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Cognition, Understanding and Behavior

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RobotCub

Development of a cognitive humanoid cub

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Deliverable no. 7.4

Novel bio-inspired sensory system for the open-loop to closed-loop transition in manipulation tasks

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CO	Confidential, only for members of the consortium (including the Commission Service)	**CO**

Table of Contents

1 Introduction

The aim of the present deliverable is the development of a novel bio-inspired sensory system for the open-loop to closed-loop transition in manipulation tasks:
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. This task is two-folded: the first part is dedicated to the development of a new set of sensors and their integration in the low level control of a potentially dextrous hand. The second part concerns the consequent tests on the SSSA iCub hand-arm-shoulder system.

1.1 The Scenario

In addition to the manipulation scenarios, it is also intended that the iCub will learn to locomote (e.g. for example to crawl and to transition from crawling to sitting or standing). In this context, the shoulder-arm-hand system for reaching and grasping objects should not be damaged by the locomotion movements. This is possible thanks to a particular crawling strategy without using the hands.

The hand and arm capabilities will be applied to experimental scenarios in which the iCub learns to develop object manipulation by playing on its own and or with another animate agent, that is, grasping objects and doing things in order to attain effects, like inserting objects into holes, building towers out of blocks etc. At this stage, social learning of object affordances becomes crucial. These scenarios will focus on the use of more than one object, emphasizing the dynamic and static spatial relationships between them. In order of complexity, examples include*:*

- Learning to arrange block on a flat-surface;
- Learning to stack blocks of similar size and shape;
- Learning to stack blocks on similar shape but different size;
- Learning to stack blocks of different shape and size.

These scenarios also require that the iCub learns a set of primitive actions as well as their combination. The tasks presented in this deliverable are aimed to implement sensor fusion among the sensors of the upper limb with the final goal of providing the iCub with automatic synergies during grasping and manipulation tasks.
Within this scenario a developmental path has been set, starting from a limited amount of innate knowledge in the form of motor synergies and learning progressively more complex actions both in terms of their variety and accuracy, and with respect to achieving more complex goals (such as using an object to act on a second one).

Starting from the tasks requirements given by the neuroscientists and the control design partners, the sensors embedded in the Cub are presented. The hardware responsible partners have already designed the kinematics, the actuation systems and the transmission systems to accomplish a wider range of tasks.

1.2 Motivations

Robotics has always had a strong interest in the design of artificial hands but these are complex and expensive to develop. Despite the control challenge posed by the many degrees of freedom in a fully actuated version, the appeal of anthropomorphic designs is in the promise of reproducing manipulation dexterity approaching that of humans.
Howe argues that effective high performance dexterous manipulation must involve fast real-time processing of information relevant to the different phases of grasping tasks, as situations change from position to force control from rolling to slipping or sliding and power grasping.
Unfortunately there is actually a lack of information about the most suitable or even necessary information for any given manipulation task. For example, to detect contact, we may have available a range of different sensing techniques, all with different characteristics, but selecting between these for a given task is a difficult problem. Howe stresses that static arrays have limited applicability and that the essential aspect for manipulating objects in real-time is smooth and accurate fine control.
The need for real-time control and dynamic sensing for rapid detection of contact events raises various issues. Some of these issues are dealt with by Son and Howe [J. S. Son and R. D. Howe. *Tactile Sensing and Stiffness Control with Multifingered Hands*, IEEE International Conference on Robotics and Automation, Minneapolis, April 1996] in which contact events, the contact shape and incipient slip are all handled using a stress rate sensor that can detect transients. Moreover they show how tactile sensing can reduce kinematic errors in stiffness control by locating precise contact points and tracking their changes. However, the method relies on assumptions about the shape of the grasped object [Nicholls H.R., Lee M.H., *A tactile sensing for mechatronics – a state of the art survey* , in Mechatronics, 9, 1-31, 1999].

Tactile sensing capabilities are thus extremely important; nevertheless this work is aimed to show the relevance of the proprioception and its interaction with exteroception. An advanced tactile sensors will lose part of its function if the other sensors in the hand are not adequate, and vice versa.

2 The Artificial Sensory System

As it happens in the human hand, the artificial sensory system developed for the iCub is composed of two parts:

- The Proprioceptive Sensory System. Proprioception (from Latin proprius, meaning "one's own" and perception) is the sense of the relative position of neighbouring parts of the body. Unlike the interoceptive senses, by which we perceive the pain and the stretching of internal organs, proprioception is a third distinct sensory modality that provides feedback solely on the status of the body internally. It is the sense that indicates whether the body is moving with required effort, as well as where the various parts of the body are located in relation to each other. Proprioceptive sensors sense the position, the orientation and the speed of the humanoid's body and joints.
- The Exteroceptive Sensory System. Exteroceptive senses are what it is universally known as 'senses' (sight, taste, smell, touch, hearing, and balance) by which a human perceives the outside world. Exteroceptive sensors give the robot information about the surrounding environment allowing the robot to interact with the world. The exteroceptive sensors are classified according to their functionality.

According to the cognitive nature of the iCub, the systems exploiting the sensory-motor coordination are very interesting for this project.
A sensor is a device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.).
In the purposes of the iCub designers, the sensors have two basic functions:

- the sensors are needed components in order to close the control loop and operate in *unstructured environment*
- the sensors are essential components in order to implement a sensory-motor coordination loop and a cognitive robot.

A scheme of the sensory system developed for the iCub hand is shown in figure 2.1.

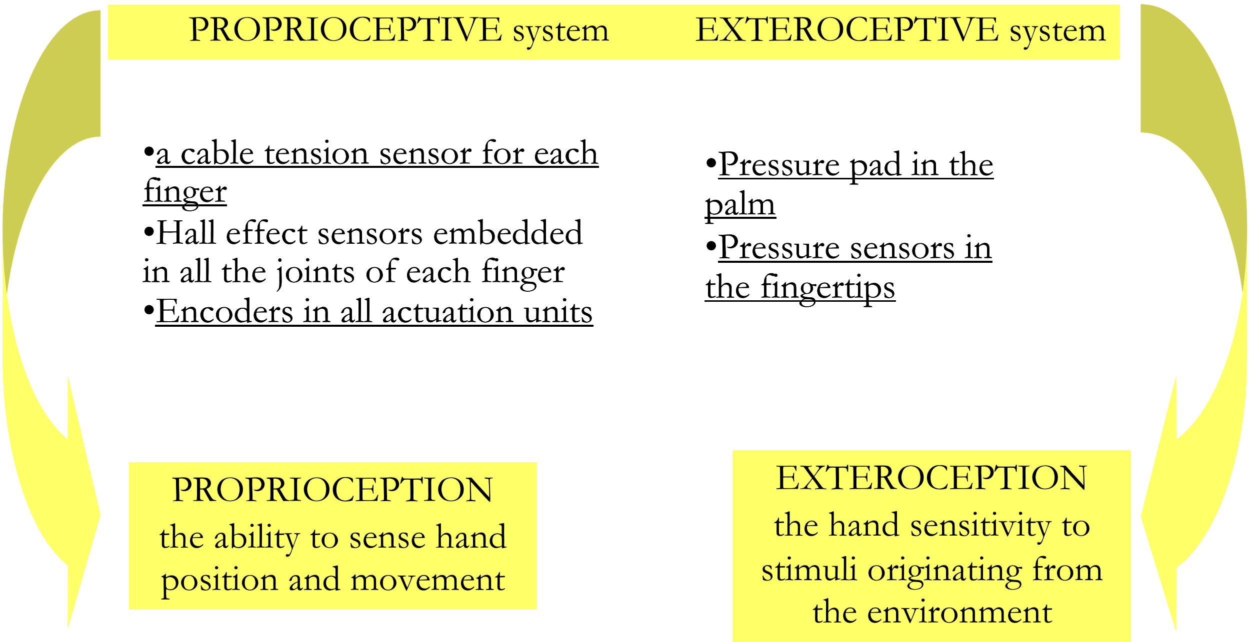

Fig 2.1 The artificial sensory system implemented.

2.1 Proprioception

The bio-inspired artificial proprioceptive apparate proposed in this work consists of joint angular sensors (Hall effect sensor based) embedded in all the joints of each finger, incremental encoder on each motor, and sensors measuring the tension of the cables acting as the tensiometer.

2.1.1 Encoders

Every actuation unit is provided with an encoder. In case of a direct joint actuation (MP joint of thumb, index and middle; intrinsic actuators in the palm), the information given by an encoder is enough to understand the actual position of the joint.
Concerning the pinky and ring fingers and the PIP and DIP joints of the thumb, index and middle, the underactuated design requires additional information. The detection of angular displacement of the underactuated joints is thus mandatory. To this purpose, hall effect sensors was designed and integrated in the fingers.

2.1.2 Hall effect sensors

The working principle of these sensors could be found in the deliverable 7.2.
In order to create a linear monotone magnetic field on the fingers joint permitted angles (0°-90°), a mechanical structure mounting magnets has been developed considering the following parameters influencing the relationship between output voltage and joint angle: the sensor voltage supply, the magnets polarity, the number of magnets, the angular magnet displacement and the gap d between Hall sensor and the magnetic structure.

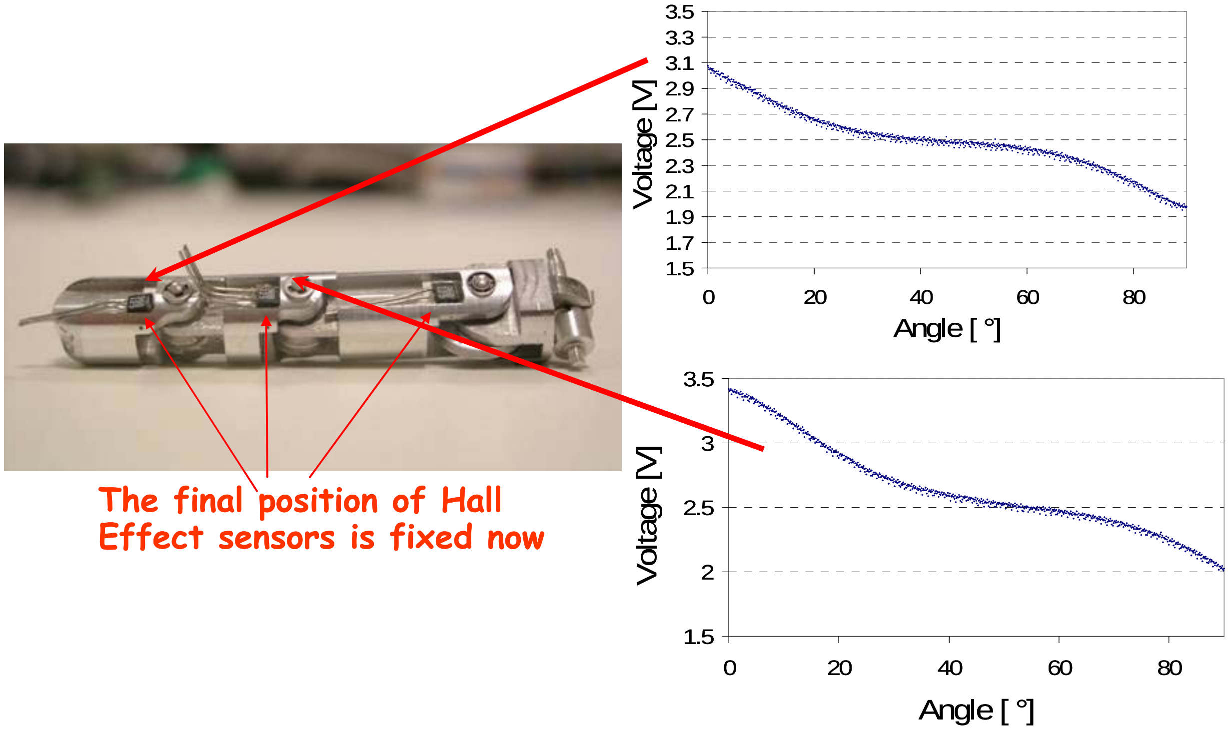

Fig 2.2 The artificial sensory system implemented

As already anticipated, the hall effect sensors give the missing information about the hand configuration, especially during the grasp. These sensors are helpful to understand further the overall dimensions of the object grasped and its shape.

2.1.3 Cable tensiometers

The tensiometer proposed is a strain gages based cable tendon sensor. The micromechanical structure has been fabricated to obtain a cantilever (Fig. 2.3) elastically strained by the cable, in order to continuously monitor the cable tension applied by the motor. Glued on the sensor cantilever there are two strain gauges (Entran Device Inc, Fairfield, NJ, USA, model ESU-025-1000,): one is the varying resistor; the other is a dummy resistor used for temperature compensation (perpendicular to the beam axis). The acquisition circuit was a standard Wheatstone bridge whose signal was amplified by an AD524 (Analog Devices); the amplifier gain was fixed by a trimmer.

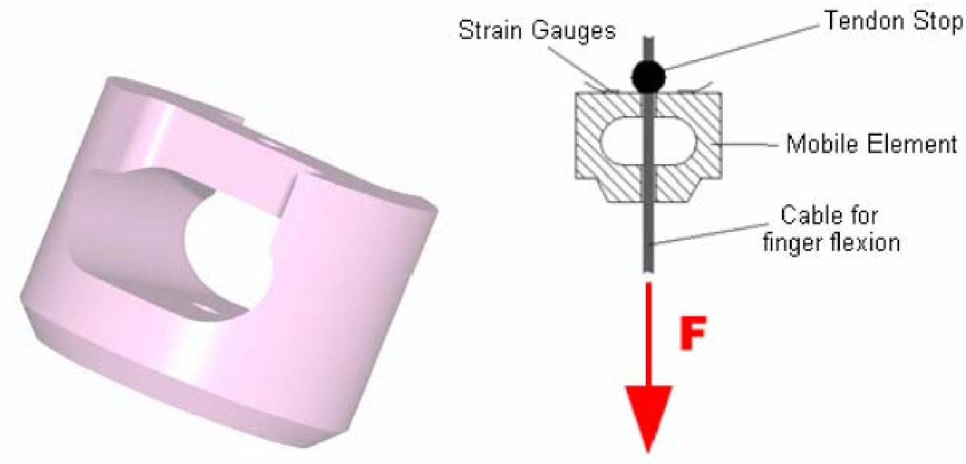

Fig. 2.3 Operating description of the tensiometer.

In order to obtain both high sensitivity and mechanical strength, a FEM analysis has been performed, using width, thickness, radii of the cantilever as parameters (material is defined by the tension and the overall dimension: C40 steel). Staring from a CAD model obtained with ProEngineer, the symmetries have been exploited: a quarter of the structure has been modeled. An alternative design was also developed with a reduced geometry and a stiffer steel (AISI 630). The second design has a better mechanical behavior but a worse electronic reliability.

Fig. 2.4. The two geometries of the tensiometer developed

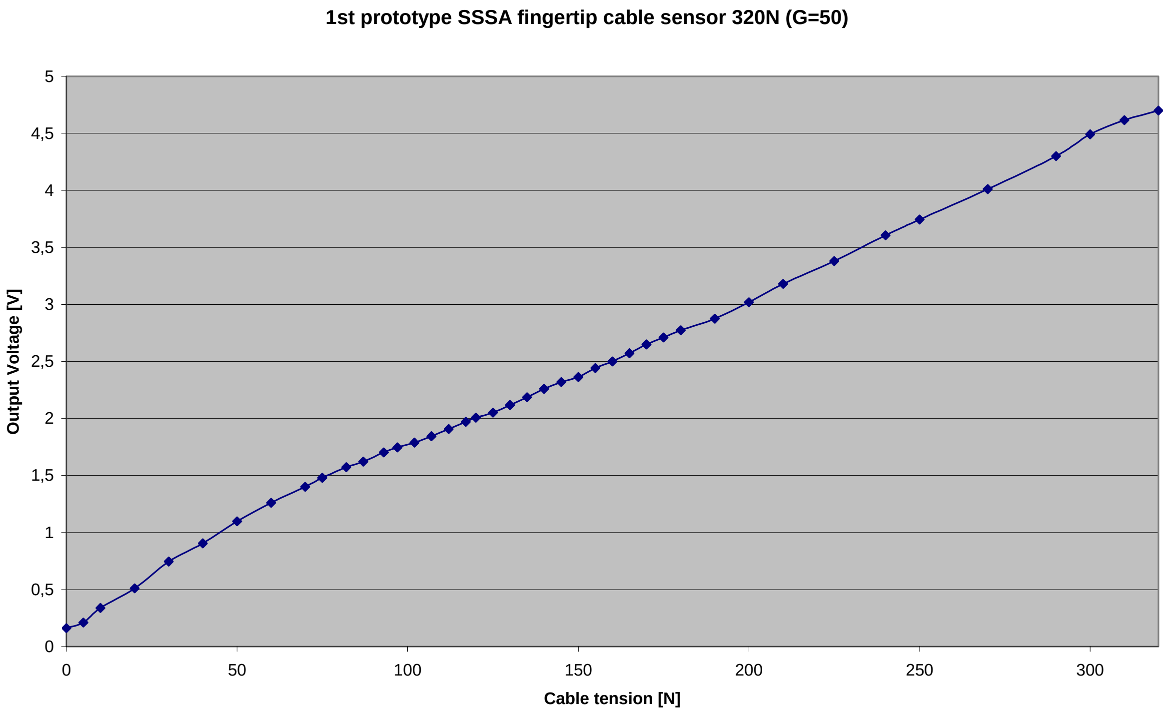

Fig. 2.4. The output of the sensor (alternative design)

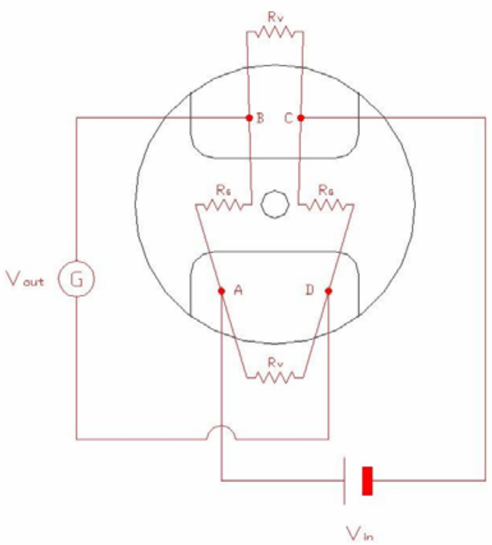

Fig. 2.5. The electric scheme of the sensor

2.2 Exteroception

Concerning the hand, it is clear that the study of the exteroceptive sensory system is limited to the sense of touch. Anyway, it is important to notice that tactile sensing does not involve only a transduction of one physical property into an electronic signal. Touch takes many forms and includes the detection of shape, texture, friction, force, temperature and many other related physical properties.

2.2.1 Critical issues of tactile sensors

By definition, tactile sensing is the continuously variable sensing of forces and force gradients over an area. This task is often performed by an m·n array of industrial sensors called forcels. By considering the outputs from all of the individual forcels, it is possible to construct a tactile image of the targeted object. This ability is a form of sensory feedback which is important in development of robots. These robots will incorporate tactile sensing pads in their end effectors. By using the tactile image of the grasped object, it will be possible to determine such factors as the presence, size, shape, texture, and thermal conductivity of the grasped object. The location and orientation of the object as well as reaction forces and moments could also be detected. Finally, the tactile image could be used to detect the onset of part slipping. Much of the tactile sensor data processing is parallel with that of the vision sensing. Recognition of contacting objects by extracting and classifying features in the tactile image has been a primary goal. [Kok-Meng Lee, *Mechanical Engineering Handbook*, chapt. 14, Ed. Frank Kreith, Boca Raton: CRC Press LLC, 1999]
In most cases however, the development of tactile sensors have focused on the individual sensor components rather than on complete systems for tactile sensing.

A review of past investigations [Harmon L. D., *Tactile sensing for robots* in Davidson H.F., Brady M., Gerhardt L.A., editors, Robotics and Artificial Intelligence (NATO ASI series), Springer & Verlag, New York, 1984, pp. 109-158], [Nicholls H.R., Lee M.H., *A tactile sensing for mechatronics – a state of the art survey* , in Mechatronics, 9, 1-31, 1999] has shown that a tactile sensor should have the following characteristics: most important, the sensor surface should be both compliant and durable, and the response of individual forcels should be stable, repeatable, free from hysteresis. The response must be monotonic, though not necessarily linear. The Harmon's analysis has also generated extended tentative specification for tactile sensors:

- the sensor surface or its covering should combine compliance with robustness and durability
- the sensor should provide stable and repeatable output signals; loading and unloading hysteresis should be minimal
- since some degree of viscoelasticiy is always present in plastic and elastomers, the mechanical loss tangent should be independent of frequency in the range of use
- linearity is important although only monotonic response is absolutely necessary; some degree of non-linearity can be corrected through signal processing
- the sensitivity of each individual sensing unit should accordingly possess a faster response, related to their number, when multiplexing is performed.
- spatial resolution should be at least of 1-2 mm as a reasonable compromise between gross grasping and fine manipulation tasks; the area covered and the number of sensing units depend on the geometry and kinematics.

2.2.2 Tactile sensing: comparative review

For a comparative review of tactile sensors in the State of the Art, please refer to Deliverable 7.2

2.2.3 SSSA Optical tactile sensors

The design, development and experimental characterization of a high sensitive, fast, repeatable, compliant optical contact sensor that can be useful for different applications (e.g. sensitive skin for hand prostheses and for humanoid robotic fingers) is here presented [Persichetti, A.; Vecchi, F.; Carrozza, M. C., *Optoelectronic-Based Flexible Contact Sensor for Prosthetic Hand*, ICORR.2007].

Each sensor is composed of a infrared (IR) photodiode, a phototransistor, and a silicone cover. The IR photodiode emits light that is transmitted in the channel obtained in the compliant skin layer; the light beam is reflected by the channels walls and then is received by the phototransistor located at the end of the channel, corresponding to the end of the optical path. The channel is made by means of a silicone cover fixed on a Kapton layer that is also used to support the electronics. Figure 2.6 shows the working principle and the effect produced by an external force where the deformation of an imaginary optical beam (in red) is shown to emphasize the effect of the disturbance force applied to the compliant skin.

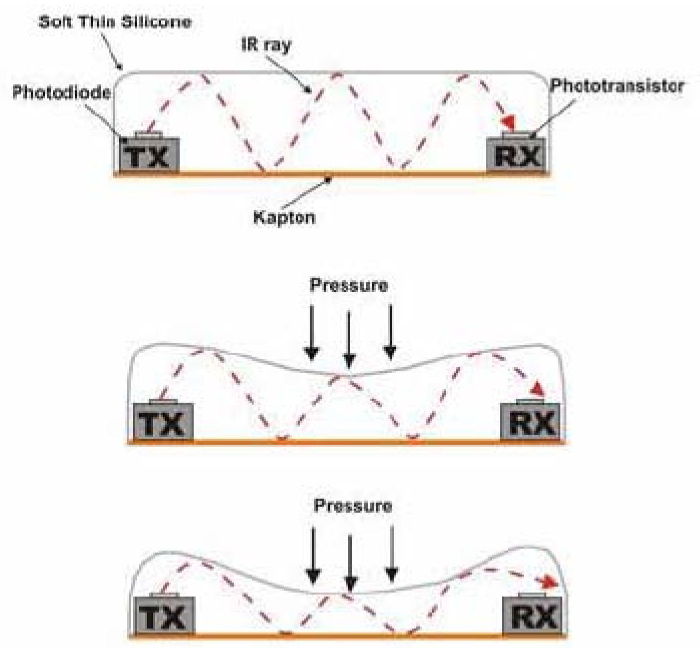

Fig. 2.6. The functioning principle of the developed optoelectronic contact sensor

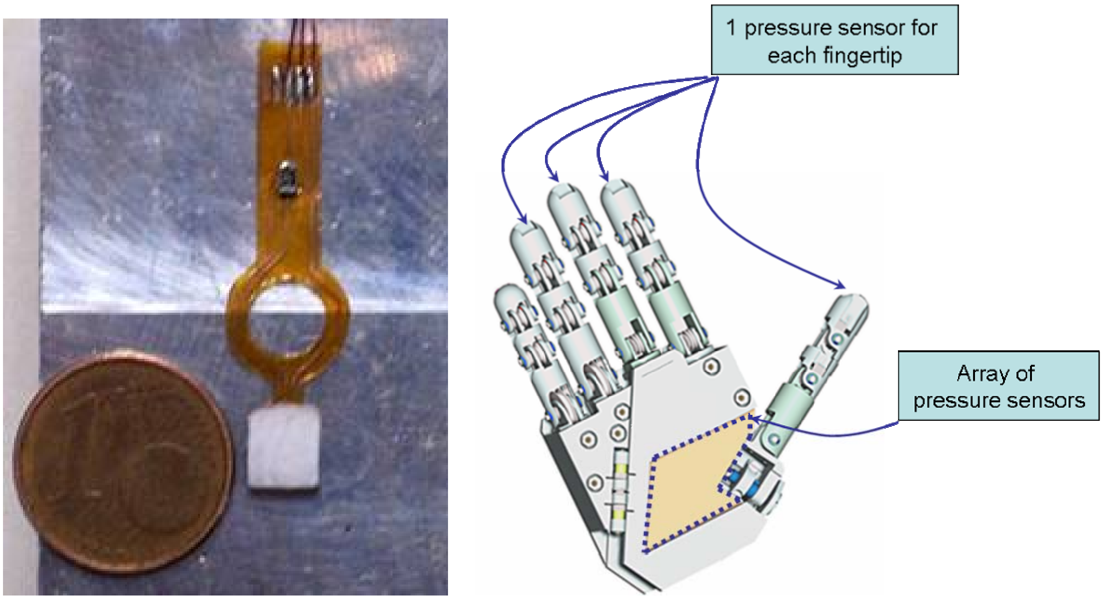

Fig. 2.7. The sensor developed and where it is placed in the hand

Two sensor designs have been exploited: one palm pad with an array of seven pressure sensors and a single pressure sensor to be placed in the fingertip (except for the pinky). The following table resumes the main characteristics of the latter one.

Features	***Qualities***
Minimum area (for each sensor)	*3.5 x 2.5 mm*
Height (for each sensor)	*1.5 mm (min)*
Threshold	*Modifiable changing silicone cover thickness, distance between optoelectronics components and reflection properties*
Force range (version without silicone filling)	*Variable but not high, about 2-3 N*
Force range (version with silicone filling)	*It depends by the configuration, about 30 N*
Indentation	*Modifiable changing silicone cover thickness, distance between optoelectronics components and reflection properties (minimum threshold in our application: 0.3 mm)*
Space dependence	*Threshold and indentation depend by the point of stimulus application*
Frequency response	*To test*
Indentation=f(Frequency)	*To test*
Consumption	*5-6 mA*

Tab 2.1. The main characteristics of optoelectronic contact sensor of the fingertip

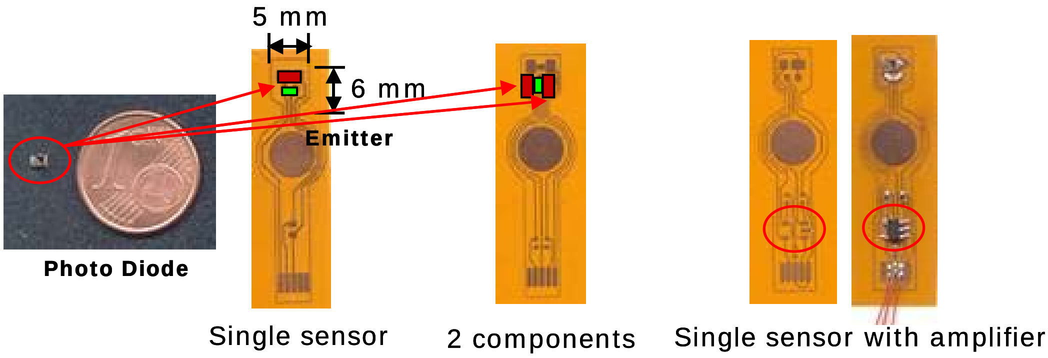

Fig. 2.8. The progressive development of the optoelectronic contact sensor. The electronic scheme is a simple comparator

3 The experimental platform

3.1 Overview

The final experimental platform will be composed by the iCub upper-torso, right arm, forearm and hand. At the current stage of development (date: 2008/03/01), the system is limited to the forearm and hand. The platform will be completed by April 2008 (M44). Figures 3.1 and 3.2 show the hand/forearm system and an example of palmar grasp.

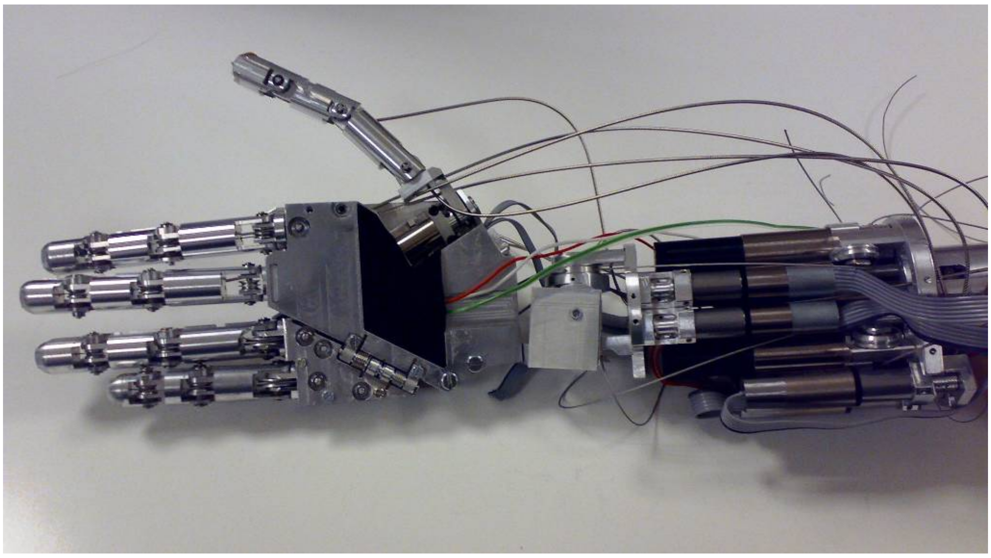

Fig. 3.1. The functioning principle of the developed optoelectronic contact sensor

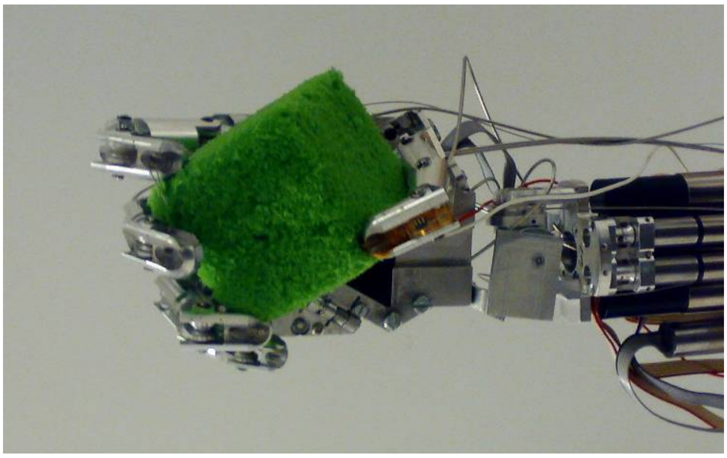

Fig. 3.2. The functioning principle of the developed optoelectronic contact sensor

The hand characteristics (dimensions and range of movements) are summarized in the following table (Tab 3.1). The weight (with the two motors in the palm and the electronics) is 180 grams. The joints are 20, actuated by 9 motors (7 in the forearm).

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*

Tab. 3.1. The main characteristics of the hand

3.2 Results expected by Month 60

The second phase of Task 7.4 is focused on sensor fusion. Similar experiments have already been done on similar platform at the ARTS Lab of Scuola Superiore Sant'Anna. Every sensor gives important information about the hand, the object grasped and the environment. Moreover all the input could be correlated together during a specific movement or task. If these relations are elicited, then the robot can distinguish and learn a specific task when the correspondent data are detected by the sensors thus repeat it.
The ultimate goal is to recognize this relations and traduce them into algorithms. In the low level control of the hand and of the upper limb, artificial synergies will be created. These actions remind the muscular synergies of the human body.
For sure an object manipulation is a challenging task; nevertheless simple synergies were already developed coupling only the encoders and the cable tension sensors.