DESIGN OF LARM HAND: PROBLEMS AND SOLUTIONS

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Abstract: *This paper addresses main design issues for developing a low-cost easy-operation robotic hand named as LARM Hand. Design evolution of LARM Hand is reported by describing peculiarities and differences among LARM Hand from version I to version IV. Special attention has been addressed to the design characteristics of a 1 degree-of-freedom (DOF) driving mechanism that can be embedded into the finger body and can actuate the three phalanxes of a human-like robotic finger. Attention has been also focused to selection, location, and use of proper force sensors together with an easy operation force control architecture.*

Keywords: *robotic arm, multi-fingered robotic devices and artificial hands*

1. INTRODUCTION

Several industrial and non-industrial applications could be conveniently achieved by means of devices that are capable of mimicking human grasp in terms of weight, shape and size of objects that can be grasped and handled, (Ceccarelli, 2004a). Therefore, design solutions have been proposed in the literature for multi-fingered robotic devices and hands, (Cutkosky, 1989; Shimoga, 1996; Iberal,1997; Pons, et al. 1999; Bicchi, 2000; Laschi, et al.; Gosselin, et al., 2004). Design solutions attempt to have an high flexibility multi-purpose operation. Significant examples can be identified in the Stanford/JPL hand, the TUAT/Karlsruhe Humanoid Hand, the DLR's Hand II, the BUAA/Bejing University, Manus Colobi, the TBM hand, the Barrett Hand, (Casalino, et al., 2000; Fukaya, et al.,2000; Ambrose, et al., 2000; Townsend, 2000; Androidworld webpage, 2007; Barrett Technology webpage, 2007; DLR webpage, 2007; NTU robotics laboratory webpage, 2007; Robosoft webpage, 2007).

Available multi-fingered robotic hand prototypes are still not able to fully reproduce the highly flexible multi-purpose operation of a human hand. On the other side, most of the available prototypes have a high number of DOFs, a complex control, and a high cost. These aspects have significantly limited a wide spread of robotic hands in the market. Therefore, since late '90s at LARM: Laboratory of Robotics and Mechatronics, in Cassino design and research activities have been carried out in order to design a multi-fingered robotic hand having low-cost and easy-operation features, as outlined for example in (Ceccarelli, et al., 2003; Ceccarelli, et al., 2004b; Ceccarelli, et al., 2006a; Ceccarelli, et al., 2006b; Carbone, et al., 2007; Civitillo, 2001; Iannone, 2006). Main design issues have been the development of a suitable driving mechanism and use of force sensors. In particular, a driving mechanism moves the three phalanxes of a finger with only one active degree of freedom by mimicking a human-like cylindrical grasping. Moreover, the designed driving mechanism remains completely embedded in the finger body during the whole movement of the finger. The force sensors should be carefully selected and located in order to be implemented within a low-cost easy-operation force control architecture.

In this paper, LARM Hand is described by addressing its low-cost easy-operation features since the design stage. Design evolution of LARM Hand is reported by describing peculiarities and differences among LARM Hand prototypes from version 1 to version 4 (that is shown in Fig.1). Advantages and drawbacks of LARM Hand design are described also with the aim of proposing a novel design for the driving mechanism with underactuation properties.

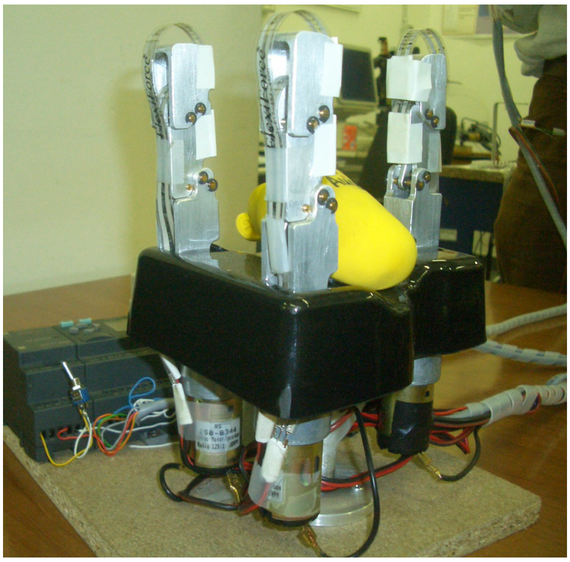
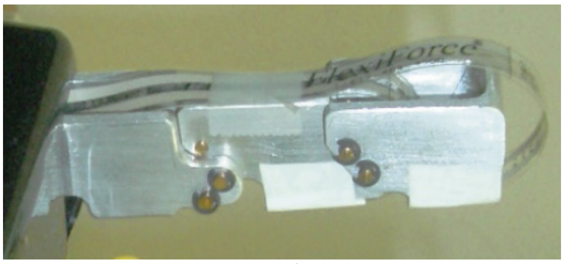


Fig. 1. LARM Hand version 4 at LARM in Cassino.

2. DESIGN PROBLEMS FOR A 1 DOF FINGER MECHANISM

A suitable knowledge of the human grasp can be very useful for designing an anthropomorphic hand. In particular, dimensions of fingers, grasping forces and contact points between fingers and objects have been investigated in human grasping for designing LARM Hand prototypes. As first step, several videos of the human hand grasping have been processed. The dimensions of each phalanx of index, medium and thumb have been measured for five persons as also reported in (Ceccarelli, et al., 2003; Ceccarelli, et al., 2004b; Ceccarelli, et al., 2006a; Ceccarelli, et al., 2006b; Carbone, et al., 2007; Civitillo, 2001; Iannone, 2006). It is worth noting that it has been decided to measure only index, medium and thumb since they are the most used in human grasping as reported, for example, in (Ceccarelli, 2004a; Iberal,1997). By analyzing several videos of the human cylindrical grasping of a given object it has been observed that there are almost constant ratios between the motions of each phalanx in the approaching motion to the object. Therefore, this motion can be reproduced with a suitable 1 DOF finger mechanism. This aspect motivates the use of only one motor in order to actuate all the phalanxes of a robotic finger since it can give a considerable reduction of costs and complexity of the control. However, it is necessary to design a driving mechanism with suitable link lengths and transmission ratios between phalanxes to mimic a human-like cylindrical grasping. Moreover, this driving mechanism should remain completely embedded in the finger body during the whole movement of the finger.

The above-mentioned design considerations have been taken into account for designing a one-DOF human-like finger for LARM Hand as shown in Fig.2. Figure 2b) shows a scheme of a finger of LARM Hand with a kinematic model of its driving mechanism. Each finger is composed of two four-bar linkage mechanisms as shown in Fig.2c). The first phalanx (labeled with 1 in Fig.2b) is the input bar of the first four-bar linkage mechanism. The first phalanx is also the base frame of the second four-bar linkage mechanism. The second phalanx (labeled with 2 in Fig.2b) is the input bar of the second four–bar linkage mechanism and it is also the coupler of the first four-bar linkage mechanism. Then, the third phalanx (labeled with 3 in Fig.2b) is the coupler of the second four-linkage mechanism.



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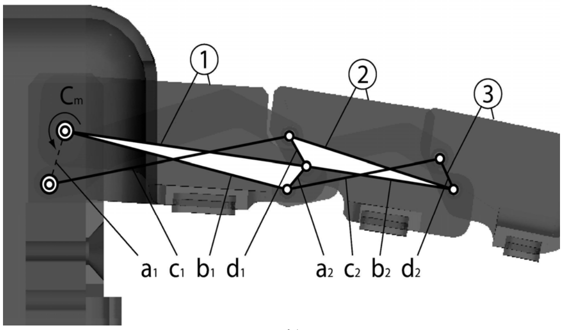

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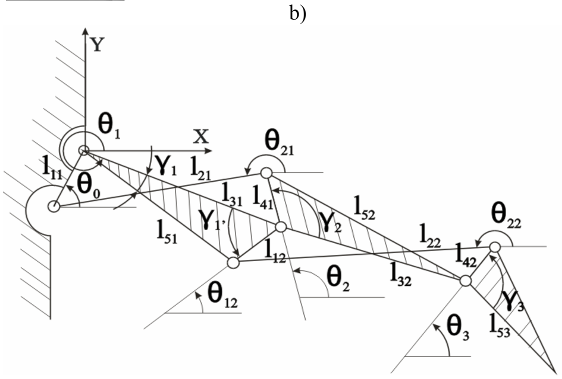


c)

Fig. 2. A finger of LARM Hand: a) a preliminar prototype at LARM; b) a 3D CAD model; c) a kinematic model for the driving mechanism .

One can notice that there is only one feasible contact point between a rigid object of feasible cylindrical shape and a finger of LARM Hand, since each finger has only one DOF. This aspect limits the operation of LARM Hand to objects that can be grasped with a cylindrical motion of the fingers. Moreover, contact points between a object and the grasping surface of the phalanxes should be within the sensing area of the force sensors in order to implement a force control. Thus, force sensors should be carefully selected and located.

Piezoresistive force sensors have been selected since they are lightweight and they have small size, low-cost and easy-operation features as described, for example in (Konteck Comatel. Specification Sheet, 2001). Analytical expressions of the surface of objects to be grasped have been intersected with the grasping surface of the phalanxes of a finger of LARM Hand in order to obtain the feasible contact points. For example, Fig. 3 shows the position of the contact point among three cylindrical objects of different size and a finger of LARM Hand. Then, the location of force sensors has been selected to provide the best choice in terms feasible sizes of objects to be grasped as shown, for example, in Figure 4 for two cylindrical objects having radius equal to 50 mm and 30 mm, respectively.

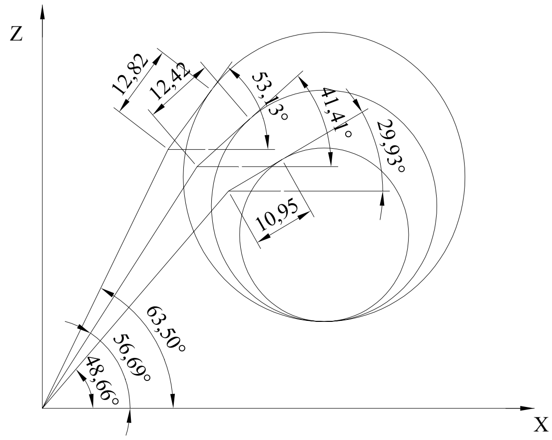
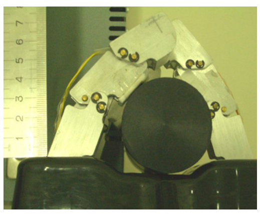


Fig. 3. A scheme for grasping cylindrical objects with radius R from 30 to 50 mm.



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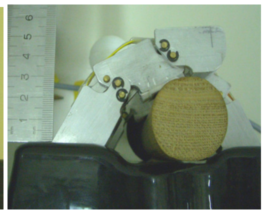


b)

Fig. 4. Contact point of a finger of LARM Hand IV with cylindrical objects of different radius r: a) when r=50 mm; b) when r=30 mm.

Main advantages of the design solution of the driving mechanism in Fig.2 are the low-cost, the light weight, the possibility to mimic the human-like cylindrical grasping with only one actuator, the possibility to have an easy-operation force control. Main limit of the proposed design solution is given by the location of the contact points. A possible solution for overcoming this limit can be obtained by replacing the 1-DOF driving mechanism in Fig.2 with a novel design for the driving mechanism with underactuation properties as proposed for example in Fig.5. In particular, the driving mechanism in the scheme of Fig.5a) has 3-DOFs but two DOFS are passive. Thus, the overall mechanism has only one active DOF. The 3D CAD model in Fig.5b) shows how this mechanism can still remain completely embedded in the finger body.

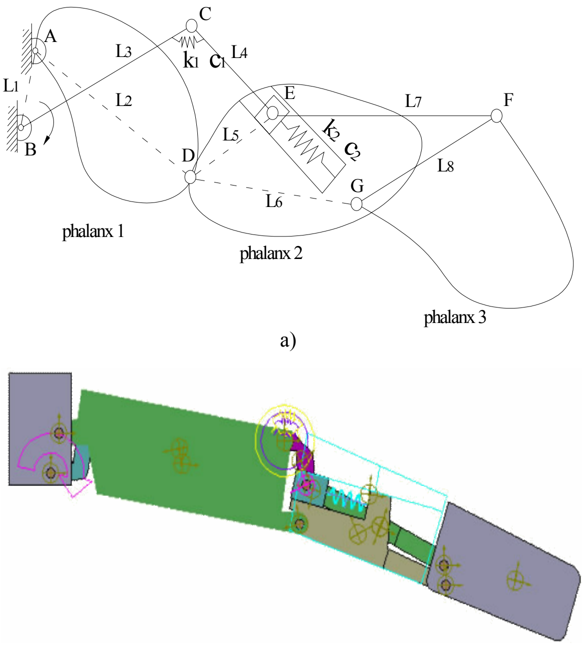


Fig. 5. A new 1-DOF LARM finger mechanism for underacturated grasping operation: a) a kinematic scheme; b) a 3D CAD model.

3. DESIGN ARCHITECTURE OF LARM HAND

A LARM Hand prototype is composed of three fingers, a palm, and a standard flange, as shown in Fig.1. The flange is used for connecting the hand to the wrist of a robot. The palm is made of a flat aluminum plate that is supported by springs. This design solution permits small passive motions of the palm to adjust itself to the size and shape of grasped objects. The actuation system consists of three DC motors with a planetary reduction gear train on each axis. These DC motors can be attached to the base frame. This design solution significantly reduces the mass and inertia of the phalanxes. Thus, the dynamic performance is significantly improved. In particular, the built prototypes make wide use of commercial components such as standard aluminum plates and low price standard DC motors.

Piezoresistive force sensors have been installed on the LARM Hand prototypes to monitor the grasping force. Piezoresistive effect consists in a resistance variation of a suitable material when a contact force is applied on it. Therefore, it is necessary to use a proper conditioning board with the aim to obtain a tension output from a resistance variation.

The control architecture should be able to operate three DC motors and to manage at least three force sensors (one for each finger) with easy-operation user-friendly features. The operation hardware can be based on the scheme in Fig.6.

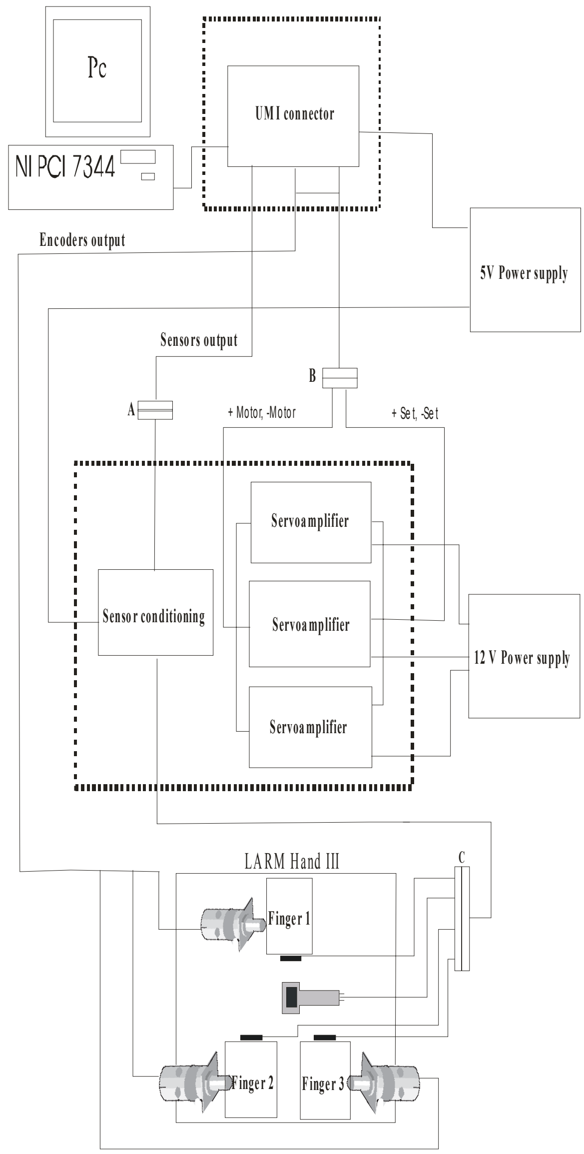


Fig. 6. A scheme of the hardware that is needed for the operation of a LARM Hand prototype.

4. EVOLUTION OF LARM FINGER DESIGN

Up to now, four versions of LARM Hand have been developed and built at LARM in Cassino. The first version (LARM Hand 1) is shown in

Fig.7. It is composed of three fingers being 1.5 times bigger than the average human size. The phalanxes and palm are made of aluminum alloy. Pins and input shafts are made of brass alloy. Several screws are needed to assemble the phalanxes together. DC motors with planetary gear trains are connected to the input shafts through universal joints in order to compensate small misalignments between the axes of motors and input shafts. The three motors can be only operated simultaneously. The palm permits significant passive motions of to adjust itself to size and shape of grasped objects. The maximum grasping force is about 10 N. Even if the LARM Hand 1 is equipped with force sensors, DC motors can be controlled only in open loop by means of a low-cost commercial PLC Siemens LOGO! (PLC LOGO!,2007).

A prototype of LARM Hand 2 is shown in Fig.8. It is composed of three fingers having the size of an average human index. The phalanxes and palm are made of aluminum alloy. Pins and input shafts are made of brass alloy. Several screws are needed to assemble the phalanxes together. Two conical gears connect each input shaft with its own DC motor. The three motors with planetary gear trains can be only operated simultaneously. The maximum grasping force is about 8 N. Even if the LARM Hand 2 is equipped with force sensors, DC motors can be controlled only in open loop by means of a PLC Siemens LOGO! (PLC LOGO!, 2007).

A multi-objective optimization process has been carried out for one finger of LARM Hand 3 in order to achieve optimal human-like motion of the phalanxes, and minimal power consumption under several design constraints. The LARM Hand 3 (Fig.9) is composed of three fingers having the size of an average human index. The phalanxes and palm are made of aluminum alloy. Pins and input shafts are made of brass alloy. Several screws are needed to assemble the phalanxes together. DC motors with planetary gear trains and encoders are directly connected to the input shafts. DC motors can be controlled independently in close loop with force feedback. The maximum grasping force is about 10 N. LARM Hand 3 is operated via an user-friendly virtual instrument in LabView environment. But, DC motors require expansive amplifiers and a National Instruments motion control board, (National Instruments homepage, 2007).

LARM Hand 4 (Fig.1) is composed of three fingers being 1.5 times bigger than an average human index. The shape of each phalanx has been carefully designed to be more human-like, have a wider contact surface for the force sensors, higher stiffness, lower weight. The phalanxes and palm are made of aluminum alloy. Pins and input shafts are made of brass alloy. Screws are no more needed to assemble the phalanxes together since they are built in a single piece. Two conical gears connect each input shaft with its own DC motor. The maximum grasping force is about 15 N. LARM Hand 4 could be easily equipped with more or less than three fingers just by adding or removing one independent module that is made of a finger with its own DC motor. DC motors can be controlled independently in close loop by means of a PLC Siemens LOGO! (PLC LOGO!, 2007).

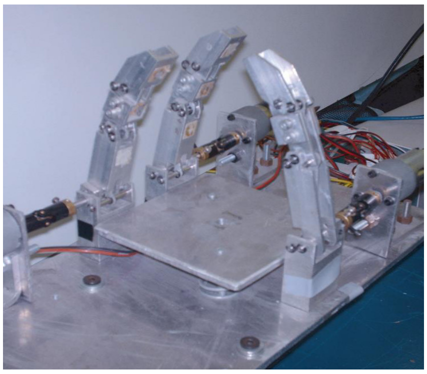


Fig. 7. A built prototype of LARM Hand 1 at LARM in Cassino.

Fig. 8. A built prototype of LARM Hand 2 at LARM in Cassino.

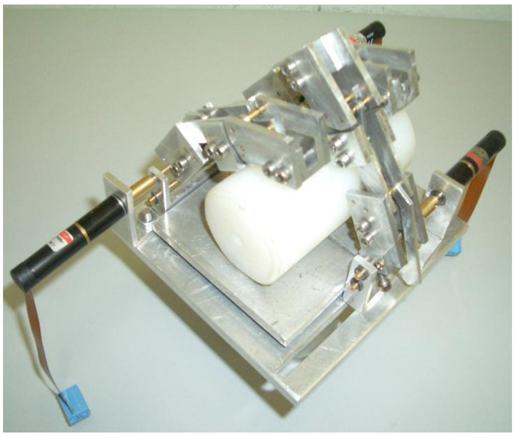
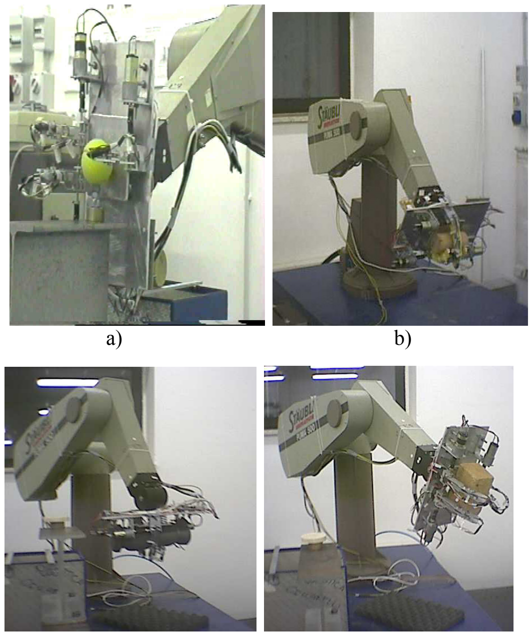


Fig. 9. A built prototype of LARM Hand 3 at LARM in Cassino.

5. OPERATION TASKS FOR LARM HAND

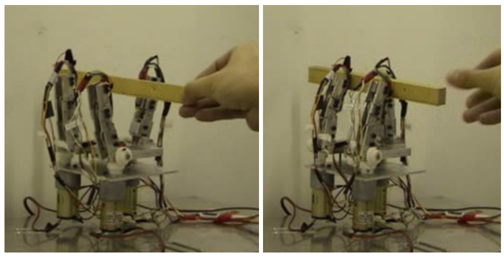
LARM Hand prototypes have been tested for various operation tasks with objects of wood, plastic, aluminium having various shapes and sizes (ranging from 10 mm to 50 mm). For example, Fig. 10 shows a prototype of LARM Hand 1 attached to the wrist of a robot PUMA while grasping a tennis ball (Fig.10a), a cylinder of wood with radius r=50 mm (Fig.10b), a cylinder of teflon with radius r=30 mm (Fig.10c), a cube of wood with side l=60 mm (Fig.10d). Figure 11 shows a prototype of LARM Hand 2 while is performing a tip grasping of a thin box of wood having side l=10 mm.

Figure 12 shows a prototype of LARM Hand 3 while grasping a balloon filled with flower by using a position control algorithm with force feedback. This control algorithm can be very useful for grasping delicate objects or for quickly react to external disturbing forces. For example, Fig.13 shows the plots of the grasping force while a random external force is applied to one finger (at about 28 s). The control algorithm quickly brings the grasping force back to the desired value of 3 N. Dynamic simulations. Further details on control algorithms and dynamic behavior of LARM Hand 3 can be found in (Carbone, et al., 2007).



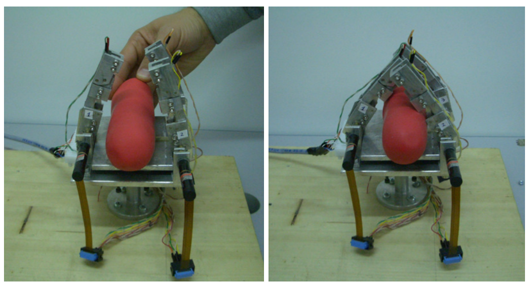
c) d)

Fig. 10. A prototype of LARM Hand 1 attached to the wrist of a robot PUMA 562: a) grasping a tennis ball; b) grasping a cylinder of wood with radius r=50 mm; c) grasping a cylinder of teflon with radius r=30 mm; d) grasping a cube of wood with side l=60 mm.



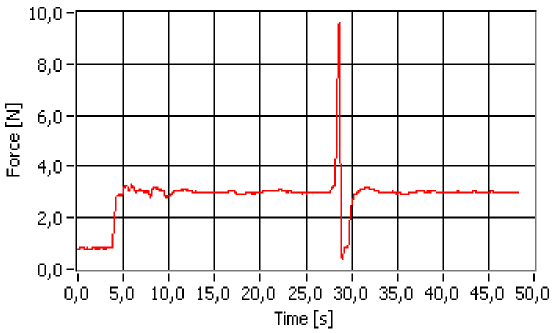
a) b)

Fig. 11. A prototype of LARM Hand 2 while grasping a thin box of wood with side l=10 mm: a) approaching motion; b) firm grasping.



a) b)

Fig. 12. Main phases of a tests carried out by using the position control with force feedback: a) positioning the object on the palm ; b) grasping the object.



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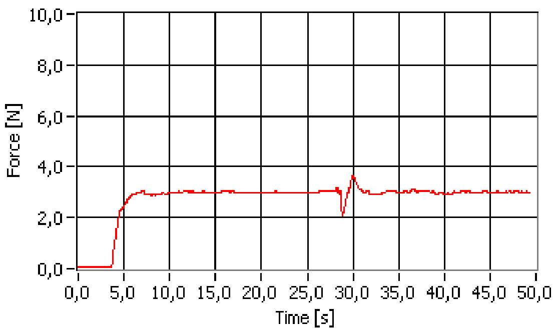

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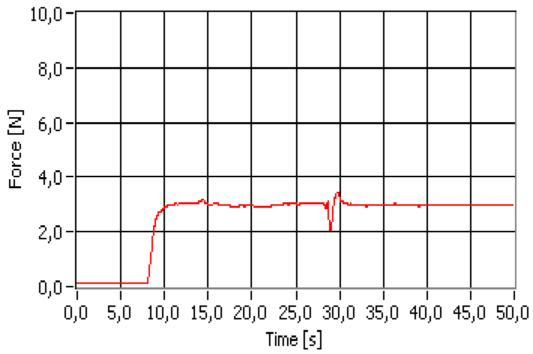
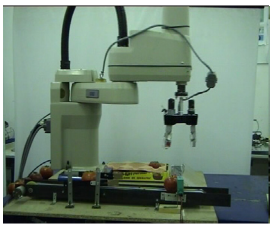


c)

Fig. 13. Measured grasping forces during the grasping of a ballon filled with flour in Fig.12 (when the position control with force feedback is used and a random impulsive force is applied on finger 1 at about 28s): d): a) sensor on finger 1; b) sensor on finger 2; c) sensor on finger 3.

Figure 14 shows a solution for automated packaging of tomatoes by using a prototype of LARM Hand 4. This application has been selected also because tomatoes are very delicate. Thus, force control become very useful in this case.



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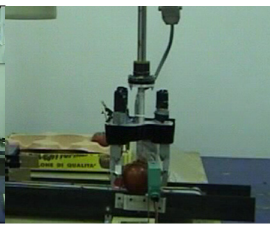

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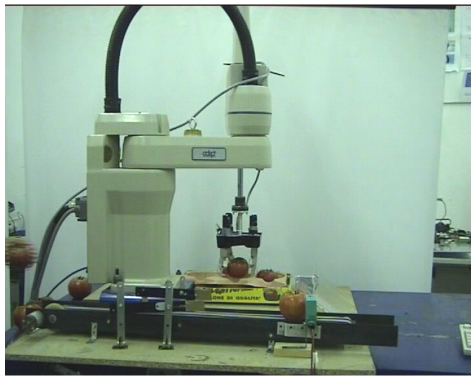

c)

Fig. 14. Packaging tomatoes with LARM Hand 4 and a SCARA Adept Cobra robot: a) approaching a tomato on a conveyor belt; b) grasping a tomato; c) handling a tomato.

6. CONCLUSIONS

This papers describes main issues for designing a low-cost easy-operation robotic hand by referring to LARM Hand prototypes. The design evolution of LARM Hand from version 1 to 4 is described by focusing to the peculiarities of each prototype. Advantages and drawbacks of LARM Hand design are described also attempting to propose suitable design improvements. A novel design for the driving mechanism with underactuation properties is proposed. Feasible operation tasks are presented for each prototype in order to better clarify operation performances and peculiarities of LARM Hand prototypes.

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