Low-Cost Robots for Research and Teaching Activities

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Low-Cost Robots for Research and Teaching Activities

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ABSTRACT
Increase robot utilization may be viewed in term of low-cost designs and operations, which are based on the use of products from the market for the robot components. Low-cost robots are related to new emerging application areas. The market components give the possibility to build robots at a low price but they also reduce the capability of robots to specific tasks. Low-cost robots can be also operated in a simpler way compared to the typical industrial robots. In this paper, an overview is presented on low-cost robots by discussing basic characteristics, applications, and motivation for a future success. The importance of low-cost robots can be recognized in the fact that they can be available everywhere at different level of cost and complexity. Therefore, the aim of the paper is to suggest the use of low-cost robots both for teaching and investigation to any teacher and researcher in any Institution with the possibility to achieve significant results both in teaching and research activities. Particular attention has been addressed to research and teaching activities in University Institutions with the aim to stress the fundamental role of engineers formation in Robotics by using low-cost robots with even novel solutions for. Examples of a successful activity by using low-cost robots have been illustrated as those developed at LARM, the Laboratory of Robotics and Mechatronics in Cassino, Italy.

Keywords : Robotics, Low-Cost Robots, Robot Design, Experimental Robotics, Teaching.

LOW-COST ROBOTS

A robot can be defined as a flexible versatile system whose basic components are, Fig.1:
- a mechanical structure or manipulator, which is the mechanical architecture that performs the manipulative tasks and/or interaction with the environment;
- a power unit, which provides the necessary energy to the system in a proper form and level (in the case of electric energy, generally it is the connection to the electric network);
- a sensor equipment, which can be inside and outside the manipulator, and consists of sensors that are useful to detect the manipulator state and environment characteristics;
- a control unit, which has the purpose to elaborate information received from the sensor equipment, to program the task operation and regulate the robot and particularly each component for a prescribed task through control signals that operate the systems;
- an additional computer equipment, which is necessary to increase the elaboration capability and controller power, but mainly to perform an artificial intelligence capability and/or autonomous behavior.

The flexibility of a robot refers to the capability of reprogramming the operation of the system for a variety of tasks. The versatility of a robot refers to the capability of performing a variety of manipulation tasks. A manipulation can be considered an operation of the manipulator architecture in order to move a grasped object or the manipulator extremity. Consequently, the design and operation of a robot requires integration of many different systems with a multi-discipline mechatronic approach.

Low-cost robots can be identified as those robots whose cost is at low level but also the components are taken from the market. Consequently, they have the main characteristics of being of simple design, easy operation, and with limited programming capability so that generally they can be devoted to specific tasks for easy manipulations.

However an estimation of cost of a robot can vary from time to time and from architecture to architecture. But nevertheless a robot can be considered a low-cost robot when its cost is considerable less than that one of other comparable industrial robots and its components are taken from the market of common Automation. Therefore, a low-cost robot can even have a complex architecture. Examples are shown throughout the paper.

Since the beginning of '90s attention has been addressed to low-cost robots as a promising evolution of industrial Automation and a simplification of robots in order to achieve a wider diffusion of robots as an industrial machinery and friendly user-oriented systems, as pointed out in (Ceccarelli 2001). Therefore, in the last decade low-cost robots have been built and can be recognized mainly in:
- robotic manipulators;
- grippers and grasping devices;

- mobile robots and walking machines;
but not yet in a whole design for humanoid robots and complex robotic systems.

Most of the recent developments for low-cost robots have been focused in the actuation system and mechanical design that are related to the main mechanisms in the robot. The simplified mechanical design has suggested and further permitted also the use of control and programming equipment with low-cost and market components from common automation systems. But the simplification of the components brings to a considerable reduction of robot capability. Nevertheless this reduction can be acceptable in many applications where the prescribed task is well defined with low level of manipulation and operation variability for duration of the robot life yet. In those cases great versatility and flexibility are not used and therefore not required. Therefore, it is recognized that in most of the cases a full versatile robot is not convenient both from financial viewpoint and technical operation efficiency. Full versatile robots can be considered for example the humanoid robots that are designed and still under development with an intense research activity for the aim to replicate human beings with their skills and even more, as reviewed in (Fukuda et al. 2001). Nevertheless, even humanoid robots can be designed and built at different levels of complexity and capability as depending of the practical purposes.

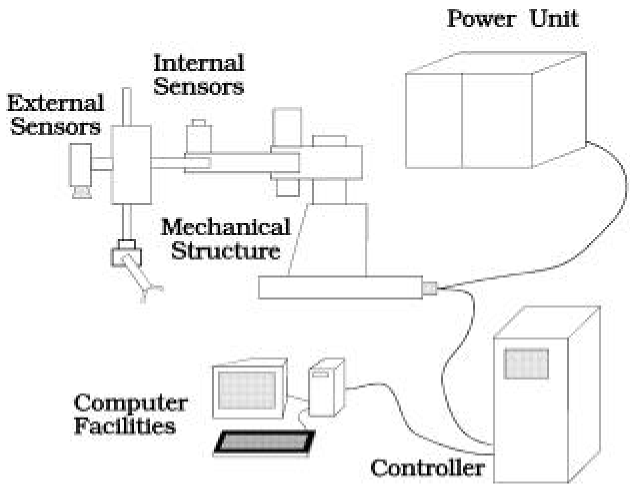
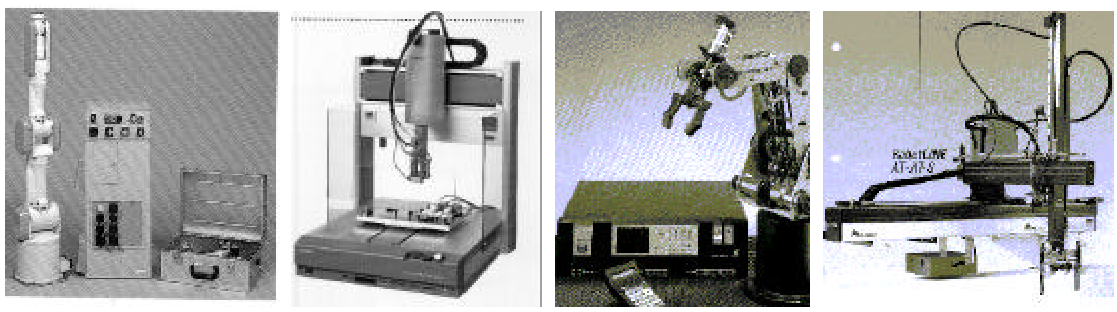


Fig.1 A robot system with basic components.

Low-cost robots can be found and will be developed more and more not only for industrial applications but even in new emerging areas for the use of robots. Thus, one can find robotic arms, which are advertised with low-cost features as main characteristics, as for example in the cases shown in Fig.2 and Table 1. A table of examples of existing low-cost robots is reported in Table 1 together with Fig.2 to show basic characteristics of low-cost robots with the aim to illustrate also the variety of solutions and characteristics that can be comparable even with those of traditional industrial robots. Indeed, the success of low-cost robots makes possible more and more applications so that they can be even considered industrial robots in some case.



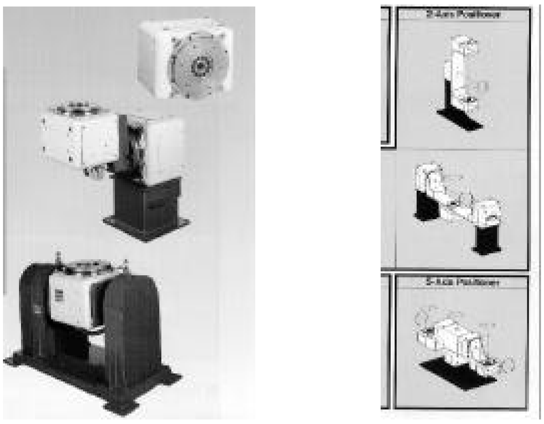
a) b) c) d)

Fig.2 Examples of robot arms with low-cost design and operation: a) PA-10 Portable General Purpose Intelligent Arm, (Mitsubishi 1998); b) Personal FA Robot CAST, (Sony 1998); c) Scorbot-ER V, (Eshed Robotec 1995); d) Robot Line S-ST-STD, (Moretto 1999).

Table 1 - Basic performances of the low-cost robots in Fig.2

low-cost robot figure of reference	PA-10 Fig.2 a)	CAST Fig.2 b)	Scorbot-ER V Fig.2 b)	Robot Line Fig.2 b)
arm weight (N)	343	490	1020	392
payload (N)	98	196	98	245
number of axes	7	4	5	3
actuators	AC servo motors	pulse motors	DC servo motors	pneumatic pistons
max speed (mm/sec)	1550	100	600	420
repeatability (mm)	0.1	0.02	0.5	not available
max reach (mm)	950	100	610	550

In Fig.2 a) a portable robot arm that has been designed in the late '80s is shown with its basic components with a light design for an easy operation. The robot CAST of Fig.2 b) is compact and easy to operate for many applications for small manipulations of small products. The Scorbot arm of Fig. 2 c) is a low-cost robot that was designed for teaching purposes, but it has been successfully applied in industrial applications for manipulating small pieces. Its mechanical design is based on transmissions with market components. The robot arm of Fig. 2 d) is an example of the renewed interest on pneumatic actuated robotic arms for fast movements but limited to specific applications. In addition the case of Fig.2 d) is an example of a new compact design with a very easy programming capability.



a) b)

Fig.3 Modules for robotic architectures with low-cost features, the case of Pana Robo Peripherals (Panasonic 1998): a) modules; b) illustrative assembling.

The renewed attention to low-cost systems has brought back to the market robot arms with a design of first generation, i.e. with pneumatic actuation and a very compact mechanical design, as the example of Fig. 2 d). But the new solutions may have interesting performances in comparison with other designs mainly in term of movement velocity, as shown in Table 1.

From the examples of Fig.2 one can deduce that low-cost robots can be built with any simple architecture having specific characteristics. In fact, one can observe no limitations in the design of low-cost robots not only as robotic arms but even within other robotic designs, as walking machines, grippers, and robotic work cells.

Another peculiar solution is the development of modular architectures by using basic modules, as in the case shown in Fig.3. Assembling modules is based on the idea to develop market robot components that are useful to build robotic systems as one can do with an automatic system.

MOTIVATION AND APPLICATIONS FOR LOW-COST ROBOTS

Basic motivation for further work in developing low-cost robots can be recognized in requirements and needs for robots with low-cost, easy operation, and simple design with market components.

The fundamental motivation for low-cost robots can be also advised in financial reasons, as shown in the diagrams of Fig. 4. The cost of robot use can be recognized as fruitful for manufacturing processes, which have the characteristics of being non-massive production and variable in terms of variety of products and up-dating design.

The low-cost robots expand the field of practical application of robots as clearly stressed in the plots of Fig.4, both for small and massive productions. This effect of expanding the field of application of robots is even increased by the technical features of the low-cost robots that do not require very expert operators.

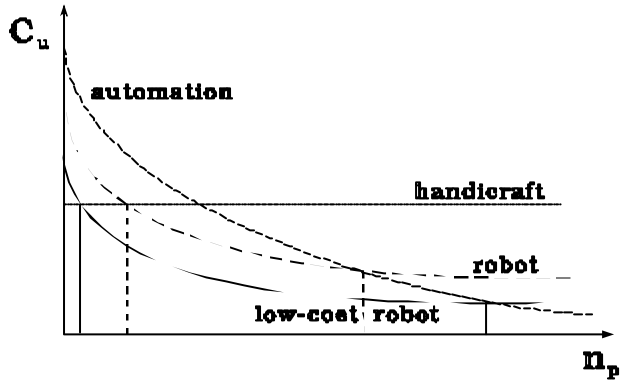


Fig.4 Unit cost of products versus number of products in terms of different production systems.

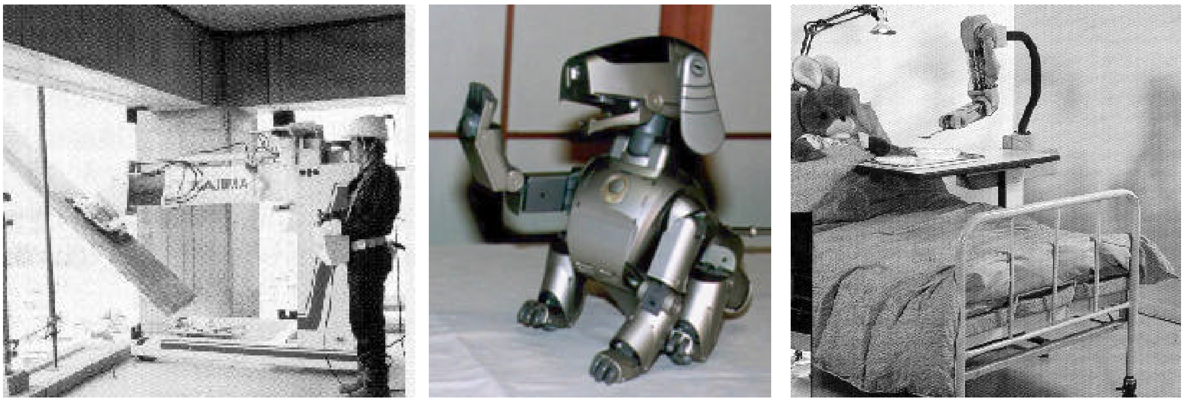
In fact, another fundamental motivation for developing low-cost robots can be advised in the psychological fact that they will be approached by plant engineers and operators as any other Automation equipment without requiring the particular care and training that the current industrial robots need. Therefore, the low-cost robots can easily find an application in the existing Automation equipment when they are recognized as additional automatic devices. In addition, the acceptance of low-cost robots in industrial plants is facilitated when the maintenance does not require particular attention, instrumentation, and expertise. Furthermore, the acceptance can be recognized easy because of the market components from the Automation systems that can be used in low-cost robots. The increase of the low-cost robot uses can be thought not only in industrial applications but also mainly in the new fields where robots are and will be applied more and more. In the fields of robot applications the simplicity of the robot design and operation is fundamental even for the robot acceptance at large. Significant is the example concerning with so-called service robots, which are robotic systems for manipulative tasks in servicing in diary actions, like house keeping and cleaning, or in medical applications, like nursery assistance in hospital or even in the house, or like surgery help to improve the quality and efficiency of surgeons' skills. A simple design (or even anthropomorphic shaped design) and easy operation of these service robots seem to be fundamental for accepting them by those users, who may have no knowledge of Robotics neither of Engineering and can be frightened by the presence of a robotic system in their environment.
A friendly oriented design of robots can be obtained by using market components, which can be familiar to non-expert robot users too. Indeed, the use of market components in robotic systems can help to obtain a low-cost robot also because they can facilitate the design, construction, operation, and maintenance, but even programming and adjustment to specific applications.
In addition, one can even see the use of market components in low-cost robots from another complementary viewpoint when one takes advantage of market components with low-cost and easy operation as a primary goal in order to build complicate systems by using their known characteristics. This last consideration makes low-cost robots as results and not goals of an engineering approach for developing popular user-oriented systems.

RESEARCH LINES

The further development of low-cost robots requires investigation and enhancement in many aspects as:
- design and operation of single market components;
- design methodologies for using market components;
- new architectures;
- exploring new applications.

Many market components are continuously under investigation in order to obtain better solutions and lower price as a demand of the market yet. But for applications in robots they require some additional care in terms of the specific use in robots, size, reprogrammability and versatility.
The specific use of market components in robots can be thought as characterized not only by installation peculiarity but also mainly by the irregularity of the operation, which affects the performances and durability of robot components. The size of the market components concerns with the installation in robots and size of the robots. Today robots are designed and built at any scale for any environment, like for example from huge size of hundred meters for airplane painting to micromechanisms of few millimeters for microassembling, from space to submarine missions, from mining works to manufacturing applications in clean rooms.
Market components are usually offered for automation applications for which reprogrammability and versatility are not asked at a great level, and therefore these components are often oriented to specific operations or tasks. Consequently, the application in robot architectures requires that the market components will be easily adapted to the several robot architectures and they should be reprogrammed during the operation, as the robot operation will need.

The above-mentioned research lines address attention of the producers of market components but even the investigators at Robotics Laboratories are involved by attempting successful applications and adaptation of the existing automatic market devices.
In addition, design methodologies are studied and investigated to design the use of market components in robotic systems on rational bases, although empirical solutions can often be very practical for successful applications in low-cost robot designs.
A greater and greater practice of market components in robot designs gives more and more experience to build new robot architectures, not only for theoretical studies but even for market sell.
The new architectures are usually designed without referring to the construction constraints. But low-cost robots require taking into account of the characteristics of the market components since the first stages of the design process for low-cost robotic systems.
In addition, the new architectures of low-cost robots can be available for new applications of robots, but they need experimental activity of validation in research laboratories in order to test the performances and even feasibility of the proposed new application.
In a recent past, the reduction of the robot cost together with a simplified operation has given the possibility to apply robots in many new different fields or at least has addressed attention and great expectation for future applications. Thus, for example robots can be used in civil engineering for transportation and installation of building elements, as shown in Fig.5 a); in entertainment area, not only as intelligent toys or maid servants but even as new pet for human beings, as shown in Fig.5 b); in medical applications to help doctors and surgeons in laborious or accurate operations or in nursery assistance, as shown in Fig.5 c). Because of the above-mentioned definition for low-cost robots the examples of Fig.5 can be considered emblematic illustrative examples of low-cost robots in different fields. They are built by using commercial components and their low-cost architecture has been successfully used as shown in Fig.5. In particular, the Aibo pet dog robot can be considered a low-cost robot because of its mechanical design and overall construction, but even because of its reduced cost when compared with the more sophisticated and expansive humanoids.
In addition, since always low-cost robots or simplified robotic systems have been used for education and training purposes. Teaching activity is a field of activity with robots that has been increased in the last decades, since it has been recognized as fundamental to form engineers and experts not only in Robotics, but in Automation at the large. Indeed, more and more attention will be given to the teaching practice with low-cost robots that can be useful to give basic expertise on robots and automatic systems with low-cost investment and short time of training.
A promising future for a wide use of low-cost robots is expected for entertainment applications, production of small simple products, and medical support, only to cite some fields with great differences and potentiality.
Summarizing, low-cost robots can be built for new applications expanding the area of robot use and enlarging the number of robot users.



a) b) c)

Fig.5 Examples of new applications of robots: a) in civil engineering, (Komatsu 1998); b) in entertainment area, (Aibo 2000); c) in medical support for nursery, (Bridgestone 1998).

TEACHING WITH LOW-COST ROBOTS

Teaching is one of the most important practices with low-cost robots since it can be used to form experts and users at the different level of expertise. In fact, even with low-cost robots one can perform very complicate manipulative tasks as well as setting up a complex workcell with many assisted automatic devices, although the performances cannot be very high, mainly in terms of accuracy and velocity.
In general, teaching activity can be carried out with low-cost robots for:

- student practice within courses on Robotics and /or Robotic Systems;
- (basic) training of users;
- development of master theses;
- laboratory experiments/validations on specific components and/or aspects.

Low-cost robots can be used in student practices to make experiences with robotic systems mainly in terms of mechanical design and programming development. Thus, in a student practice one can ask to adapt the available robot and its extremity to a specific manipulative task by using both suitable end-effectors and ad-hoc programming. This activity requires that the students have an in-depth knowledge of the available robotic system as well as understand the manipulative task in its basic features and action sequence. The familiarity with the market components can be thought helpful for the students to be confident with the low-cost robots in a short time. In addition, the programming language for the robot must be known in detail and then used properly in order to obtain a flexible programming of the robot. Nevertheless, such a student practice can be very laborious and generally it is convenient for teamwork so that the students can appreciate the multi-discipline knowledge that they need to acquire, although they can operate separately for solving sub-tasks and sub-problems of the practice.

The student practice can be conveniently oriented to perform manipulations or designing and operating robotic work cells as a final experience for many courses dealing with design, modeling, and simulation of robotic systems.

The above mentioned viewpoints for student practice can be used even to train new users of robotic systems, who need to get experience and be familiar with robots and robotic manipulations. In fact, the training can be carried out to get a user aware of the architecture and components of the robots before to attach the programming of a robotic manipulation.

Low-cost robots are usually built in such a way that is quite easy to understand the architecture and construction of a robot with its basic mechanical limits without disassembling it. Usually a low-cost robot can be used for a basic training since the limited performances of these kind of robotic systems can be useful to facilitate the teaching and learning. But one can teach by using a low-cost robot even how to exploit a robot at its extreme capability, likewise a good car driver can be in principle a successful pilot of Formula 1.

Similarly, in-depth studies can be carried out with low-cost robots in order to develop master theses, as for example on:
- the use of the robot itself;
- investigation and design on specific aspects, (for example the manipulation programming or the grasping efficiency during the manipulation);
- experimental validation of theoretical aspects and simulation results;
- experiencing new applications.

In fact, low-cost robots permit to achieve good results with no great expenses and no large duration of the preliminary work that is needed to a student to be confident with a robotic system.

In addition, laboratory experiences with low-cost robots can be very useful to form young engineers and investigators to attach problems with complex systems without great initial problems, since by using low-cost robots they can study specific problems or aspects without loss of generality.

Summarizing, teaching with low-cost robots can give interesting results and satisfactions, even in research oriented aspects, with no great expenses and complexity. Low-cost robots can be used successfully for teaching robot use and advanced Automation at the large with a basic background that can be considered world wide similar, since the low-cost robots can be available everywhere.

EXPERIENCES AT THE LABORATORY OF ROBOTICS AND MECHATRONICS IN CASSINO

Specific experiments with satisfactory results for teaching and research are illustrated by referring to teaching and research activities that has been and are carried out at LARM in Cassino. Author himself in an Institution, which can be considered an illustrative example of small dimensions and limited resources, has experienced them.

The shown results in Figs. 6 to 9 can be considered as illustrative examples of what can be done with such approach even with a small group of investigators and no great funding. In fact, the staff of LARM consists of a professor, an assistant professor, one Ph. D. student and five master students per year. Indeed, the design approach, by which robotic and mechatronic systems have been and are still investigated and experimentally studied at LARM, has been based on the aim to develop systems that can be considered as an extension of automatic systems, and therefore can be easily built and operated. Thus, at LARM design and practice activities have been carried out and are still undergoing through research project and master theses mainly with the following robotic systems, Fig.6:
- a biped walking robot;
- two-finger grippers;
- an articulated finger for human like hands;
- a parallel manipulator

Details and a list of published paper and theses on the several aspects of design, operation, and experimental validation of those robotic systems are available at the LARM web page (LARM 2000).

However, the following basic concepts can be stressed as referring to the low-cost robots concern.

a) b) c) d)

Fig.6 Robotic mechanical systems developed at LARM in Cassino: a) the biped EP-WaR (ElectroPneumatic Walking Robot); b) a test-bed two-finger gripper; c) a 1 dof articulated finger; d) the CaPaMan (Cassino Parallel Manipulator).

The EP-WaR of Fig.6 a) has been designed since 1995 with a pantograph as the basic leg mechanism, but double parallelograms have been added to obtain that a foot can move keeping a horizontal posture to facilitate the contact with the terrain and operation of the suction cups. Suction cups that are located beneath the foot, operate to grasp the terrain and avoid complex control for dynamic stability, since it can be assumed that such biped robots work usually in a structured environment with quite flat floor. The actuation system has been designed with pneumatic pistons whose operation is programmed and regulated via a standard PLC (Logic Programmable Controller), once the sequence of walking actions has been suitably analyzed. The PLC has been also used to receive signals from additional suitable sensors that can give an autonomous operation of EP -WaR from a start point to a prescribed target position.
The test-bed two-finger gripper of Fig.6 b) has been designed mainly to investigate and let students practice on the Mechanics of Grasp with two fingers and the efficiency of two-finger grippers in term of mechanical design and force control of grasping. In addition, this two-finger gripper has been used even for practical purposes in verifying the feasibility of two-finger grippers in innovative applications, as for example in a robotic harvesting of horticulture products. The two-finger gripper of Fig.6 b) has been designed by using basic mechanisms as a parallelogram linkage and a slider-crank mechanism with electropneumatic actuation that has permitted to sensorize and control the grasping force by means of commercial equipment and sensors.
The articulated finger of Fig.6 c) has been designed to mimic the human grasping but with 1 dof (degree of freedom) actuation only and an easy mechanical design by using commercial components for the gear trains and belt transmissions.
Electrical actuation for the leg mechanism, two-finger gripper, and articulated finger has been attempted and under further development.
A new design for a 3 dof parallel manipulator has been conceived in the form of the architecture of CaPaMan (Cassino Parallel Manipulator), (Ceccarelli 1997), by using four-bar linkages in the legs and a symmetric design in order to obtain a friendly user-oriented design and easy operation, although parallel manipulators may have complex design and non-intuitive operation. In fact, the CaPaMan prototype of Fig.6 d) has been machined in a small commercial machining store at a cheap cost because of the familiar four-bar mechanisms in the leg architecture. In order to improve the design approach for a low-cost robot and user-oriented mechanism, the CaPaMan design has been evolved as shown in Fig.7. A prototype of the second version CaPaMan2 has been built as shown in Fig.7 b) by replacing the sliding pairs with revolute joints in order to give a more compact design and more reliable operation by avoiding the strong influence of the friction in the sliding joints. Recently a third version of CaPaMan has been conceived as shown in Fig.7 c) by replacing the four-bar linkage with a slider crank mechanism. Its actuation can be obtained by linear pneumatic piston in order to simplify the motion programming and control, and to attempt pneumatic actuation in a parallel manipulator. Indeed, the CaPaMan design can be thought as a successful application of the low-cost robot concept in all its aspects.
In addition, following the design guidelines for low-cost robots, very recently at LARM a study of feasibility has been carried out for a low-cost humanoid robot as shown in Fig.8 by using the above-mentioned robot for the legs and trunk, and adding arms with a simple mechanical design. The mechanical design of low-cost LARM humanoid of Fig.8 is based on common mechanisms with easy mechanical design such as articulated parallelograms and pantographs, on market actuators like linear and rotative pneumatic pistons, on industrial control systems like a commercial PLC and electrovalves, on market sensors like optical sensors and force sensors. Comparing the design of the low-cost LARM

humanoid with famous humanoids (like Sony robot, Wabot, etc.) that recently have been made available in the market, one can recognize great differences in the mechanical design but also in the actuation and control system, and finally in the cost. The cost for the LARM humanoid has been estimated less that 15,000 USD.
At LARM teaching activity is carried out with student practices for the courses on Mechanics of Robots, and Regulation of Mechanical Systems, and with the development of master and Ph.D. theses. Examples of results are shown in Fig.9.

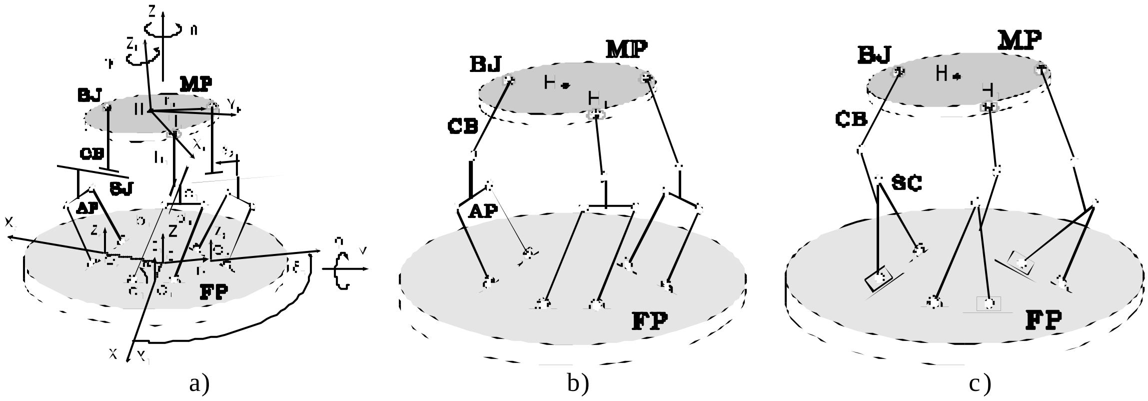


Fig.7 Evolution of the kinematic architecture of CaPaMan (Cassino Parallel Manipulator): a) the basic kinematic architecture and its design parameters for the first conception of Fig.6 d); b) the kinematic design of the second version CaPaMan 2; c) the kinematic design of a third version CaPaMan3.

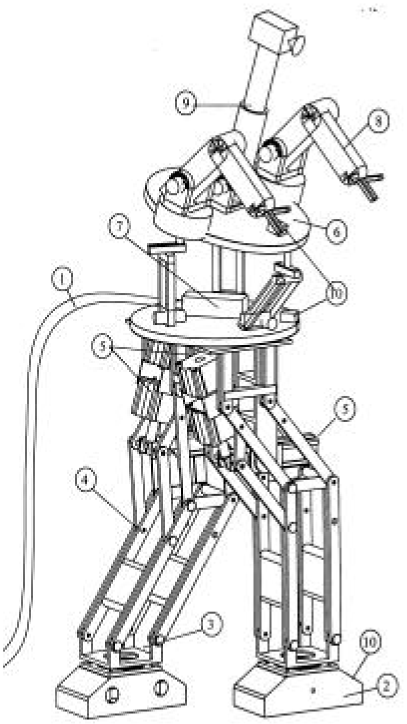
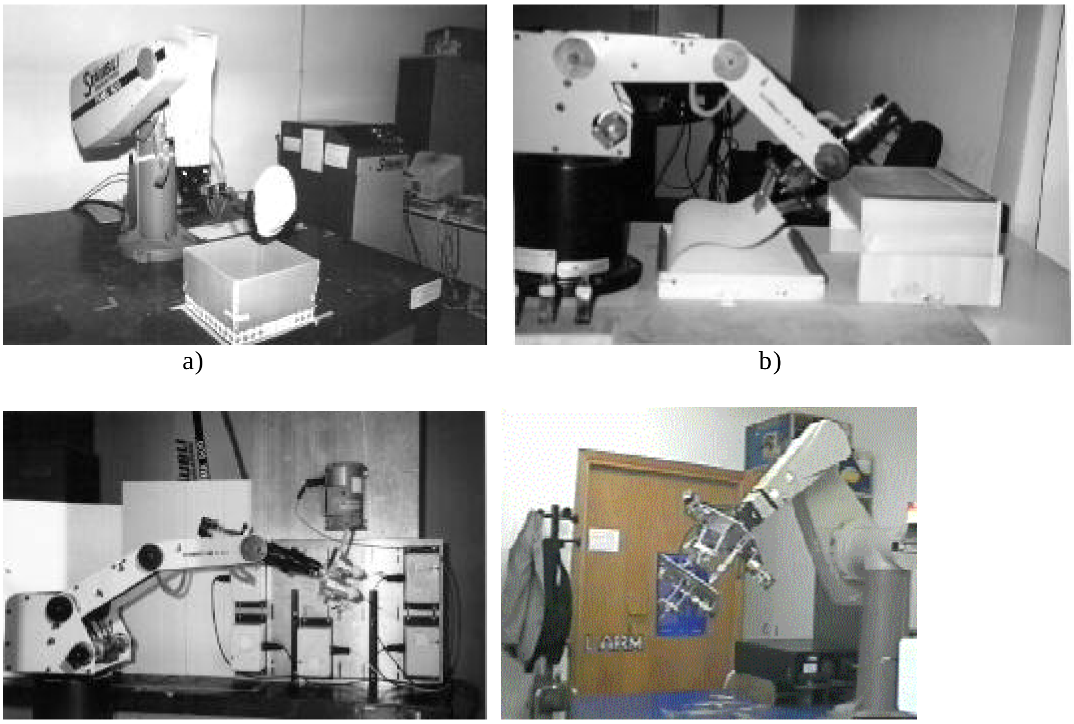


Fig.8 The mechanical design for a low-cost humanoid robot as proposed at LARM.



a) b)

c) d)

Fig. 9 Examples of results in teaching activity by using low-cost robots at LARM: a) a student practice simulating an industrial application; b) a student practice for a robot writing application; c) a validation test in a master thesis; d) a new robot architecture with a serial-parallel-serial manipulator as studied in a master thesis.

Student practices are organized by using the available robots PUMA 562 and Scorbot ER Vplus to teach the use of robots and program robots for robotic manipulations. A practice is usually scheduled for 15 to 24 students to obtain a robotic manipulation for a prescribed task that can be a simulation of an industrial application or a manipulation of interest for the students, as for example the cases shown in Fig. 9 a) and b), respectively. Usually, the students are grouped in teams of 4 to 6 students. The student team is organized to cover all the aspects concerning with the mechanical design of the robot and its gripper by developing further designs and adjustments; with the analysis and programming of the manipulation; with the experimental testing of a final acceptable solution. Thus, Fig. 9a) shows the obtained workcell in a student practice simulating the industrial process for finishing the plate production with a deposition of a suitable layer of crystalline. Figure 9 b) shows the Scorbot writing on a sheet that the robot has properly manipulated from a pile to a suitable plane for the writing.

Further activity is carried out with master theses for studies of feasibility, designs, experimental tests and validations regarding new solutions, optimizations, and new applications of robots. For example Fig.9 c) shows a validation test of CATRASYS (Cassino Tracking System) by using the Scorbot robot of Fig.2 c). CATRASYS is a new measuring system that has been conceived at LARM as based on a wire parallel manipulator for the mechanical design and on the triangularization technique for the operation. Figure 9 d) is new robot architecture of a serial-parallel-serial manipulator by using the PUMA industrial robot, CaPaMan2, and a telescopic arm. It as been conceived at LARM and several master theses have been developed and are still undergoing in order to better design and operate the system as well as to characterize its performances.

A further interesting example of a new application of a low-cost robot can be advised in the use of CaPaMan as earthquake simulator, that has been studied in master theses.

Summarizing, at LARM in Cassino most of the work in the field of Robotics has been and is carried to get experience and investigate on robotic systems with a low-cost robot design approach. This approach has not limited the research and teaching activities but has had the aim to give an easy acceptance of the proposed designs by peoples from Industry and a successful teaching to form young engineers and experts in Robotics and Automation at large.

CONCLUSIONS

In this overview the low-cost robots have been presented with their basic characteristics and future development. The fundamental motivation for an optimistic future of low-cost robots has been recognized in financial convenience, use of market components, user-oriented design and operation. These features are subject of investigation but they give also the possibility to use and investigate on low-cost robots all around the world with no limitation for available funds, instrumentation, and past experience in Robotics. In addition, the practice with low-cost robots is a suitable basic education and even training for young engineers in the fields of Automation and specifically Robotics. The content of the paper is focused both on teaching and research activities with low-cost robots since the two aspects can be thought related to each other even because in Robotics a teacher may use research equipment for course practices and novel applications. Indeed, the aim of the paper consists also to show that low-cost robots can be used successfully both in teaching and research. Thus, personal experiences of the author are shown as developed at LARM (Laboratory of Robotics and Mechatronics) in Cassino with the aim to encourage colleagues, even from small Universities, to work with low-cost robots as a fundamental area in the evolution of Robotics and Automation at large.

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The literature on Robotics is very rich and easily available on the several viewpoints and aspects. In this paper the reference list has been limited for space limits, mainly to the sources for the reported examples.

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