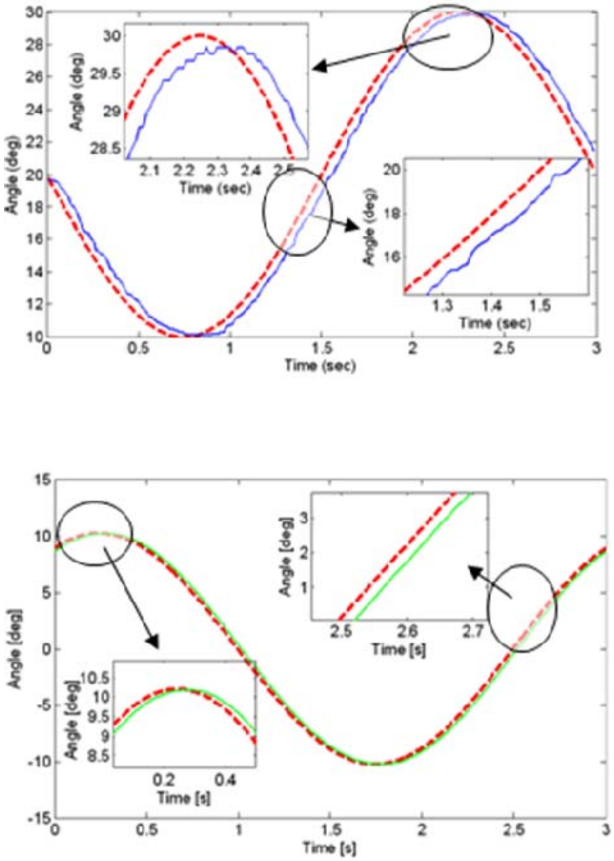


Figure 11: Joint tracking performance improvement.

Torque sensing

In addition to the enhanced position sensing, torque sensing was integrated within the new motor group as force control and not position control is the key technology for natural physical interaction for robots. In contrast, most humanoids, as the lower body of the iCub v1.0, are position controlled with high gain PD. More recent research has also focused on the use of individual joint torque control using software controlled active compliance or passive compliance. To achieve this research was directed into the integration of torque sensors. Since commercial motor torque sensors are both expensive and often not mechanically compatible (size, mechanical interface) with high degrees of freedom robots where space is limited a customized torque sensor with additional advantage of dimensional optimization was developed, Figure 12.

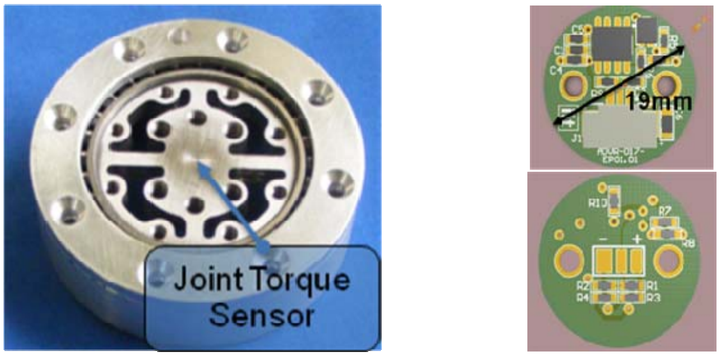


Figure 12: Structure of the joint torque sensor and the associated signal conditioning electronics prototypes.

The joint torque sensor is based on a four spoke structure mounted between the harmonic drive output and the output link. The strain is measured with semiconductor strain gauges and customized design electronics mounted close the motor.

Lightweight materials

In addition to the sensing additions further modifications to the motor group module aimed at investigating the feasibility of using new materials in the structure of the actuator group were investigated. The purpose was to reduce the weight of the module while maintaining the high power properties of the motor/gearbox assembly. Carbon fibre material was selected to replace some of the aluminium components of the motor assembly as shown in Figure 13. The parts were manufactured using mould fabrication techniques. To achieve the high tolerance requirements negative moulds were produced using the existing aluminium parts. Compared to the weight of the aluminium parts the weight of the carbon fibre parts was reduced by 47%.

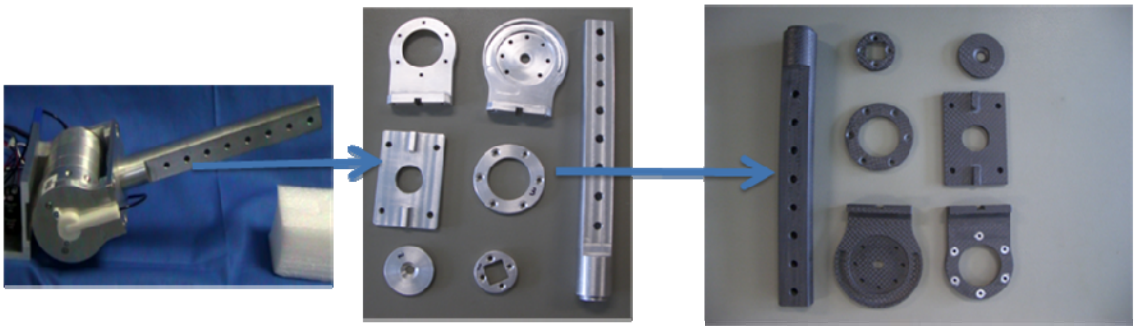


Figure 13: carbon fibre parts of the motor assembly.

3.9 Forearm redesign

Resulting from feedback from IIT, the forearm design was upgraded with ring al little finger actuation redesign and crimp tendons on wrist pitch/yaw joint already made in the fourth period was further reviewed integrating absolute sensors on the two foremost wrist joint and modifying the proximal tendon routing on index and middle finger. This final design was realized and tested in TLR in this last period although it will not see integration until the next series of iCub's (version 2.0, see above). A prototype is at the moment under testing at IIT. Preliminary tests done in Telerobot on the modified forearm show higher reliability and easier integration: wrist tendon assembly was probably, before this improvement, one of the hardest tasks of the mechanical integration. Further tests are required before accepting these modifications (and possibly upgrading the existing iCub's).

3.10 Forearm/Hand redesign

The forearm was partially redesigned, according to discussion in section 4 of this document. The new design includes a new rigid actuation of 4th and 5th finger, with crimp tendons connection for wrist actuation (including pitch and yaw axis), increasing significantly the robustness of the most stressed joints of the forearm, and integrating absolute magnetic encoders on the two joints for direct position reading. Wrist pitch range was also extended from previous 0/+90° to -30°/+90°. Intermediate tendon routing for thumb index and middle finger was also moved to the external side of the hand to avoid the wear of the tendon tubes and consequent excessive tendon wearing. This final design was also manufactured and tested and is now being subjected to stress test in IIT to measure the improved reliability.

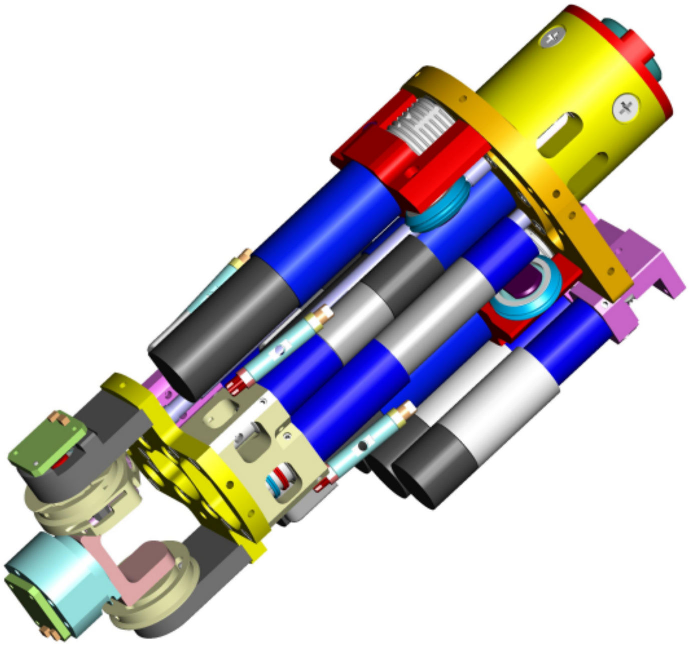


Figure 14: New wrist design and removal of the elastic coupling between the 4th and 5th finger.

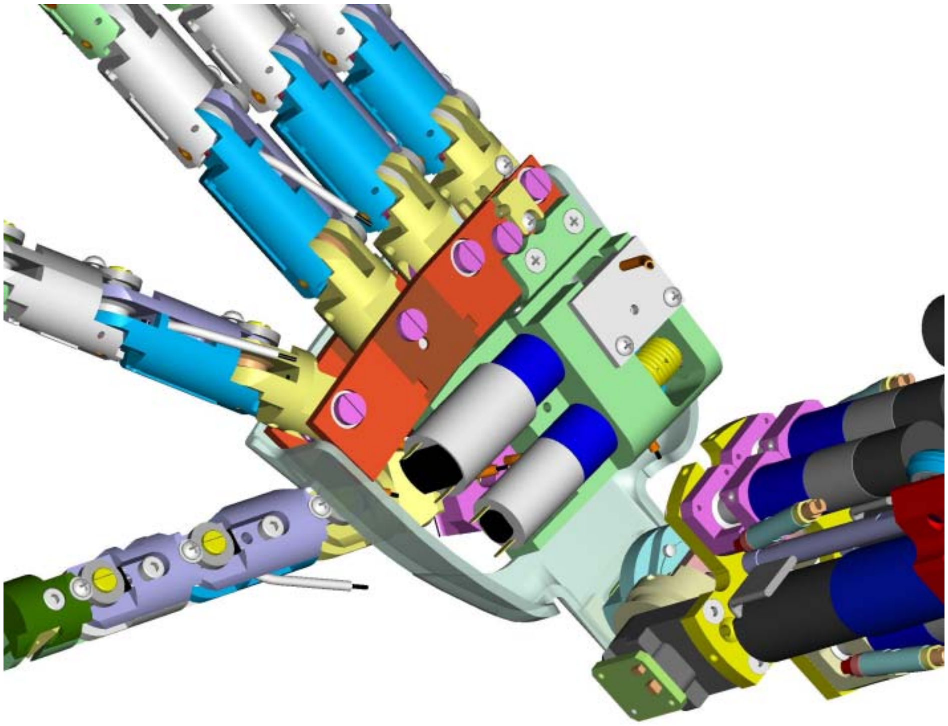


Figure 15: New wrist and new tendon routing (see index and middle finger).

4 Open issues (M48, partially solved)

The debugging activity is still on going. In particular, there are a few issues that are still open. Maintaining the already proposed structure, these issues fall into the following categories:

- Performances of the position sensors.
- Robustness of the tendon actuation.

Many of these issues are under active design (and will continue beyond the duration of the project).

4.1 Improving position measurement

4.1.1 Controlling the joint position with sensors at the joint

As already pointed out, some joint positions are controlled by measuring the actuator position. This solution is affected by systematic errors in presence of tendons or belt elasticity. Currently, there are still joints presenting this issue:

- two degrees of freedom of the wrist (pitch and yaw),
- three degrees of freedom of the head: eyes version, vergence and tilt,
- six degrees of freedom of the hand: thumb proximal, thumb distal, index proximal, index distal, middle proximal and middle distal.

At the current state, the hand joint are already sensorized and the implementation of a precise position control will only require some minor software modifications. The other considered joint still require a sensorization which is already planned as a future improvement.

Comment: the wrist measurement is solved in the new release (v2.0), the head calibration will be solved in the new design (also incorporating absolute position sensors) and the hand sensors are fully integrated in version 1.1 (already implemented). Further in v1.1 small modifications allowed reduction of magnetic/electric noise on the absolute position sensors improving consequently the controller precision.

4.1.2 Improving the joint calibration

There is currently an issue concerning some joint calibration.

The calibration procedure is meant to determine the zero position of each joint. A zero position for each joint can be easily defined on the CAD model but achieving a precise correspondence between the model zeros and the actual robot zeros is not an easy task. This is a well known problem and there exists different solutions. Future work will try to identify the solution which is the most convenient for the iCub platform.

4.1.3 Improving position measurement

In the current design, the brushless motors are controlled with position sensors placed on the slow side of the gear box. This solution has a drawback related to the resolution of the encoders. The current resolution seems to be relatively poor with respect to the desired precision. Future work will investigate the possibility of moving the encoders to the fast side of the gearbox or increasing the encoder resolution.

Comment: see discussion above about the addition of an encoder on the motor shaft.

4.2 Improving tendon robustness

Recent experiments with crawling revealed some issues concerning the shoulder and wrist tendons. Specifically, strong dynamic impacts with the ground overstress these tendons and sometimes cause their breaking.

4.2.1 Shoulder tendons

In the shoulder case, it was noticed that tendons tend to break at points where they were already corrupted by an undesired friction (see Figure 16). This problem needs to be fixed for achieving a more robust actuation.

Figure 16: Shoulder tendon. The picture shows the point were two tendons tend to slide one over the other. This usually corresponds to an high friction which corrupt the tendon until its breaking.

Comment: several changes were implemented to help in maintaining the tendons along the intended path and therefore reducing undesired friction.

4.2.2 Wrist tendons crimping

Similarly, the wrist tendons will be improved. In particular, the design of the mechanics has already been improved in order to accommodate crimps in place of the knots (currently used- see next section for mor e detail). This solution is still to be tested and implemented on the platform and is planned as part of the already designed improvement for beginning of Y5.

Comment: this activity has been completed for V2.0.

4.3 Electronics development

Further, there is still development to complete the iCub electronics, in particular:

- New PC104 CAN bus interface, under design, a feasibility study has been completed. The CFW-02 card is not completed (hardware) and we are developing the software/firmware. **A first release should be available within a month and likely be integrated into the new release of the robots (v1.2).**

- MAIS card (see iCub documentation). This is a 32-channel miniaturized ADC board. **It has been produced and integrated in iCub v1.1.**
- STRAIN card. The miniaturized force/torque sensor electronics. **This is currently being used both in version 1.1 and in the prototypes of version 2.0.**
- Face control electronics: **this has been engineered and now fully produced. It has been integrated in a few Open Call robots (depending on needs and availability of technicians for installation).**
- Sound noise and shielding has proven to be problematic in the full iCub configuration where the head is quite packed with electronics (and potentially of noise). **The new CFW-02 card solves part of these problems by using a new amplifier with manual gain control (in software). Still, the CPU fans can be problematic.**

4.3.1 Further development

With respect to the electronics development we are planning to:

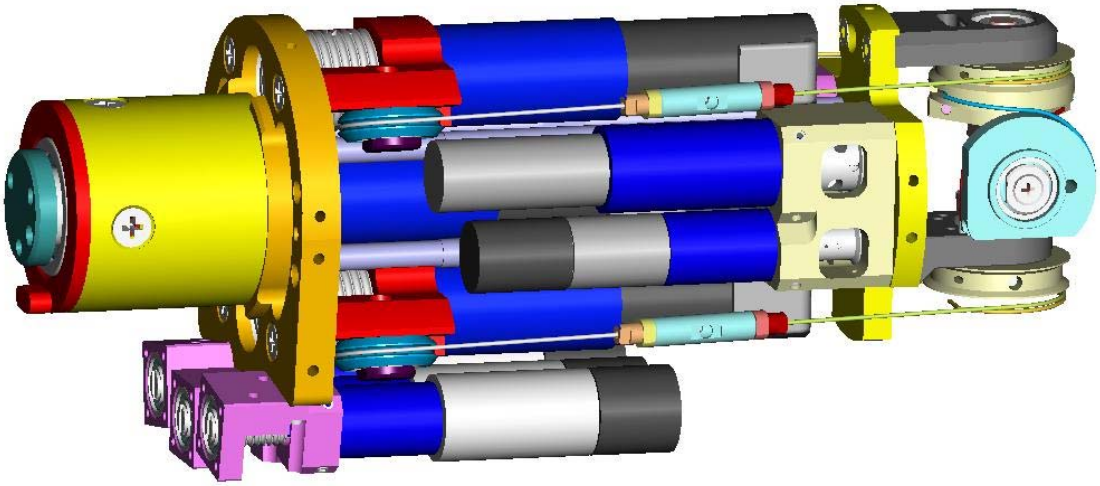
- Replace the CAN bus with a faster bus (e.g. Ethernet). **This is under design but it will take longer to get integrated on the iCub, for this reason we decided to proceed with the new CFW-02 which provides enough bandwidth (by using more CAN bus ports) for most applications (we tested for example closed loop force control).**
- Improve the resolution of the joint angle measurement (to improve the quality of the Brushless motor phase commutation). **See initial testing for version 2.0.**
- Provide direct joint-level torque measurement and feedback directly on the control cards. **This modification is under current design and testing for the iCub v2.0.**
- Redesign of the sound amplification stage with better noise immunity. **This has been included into the CFW-02 card.**

5 Other upgrades (details)

Some more upgrades have been already designed and will be tested first on the ITT platforms and will be then ported on existing platforms.

5.1 Finger motor group layout review

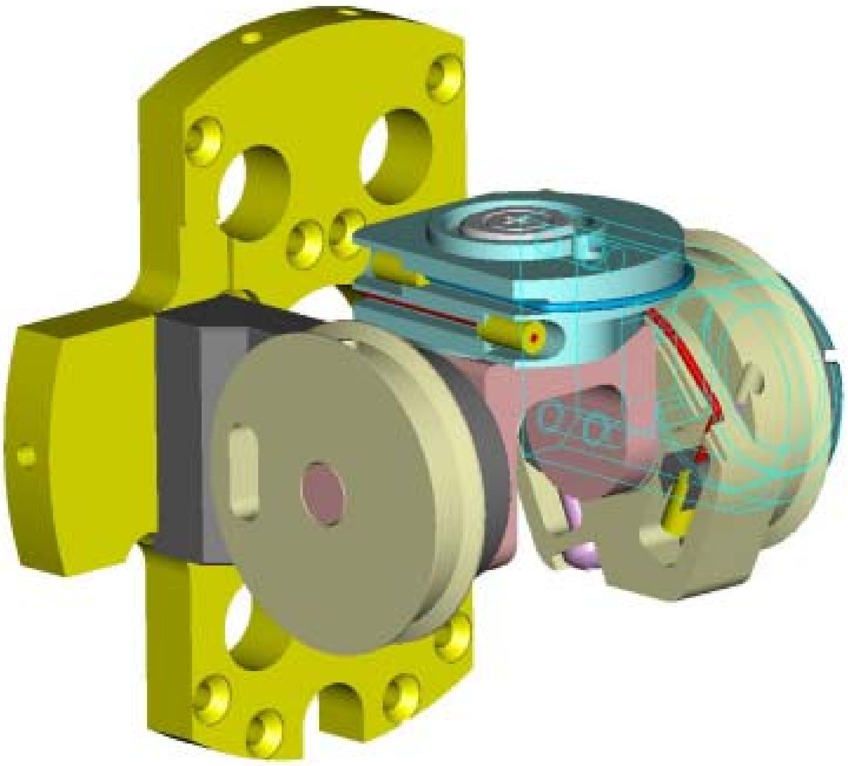
The slider used in the initial design to couple the 3rd and 4th finger will be eliminated.
The two cables that control this two underactuated fingers will be connected independently to te same pulley. The increased diameter of the pullet requires to merge this motor group with the adjacent one ending with a twin group (visible in the picture).



The three motors that drives thumb, index and middle finger first flexion have been rotated to better accommodate the tendon path.

5.2 Wrist tendons crimped connections

Some test done in the workshop shown the feasibility of crimped end for 0.7 mm steel cables compliant with the wrist articulation.
After a set of stress and fatigue tests to assess the crimp reliability the three wheels that define the wrist pitch and yaw articulation were redesigned to use crimped tendons.



The crimped tendon reduces significantly the complexity of the wrist assembly and increase also the wrist stiffness. As mentioned earlier we added also absolute position encoders in the wrist.

6 Conclusions

Part of the success of the iCub can be attributed to its open source licensing strategy. From this document, it is perhaps clear that there’s a fervent activity not only in software design but also in supporting improvements that can keep the platform alive for the years to come. We believe that this is particularly important in order for the RobotCub legacy to be preserved.