Ethical issues involved in hybrid bionic systems research

Paolo Dario
Scuola Superiore Sant’Anna
Outline of the talk

- Bionics: the connection of natural and artificial
- Case-study 1: the CYBERHAND Project
  - Developing a hand prosthesis to be connected to the nervous system
- Case study 2: the NEUROBOTICS Project
  - Investigating the development of hybrid bionic systems
- Conclusions: the new role and ethical responsibilities of robotics researchers
Bionics: the connection of natural and artificial

- New technologies for functional substitution
- Robots as physical platforms for validating biological models
“Connecting” the Man and the Robot

Man

Brain

Nerves

Limbs

Interface

Bionic prosthesis

Brain

Nerves

Artificial limbs

Robot

Artificial Brain

Electric wires

Artificial limbs

Artificially controlled limbs
Controlling biological systems by artificial stimulation

Neural tissue as a controlling device: brain-machine interface
(S. Mussa-Ivaldi)
“Brain to Computer Interface is one of the 10 Emerging Technologies that will change the world”

*Technology Review, January/February, 2001*
Cyberhand Project
IST-FET Project #2001-35094 (01/05/2002 – 30/04/2005)

1. “Biologically Inspired” Mechatronic Hand
2. Biomimetic sensors
3. Regeneration-type electrode (efferent nerve)
4. Regeneration-type electrode (afferent nerve)
5. Implantable system for neural stimulation and recording
6. Efferent telemetric link
7. Afferent telemetric link
8. External unit for decoding patient’s intentions and for prosthesis control
9. Cognitive feedback

Regeneration-type electrodes:
3. Regeneration-type electrode (efferent nerve)
4. Regeneration-type electrode (afferent nerve)

8. Decoding patient’s intentions and Embedded closed-loop control of the artificial hand

5. Implanted neural interface:
   - ENG efferent signals recording (patient’s intention detection)
   - Afferent nerves stimulation (to provide sensory feedback to the patient)

Stump

2. Embedded Biomimetic sensors:
   - within the structure
   - within the glove

6. Receiver
7. Transmitter
CYBERHAND at-a-glance

- Starting date: May 1, 2002
- End date: April 30, 2005
- Cost: 2,500 K€
- Funding: 1,683 K€
- Partners:
  1. Scuola Superiore Sant'Anna (SSSA) - Pisa (I) – Co-ordinator
  2. INAIL RTR Center (CP-RTR) – Viareggio (I)
  3. Fraunhofer Institut für Biomedizinische Technik (FhG-IBMT) - St. Ingbert (D)
  4. Centro Nacional de Microelectronicas (CSIC-CNM) - Instituto de Microelectronica de Barcelona (E)
  5. Universidad Autonoma de Barcelona (UAB), Barcelona (E)
  6. Center for Sensory-Motor Interaction (AAU-SMI), Aalborg (DK)
Objectives of the CYBERHAND project

- **Long-Term Objective:**
  to increase the basic knowledge of neural regeneration and sensory-motor control of the hand in humans

- **Middle-Term Objective:**
  to exploit this knowledge to develop a new kind of hand prosthesis which will overcome some of the drawbacks of current hand prostheses. This new prosthesis will:
  - be felt by an amputee as the lost natural limb delivering her/him a natural sensory feedback by means of the stimulation of some specific afferent nerves;
  - be controlled in a very natural way by processing the efferent neural signals coming from the central nervous system.
The CYBERHAND System

1. Biomechatronic Hand
2. Biomimetic sensors
3. Regeneration-type electrode (afferent nerve)
4. Regeneration-type electrode (afferent nerve)
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6. Efferent telemetric link
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The CYBERHAND System

CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
The CYBERHAND prosthesis

Mechanical specifications:
- 5 fingers
- 16 DoF
- 6 DoM (1 motor integrated into the palm for thumb positioning (adduction/abduction), 5 motors integrated in the forearm for each finger (flexion/extension)
- Underactuated fingers, each driven by a single cable actuated by a motor.
- 6 DC 6V motors
- Weight: Palm+fingers about 320 gr., Socket interface (actuation and transmission system) about 700 gr.
- Maximum grasping force 45 N (expected)
- Anthropomorphic size, and kinematics

The ROBOCASA Hand
Proprioceptive sensory system

5+1 Encoders in the Actuation System

15 Embedded Joint Angle Sensors (Hall effect)
(Operational range: 0 – 90 degrees, Resolution: ~0.1 degrees).

5 cable/tendon tension sensors
(Operational range: 0 – 35 N, output characteristic: linear, resolution: ~20 mN)

CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
Exteroceptive sensory system

Three-axial strain gauge force sensors integrated in the fingertips

Three-axial force sensor

Maximum Force (N)

Fx max 4.62
Fy max 5.96
Fz max 4.62

Maximum force magnitude 8.75 N

Contact sensors at fingertips and palm (threshold ~60 - 100 mN)
Sensing technologies that can be used to observe neural activity, divided by non-invasive vs. invasive, spatial and temporal resolution.

**CYBERHAND** Project: Development of a CYBERnetic HAND prosthesis
Approach #1: Development of a Brain Computer Interface (BCI)

“A Brain Computer Interface is a communication system that does not depend on the normal brain’s output pathways of peripheral nerves and muscles”

Wolpaw, University of New York, IEEE Trans Rehab Eng 2000

Several strategies can be used to implement a BCI

IBMT, Germany, Sensors and Actuators, 2002

Utah Electrode Array, Bionic Technologies

MIT Bioinstrum Lab

Several strategies can be used to implement a BCI

CYBERHAND Project: Development of a CYBERnetic HAND prosthesis
Innovative non-invasive interfaces

- Many of the limits of the non-invasive interfaces could be overcome by combining different imaging techniques such as fMRI, EEG and MEG.
- This new “combined non-invasive cortical interface” could be used as BCI and to investigate important neuroscientific problems.

**EEG + fMR**

- MRR1p

**CYBERHAND Project: Development of a CYBERnetic HAND prosthesis**
In order to restore this bidirectional link as naturally as possible, the following aspects have to be addressed:

- Development of a selective neural interface
- Development of an effective algorithm for the extraction of patient’s intentions from the efferent neural signals
- Development of a sensory feedback by stimulating the afferent nerves in a “natural” way

Many different neural interfaces can be used:

- Intraneural electrodes
- Cuff electrodes
- Regeneration electrodes

Regeneration electrodes are interesting for their high selectivity
CYBERHAND Project: Development of a CYBERnetic HAND prosthesis

In order to control many DoFs and to deliver a sensory feedback, a good selectivity is crucial.
The NEUROBOTICS IP Project (Duration: 5 years)

The fusion of NEUROscience and RoBOTICS for augmenting human capabilities

Participants
1. SSSA: Scuola Superiore Sant'Anna, Pisa, Italy (prof. Paolo Dario) - Project Coordinator
2. CDF: Collège de France, CNRS, Paris, France (prof. Alain Berthoz)
3. DLR: Deutsches Zentrum für Luft und Raumfahrt, Oberpfaffenhofen, Germany (prof. Gerd Hirzinger)
4. IBMT: Fraunhofer Institute for Biomedical Engineering, St. Ingbert, Germany (Dr. Thomas Stieglitz)
5. KI: Karolinska Institutet, Stockholm, Sweden (prof. Sten Grillner)
6. KUL: KU Leuven, Belgium (prof. Guy Orban)
7. KTH: Kungl Tekniska Högskolan, Stockholm, Sweden (prof. Henrik Christensen)
8. NTUA: National Technical University of Athens, Greece (prof. Kostas Kyriakopoulos)
10. UAB: Universitat Autònoma de Barcelona, Spain (prof. Xavier Navarro)
11. UGDIST: University of Genova, Italy (prof. Giulio Sandini)
12. UNIPR: University of Parma, Italy (prof. Giacomo Rizzolatti)
13. UPMC: Université P. et M. Curie / INSERM U483, Paris, France (prof. Yves Burnod)

International Partners:
Brown University, Providence, RI, USA (Prof. John Donoghue)
Waseda University, Tokyo, Japan (Prof. Atsuo Takanishi)
3D representation of the domain of NEUROBOTICS
NEUROBOTICS ethical events

NEUROBOTICS proposal
(ethical aspects covered in section B.9)

NEUROBOTICS proposal submission
(April 24, 2003)

Request of an ethical review by the Unit C3,
Ethics and Science of EU
(August 6, 2003)

- Identification of countries where research will be carried out
- Identification of any important national regulations relating to the research and confirmation that the national regulations in those countries will be observed
- Confirmation that the Commission will be informed of local or national ethics approval being obtained before relevant research is carried out.
- Identification of relevant EU and International legislation and confirmation that this will be observed.
- Identification of research on humans or their tissues for which informed consent will be required together with details of the information that will be provided to those taking part and any provision made for their support and welfare.
- Indication of how data storage and handling processes will ensure patient data protection and confidentiality
- Justification for use of animals especially where this relates to non-human primates and transgenic animals - this should include justification of numbers and species and indicate clearly how the principles of reduction, refinement and replacement have been employed.
- Further information on any ethics component in the proposal, including details of those involved and clarification of the role, remit and integration of that element.
Recommendations by the Ethical Panel to the proposal

- The Panel strongly recommends a new workpackage on the ethical and social implications of the research and its potential uses. This must have wide and multidisciplinary involvement across the EU from experts and the general public.
- In particular the issues of warfare and enhancement of the able-bodied should be addressed.
- The Panel recommends that the applicants abandon Key Research Action 3.2
<table>
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<tr>
<th>Recommendations of the Ethical Panel</th>
<th>Modifications on the NEUROBOTICS Annex 1</th>
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<tr>
<td>The Panel strongly recommends a <strong>new workpackage</strong> on the ethical and social implications of the research and its potential uses. This must have wide and multidisciplinary involvement across the EU from experts and the general public.</td>
<td><strong>A new Key Research Area and a new WP have been created</strong> in order to study the complex ethical and social implications of the research that will be carried on in NEUROBOTICS framework and to prevent the misuse of the technology.</td>
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<td>In particular the issues of warfare and enhancement of the able-bodied should be addressed.</td>
<td>The new KRA and WP will also focus their activities on the prevention of the misuse of the technology enhancing the capabilities of the able-bodies persons.</td>
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<td>The Panel recommends that the applicants abandon Key Research Action 3.2</td>
<td>The KRA3.2 will NOT be activated during the first 18 months. A new detailed description of the activities on invasive cortical interfaces will be submitted to the Ethical Panel at the end of the first year.</td>
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| The Techno-Ethics committee was thought to be too restrictive in terms of scope and membership. | Two internal panels:  
- An internal panel composed of prof. Dario (SSSA), prof. Berthoz (CDF), and prof. Hirzinger (DLR)  
Two workshops:  
- The first will involve international multidisciplinary experts  
- the second event (workshop or Conference) will be public and will involve also associations of disabled persons, politicians, NGO |
Turning the ethical “problems” of NEUROBOTICS into opportunities

Techno-Ethical Committee including philosophers, theologians, anthropologists

Additional workpackage: WP15 - Ethical and Social Issues

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

“It is ethically right to withhold further development of a technology that promises to increase the quality of life for the disabled and allow them to more fully participate in European society?”
The Warwick's experience

In order to assess the usefulness, compatibility and long term operability of a microelectrode array into the median nerve, an electrode has been surgically implanted in the left arm of Prof. K. Warwick implant, as healthy volunteer.

(K. Warwick et al., The application of implant technology for cybernetic systems, Arch Neurol. 2003; 60:1369-1373)

• Is the experiment ethically right?
• Is a needful brave step for the innovation?
• Is this the way to go beyond the experiments on “non human primate”? 

Ethical Questions (1/3)

- Autonomous behavior of robots: what degree of autonomy should we give to the robot...
  - If uncontrolled robot actions can be dangerous to humans (assistance robotics)
  - If we wish to deal with cases when the user’s will is “ethically” unacceptable (robots used for military purposes)
  - Are Asimov’s Laws adequate?
  - Is realistically threatening the possibility of auto-replicating artificial entities?

- Ontological status of “cyborgs” and A.I. creatures:
  - What is machine and what is human?
  - Who may be re-programmed?
  - Can we have dissidents in a world of replicants?
Ethical Questions (2/3)

- About Robotic Assistants/Rehabilitation
  - Can humans be suitably substituted by robots in assistive tasks in which emotions and empathy are involved?
  - Is it ethically right to eliminate less qualifying jobs?

- About Augmentation
  - Is socially desirable to extend the length of working life?
  - Can augmentation generate dangerous feelings of omnipotence or powerful super-humans?

- Is robotics affordable only by rich people?
“What kind of privacy safeguards are needed if a machine can read your thoughts?

Will cognition enhancers exacerbate differences between rich and poor?

Or, instead, will they relegate social diversity to the status of historical artifact?

What happens if we deduce through neuroimaging the physiological basis for morality?

Or, and by the way, what happens to free will?”

Scientific American (Editorial), September 2003
Methodology for the identification of ethical questions

1. to start with a list of fundamental rights of humans and animals (based on the Charter of Fundamental Rights of the EU)

2. to identify the effects of the
   i. results
   ii. methods
   of the NEUROBOTICS research

3. for each fundamental right, effect of a result, effect of a method, to instantiate the following schematic question:

   in which way will the effects of NEUROBOTICS results and methods affect this particular fundamental right?
Charter of Fundamental Rights of the European Union

- the Cologne European Council (3-4 June 1999) entrusted the task of drafting the Charter to a Convention,
- the Convention held its constituent meeting in December 1999 (see annex for its composition) and adopted the draft on 2 October 2000,
- the Biarritz European Council (13-14 October 2000) unanimously approved the draft and forwarded it to the European Parliament and the Commission,
- the European Parliament gave its agreement on 14 November 2000 and the Commission on 6 December 2000,
- the Presidents of the European Parliament, the Council and the Commission signed and proclaimed the Charter on behalf of their institutions on 7 December 2000 in Nice.
Intended functions, misuses and side-effects of technology

Assuming an ‘ethically right’ use of technology, we must be aware of possible misuses and side-effects of our technological innovations.
Effects to be avoided: misuses and side-effects

- **Misuses**: improper use of technology
  - **Not voluntary** (*culpable*): improper use of technology (possibly due to ignorance of advertisements) causing involuntary damages
  - **Malicious** (*fraudulent*): voluntarily improper use of technology
Effects to be avoided: misuses and side-effects

- **Side-effects**: proper use of technology, also causing effects different than those expected
  - Not yet known
  - Only vaguely known
    - (typical of just released technologies, whose side-effects have not been yet exhaustively investigated)
  - Exhaustively known
    - (affecting people in a low percentage)
First list of NEUROBOTICS ethical issues

- Bionic technologies could be fraudulently applied for military purposes, thus limiting personal freedom and security.
- The research on hybrid bionic systems could allow one to override one’s intentions, to disrupt personal free will or manipulate thoughts and ideas.
- The research on hybrid bionic systems could threaten the personal freedom of expression and information.
- What degree of autonomy should we give to neuro-robotic platforms if uncontrolled robot actions can be dangerous to humans?
- Bionic technologies could endanger right to life for humans by, for example, creating extremely powerful super-humans.
- New-generation exoskeletons could be used for physically controlling people, thus creating new forms of slavery and forced labour.
- What is machine and what is human? Which dignity and rights do hybrid bionic systems have?
- Is it socially desirable to extend the length of working life?
- Invasive research on humans could involve inhuman or degrading procedures.
- Invasive research on humans could lead to new torture or inhumane punishment techniques.
- Can humans be suitably substituted by robots in assistive tasks in which emotions and empathy are involved?
- Will be neuro-robotics results affordable only by rich people? Will cognitive and motor enhancers exacerbate differences between rich and poor?
Events in the background

- Talks on “Techno-Ethics” by Prof. José M. Galvàn at the Scuola Superiore Sant'Anna (Pisa, Italy) in 2001 and 2002
- Panel discussion at ICRA 2002 (IEEE International Conference on Robotics and Automation), Washington DC, USA, May 2002
- Discussion at the 11th International Symposium on Robotics Research, Siena, Italy, October 2003
- Creation of an IEEE-RAS (Robotics and Automation Society) Technical Committee on RoboEthics (December 2003)
- First International Symposium on Roboethics, Sanremo, January 2004
Robotics Research in the Homeland of Renaissance Engineers
The ROBOETHICS Symposium aims to open a debate, among scientists and scholars of Sciences and Humanities, with the participation of people of goodwill, about the ethical basis which should inspire the design and development of robots.

The Symposium is an opportunity to encounter scientists and scholars committed to discuss new and sensitive problems that humankind is glimpsing at the horizon.

Philosophers, jurists, sociologists, anthropologist and moralists, together with robotic scientists, are called to contribute to lay the fundations of the Ethics in the design, development and employment of the Intelligent Machines, the Roboethics.

For this reasons the Distinguished Speakers will report their experience in a general way, with a special focus on the social and ethical problems they are identifying in their fields.

Program Commitee:
Paolo DARIO
José M. GALVÁN
Fiorella OPERTO
Jovan PATRNOGIC
Gianmarco VERUGGIO

Organiser:
Scuola di Robotica

Co-Organisers:
ARTS-Lab, Scuola Superiore Sant'Anna, Pisa, Italy
International Institute of Humanitarian Law
School of Theology, Pontifical University of the Holy Cross, Rome, Italy
ETHICBOTS project
Emerging Technoethics of Human Interaction with Communication, Bionic, robOTic Systems

Proposal for a Coordination Action on Technoethics for Call 9 of the “Science and Society” Priority

Partners:

1. University “Federico II”, Naples, Department of Physical Sciences and Department of Computer and Systems Engineering, Italy (DSF) (Guglielmo Tamburrini, Coordinator)
2. Fraunhofer Institute for Autonomous intelligent Systems, Sankt Augustin, Germany (FhG/AIS)
3. Scuola di Robotica, Genova, Italy (Scuola di Robotica)
4. Institute of Applied Philosophy, Faculty of Theology, Lugano, Switzerland (IsFA)
5. University of Reading, department of Cybernetics, UK (UNIRDG)
6. Hochschule der Medien University of Applied Sciences, Stuttgart, Germany (HdM)
7. LAAS-CNRS, Toulouse, France (CNRS)
8. Scuola Superiore Sant’Anna, Pisa, Italy (SSSA)
9. University of Pisa, Department of Philosophy, Italy (UNIPI)
10. Middlesex University, Interaction Design Centre, School of Computing, London, UK (UM)
The robotics researcher assumes a new role and new ethical responsibilities

A European model for education of the new engineer

(P. Dario, EURON Workshop on Education Weingarten, Germany, July 2001)

- Inter-disciplinarity among technical disciplines and trans-disciplinarity among engineering, life science and social and human science
- Teaching to have a global vision of problems, combined with an education in depth
- Capability of formulate a “systemic thought”
- Entrepreneur spirit
- Strong expertise and attention to social and ethical problems
New PhD Program in Biorobotics Science and Engineering

Lucca, Italy

www.imtlucca.it