THE PMAR LAB IN HUMANITARIAN DEMINING EFFORT

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1 Introduction

According to current estimates, at the moment up to 90 countries throughout the world are affected by landmines [1]. Land affected by mines is inaccessible for long time (basically until fields have been cleared) and, besides mine risk education efforts, the number of injuries stays very high for long after landmine placement.
In order to give their contributions in the field, researchers in engineering disciplines can direct their efforts into two different fields: effective techniques for mine localization and clearance and mechanical tools for victims care.
Some premises are necessary. As manual mine clearing is very slow, costly and quite dangerous for personnel, the benefit of a possible introduction of automatic systems and devices is remarkable. Landmines are disseminated in ex-confrontation lines that divided military factions as river banks, abandoned industrial sites, residential areas as well as in strategically important sites or resources such as cultivable ground. Due to this large variety of operative environments, the field is open to specific environment oriented conventional techniques as well as to unconventional solutions, i.e., new locomotion principles and new localization strategies.
People living in affected areas often have no choice other then entering minefields for sustaining their families, i.e. for harvesting fruits, cultivating land, crossing the boarder for working in the near richer country, and the majority of accidents related to landmines occur when people deliberately enter such areas. For example, in Cambodia, in 2002, 33% of incidents happened while the victim was tampering with the mine for extrapolating explosive for selling, the 13% of incidents happened when the victim was farming and another 13% when he was collecting wood [2]. The need of prosthetics for upper limbs and legs in mine affected countries is high.
The effectiveness of any technique or tool aimed at developing countries depends on its acceptability by the local people who will use it. Therefore, taking into account the expectations and capabilities of local end-users, from all technical, psychological, and cultural (anthropological) points of view, is a fundamental premise to successful solutions.
This paper aims at presenting the efforts of the researchers of the PMARlab of the University of Genoa into the development of technical solutions to landmine related problems, friendly to local-users.

2 The PMARlab profile

The PMARlab is the laboratory of Design and Measurements for Automation and Robotics of the University of Genoa, Italy. The laboratory has large research interests. The main research areas are: Robotics, Intelligent Automation and Measurements. The aim of the lab is to constantly support a didactic and research environment to face the requirements of analysis and design of mechatronic systems during their whole life-cycle, with a particular attention to the development of theoretical methods. Moreover, the lab has specific skills in modeling and simulation, CAD and virtual prototyping.
From 2000, the research interests of the lab has enlarged to humanitarian issues. In particular, the lab is engaged in design of machines and systems for humanitarian demining in uneasy accessible areas covered by thick vegetation [3-5], in development of prostheses for upper limbs [6] and in design of rescue robots using unconventional locomotion, e.g., peristaltic [7].
The research work inside the laboratory is shared between researchers and students in order to reach research results and, at the same time, to form the students. Each year within the courses on Robots Mechanics and Industrial and Service Robotics a specific subject is proposed to the students and interdisciplinary teams are composed: after a deep discussion about user needs, literature proposals and market search, the design work starts. Each team works in parallel performing the design of the

specific module it is in charge of taking into account the pre-defined skeleton layout and needed interfaces.

3 Design methodology

Hereafter the service robots design methodology [8-9] adopted within the PMAR laboratory is shortly outlined. During the first part of the project, the combined knowledge, expertise and experience of the researchers and of the local field experts and practitioners are used to know user needs [10], to derive specifications and eco-requirements [11], and to set robotic devices performances. A comprehensive gathering of information from scientific literature, as well as from expert humans knowledge is done to guide in the definition of the technologies and methodologies for system design and development.
The large use of physical phenomena modelling [12], computer simulation and virtual reality testing is then scheduled, to provide the throughout characterization of the artefact life-cycle behaviour [13]; this will allow to test, at the design phase, competing architectures (of the mechanical structure, of the controller, of the sensorial system) and find out those improving the overall figure of merit. Simulation, in fact, after throughout investigation of achievements and drawbacks, offers affordable commitment, making possible to rank competing robotic solutions (Fig. 1a). The computer simulation, moreover, offers, during the system utilization phase, an important aid about the overall work management and tasks allotment; taking into account the environment-robot interactions characteristics and the system's current statics and dynamics, the simulation will be helpful to define the operating tasks. Kinematics and dynamics models are very useful for control laws setting, mainly if high performances are required and non-linear, model based control systems have to be implemented. Static models give important information about low motion intrinsic stability.

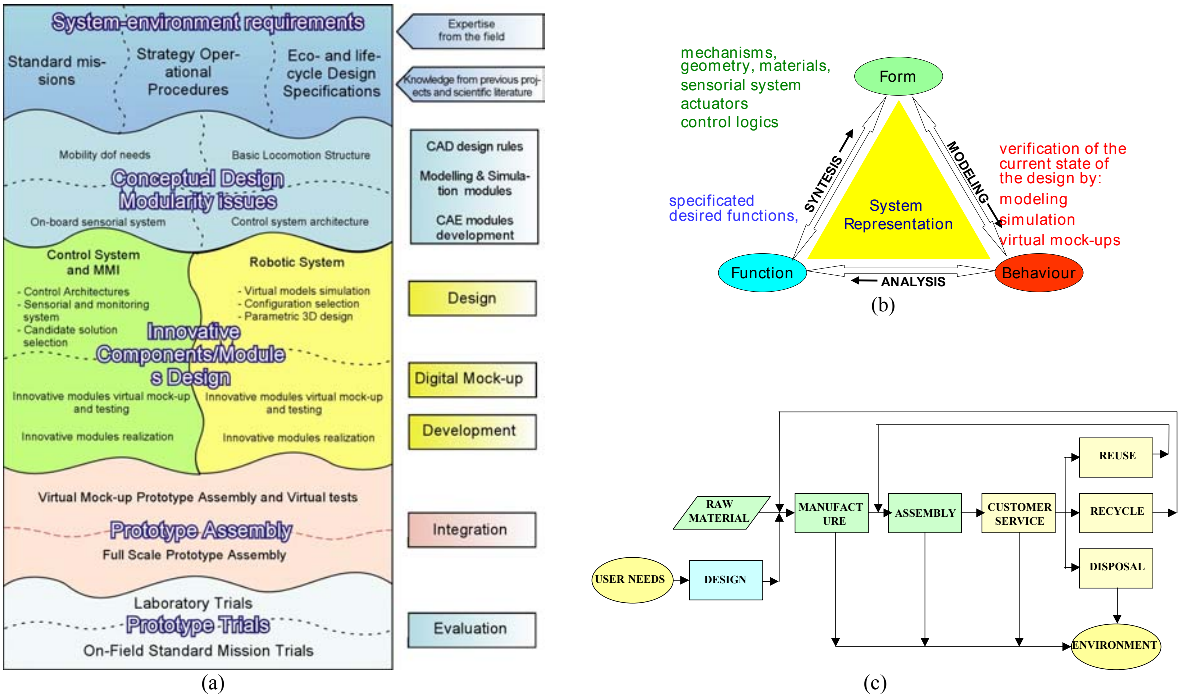


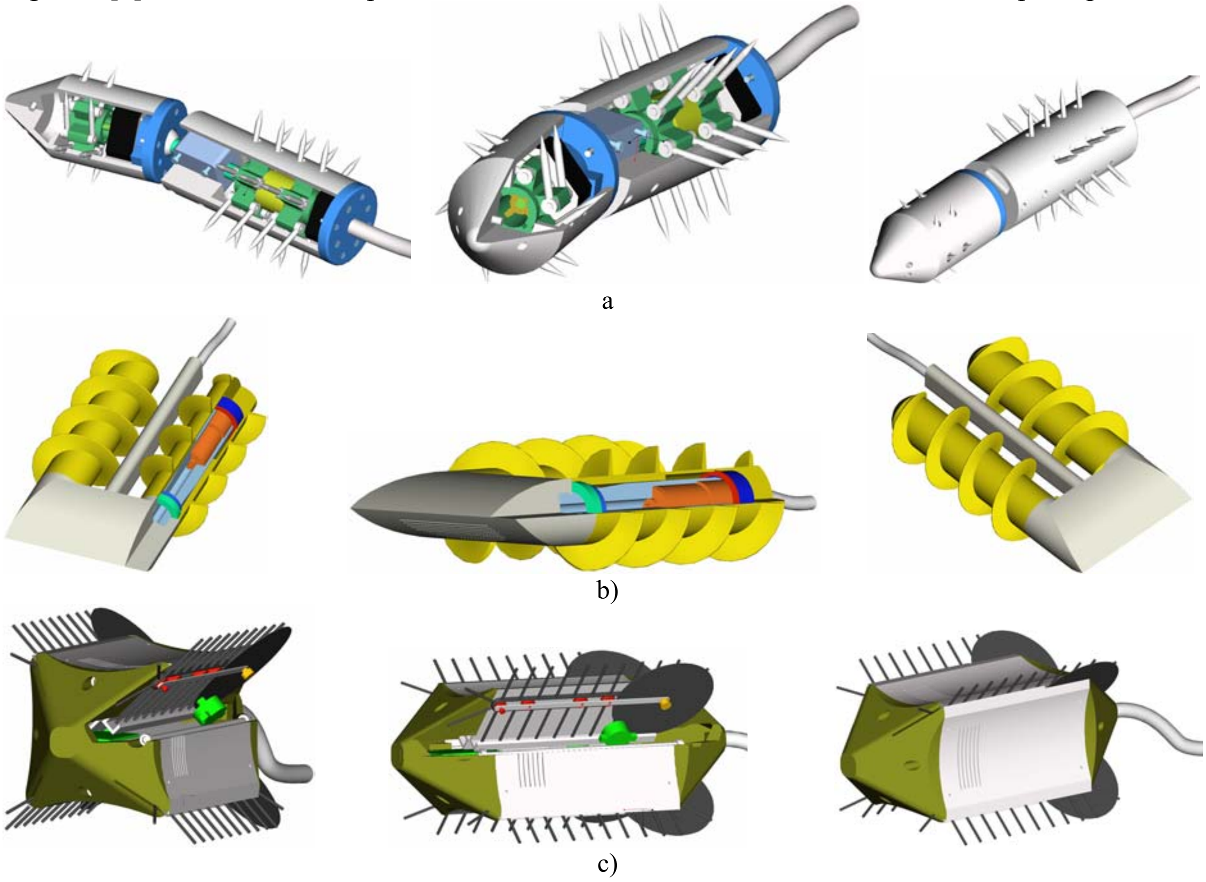
Figure 1 - Design approach and methodology (a) and relationship between form, function and behaviour of a system (b).

The mathematical models are defined and implemented in suitable software modules to be interfaced and included within the general purpose CAD/CAE packages. These modules will be useful for motion planning and mission execution purposes. Based on the selected configuration, a reduced performance digital prototype with basic control features is implemented in order to assess the system performances and to guide in further development work, while reducing risks and relevant cost of wrong physical prototypes.
Throughout all the design phases mechatronics methodology and modularity issues [14] are used to achieve an optimal design of the e-mechanical product. As a design philosophy, mechatronics serves as an integrating approach to engineering design [15]. It is important for the designer to be able to

simulate the behaviour of the current state of the design: as the design evolves its form, behaviour and function should be consistent with each other (Fig. 1b). Modularity allows economical and easy set-up and maintenance of several configuration: a modular robot is built from physically separate sub-units, each contributing to the operation of the robot.
Digital mock-up and graphic rendering, directly connected with CAD tools, enhance concept design, moving up life-cycle (Fig. 1c) assessments by virtual prototypes let, so, to devise the optimal layout and the best mechanical architecture of the robotic system [16] subject to specific cost and performance constraints. Preliminary investigation by digital mock-up is becoming the engineering mean to range the technological appropriateness and leanness between competing solutions.

4 Robots designed for rescue and landmine localization

The most of the realized and working systems for landmine localization is designed for terrains clear and, frequently, enough even and consistent. So far, effective solutions for difficult terrains, very uneven, rocky and covered by thick vegetation, are lacking.
For such difficult terrains and environments traditional machines are precluded due to size or shape and appendages such as wheels or legs may cause entrapment and failure.
The PMARlab studies robotic solutions based on biological locomotion suggested by the nature. The aim is to single out the locomotion mechanical principle and laws to be used in the design of bio inspired mechanisms.
The main applications of these bio-inspired robots are the mines localization in difficult terrains and rescue. The robots are thought as mobile devices equipped with suitable sensors in order to fulfill specific inspection tasks.
This approach led the PMARlab researchers to consider and study unconventional locomotion systems and propose innovative robotic solutions by exploiting the recalled principles of mechatronic and modular design. This section is devoted to the presentation of some of these solutions.
Figure 2 [4] shows some tele-operated robotic modules based on different locomotion principles.



a

b)

c)

Figure 2 – Virtual mock-ups of smart crawling robots for landmine localization in thick vegetation using REST (Remote Explosive Scent Tracing).

The locomotion of the module of Fig. 2a is performed by means of peristaltic movements that provide trust, while grip is provided by needles that are put inside/outside the external envelope. Figure 2b presents a module trusted by counter rotating screws, fit for muddy and sandy grounds. The module in Fig. 2c is trusted by four needle crawlers; it is equipped with suitable detaching wheels for foliage entangled in the needles of the crawlers. All these modules are powered by means of an umbilical that also includes wires for signals data. It is noteworthy that these modules have been designed in close collaboration with students involved in robotic courses.

A further activity recently launched at the PMARlab is the simultaneous design of a modular worm-like robot by the Pro/Intralink facility by PTC. Different student teams work on the same project: each one is charged of the design of a specific module. The different types of modules can be combined to satisfy different mission requirements. Typically modules are designed to perform an elementary function, such as one or more degree of freedom motion or service: e.g. trust modules (generating the peristaltic contractions-relaxations); steering modules (bending the snake to steer it in a desired direction); sensor modules (segments that host sensors, eventually endowed with some degree of freedom); head modules (with a camera, eventually carrying tools such as grippers or sampling tools).

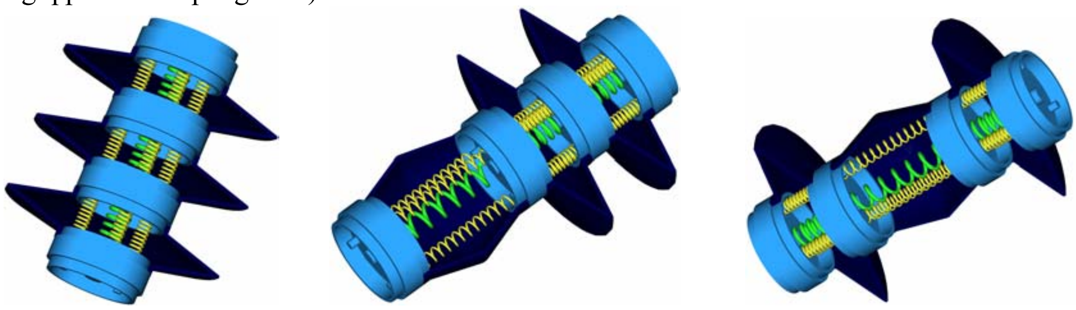


Figure 3 – Robotic modules for steering and peristaltic trust.

Figures 3 shows the motion cycle of a worm segment composed by three 3dof modules actuated by SMA springs. Each module can contract and relax or can bend in any direction to steer the snake. The central steel spring gives shear and torque rigidity to the module. The dark rubber bellows on each module preserve the inside from any dirtiness coming from the environment, such as water or ground. Moreover, these bellows provide grip by swelling and contracting depending on the distance between the two bases of the segment (that is a function of the length of the system of springs). It is possible to arrange plug&play connectors for signals and power on the interfaces in order to get smart interfacing of the modules.

Figure 4 shows some preliminary physical prototypes of the module.

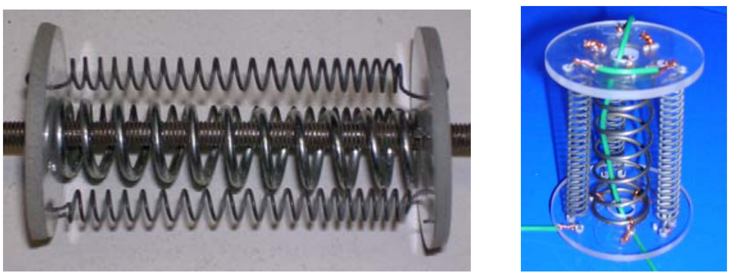


Figure 4 – Robotic modules for steering and peristaltic trust.

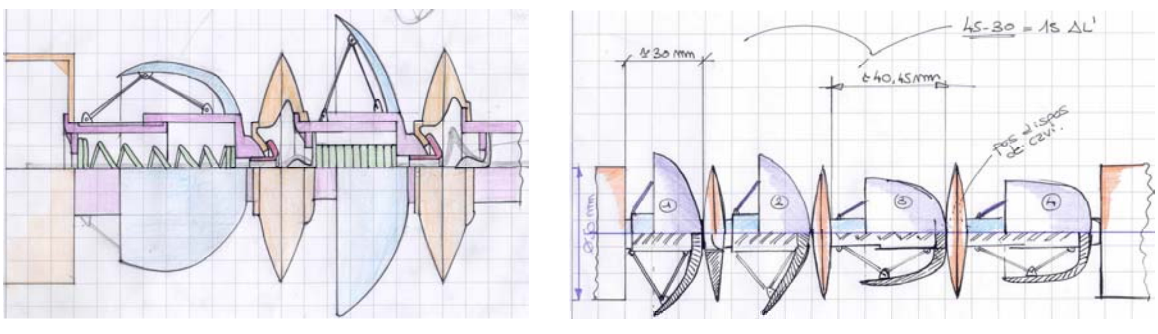


Figure 5 – Conceptual design of other new trust peristaltic modules.

Finally, Figure 5 shows the conceptual design of some innovative peristaltic modules. Small elastomeric umbrellas are opened and closed by suitable inner mechanisms with flexible joints. These umbrellas provide grip both by enlarging outside the external diameter of the snake and, mechanically, by biting the ground with the edge of the umbrella. The result is a one way movement (a preferential direction of motion, from left to right in the pictures). Once it is asked for recovering the snake, all umbrellas of the trust modules are closed and the snake is pull from the umbilical. The actuation is again by SMA elements placed inside the modules.

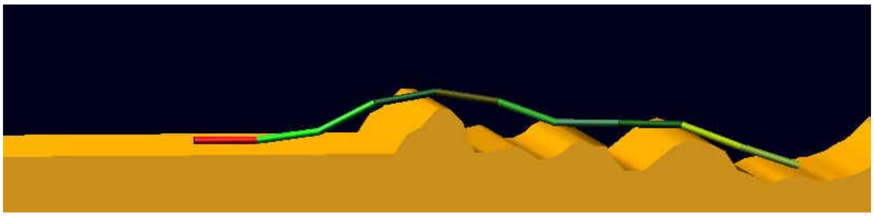


Figure 6 – Simulation of the snake robot trusted by a pushing machine; this robot has been designed for minefield area reduction by REST (Remote Explosive Scent Tracing).

Figure 6 shows the virtual mock-up of a worm robot (co-bot) [5] trusted by a pushing machine. The idea is to exploit the bending stiffness of the worm to move it forward no matter the nature of the ground and independently from the presence of obstacles that would make difficult any distributed locomotion. The body of the worm does not contain mechanics for locomotion, so it presents lot of space to host sensors. This is one of the reason why this robot can be fruitfully used for landmine area reduction by REST (Remote Explosive Scent Tracing). The sampling filters can be rolled up inside the segments and, once known the geometry of the robot and the number of segments that have been inserted, it is simple to compute the location of each sample filter with respect to the pushing machine. So doing it is possible to scan an area (by inserting the snake many times on parallel paths, collecting each time the filters and registering their location at the moment of the sampling). Once again, the researches and the design have been carried on involving students of robotic courses and one master thesis.

5 Design of prostheses for third world countries

Prostheses for people with disabilities, who live in developing countries, should be designed with requirements different from the ones for developed countries. The main characteristics of such prostheses shall be: *inexpensive to produce, purchase and maintain (local available or easy to purchase materials and technical skills), *easy to use, *effective and *designed in consultation with users in a way well suited to the users' diverse social and physical environments [17]. Other important concerns are the use of human body energy for the actuation and underactuated mechanisms to simplify the mechanics.

Figure 7 – Prototype of underactuated hand, with mechanics and actuation integrated in an elastomeric structural matrix.

Figure 7 gives an idea of the outcomes of this approach. The figure shows the underactuated hand prototype realized at the PMARlab in 2003 [6]. Main characteristics of this prototype are a very low cost, thanks to the shrewd use of everywhere-available material and very easy skills to realize it. The working principle is simple and there are no constrains about the type of actuation and control, in the first prototype body energy has been considered for actuation. This hand can fully adapt to every object shape, but it is not fit to perform manipulation tasks. In fact, dexterity is not a leading requirement compared to the others such as cost, locally production and time to use. The elastomeric polymer chosen for the structure, the TST MS 939 from Locktite (probably to be imported), is soft to the touch and its consistence reminds the one of the natural hand, this improve the acceptability from the users. The main drawbacks are a low grasping force (but this depends on the implant of the prosthesis and can be enhanced) and the weight that is a little bit heavy. Design of prostheses for third world countries-is now the subject of a PhD Thesis.

6 Conclusions

The PMAR lab carries on a branched research efforts in humanitarian demining and associated fields. In particular the PMAR lab is collaborating with: HUDEM IARP work group, EUDEM2, GICHD. At the moment we are actively involved in the study “Providing demining technology end-users need”: assessment of end-users needs for humanitarian demining technologies through extensive collection of data in the field.

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