SYNERAGH, a European Project on Anthropomorphic Grasping and Handling for Humanoid Robots

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Abstract. Directed at developing advanced neural schemes for object-oriented, adaptive reaching, grasping and manipulation in robotics, the European Union funded the SYNERAGH project, started in 1999 and involving partners from 5 different European countries. This project will attempt to transfer human planning processes for grasping and manipulation to robotics, by incorporating experimental results from behavioral, anatomical, and neurophysiological studies. This paper presents the project objectives and the current achievements by the different Project partners, that will converge on a unique really anthropomorphic robotic system for manipulation. In particular, the paper illustrates the definition of a neurophysiologically-based elementary hand gestures language by means of which to express any manipulative process, a neural algorithm applied to the tactile-visuo-motor integration for reaching and grasping tasks and the preliminary sketch of the final robotic platform. The results are expected to be applicable in humanoid robotics, to implement a reaching and grasping module as a part of a more complex system, in service robotics, especially for helping people with motor disabilities, and also in the whole area of manufacturing where adaptability and compliance is desirable to interact with the dynamic environment.

1. Introduction

The problem of manipulation has always attracted the interest of robotics researchers worldwide, since the basic need for robot dexterity posed by traditional industrial applications. Along with the evolution of advanced robotics towards service [1] and personal robotics [2], the need for human-like performance has led to the investigation of anthropomorphic solutions. In this framework, artificial hands has been developed by different research groups [3-5], based on different technological approaches [6-9], with the aim of replicating the dexterity of human hands.

The anthropomorphic approach in the development of artificial hands has also supported the application of robotics in the physiological and neuro-physiological study of human grasping and manipulation [10].

Both for the development of personal humanoid robots and, mostly, for neuroscience investigations, the focus of the research has been shifted to control and behavior. The current challenge is to replicate as closely as possible the known features of human motor control and sensory-motor co-ordination. In fact, it is worthwhile to underline that many processes of human brain and of the human nervous system are not completely known, yet. Thus, the interaction between the fields of neuroscience and robotics is two-fold (see Fig.1): on one hand, neuroscience provides the knowledge on the human nervous system to build anthropomorphic robots (or components); on the other hand, anthropomorphic robots represent a powerful platform for experimental validation of theories and hypotheses formulated by neuroscientists.

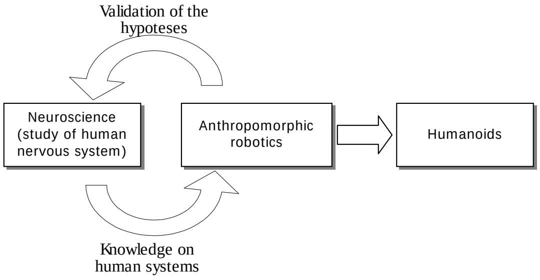

Fig. 1. Interactions between neuroscience and robotics.

The Syneragh project described in this paper aims at implementing human planning processes for grasping and manipulation in robotic systems, by incorporating results form behavioral, anatomical and neuro-physiological studies. Based on the knowledge of human motor control and sensory-motor co-ordination in humans, mathematical models are built and implemented in an experimental robotic set-up for grasping and manipulation, including anthropomorphic sensors and actuators.

To this aim the following section will illustrate the modeling of the brain areas involved in grasping and manipulation through the formulation of a language of basic gestures, along with specifically developed simulation tools. Section 3 presents the results of the implementation of a neural controller for tactile-motor co-ordination in grasping, by integrating different sensory modalities. Finally, the experimental scenario for the validation of the mathematical models and the neural controller is described, with particular reference to the anthropomorphic sensors and actuators.

2. Formulation of the Grasping Simulation Language (GSL)

The objective of this paragraph is to present the development of manipulation gesture and grasping simulation tools based on schematic representation of the brain areas functionality involved in a motor task. In this frame, the main work consisted in the formulation of the Grasping Simulation Language *GSL* .

2.1 Functional decomposition of the motor areas control

The GSL language provides the different components and data necessary to the definition, execution and control of a manipulation task. The *GSL* specification is based on the study of relevant neurophysiological parameters that characterize the human behavior. They come from our bibliography analysis and from the interpretation of our posture library. Also, the *GSL* is associated with a control model whose structure is inspired to the human brain (Fig.2).

Our hand gesture library is organized in four parts. In order to precise the fourth part of this library, we propose a description of grip and manipulation sequences for a set of usual objects which require at least 2 or 3 fingers (for example a tumbling or a pushing task [11, 12]). The first, second and third part of the library define a set of elementary grips (SomatoVisual and Somatic matching operations between the vectors attached to the object and the vectors attached to the hand and the fingers). The fourth part of the library describes all the possible transitions (condition units) between elementary grips depending on the initial and desired hand/object configurations. The movement is controlled from the goal to the activation of the intermediate grips depending on the available sensory signals, each one producing a new hand/object configuration closer to the goal. This neural architecture for hand movement control is defined by four networks working in parallel, in direct correspondence with four sets of cortical areas (Motor, Somatic, Somato-Visual, Premotor). Each of these four networks corresponds to a set of controls, that can be viewed in robotic terms as a library of primitives of hand gestures.

The functional description of the motor areas control can be decomposed as follows:

1. Motor areas (Ma, Mh) control the relations between elementary hand movements and combination of muscles which form flexible synergies. The command by the motor cortex relate elementary finger movements described as joint configurations and the control of muscles depending upon external forces.
2. Somatic areas (SSa, SSh) control the relation between two fingers and haptic information to form an elementary somatic grip, determined by the surfaces and weights of objects, whatever the object. The hand gesture library allows to propose a description of elementary grips by a set of relations (primitives) between sensory haptic and motor information , in terms of 3D vectors attached to the surface of the objects. Elementary goals are coded by a set of “matching units” which relate 1) a combination of two actual vectors (actual sensory information on two fingers) 2) a combination of two desired vectors (elementary goal described by desired sensory information on these two fingers), and 3) the motor commands that relate actual and desired combinations.
3. Somato-visual areas (Vsa, Vsh) control the relation between the vision of specific objects and the configuration of arm and fingers. There are two parts, a “somato-visual reach area” that controls the relation between arm/wrist configuration and the position of the object relative to the body, and a “somato-visual grasp area” which controls the preshaping of the hand adapted to the somato_visual” class of objects: each class can be described by the joint configuration of two virtual fin-

gers on the object (somatovisual grip). This area comes from a description of the somato-visual properties of a set of objects, based both on the literature and on the quantitative experimental analysis of the grasping of a set of objects, using a cyberglove [13]. Each type of object (visually defined) activates a visuo-somatic matching unit that induces a preshaping of the fingers related both to the geometrical characteristics and to the use of objects.

4. Premotor areas (Vpo, P, Vobj) control the sequential relation between fingers as a set of transitions between elementary visuo-somatic or somatic grips (thus controlling relations between 2 to 4 fingers): the sequence is determined as a planning control of transitions between elementary grips. In neural terms “matching units” that control elementary grips are related in sequence by “condition units” whose activation is goal-dependent and defines a transition between two elementary grips.

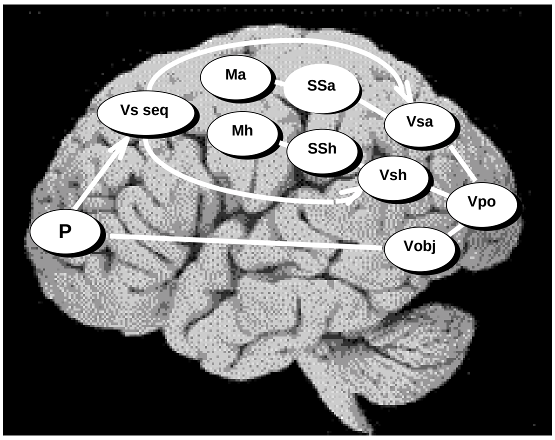

Fig. 2. Functional decomposition of the Motor areas control. (P : Planification function in the Prefrontal cortex , Vs seq : Visuo-somato sequence, Ma, Mh : brain areas involved in hand and arm control, SSa, SSh : somato-sensory arm and hand functions, Vsa, Vsh : Visuo-somato of arm and hand functions, Vpo and Vobj: Visual information gathering).

2.2 Proposition of an anthropomorphic architecture

The hierarchical approach, inspired from "localisationist" theories [14], postulates that the accomplishment of a motor action passes through the activation of largely independent cortical structures acting in a pre-determined order. It works in a sequential manner and a structure or group of structures are activated only when the previous has finished its task. One structure is devoted to the organization of the higher level of a motor action and control those devoted to its execution. Thus, two main steps are considered. The first one concerns the planning or scheduling and its role is to define the action goal and the means necessary to its accomplishment. The second one deals with its execution. In the same point of view, a three step organization is proposed:

1. a high level of decision converts an idea into a muscular activation form in order to accomplish a given movement,
2. an intermediate level which manages the coordination problem,

3. a low level which activates the muscles motor neurons .

In order to take into account in a global way all the parameters involved in a manipulation task, we have adopted a hierarchical structure. It allows to separate partially the movement organization aspects from the ones devoted to the control of their execution. Moreover, in each level, we define a distributed structure dealing with the control of each particular type of elementary movement.

Level 1: "*Supervisor*" manages the movement definition of the arm, hand and finger motion. In this level, we use the posture library based on experimentation results and on the different operations associated with the GSL specification of gesture and elementary movements.

Level 2: "*Coordinator*". Its role is to coordinate the action of arm and hand during an object manipulation. In this level, two main functions are insured, object dynamic stability and trajectory tracking.

Level 3: "*Joint level*". This level gathers information from the "*Supervisor*" and "*coordinator*" levels in order to determine the joint actuation of the arm and hand and perform a manipulation.

This architecture for hand movement control is defined by four parts working in parallel, defined from the four sets of cortical areas (Motor, Somatic, Somato-Visual, Premotor). A global view of neural anthropomorphic architecture is proposed in Fig.3.

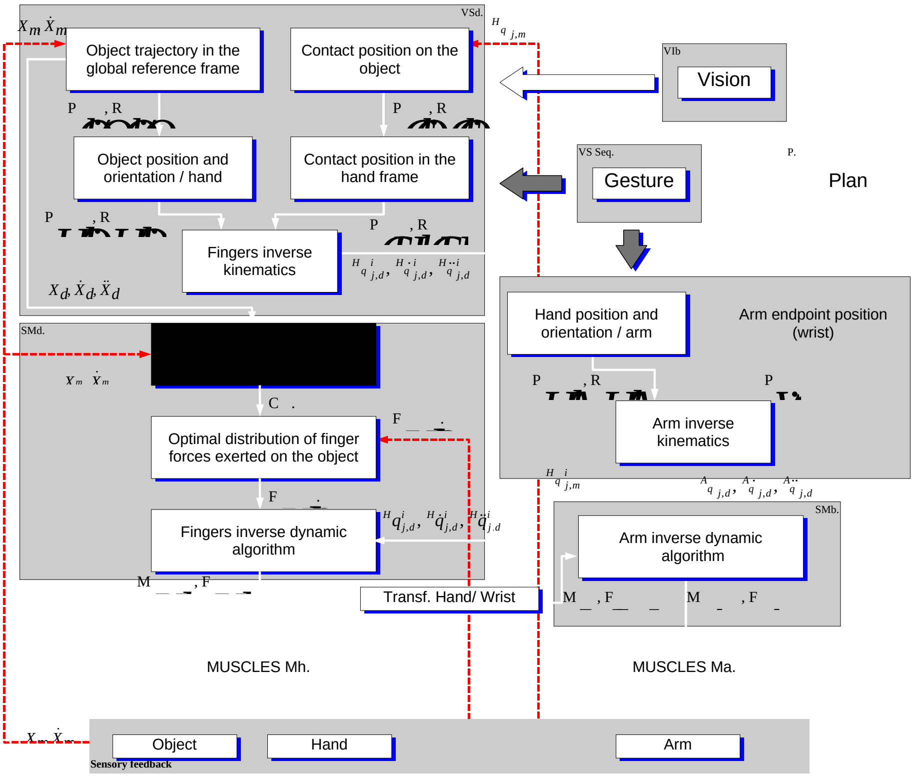

Fig. 3. Human motor system architecture

2.3 Grasping simulation tools

In order to implement the *GSL* components, we have defined a model of the upper extremity. The arm is composed of two segments and have 7 degrees of freedom. The hand is composed of 5 fingers and 20 degrees of freedom. This model is represented in Fig.4, which shows the morphological representation of the hand. The parameters are based on biomechanical data [12].

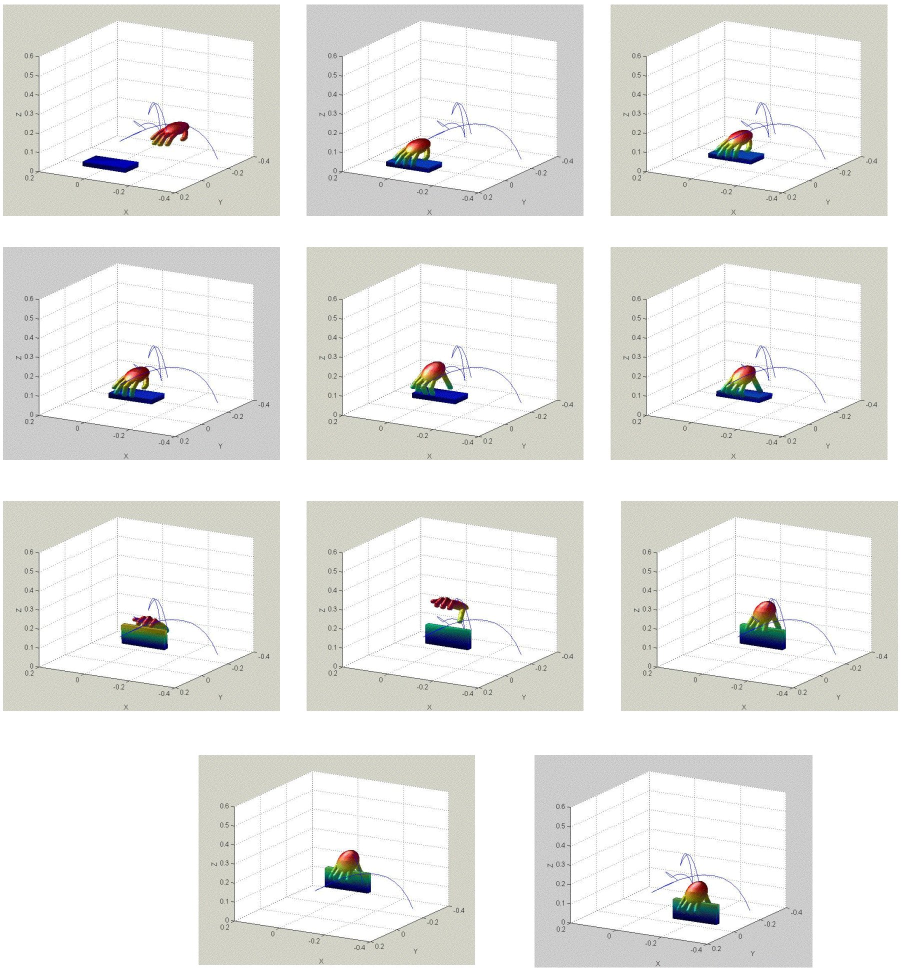

Fig. 4. Simulation of manipulation movement

All the different functionalities previously developed have been implemented with MATLAB software. To illustrate the efficiency of the previous controller, we propose a simulation of a manipulation sequence (reaching + tumbling + grasping phases) (Fig.4). This sequence is based on an experimental protocol in unstructured environment [11] and on the use of biomechanical data.

3. A neural algorithm applied to the tactile-visuo-motor integration for reaching and grasping tasks

In this paragraph, a solution to the visuo-tactile-motor coordination problem with a neural sensory-motor control system in a robot installation formed by a stereohead, a robot arm and a two fingered robot with artificial tactile skins is presented. This system guides the movements of the robotic arm and hand to grip an unknown object on the tactile surface center. The process is divided in two parts: The head-arm motor control based on visual information for guide the arm-hand robot to the target in the reaching phase and the hand-arm motor control based on tactile information for the grasping task.

The installation in which the control system has been implemented is depicted in Fig.5.

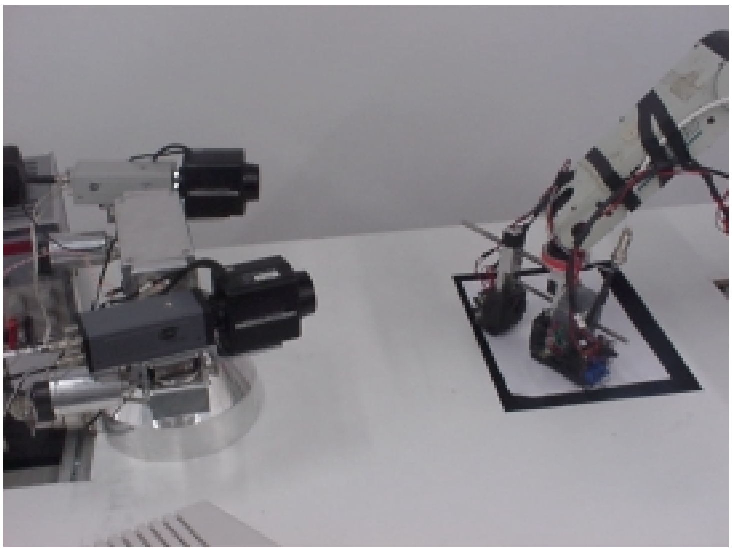

Fig. 4: Experimental Installation

3.1 Description of the neural controller

The tactile visuo-motor control scheme of the positions of the cameras is implemented by means of the five d.o.f LINCE stereohead developed by the NEUROCOR research group, and a two fingered hand robot, with artificial tactile surfaces. This control scheme implements several neural networks that imitate the human biological structure of the sensory-motor control.

The neural network carries out the following tasks [15]:

1. neural representation of a visually perceived objective inside a reference frame centered in the head;

2. transformation of this representation to a reference frame fixated to the body;
3. formation of a spatial trajectory from the actual position of the hand until the objective;
4. generation of the grasping movements towards the objective based on the force distribution information of the tactile surfaces.

The control system based on tactile information have been implemented in a two fingered robot hand, with artificial tactile skin for measuring the contact force distribution in grasping, situated in the end of the robot arm. This controller implements a self-organized neural network with a VAM structure [16]. Taking advantage of the matricial design that it possesses, it is possible get the sensory maps in grasping objects in real-time, determining the centroids of the object in the surfaces, by means of the force distribution gotten. In Fig.5, the scheme of this control algorithm is shown.

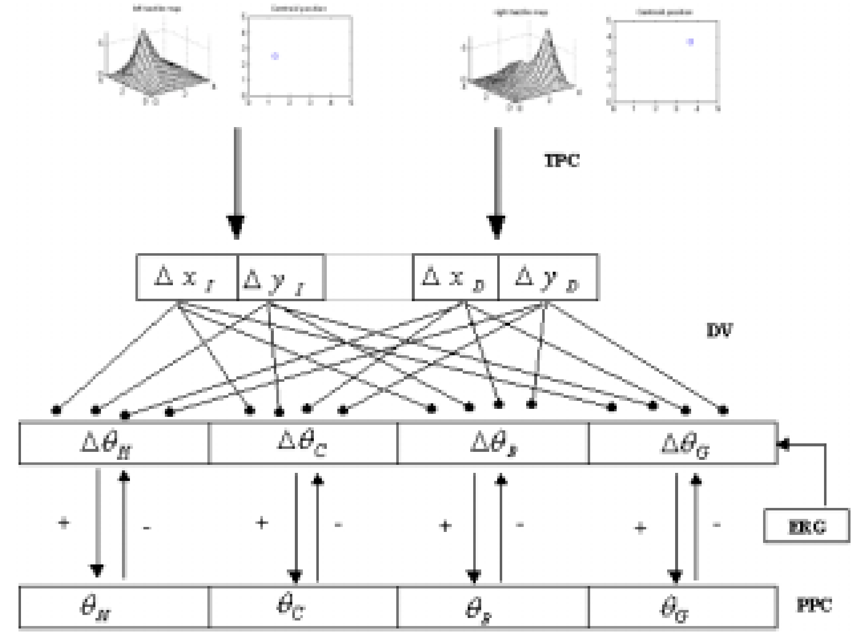

Fig. 5: Neural Control Algorithm, where $\theta_{H,i}\theta_C, \theta_B, \theta_G$ are the joints position angle and $\Delta x_I, \Delta y_I, \Delta x_D, \Delta y_D$ the centroids increment.

This neural algorithm makes corresponding the directional mapping between the pressure distribution detected in the tactile surface when the system touches an object, and the joint movements. In the learning phase, random increments are produced in the robot joints, which are related with the displacements of the tactile image centroids on the sensorial surfaces. In the operation phase, the algorithm calculates the position of the tactile image centroids and moves the robot joints with the purpose of centering them over a selected cell of the artificial tactile skins.

Once the robot hand has reached the object, guided by the vision system, the grasp task is divided in two processes: at first the robot hand detects the objective with the tactile sensors; next, only one simple gripping manoeuvre is necessary to centre the tactile images on the sensorial surface.

3.2 Results

The algorithm proposed has produced good results in reaching guided movements and in centred grasping manouvres with different type of objects. Indeed, the employment of the artificial tactile skins allows to carry out precise and centered grasp. In Fig.6 and Fig.7, the experimental results show the evolution of the centroids and the evolution of the robot joints in a grasping maneuver, respectively.

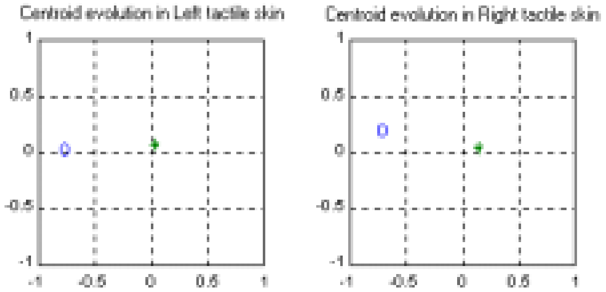

Fig. 6. Evolution of the centroid: the circle indicates the initial positon and the star the final position.

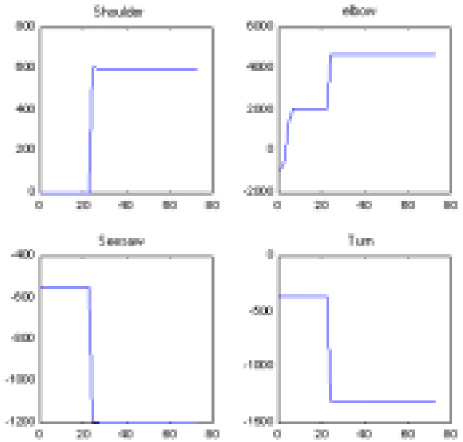

Fig. 7. Joint movements of the Robot

The system has presented a good behaviour when some of the joints in the robot system have beeen blocked., due to the adaptive capability of the implemented neural algorithms in the visuo-tactil-motor system.

4. The Syneragh experimental robotic platform

A robotic platform capable of integrating different sensory modalities with the aim to control the manipulation actuators using the innovative neural schemes that will be obtained in this project has been outlined and realized, as illustrated in the Fig.8.

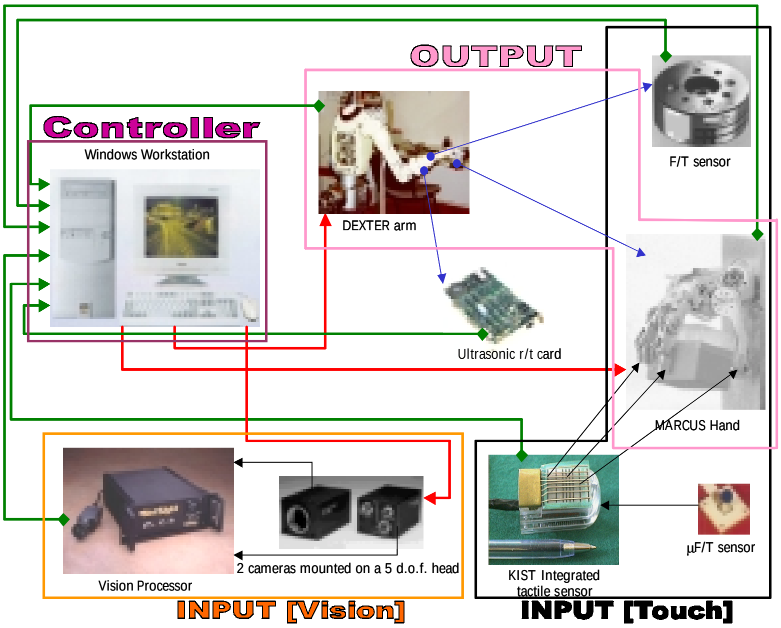

Fig. 8: SYNERAGH robotic platform

Some aspects on this platform are discussed in the following paragraphs.

4.1 Tactile-Visual sub-system

The integrated tactile fingertip sensor

The integrated fingertip is a multi-functional miniature sensor comprising of a “Tactile Array sensor”, a ”Dynamic sensor” and a “Thermal sensor” (not yet mounted).

The Tactile 8x8 Array sensor, based on FSR technology, possesses a space-variant disposition of the sensing sites, aiming at increasing the size of the tactile sensing area and reproducing the concept of tactile "focus of attention" at the fingertip .

The Dynamic sensor is based on a bimorph piezo-ceramic element, generating a signal related to the applied stress.

The Thermal sensor is composed of two miniature resistors embedded in thermally conductive rubber so that the sensor can measure the thermal flow from the fingertip to the explored material.

The integrated fingertip is contained in a compact and lightweight frame of 27.4 x 25 x 52 mm that is intended to be mounted on the Barret Hand. The electronic boards for data acquisition are embedded inside the fingertip structure, too. The tactile acquisition electronics is connected to the Tactile Sensor through a custom connector thus optimising compactness.

The Fig.9 shows the integrated fingertip while the table 1 contains further details.

Tactile Array Sensor Physical Characteristics	
External Dimensions	24.36mm x 34.9 mm.
Overall Area	850 mm^2
Sensitive Area	432 mm^2
Number of sensitive sites	64
Maximum resolution (in the centre)	1 mm.
Minimum resolution (at the periphery)	5 mm.
Number of wires	16
Signal Pad Area	2.25 mm^2 (each)

Table.1

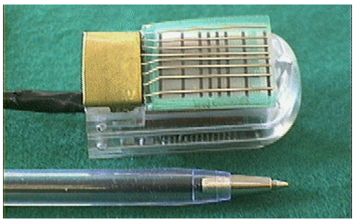

Fig. 9: The integrated fingertip

Vision processor

The adopted vision system is a stand-alone vision processor with its own operating system and communicating with the external world via an Ethernet adapter. Its characteristics are as follows:

- on board Pentium MMX enabled processor
- 32 MB RAM
- Ethernet 100 baseT communication to 100Mbits/sec
- 4 monochrome analog/digital cameras input, up to 1024x1024 pixels or 8000 pixels x line
- disk-less Windows CE 2.11 OS
- software development under Windows NT 4.0 Workstation with Visual C++
- MVTools CE programming libraries

Two JAI M-50 b/w cameras constitute the input to the NetSight and they will be mounted on a 5 d.o.f. stereo head.

A graphic interface for sensory acquisition and actuators basic control

A graphic interface for sensory acquisition and actuator basic control has been developed with the objective of monitoring the status of the sensory apparatus and to furnish a communication method with the sensors and the actuators in a unique developing environment.

Fig.10 shows a view of the graphic interface.

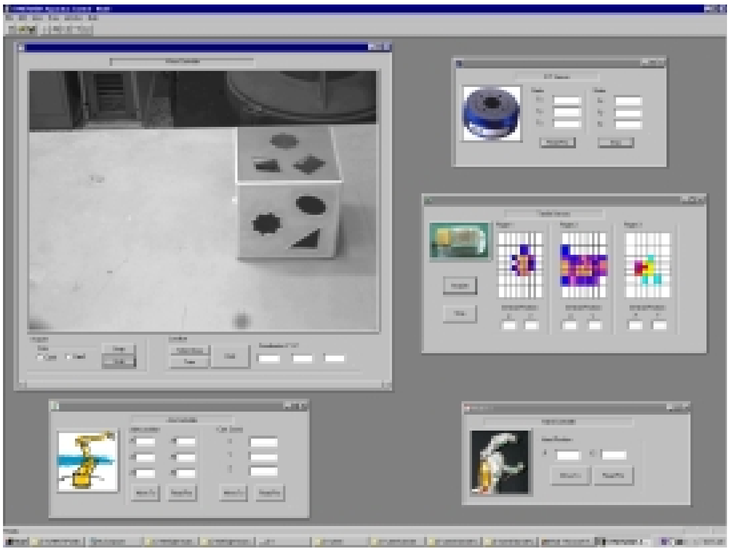

Fig. 10: The SYNERAGH graphic interface for monitoring the robotic platform

The graphic interface comprises of different modules:

a) <u>vision module</u>: it allows to grab and snap images in real time and to train the system to learn to recognise virtually any areas of the screen and to localise the centroid co-ordinates. At the moment a 2-dimensional version of the localization procedure has been written but as soon as the second JAI camera could be connected to the system, the 3-dimensional version will be available;

b) <u>F/T sensor module</u>: it allows to measure the 6-dimensional components of the force and of the torque applied;

c) <u>tactile sensor module</u>: it allows to acquire the fingertip sensor signal and to display in real time the position and the intensity of the normal forces applied to the tactile array. Currently, only one sensor is active but sooner 3 sensors will be integrated on the MARCUS hand;

d) <u>hand module</u>: it allows to read the position of the two active joints of the MARCUS hand and to position them to the desired value;

e) <u>arm module</u>: it allows to read the PUMA arm position in the joint and in the cartesian spaces and to move it in the two spaces.

At the moment, the interface for ultrasonic sensing is not yet integrated in the graphic interface but as soon as a more complex hardware will be available, the dedicated interface will be added.

4.2 Visual localization

Localization of the object to be grasped and its tracking during manipulation is a central problem for the SYNERAGH objectives. To this aim, a first series of experiments have been conducted, for the moment in the 2-dimensional space for the lack of the specific stereo-connector to the frame-grabber, by using the SmART algorithm from Imaging Technologies.

SmART incorporates a highly innovative geometric method that has proven to be extremely reliable in locating the position and orientation of objects despite highly degraded run-time patterns or images. SmART Search is 15 times more accurate at locating patterns than most other tools (i.e., Normalized Grayscale Correlation).

Using this built-in procedure, the vision module is able to:

a) graphically select a rectangular portion of the screen with the mouse;

b) train the system over the selected area;

c) find the selected area in a new image, displaying the rectangular edges, the centroid position, and the score value (the degree of recognition confidence).

We applied such module in a unstructured environment with no light control, first with geometric objects (trial 1) and then with a more complex pattern (trial 2); the results are depicted in the following figures (11 and 12). The blue border indicates the training area, the green (high confidence) or red border (low confidence) the result of the recognition and localization procedure in the new image.

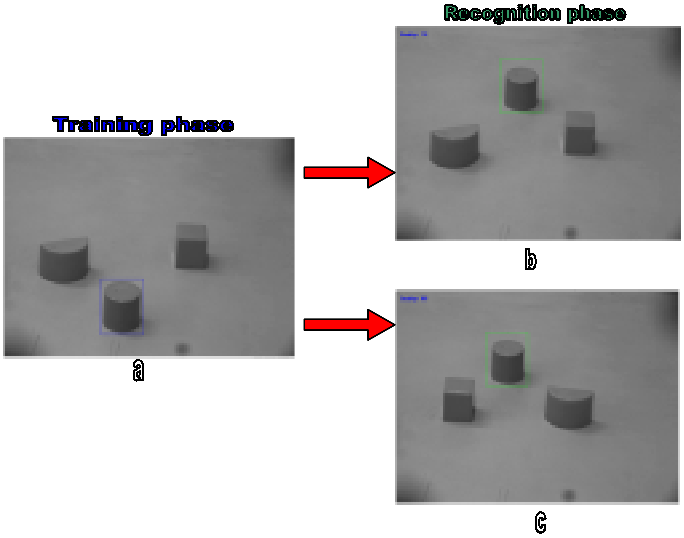

Fig. 11*:* (a)training over a cylinder and (b) (c) localisation of the same cylinder in new scenes; in (b) the score is 78%, in (c) 80% respect to the original frame (a).

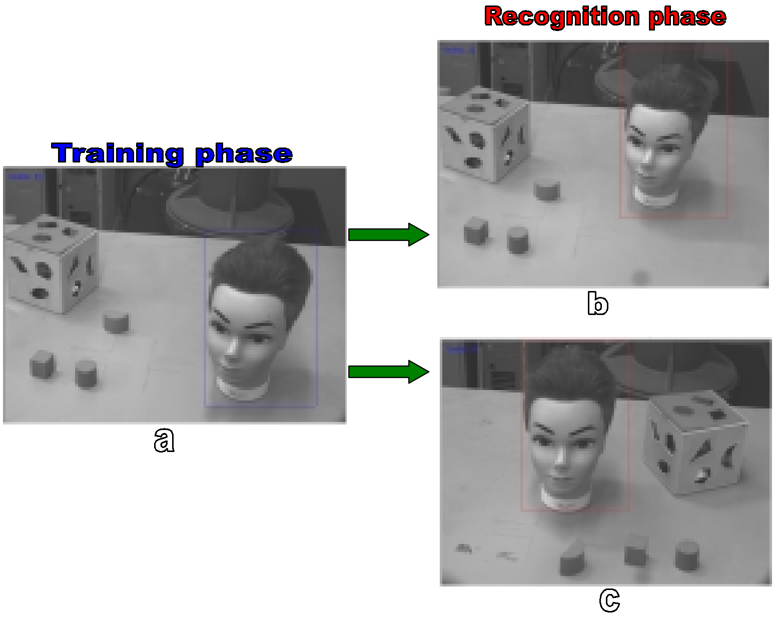

Fig. 12: (a) training over a more complex object in a complicated scene and localization of the scaled and shifted head (b) and of the rotated head (c) . Even if with a low score (32% in (b) and 43% in (c)), the system is able to localize the object in the noisy and complex scene.

5 Conclusions and future work

In the paper, the general objectives of the SYNERAGH project and the first scientific achievements have been reported and discussed.

In order to develop a robust, adaptive and hardware-independent reaching and grasping robotic system, we have focussed our attention on the cognitive manipulative behavior in humans and we are trying to replicate part of its underlying neural mechanism on an anthropomorphic robotic platform.

The first step was the definition of the Grasping Simulation Language, an universal hand “alphabet” capable of expressing any complex grasping procedure as a composition of its elementary hand gestures. A controller for the generation of the correct sequence of elementary movements able to generate any complex grasp was implemented and tested with a simulation. The controller structure mimics the interaction and functions of four different areas cortical areas (Motor, Somatic, Somato-Visual and Premotor).

The next step consisted in the integration of different sensor modalities to control the grasping procedures, overall in the final part of fingers adjustment around the object. An algorithm based on a novel neural network model guides the movements of the robotic arm and hand to grip an unknown object on the tactile surface center. The process is divided in two parts: the head-arm motor control based on visual information for guiding the arm-hand robot to the target in the reaching phase and the hand-arm motor control based on tactile information for the grasping task.

Finally, the experimental robotic platform integrating artificial vision, touch and ultrasonic sensing able to control a 8 d.o.f. arm and a robotic hand is presented with the dedicated graphic interface that monitors the entire sensory and motor apparatus. Some experiments in two-dimensional visual localization of any trainable areas are discussed and the encouraging results shown.

The future work will be addressed essentially in integrating the different scientific contributions on a common robotic system while augmenting the anthropomorphic structures of the controllers and of the sensors to be used in the final demonstrator.

Concerning vision, a robust procedure of 3-D localization of common-use objects, geometric features extraction and hand tracking are being implemented. Concerning the touch sensing, a more sophisticated version of the current available tactile sensor will be introduced. More complex neural schemes will be adopted to control the fine manipulative process.

Acknowledgments

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