Roboethics in Biorobotics: Discussion of Case Studies

Pericle Salvini, Cecilia Laschi *Member, IEEE*, and Paolo Dario, *Fellow, IEEE*

Abstract— **In this paper, we focus on the research activities carried out in our laboratories ARTS (Advanced Robotics Technology and Systems) and CRIM (Center for Research in MIcroengineering) of the Scuola Superiore Sant'Anna, in Pisa, Italy. We present some of the ethical issues deriving from research and development on biorobotics systems and technologies. Drawing on direct experience, we point out and discuss a few case studies taken from the following biomedical domains: surgery, personal assistance, prosthetics and bionics. The issues span from animal and human experimentation, human dignity, human replacement, to the relationship between media and scientific research, and to economic issues concerning accessibility and patenting. As mainly roboticists, the authors' aim is not to provide the reader with answers to ethical problems, but to raise questions and elicit discussion among cross-disciplinary communities.**

I. Introduction

BEFORE turning to the analyses and discussion of ethical issues, it is necessary to clarify some terminology. Basically, we need to make clear the terms biorobotics, techno-ethics and roboethics. Biorobotics is the study of biological systems, from a biomechatronic point of view, with a twofold objective. On one hand, to develop methodologies and technologies for designing and realising bio-inspired systems and devices, such as humanoid and animaloid robots. On the other hand, biorobotics second goal consists of designing and developing devices for biomedical applications, including diagnosis, surgery, rehabilitation, assistance, bionics and neuro-robotics. In what follows, we deal with the ethical implications deriving from the second objective of biorobotics.

Likewise bioethics, techno-ethics can be described as a discipline dealing with the ethical implications of technology. According to Josè Maria Gálvan, technoethics is 'a sum total of ideas that bring into evidence a system of ethical reference that justifies that profound dimension of technology as a central element in the attainment of a "finalized" perfection of man' [1]. As pointed out by Galván himself, however, such a definition implies a positive view of technology. On the contrary, it is the authors' opinion that scientific and technological progress may bring about also negative consequences. For instance, environmental change, warfare, and human relations, are all areas which might be negatively affected by technological change Therefore, we believe that the role of ethics within technological research should be to warn against the negative consequences deriving from designing, manufacturing and using technological devices.

Finally, as to roboethics, it can be considered as a branch of technoethics, dealing specifically with robotics systems and technologies. According to Gianmarco Verruggio, the inventor of the neologism, '[r]oboethics is an applied ethics whose objective is to develop scientific/cultural/technical tools that can be shared by different social groups and believes. These tools aim to promote and encourage the development of Robotics for the advancement of human society and individuals, and to help preventing its misuse against humankind' [2].

As roboticists, we have felt the need for considering the ethical issues arising from our research and development activities, since robotics technologies have evolved towards applications in environments densely populated by human beings. In some cases, such as bionics, the "environment" is the human body itself. Moreover, as roboticists we feel that our chief contribution to current research in roboethics consists in participating in multidisciplinary projects and activities, sharing our experiences with other communities of researchers and promoting public events about roboethics

Currently, our institution is participating in a European project, ETHICBOTS, coordinated by the University of Naples "Federico II" and started in 2005 [3]. The project consortium consists of a multidisciplinary group of researchers and practitioners in the fields of artificial intelligence, robotics, anthropology, moral philosophy, philosophy of science, psychology and cognitive science. The aim of the project is to identify and analyse techno-ethical issues deriving from the integration of human beings and artificial entities, both software and hardware. The results of ETHICBOTS will be used by the European Union for techno-ethical monitoring, warning, and opinion generation. As ETHICBOTS partner, we are called to contribute on the state of the art of bionics and robotics by drawing on our expertise on biorobotics research.

ETHICBOTS can be considered as the state of the art in research on techno-ethics, including also roboethics, at least at the European level. The methodology used in ETHICBOTS in order to identify and analyse techno-ethical issues is based on the definition of ethical values. The European Charter of Fundamental Rights of Human Beings is taken as the reference point. Once defined, the values are

Manuscript received February 12, 2007. This work is partially supported by the Integrated Project "NEUROBOTICS: The Fusion of Neuroscience and Robotics", funded by the European Commission in the IST-FET Programme, under Contract #001917.

Paolo Dario and Cecilia Laschi are with the ARTS Lab, Scuola Superiore Sant'Anna, Pisa, Italy.; (e-mail: {dario, cecilia}@ arts.sssup.it).

Pericle Salvini is with the Doctoral School IMT - Institutions, Markets and Technologies, Lucca, Italy. (e-mail: {pericle.salvini@imtlucca.it).

used as reference points against which to evaluate how robotic and AI technologies negatively or positively affect a particular rights.

The purpose of this paper is to point out and discuss some of the ethical implications derived from our research activities by drawing on a few case studies taken from biomedical applications. The methodological approach used in this analyses is bottom up, that is, deriving ethical issues from case studies analyses. In so doing, we hope to contribute towards the identification of further ethical implications of biorobotics research.

In section two we discuss animal experiments in the context of robotic surgery; in section three we focus on the past experience of MOVAID, a project for designing and developing a robotic assistant for human care; in section four we deal with bionics, drawing on the CYBERHAND project and pointing out the difficult relationships between researchers, on the one hand, and mass media and patients, on the other; finally, in section five we report on the ethical implications derived from the NEUROBOTICS project.

II. Biomedical Robotics applications: surgery, diagnoses, and therapy

In the field of surgery, there already exist robotic devices, such as Da Vinci (Intuitive Surgical Inc.) and Zeus (Computer Motion Inc.), for Minimally Invasive Surgery, as well as for knee and hip replacement, such as Acrobot (Acrobot Company Ltd.) or Caspar (U.R.S. – Ortho GmbH), respectively. These devices are already market products and are used in many hospitals worldwide. Basically, the presence of robots in the operating theatre is motivated by the possibility to enhance the surgeon's dexterity, improving his/her precision and accuracy, and reducing the patient's recovery time. However, the "grand challenge" for robotic surgery is to allow for new surgical techniques which go beyond human possibilities.

The design and development of biomedical robotic devices for diagnosis, therapy and surgery has been one of the main goal of our research activities. Many research projects in which our labs have been, and currently are, involved are devoted to designing and developing such innovative biomedical devices. Among the most relevant and innovative projects in the field of surgical robotics are ARES and EMILOC.

The objective of ARES – which stands for Assembling Reconfigurable Endoluminal Surgical system and has started in 2006 – is to investigate a customizable self assembled and self reconfigurable robot for the gastrointestinal tract, able to adapt its configuration to the specific site of intervention and to the task that must be executed. The modules are introduced inside the body through oral ingestion, injection or inhalation. ARES is based on new and revolutionary diagnostic, therapeutic and surgical approach: from outside to inside the patient's body [4].

EMILOC is the acronym of Endoscopic MIcrocapsule LOcomotion and Control. The project, founded by the South Korean government, has started in 2004 and is coordinated by Intelligent Microsystem Center (IMC) Seoul. The goal is to design a disposable and swallowable autonomous robotic capsule, for wireless intraluminal explorations. A group of researchers at CRIM lab is collaborating with IMC for developing the autonomous robotic capsule. The capsule is endowed with a bioinspired locomotion system and is controllable by the outside. A camera allows surgeons to explore the gastro intestinal tract of interest. [5]. Whereas ARES has just started and results are expected not earlier than a few years time, EMILOC has already produced a prototype that has undergone in-vivo tests on animals.

There are a large number of noteworthy ethical remarks to be made about surgical robots and biomedical applications in general. A first, and positive consideration, is that these robots are meant to improve the quality of life, by providing surgeons with new medical tools, reducing recovering times and pain for patients. However, to improve the quality of life, dignity and health of human beings should go hand in hand with making such improvements available to everyone.

Unfortunately, very often high-tech is equivalent to high-costs, mainly due to patenting rights: i.e. fees have to be paid to the patent holders. The challenge, therefore, is to realize high-tech but low-costs devices so as not to exacerbate differences between rich and poor. Nevertheless, how to encourage scientific progress and at the same time grant fair access to new technologies, especially in the health care system? As to this, it is interesting to read the opinion of the European Group on Ethics (EGE) which believes that in some cases compulsory licence can be an appropriate solution: '[t]he EGE considers that the recourse to compulsory licence should be encouraged when the access to diagnostic and treatment is blocked by misuses of patent rights and stresses the fact that it is the responsibility of the States to establish legal procedure for the delivery of compulsory licence and to examine if fair access to health care justify such a procedure' [6].

These are just a few and general ethical implications; to provide an exhaustive list would be too ambitious for the objective of this paper. On the contrary, we prefer to narrow the focus to a specific ethical issues: i.e. animal rights. During the experimental phase of the capsule, in EMILOC, in-vivo tests on pigs were performed in collaboration with the partners in Tuebingen, Germany. As reported by the colleagues who participated in the clinical trials, strict regulations surround animal experiments and extreme care in respecting those regulations is used by the people involved in the experiments.

Drawing on our experience in scientific research, in particular in the field of surgical robots, where animal experiments are often needed, we have identified the following ethical questions: "What are the scientific goals that *justify* the use of special methodologies? In other words, what are the research objectives that *do not justify* the use of special methodologies, such as animal experimentations?". Secondly: "How important it is to apply a special methodology in research? In other words, are there any *alternative to traditional scientific methodologies* that can be used to validate a certain theory or a certain application?".

On the whole, we believe that it is ethically sensible to avoid animal experiments for developing robotic prototypes when performances can still be evaluated using artificial bio mimetic set ups or, at least, by conducting ex-vivo tests using animal parts taken from butchers. As a matter of fact, due to the ambitious goal of the ARES project, it was decided to avoid both in-vivo or ex-vivo animal and human experiments, and instead to perform trials using a virtual simulation of the human body.

As to the second question – about alternative methodologies – we found extremely relevant the activities of the ECVAM, the European Center for the Validation of Alternative Methods. The Center was created in 1991 in response to a Directive (86/609/EEC) on the protection of animals used for experimental and other scientific purposes. According to such directive, 'the Commission and the Member States should *actively support* the development, validation and acceptance of methods which could *reduce*, *refine* or *replace* the use of laboratory animals' [7]. Among the duties of ECVAM are:

1. To coordinate the validation of alternative test methods at the European Union level.
2. To act as a focal point for the exchange of information on the development of alternative test methods.
3. To set up, maintain and manage a data base on alternative procedures.
4. To promote dialogue between legislators, industries, biomedical scientists, consumer organizations and animal welfare groups, with a view to the development, validation and international recognition of alternative test methods.

The ECVAM is mainly focused on finding alternative methodologies in the field of pharmacological experimentation. However, applications could be extended to biomedical robotics too. In addition to ethical motivations, there are also economic and scientific reasons behind the realization of artificial biomimetic set-pus. Animal experiments are expensive and imply long procedures before approval (i.e. bureaucracy); moreover, sometimes tests with animals do not provide effective results due to the complexity of the animal model. Alternative experimental methodologies, therefore, may give researchers an additional tool, quicker and cheaper than animal experiments, but of the same scientific value. The use of alternative methodologies will also contribute to rationalise the use of animal experiments in scientific research and to counter a common behaviour among scientific researchers, i.e. to abuse of the animal model, just because "ready to use", and to change the widespread practice of considering animal experiments as a way to give authority to scientific work.

III. Assistant Robots in Human Care

Personal robots for the assistance of elderly and disable people is another major application domain of biomedical robotics. Looking at demographic trends for the next years one realises that Italy and many industrialised countries suffer of ageing population problem, a problem endemic to rich countries. One of the solutions proposed by the robotics community is to design and develop personal robots capable of helping elderly and disabled people to regain autonomy and ensure satisfactory quality of life. Some of the benefits expected by such approach are: restoring, partially, independence and autonomy; reducing work load for nurses and relatives; economic savings for individuals and government; and finally ensuring satisfactory quality of life for elderly and disabled. Nowadays, there exist many prototypes of robotic caregivers such as Pearl (by the University of Pittsburgh and Carnegie Mellon University, USA), Caro-o-bot II (by Fraunhofer Institute for Manufacturing Engineering and Automation, Stuttgart, Germany), and RI-MAN (by Riken's Bio-Mimetic Control Research Center); and there are also few commercial products, such as CareBot™ MSR 3.4 produced by GeckoSystems.

However, notwithstanding the efforts made in this field, it is still unclear whether or not robots for personal assistance will ever achieve a high degree of social pervasiveness. This is mainly due to functionality, high costs, safety issues and, finally, but not the least, and ethical acceptability.

In this section, we will give an account of the MOVAID EU project, in which the authors were directly involved. MOVAID, MObility and actiVity AssIstance System for the Disabled, started in 1994 and finished in 1997. It consisted of a system comprising fixed workstations (PCs) and a mobile robotic unit able to navigate in the house avoiding unexpected obstacles and to grasp, as well as manipulate, objects. The project aimed at providing disabled people with a useful device to help them partially regain autonomy and independence. The user, by controlling the robot via a computer interface, was able to perform simple daily activities such as warming up food and cleaning the kitchen.

A prototype of the MOVAID system was developed and tested with disabled people in Italy in 1997. The results of such experimentation have been widely published in the literature [8]. On the whole, denial or acceptance of the robot depends on what the machine can or can't do. However, also social/ethical factors may determine acceptability. Before designing the MOVAID prototype a survey was carried out among disabled and elderly people. Among the questions, some were meant to ascertain whether the appearance of the robot should be anthropomorphic or machine-like. The result was that anthropomorphic robots were less socially acceptable compared to machine-like robots. For this reason, in the design of the MOVAID prototype it was chosen to give the robot a neutral appearance, very much like that of a domestic tool. Appearance is a culturally specific issues, which bears also many relations with religious beliefs. Contrary to countries like Japan, where robots are highly accepted by people, in Western countries, due to religious and to a popular culture rich of fearful monsters, anthropomorphic robots are not easily accepted. Furthermore, the MOVAID project produced also another interesting result. The user's level of involvement in the task (level of robot autonomy) was determinant for the acceptance of the robot-assistant. Finally, an ethical issue emerged during the survey in the form of a question: is it ethical to design robotic assistants? Actually, many of the people involved in the survey shared a common feeling about the robotic assistant: namely that it could increase the social isolation in which they already lived. According to the users' psychology, there seems to be a clear difference in accepting the technical help between elderly (in the frequent condition of solitude) and younger or handicapped. The elderly do not easily accept efforts to understand and rely on technical help. This comes, of course, from the general tendency to refuse innovation, but also from the fact that *the need of "help" is very frequently just an "alibi" to receive human help, that often means just to receive a visit and chat with somebody*. Some of the comments provided by the participants in the questionnaire point out a general mistrust in the real technical performance, a sort of "fear" for depersonalisation of their personal assistance. The users expressed their preference in research on medical solutions to the disability itself. For instance, the following are a few answers given by users during the survey: 'can be helpful, give autonomy, don't neglect human side'; 'scary because they will substitute the human being'; 'must not replace human help'; 'hope they will never replace human being'; 'no robot will ever replace the humans'; 'useful but cold'. These results can be compared with those obtained by a more recent survey carried out during the "Robotics" exhibition at the Swiss National Exhibition Expo.02, in Switzerland, which counted over 2000 participants. The result was quite the same of that of MOVAID project: the people participating in the survey were positive for a robot to regain independence when they could no longer fulfil daily tasks', but 'fell most autonomous when assisted by human helper opposed to robotic aid'. The authors of the survey explain that among the possible causes, there is the *'fear that robot care-giver will amplify the user's social isolation'* [9].

IV. PROSTHETICS

Among the prosthetic devices currently available, cochlear implants and upper and lower limb prostheses or orthotic devices are the most popular. Research on developing artificial organs, such as hearts (AbioCor by AbioMed) is still at the level of clinical trials. In this section, we focus on the ethical and social issues brought about by prosthetic devices. In particular, we report on CYBERHAND, a EU project started in 2002 and coordinated by the authors' group. The main objective of CYBERHAND is to increase the basic knowledge about neural regeneration and sensory-motor control of the hand in humans and to exploit this knowledge to develop a new kind of hand prosthesis. Indeed, the CYBERHAND project can be considered as a breakthrough in the field of prosthetic hands, since it aimed at providing sensory feed-back and at achieving control by processing efferent neural signals, and not by EMG signals, as it is for the hand prostheses currently available in the market [10]. The CYBERHAND project has finished and by the end of 2007, the first acute implant of electrodes on human patients will be carried out in Italy.

A first ethical statement about the CYBERHAND project regards the decision to use peripheral instead of cortical implants. As a matter of fact, according to the team, it is not ethically acceptable nor justifiable, in terms of costs/benefits for the patient, to use cortical implants on amputee. However, such a decision was also determined by scientific as well as "historical" reasons. From a scientific standpoint, peripheral implants are better for providing sensory feed-back to the user in a natural way [11]. Moreover, this approach is consistent with the project team's commitment in fostering research dealing with peripheral and non invasive techniques.

In the following, we focus on the relationships between scientific researchers, on the one hand, and mass media and patients on the other. Apparently, this issue seems to be less salient if compared to the ethical implications derived from choosing between peripheral or cortical implants or performing in-vivo clinical trials on human beings. Nevertheless, we believe that the experience derived from the CYBERHAND project on this topic may have relevant implications for ethical research.

Since the beginning, the CYBERHAND project has received a widespread coverage by the mass media, especially via press and television: from reports on Disney Channel to broadcasts on main international news programs (BBC, RAI, TSR, etc.). This gave CYBERHAND international diffusion and raised the expectations of many amputees. Notwithstanding the efforts made by the CYBERHAND team to provide final users with accurate and transparent information about the objectives and expected results of the project, the risk of creating false expectations was not completely avoided. This is a very common problem for scientific researchers in general, but especially for those working in the biomedical field. Very often, scientific researchers have ambitious goals, and may be difficult for them to communicate in understandable ways with journalists, final users and non experts audiences. Developing the capabilities to interfacing and managing the relationships with both the final users and the mass media becomes a crucial point in the education of researchers.

The relationship with patients is fundamental for getting to know the specific clinical problem that the researcher intend to solve. Nevertheless, since final users are usually people in need, in order to communicate with them, researchers need to be prepared, possibly drawing on the help of psychologists. From the final users' point of view, the only thing that matter when communicating with researchers is to know *when* the results will be *available* and *usable* for them. Moreover, scientific honesty obliges researchers to pay attention on how they describe the results of the projects and to be as transparent as possible about the benefits, limitations and possible risks of their scientific research. In CYBERHAND the involvement of final users has been an integral part of the project, essential for the accomplishment of the scientific goal. There have been many collaborations with public associations of disabled people and extreme care was given to preparing researchers to deal with patients.

As to mass media, researchers must be aware of the possible risks of creating false expectation on final users when interfacing with mass media. It is the researcher's choice, therefore, to decide whether or not to interface with media. A critical decision for researchers is also to decide when to make available information to the public opinion, namely before having tangible results or only when results are obtained. An alternative to mass media are scientific journals. However, it is worth bearing in mind, that mass media can play also a positive and useful role in scientific research, especially by creating critical mass and highlighting social problems among the public opinion, for instance making more easier to get research funding. In the case of CYBERHAND, the problem of thousands of civilian amputees received unprecedented attention, and today, there exists a large community of international researchers and students gravitating around the CYBERHAND project.

V. Bionics and Brain-Machine Interfaces

The connection of biology and electronics (i.e. bionics), once the favourite topics of sci-fi novels, is nowadays a matter of fact, especially as far as prosthetic technologies are concerned.

One of the most advanced research areas in bionics consists in developing neural prostheses or Brain-Machine Interfaces (B-MI) for the integration of technology with the human central nervous system. The possibility to connect brains with computers and machines – i.e. to control artificial devices by using the brain's signals – is more and more investigated world-wide. The first experiments on brain implants using animals and humans go back to the last decade of XIX century. In 1896, the German professor Julius R. Ewald implanted and stimulated an electrode on the cortex of a dog [12]. Compared to previous works with EEG, brain implants allowed neuroscientists not only to record brain activity, but also to stimulate a particular region of the brain in order to alter the subject's behaviour.

Research on B-MI can be divided into two main scientific approaches: invasive, by the implantation of arrays of electrodes in the brain cortex; and non invasive, by adapting brain imaging techniques (like EEG, fMRI, MEG, NIRS) to detect the brain signals of a person's intentions. As to applications of neuroscience findings to robotics, encouraging results have been reached with both approaches, using animal subjects, for instance in guiding robotic systems [13]. The rationale behind current research in neural prostheses is to develop new therapeutic solutions. Electronic neural stimulation can be used to treat epilepsy, Parkinson's disease, paralysis, and other severe disorders. As we saw in the previous section, neural prostheses are currently used to restore hearing, while promising results have been obtained by using implants of electrodes for treating blindness [14-15]. There are also neural prostheses which will be soon commercially available in the market, such as Brain Gate by Cyberkinetics, an invasive B-MI designed to restore functionalities for motor impaired people Brain Gate consists of a sensor that is implanted on the motor cortex of the brain and a device that analyzes brain signals. Currently, Brain Gate is undergoing clinical trials under an Investigational Device Exemption (IDE) from the Federal Drug Administration, in USA [16].

Nevertheless, notwithstanding the promises of this innovative research field, according to neurobiologist Miguel A. L. Nicolelis, 'the full extent to which BMIs would impact human behaviour is vastly unknown'[17]. He argue that BMI have the potential to transform the brain itself. Cortical areas especially devoted to representing the robot could emerge in the brain due to repeated use of BMIs, more rapidly and extensively than traditional forms of learning.

Among the most crucial and debated ethical issues concerning research in bionics, and especially B-MI, is whether new breakthroughs will lead to *therapy*, that is the restoration of lost functions or to *enhancements*, that is, augmentation of human capabilities. Moreover, although research on B-MI can be very useful especially in those cases in which human functions are impaired by disabilities, it might become a matter of concern if used for other purposes, such as to control people's behaviour or reading their thoughts. A notorious case of misuse is the military exploitation of B-MI by CIA, with the Mind Control Research Programme, initiated in the 1950 and abandoned in the 1960. The goal was to find new methods to manipulate thoughts by using drugs but also electronic signals [18].

No surprise, therefore, if also neurosciences have become the subject of ethical analyses. Neuroethics is a new discipline 'concerned with the ethical, legal and social policy implications of neuroscience, and with aspects of neuroscience research itself' [19].

In this section, the story of the NEUROBOTICS EU project is taken as a case study. NEUROBOTICS is a European project started in 2004, due to finish in 2008, and coordinated by the author's group. The project aim is to go beyond robotics by taking advantage of the alliance with neuroscience [20]. NEUROBOTICS research goals in bionics gravitate around three main objectives, which are all based in achieving new direct links between the nervous system and robotic devices. The NEUROBOTICS seek to go beyond tele-operation, ortheses, and prostheses by producing three platforms: robotic aliases for explorations in remote and/or difficult to access environments, a smart exoskeleton for improving accuracy, endurance and strength of human arm and hand movements; a novel highly anthropomorphic arm/hand system, for limb substitution or for adoption of additional limbs.

The story of NEUROBOTICS is emblematical as far as scientific research and social/ethical issues are concerned. During the negotiation phase, the EU Unit C3, Ethics and Science, requested an ethical review of the project proposal. The EU ethical panel raised a number of ethical issues about the objectives and methodology of the project and in particular regarding potential misuses of the technology (e.g.) warfare, enhancement of the able-bodied, and *in vivo* experiments on non human primates. To address the ethical issues raised by the Ethical Panel a new Work Package (WP15) was added in the NEUROBOTICS work plan. The new workpackage is specifically devoted to the analyses of the bioethical, technoethical and societal issues arising in the framework of the project. The main objectives of WP15 are:

1) To monitor the experimental protocols and methodologies according to the European and national regulations.

2) To analyze the ethical impact of human augmentation.

3) To investigate and define an appropriate ethical and methodological framework for exploring the relationships between robotics, neuroscience, and ethics in a broad sense.

A methodology for the generation of ethical questions was developed by the NEUROBOTICS consortium and applied to the activities carried out in project. Drawing on the Charter of Fundamental Rights of the EU, ethical issues were identified taking into account the following general question: "in which way will the **effects** of NEUROBOTICS **results** and **methods** affect this particular fundamental **right**?".

Beyond the methodological results obtained by WP 15, it is also worth mentioning the many activities derived from NEUROBOITCS. In order to discuss the ethical issues in a wider cultural context, the authors launched initiatives involving experts in different disciplines and different countries, like the Italy-Japan Workshop on Humanoids – A Techno-Ontological Approach held in Tokyo (Japan) in 2001 [21], the IEEE RAS TC on Roboethics founded in 2004 [22], the ICRA Workshop on Roboethics held in Barcelona (Spain) in 2005 [23] and many more. From an initial problem, ethics, and has been turned into an important area of investigation, which is now receiving attention and interest all over the world.

VI. Conclusion

In this paper, we presented a few case studies about roboethics in biorobotics. In writing this paper, we realised to have replied to an ethical question we often ask ourselves, concerning our "social and ethical responsibility" in managing public funding for research: "What doing with all this (public) money?" Which expectations from these projects? As it appears from what has been reported so far, the answer to this question lies in the ambitious scientific goals carried out in our laboratories, which are all devoted to solving scientific problems linked to medical research.

Moreover, in participating and promoting cross-disciplinary researcher and activities on ethics, we believe to contribute towards the education and design of the new engineers of the 21st Century. As pointed out by Maria Teresa Russo, 'the ethical issue of technology is an issue of technicians' ethical education' [24]. Indeed, among the qualities of the new engineers we have envisioned there is also a strong expertise and attention to social and ethical problems [25].

Acknowledgment

This paper has many contributors, who are all the colleagues and professors involved in the projects and the activities reported in the case studies. We would like to thanks all of them. In particular, special thanks go to Lucia Beccai and Franco Zaccone, for their help with CYBERHAND; Paolo Corradi for the part concerning animal experiments; Arianna Menciassi and Oliver Tonet for providing important remarks on surgical robots and finally Giancarlo Teti, Vito Monaco and Benedetta Cesqui for their feed-back.

References

[1] J.M. Galván, "On technoethics," *IEEE Robotics & Automation Magazine*, December 2003 [Online]. Available www.usc.urbe.it/html/php/galvan/technotehics%20ieee%20tradotto.pdf.

[2] G. Verruggio, "The birth of roboethics," *ICRA 2005*, IEEE International Conference on Robotics and Automation Workshop on Robo-Ethics, Barcelona, April 18, 2005

[3] http://ethicbots.na.infn.it/

[4] www.ares-nest.org

[5] A. Moglia, A. Menciassi, M.O. Schurr and P. Dario, "Wireless capsule endosopy: from diagnostic devices to multipurpose robotic systems," *Biomed Micordevices*, Dec., 2006

[6] The European Group on Ethics makes public in Brussels its opinion on the "Ethical aspects of patenting inventions involving human stem cells", Brussels, 7 May, 2002, [Online]. Available: http://europa.eu.int/comm/european_group_ethics

[7] ECVAM, European Center for the Validation of Alternative Methods [Online]. Available http://ecvam.jrc.it/index.htm

[8] P. Dario, E. Guglielmelli, C. Laschi, G. Teti, "MOVAID: a personal robot in everyday life of disabled and elderly people," *Technology and Disability*, Volume 10, Number 2, Pages: 77 - 93, 1999.

[9] K. Arras and D. Cerqui, "Do we want to share our lives and bodies with robots? A 2000-people survey," Technical Report Nr. 0605-001 Autonomous Systems Lab Swiss Federal Institute of Technology, EPFL, June 2005.

[10] http://www.cyberhand.org/

[11] S. Micera, M.C. Carrozza, L. Beccai, F. Vecchi, P. Dario, "Hybrid Bionic Systems for the Replacement of Hand Function," *Proceedings of the IEEE*, Vol. 94, No. 9, September 2006.

[12] Keiper A., (2006, October) "The Age of Neuroelectronics," *The New Atlantis*, Vol. Issue, [Online]. Available: http://www.thenewatlantis.com/archive/

[13] M. Nicolelis, D. Dimitrov, J. Carmena, R. Crist, G. Lehew, J. Kralik and S. Wise, "Chronic, multisite, multielectrode recordings in

macaque monkeys," Proceedings of the National Academy of the USA, Vol. 100, No. 19, 2003.
[14] J. Rizzo, J. Wyatt, M. Humayun, E. DeJuan, W. Liu, A. Chow, R. Eckmiller, E. Zrenner, T. Yagi, and G. Abrams, "Retinal Prosthesis: An encouraging first decade with major challenges ahead," *Ophthalmology*, Vol. 108, No. 1, 2001.
[15] W. Dobelle, "Artificial vision for the blind by connecting a television camera to the visual cortex," ASAIO Journal, Vol. 46, 2000.
[16] Cyberkinetics Neurotechnology Systems Inc. web-site [Online]. Available http://www.cyberkineticsinc.com/content/medicalproducts/braingate.jsp
[17] C.T. Rubin, "Man or Machine?," *The New Atlantis*, Number 4, Winter 2004, pp. 31-37.
[18] Foreign and Military Intelligence, Book 1, Final Report of the Select Committee to Study Governmental Operations with respect to Intelligence Activities United States Senate Together with Additional, Supplemental, and Separate Views, April 26, 1976, U.S. Government Printing Office, Washington, 1976, [Online]. Available http://www.aarclibrary.org/publib/church/reports/book1/contents.htm
[19] J. Illes and S.J. Bird, "Neuroethics: a modern context for ethics in neuroscience," TRENDS in Neurosciences, Vol. 29, 9, 2006.
[20] www.neurobotics.org/
[21] www-arts.sssup.it/ItalyinJapan/
[22] http://www.roboethics.org/ieee_ras_tc/index.php
[23]
[24] M.T. Russo, "Biomechatronics and Anthropology," in Ethics of Human Interaction with Robotic, Bionic, and AI Systems. Concepts and Policies, Book of Abstracts, Workshop, Istituto italiano per gli studi filosofici, Naples, October 17-18, 2006.
[25] P. Dario, EURON Workshop on Education Weingarten, Germany, July 2001.