Experimental activity on grasping objects in free-floating conditions

L. Biagiotti[1], C. Melchiorri[1], G. Vassura[2]
1. DEIS, 2. DIEM
University of Bologna - Via Risorgimento 2,
40136 Bologna, Italy
{lbiagiotti,cmelchiorri}@deis.unibo.it, gabriele.vassura@mail.ing.unibo.it

Abstract

This paper reports an experimental activity for the validation of a robotic gripper for space applications. A key point of this gripper, besides the compatibility with the carrying arm (in this case the SPIDER manipulator developed by ASI) and some other mechanical features, is its capability to deal with free-flying objects in no-gravity conditions. This capability is achieved because of the sensorial equipment and the implementation of proper control strategies. After a brief illustration on the main features of the gripper, the experimental activity is presented and the results discussed.

Keywords: *Space Robotics, Robotic Gripper, Proximity Sensors, Force sensors.*

1 Introduction

In space, as it has already happened in more classical industrial applications, the use of robotic devices to execute automatic operations is expected to grow and cover a relevant part of the activities. With this respect, as already demonstrated in industrial applications, a bottleneck may be constituted by the end-effector, that often is a very simple device with poor sensoriality and limited operational capabilities.

Besides the numerous prototypes of articulated robotic hands, developed in more than 20 years of research, mainly in academic environment, see e.g. [1]-[3] among many others, limited effort has been devoted to seek and evaluate alternative solutions, maybe simpler from the mechanical point of view than a multi-fingered hand, but with sufficient dexterity to perform in any case non trivial operations on a wide range of (possibly unknown) objects.

Moreover, referring specifically to the case of space applications, a scenario could be considered in which operations have to be performed in a no-gravity environment, where eventually objects could be free from constraints and therefore float in space.

In order to face to some of the above problems, a development activity has been started at the University of Bologna in the framework of a research programme supported by ASI, the Italian Space Agency, to design and experimentally test a robotic gripper for space applications, see Fig. 1, [4]-[6]. This paper presents the current state of this research activity.

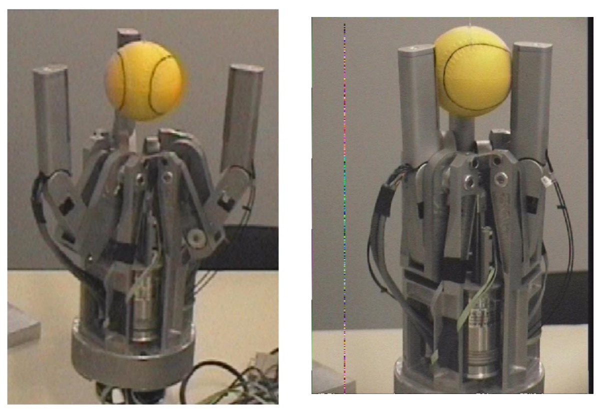

Figure 1: The gripper in different configurations.

2 The Gripper

The gripper has a modular structure, with three one-dof fingers, see Fig. 2, whose distal phalange can move on a linear trajectory. These fingers are disposed radially, in a symmetric configuration as shown in Fig. 1. This kinematic configuration has several interesting features, as described with more details in [4]-[6], including the capability of firmly grasping objects with irregular shapes and with a rather wide range of dimensions.

The gripper has been designed considering its installation on the SPIDER arm by ASI, [13], and a possible use within PaT, the Payload Tutor, proposed by ASI (Italian Space Agency) [8]. This system aims to substitute the astronauts in periodical operations with a semi-autonomous robotic device. The solution proposed by ASI integrates a small robot arm within a fixed structure, where a set of drawers can host and protect as many different experiments: the mobility of the robot arm is increased by placing it on slide joints, in order to cover all the front surface of the facility even with reduced size of the robot limbs. The experiments to be performed inside each drawer may include manipulation of complex-shape "non-technical" objects, freely floating within their allowed space. The end-effector for the PaT manipulator needs therefore compactness, simplicity and reduced weight as well as capability of operation even on irregular floating objects.

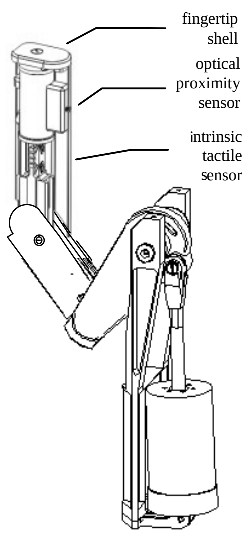

Figure 2: The actuation module and a schematic view of the sensory equipment of each fingertip.

Each finger is equipped with a position sensor, a proximity sensor and a miniaturized force/torque sensors, see Fig. 2, [9], [10]. In this manner, it is possible to control the motion of each finger, its distance from the object and the forces applied on it during the grasp. Obviously, this arrangement does not exclude the possibility of further integration with additional or more efficient sensors, like distributed tactile sensors, stereo vision or more sophisticated scanning devices.

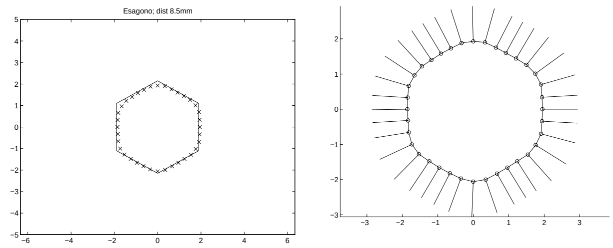

Figure 3: Reconstruction of an object by exploration with the proximity sensors and computation of the normal directions.

3 Control system

The real time control architecture is based, at least in this first phase of activity, on standard HW/SW components. The adopted architecture consists in a PC equipped with a DSP (TMS320C32) board and connected with the motor drives and to an input board for the sensors. This board has been purposely designed because of the relatively high number of signals (30) to be acquired in real-time. From the software point of view, besides a real-time kernel on the DSP board, an interface between the DSP and the PC has been developed, allowing to use in an integrated fashion both real-time software and high-level environments for user interface.

The control of the gripper can be subdivided in an hierarchical structure, in which at least three levels can be considered, as schematically shown in Fig. 4.

Servo control level, in which the basic position/force controllers are implemented;

Supervision level, scheduling the activation of the proper control at the servo level (e.g. position, proximity, force);

Task planning level, defining the general procedures of the gripper, e.g. exploration of an unknown object, selection of the "best" grasp, coordination with the carrying arm, ...

At the moment, the servo control level has been implemented considering a simple logic switching between three classes of controllers: a position control (based on the position sensor), a proximity control (based on the proximity sensor) and the force control, based on the force/torque sensor.

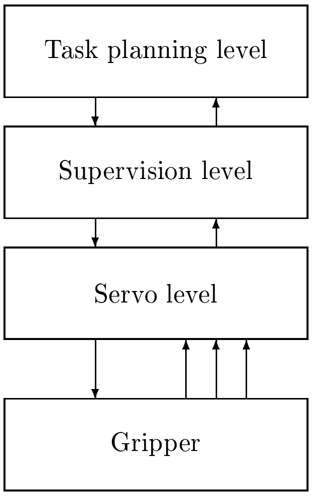

Figure 4: Hierarchical control structure of the gripper.

The position control of each finger is based on a classical PI controller, as depicted in Fig. 5. A difficulty has been the compensation of nonlinearities caused by the actuation system, in particular a relevant (and non constant) dead zone and the nonlinear characteristic of the Hall effect position sensors.

The set points and the controlled variables of the servo loops are considered according to two main modalities: position control or proximity control. In the first case, the absolute position of the fingertip is controlled by planning the desired motion with a fourth-order polynomial function and assigning the desired motion time. The controlled variable is the position x (the radial distance from the center of symmetry of the gripper) of the fingertip obtained by means of the forward kinematics from the joint position measured by the Hall effect sensor:

$$x = 2l \sin\theta$$

where l is the length of the inner phalanxes and θ the angular position of the joint, see [4].

In the second case, the controlled variable is the distance of the finger with respect to the approached object. This modality is activated when the finger is sufficiently close to the object (e.g. 5 mm). The controlled variable is now the distance from the object, as measured by the proximity sensor. This information can be used both to start the grasp of the object (if all the fingers are at the same distance from it) or to maintain constant the distance between the finger and the object (e.g. if the object is moving).

The force control is based on the same PI structure of the position and proximity controllers, and at the moment can be classified as a simple compliance control obtained by specifying the compliance parameter K, see Fig. 5, see also [7].

Obviously, a proper switching logic between the above three control modalities must be adopted in the different phases of the execution of the tasks in order to ensure a smooth behavior of the gripper.

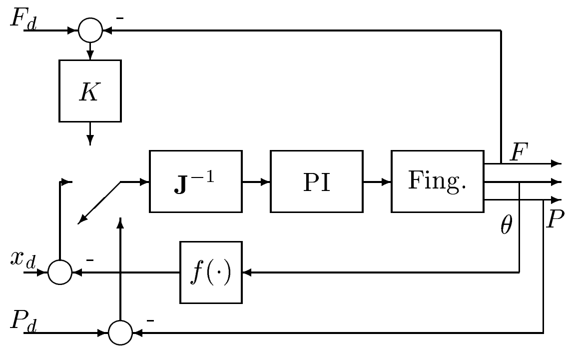

Figure 5: Position/force/proximity control scheme.

4 First experimental results

A number of laboratory experiments has been performed both on single finger modules and sensorial/actuation subsystems in order to test the efficiency of each finger structure and of the control system. The validation has also included verification of the procedures for the object approach, based on the use of both the distance and the position sensor information, and the use of the force/torque sensors.

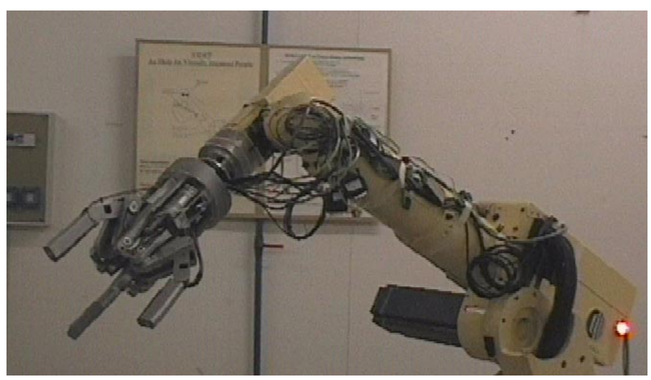

Figure 6: The gripper installed on a SMART-3S manipulator.

At the moment, a first prototype of the gripper has been completed and installed on a 6 dof anthropomorphic robot, a COMAU SMART 3S with a open-control architecture, a PC connected to the standard robot controller C3G9000, and equipped with a force/torque sensor on the wrist, see Fig. 6. The open control architecture allows in particular to synchronize the tasks of both the gripper and the arm for micro-motion during task execution. Moreover, a set-up has been prepared in order to perform different experiments using the prototype, where absence of gravity is partially simulated by suspending the objects with a wire.

The first experiments include demonstrative tasks of the following procedures:

1. use of proximity sensors for coordinating the approach phase of the fingers;
2. control of the approach/contact phase of floating objects;
3. scanning of the object surface for shape recognition by means of the proximity sensors;
4. choice of optimal grasp configuration according to a criterion of maximum area of friction cones convex [11, 12];
5. control of the applied force(s);
6. simultaneous application of contacts and test of grasp accuracy and stability.

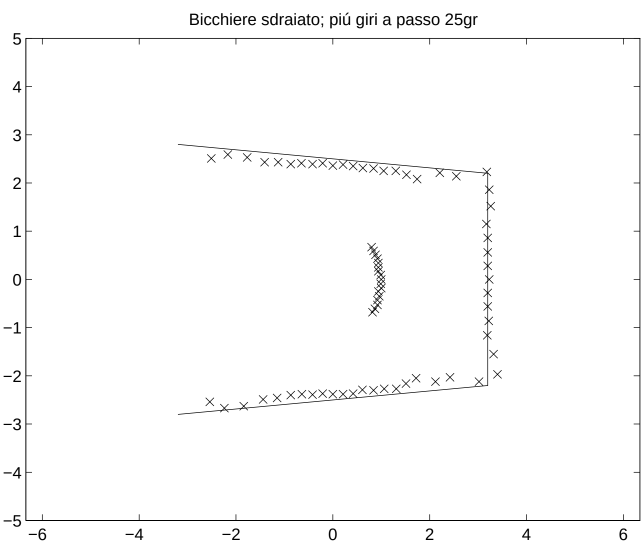

Figure 7: Reconstruction of an object (a glass) by exploration with the proximity sensors.

Typical results of the exploration of the objects' surface are reported in Fig. 3 and Fig. 7. Although still not optimal, the proximity sensors allow a precise reconstruction of surfaces at a distance up to 1 cm, and the detection of obstacles up to 5 cm.

Concerning the approach and contact phases, it must be observed that the possibility of independently moving the fingers has noticeably increased the capability of grasping moving objects. As a matter of fact, the object may be tracked (if moving) with a coordinated movement of both the arm and the fingers. Once the motion is tracked (i.e. the fingers move synchronously with the object), the grasp may be firmly applied without loosing contact.

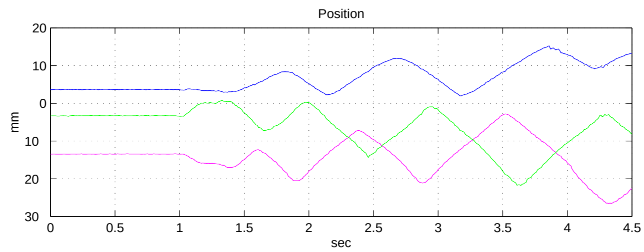

Figure 8: Tracking a moving object without grasping it.

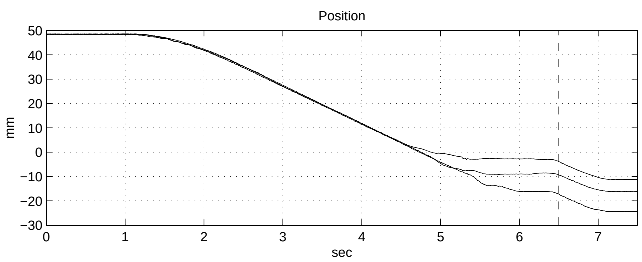

Figure 9: Grasp of a floating object: the fingers are moved until a given distance from the object surface is reached, then the contacts are applied synchronously.

Examples of this procedure are shown in Fig. 8-Fig. 10. In Fig. 8 the positions of the three fingers are shown while tracking a moving objects, maintaining a fixed distance from it. In Fig. 9, the three fingers first approach a fixed object until each of them is at a desired distance from it (8 mm), then the contacts are applied. In Fig. 10 the signals from both the position and proximity sensors are reported. The finger is moved towards a moving object, plot (a), until a desired distance (10 mm) is reached and maintained, plot (b), also with the object in motion.

Finally, an experiment involving force control is shown in Fig. 11. Again, an object is approached under position control (phase 1), then the proximity control is switched on (2) and finally, once contact has been es-

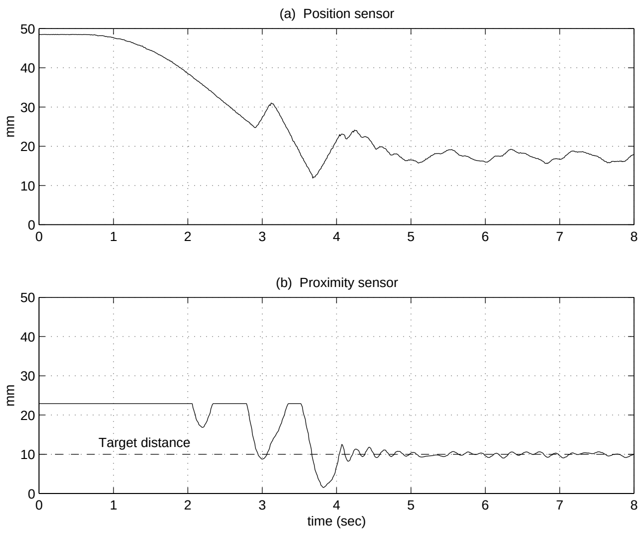

Figure 10: Measurements of the position (a) and proximity (b) sensor. The task is to approach a moving object and then to maintain a desired distance from it of 10 mm. The output signal of the proximity sensor is saturated at 23 mm.

tablished, the applied force is controlled (3, 4). In this case, the reference force is changed during manipulation force (form $f_d = 12\ N$ to $f_d = 15\ N$) to show the effectiveness of the force control. At the end, the object is released and the force is null (phase 5).

5 Conclusions

An activity for the validation of a three-fingered, three degrees of freedom robotic gripper for space applications has been presented.

Although this activity has not been concluded yet, the system confirmed so far some very interesting properties. As a matter of fact, it is relatively simple in the kinematics, actuation and control, since it has only three actuators and three degrees of freedom; it can provide adaptable and synchronous application of contacts to objects of any shape, thus allowing to grasp objects not centered with respect to the gripper axis of symmetry, without disturbing their initial posture; it presents a very large workspace with respect to its body size, and is capable of operation both on small and on large objects; its sensory equipment seems to be sufficiently rich and more than adequate for the expected tasks.

Future activity will concern the refinement of the current version of the gripper and the conclusion of the verification phase, in particular with respect to the force control and to the possibility of applying simple manipulation procedures on the grasped objects. A longer term project is the re-design of the gripper, in order to obtain a more compact device and to achieve the capability of applying also form closure grasps.

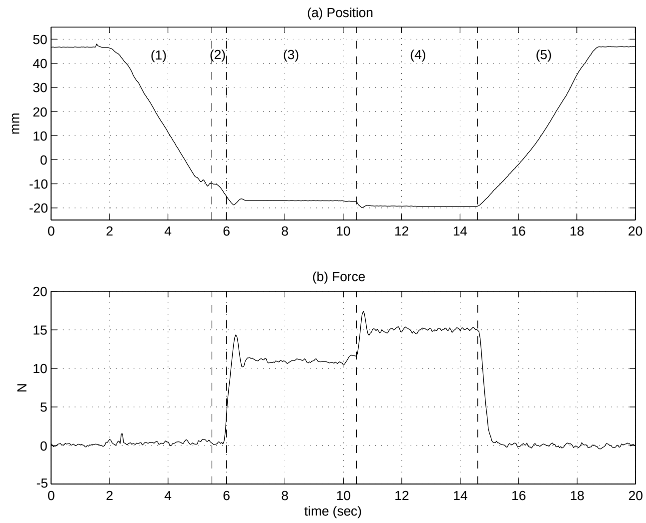

Figure 11: Motion of the finger (a) during an approach and a grasp and force applied on the object (b).

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