Humanoids Meet Rehabilitation
Concept and Potential

Diego Torricelli and Jose L. Pons
Group of Bioengineering (GBIO), Spanish National Research Council (CSIC), Madrid, Spain

Keywords: Neurorehabilitation, Neurorobotics, Neuroscience, Motor Control.

Abstract: The development of humanoids is receiving attention in the bioengineering and health care communities, due to the high potential of bio-inspired robotics to serve as test bed of motor control theories. To this aim, Neurorobotics is gaining relevance as a way to translate the biological principles into "intelligent" machines. The result of this process is twofold: i) validating the biomechanical and neural control principles found in humans, and ii) developing more effective rehabilitation devices and strategies. In this paper, some of the main challenges of this process will be presented, with particular emphasis on the implications in diagnostic and rehabilitation of walking. As a first step in this direction, the European project H_2R aims at developing a humanoid that includes the most relevant biological principles of human locomotion and posture. This new neurorobot is expected to result in a versatile test bed of future neurorehabilitation solutions.

1 INTRODUCTION

In this paper we will present Neurorobotics, as an emerging discipline used to transfer neuroscientific principles to practical robotic devices. Before introducing Neurorobotics, we will be focusing preliminary on the term "robot". The definitions of robots that can be found in the literature are controversial, and at the same time they share similar and interesting features. A robot can be defined as "any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or functions" (Encyclopaedia Britannica online). The Merriam-Webster Dictionary gives a threefold definition of a robot: i) A machine that looks like a human being and performs various complex acts of a human being, ii) A device that automatically performs complicated often repetitive tasks, and iii) A mechanism guided by automatic controls (Merriam-Webster online).

In summary, even if it is not completely clear which distinctive features a robot should have, two key aspects can be identified. On the one hand a robot has to resemble human properties, namely appearance and/or functions. On the other hand it should perform actions in an automatically and repetitive way. These two features are at the same time different and strictly interconnected to each other. In fact, one of the primary goals of intelligence is to prevent actions to be completely automatic and repetitive, allowing adaptation to an ever-changing environment. At the same time, a repetitive and automatic behaviour is key for highly efficient movements (e.g. central pattern generators In walking). In other words, we could say that purely automatic and repetitive functions are turned into biological-like behaviours by means of intelligence.

Unrespect to the specific functional goal of a robot, the ultimate goal of robotics is to include more and more intelligent features into the automatic control of the machines. In this respect, an intelligent process can be characterized by four main areas: i) interaction with external environment (physical and cognitive), ii) data perception and absorption, iii) response to various stimuli, and iv) decision making (Neisser et al., 1998).

In rehabilitation, and more specifically in neurorehabilitation, the use of robotics has increased significantly over the last decade. Nowadays, complex robotic machines for re-training the upper and lower limbs after neurological impairments are commercially available and included in the clinical practice. Nevertheless, no clear evidence of improvements with respect to traditional manual therapy has been demonstrated so far (Lo et al,

Torricelli D. and Pons J..
Humanoids Meet Rehabilitation - Concept and Potential.
DOI: 10.5220/0004645102130217
In *Proceedings of the International Congress on Neurotechnology, Electronics and Informatics* (RoboAssist-2013), pages 213-217
ISBN: 978-989-8565-80-8

2010). The only clear advantage of robotic therapy is related to the possibility of improving the intensity of the session in time and repetitions, normally limited in manual-based sessions. The reason for the low robotic performance is still under debate. One of the possible factors is related to the poor physical and cognitive adaptability to the subject (Pons, 2008).

The ideal rehabilitation machine – similarly to what a human therapist normally does – should assist the patients only if needed, in order to ensure the completion of the task as much as possible while maximizing the active participation of the patient. Recalling the four basic features of an intelligent process previously mentioned, the ideal robot should: i) optimize the physical and cognitive interaction with the user, ii) perceive and analyse the subject status, iii) appropriately respond to the events that may occur, and iv) making the right choices when different strategies are envisioned. Unfortunately, the currently available robots are still made of rigid structures with automatic trajectory-based control, which permit very low adaptation and almost no decisional strategy implementation.

In order to fill the gap between rigidity and adaptability, i.e. between purely automatic and intelligent behaviours, some new solutions are arising in research. Among these, we found the approach based on Neurorobotics of particular interest.

2 NEUROROBOTICS

Neurorobotics can be defined as the discipline that combines Neuroscience, Robotics, and Artificial Intelligence in order to embody neural principles into physical robots. Robotics and Neurorobotics are similar, but present some crucial differences. The turning point is how to look at *functionality*. In Robotics, functionality is the primary goal, from the design to the testing phases. Instead, Neurorobotics focuses on the *biological principles* embedded in the machine, which should resemble those found in nature. Functionality, from the point of view of Neurorobotics, is considered a way of *testing* the biological principles implemented. The basic hypothesis behind this approach is that an intelligent functionality will emerge naturally from the correct implementation of an intelligent principle.

To formalize and schematize this approach, a closed-loop process can be identified, as depicted in Figure 1. As a first step in this process, neuroscientific evidences on neural mechanisms are identified and translated into robotic control algorithms. In a second step, the emergence of an intelligent behavior of the machine, i.e. a human-like or biological-like functionality, is tested and compared with the real biological behavior. At last, results are analysed, and the degree of "intelligence" of the behaviour is assessed. A final discussion on the validity of the neurophysiological hypothesis and its correct implementation is prone to generate new scientific questions and new experiments, from which a new loop can be initiated.

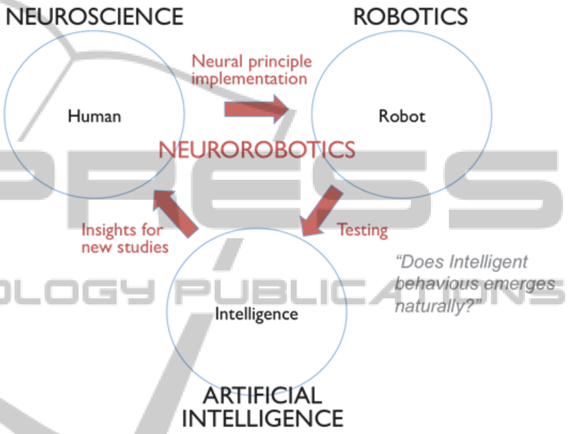

Figure 1: Neurorobotics is a closed-loop process that starts and ends in neuroscience, passing through robotic implementation and testing of intelligent behavior.

The advantage of this approach is threefold. First, it constitutes a controllable testbed for neurophysiologic principles. Secondly, using a robot as testing environment, introduces simplifications that permit to isolate the biological mechanism object of study from all the possible sources of external and not relevant disturbances (Rucci, 2007). Third, a robot is accessible all time, differently from what happens in human or animal experiments.

In conclusion, Neurorobotics can improve the range of tests and experiments that can be performed in the study of neural processes.

3 POTENTIAL FOR REHABILITATION

According to (Chiel, 1997), the brain, the body and the environment cannot be considered separately. The brain is embedded in the body, and the body in the environment. According to this holistic view of the motor control system, adaptive behaviours emerge from the close interaction of these three elements (Figure 2). This hypothesis has two logic consequences. The first is that interaction is a crucial part of the system. The second is that the whole system is much more that the sum of its parts.

As applied to Neurorobotics, these concepts have important practical implications. The first one is that neurorobots should be *real* structures that interact with *real* environment. Use of simulation, in this context, should be limited only to the first stages of robot design. In fact, the interaction between real structures (e.g. contact with the ground during walking) embeds physical phenomena that are yet to be accurately represented in simulation. Another important implication is that even very complex behaviours can be potentially studied using a few simple elements in interactions to each other (Giszter, 2001).

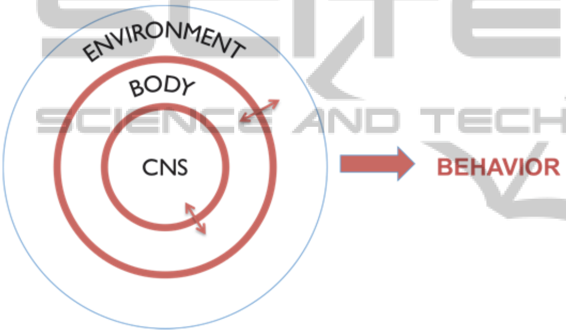

Figure 2: Holistic view of the biological motor control system and the fundamental role of the interactions in the generation of behaviours.

How can the principles of Neurorobotics be used to develop more effective rehabilitation and neurorehabilitation machines? Let's consider the case of rehabilitation of locomotion.

As opposed to a classical rehabilitation engineering approach, which aims at solving the problem in functional terms (e.g. by developing a neuroprosthesis that allows restoring gait), the neurorobotics approach is strongly based on preliminary observation of the mechanisms that emerge in a neurorobot. These mechansims are the result of the interaction between the three main elements resembling those of humans, i.e. the control system (brain), the plant (body) and the environment (Figure 3). The key point is that some of these interactions may have not been modelled previously, but emerge naturally from the correct implementation of neural control into the biomechanical structures. The effects of them can be studied in deep detail at different levels, because robotic structures offer many advantages for experimental observation with respect to human subjects.

Practically, this process includes two main actions. The first is to create a neurorobot that embeds the main known physiological principles of human locomotion. The second is to extract, from the analysis of the behaviour of the robot, clues that can be turned into design principles for rehabilitation machines.

As for the first action, i.e. the development of the neurorobot, the following main steps should be followed:

1. The basic biomechanical and neural principles of human locomotion are first translated to a human-like neurorobot, represented by a humanoid (or part of it).
2. The functionality of walking is then tested and mechanisms refined in an iterative fashion, in order to obtain intelligent behaviour, i.e. human-like walking.
3. Once stable and human-like walking is achieved, the different levels of interaction of the neurorobot (brain-body interaction, body-environment interaction) are analysed.
4. These interaction mechanisms are then formalized in order to understand the cause-effect relation between internal control and functional behaviour.

As for the second action, i.e. transferring the acquired knowledge to the rehabilitation scenario, different approaches can be envisioned. The neurorobot can be include either mechanisms of a healthy subject, or can be modified to match a specific known motor disability.

In the “healthy neurorobot” scenario, once the neurorobot is developed, the principles of actuation implemented in the machine are prone to be transferred to rehabilitation machines. For instance, feed-forward control strategies implemented in the robot can be used to implement biologically based neuro-prosthetic control algorithms. In a similar fashion, local reflex-based robotic principles, which describe the reaction of the robot joint to the interaction with the environment, may be translated into control algorithms for lower limb prostheses.

In the “pathologic robot” scenario the efforts are devoted at reproducing a specific impaired behaviour, by modifying internal control or biomechanical parameters of the robot. In this case, different rehabilitation potentialities can be identified. If the pathologic behaviour is successfully reproduced, the cause-effects relation between the affected biological principle and the functional performance can be estimated on a quantitative basis. This information can be thus converted into quantitative metrics to be used to infer the neural/biomechanical causes of a pathological function in patients.

The “healthy robot” and “pathologic robot” scenarios may be used either separately, as above described, or interactively. In the interactive approach, a healthy neurorobot can be used to compensate its pathologic counterpart. The compensative robot may be constituted by a real part (or subpart) of a healthy neurorobot, or by a sort of neural substitute (e.g. control systems representing neural prosthesis). The combined systems (pathological robot + compensative robot) are then iteratively assessed and adjusted in order to maximize the compensative action, similar to what is done during a robotic-based therapeutic process. The expected outcome of this interactive approach is to produce clues for the design and development of orthotics or exoskeletal devices.

All these levels of possible applications are reflected in Figure 3.

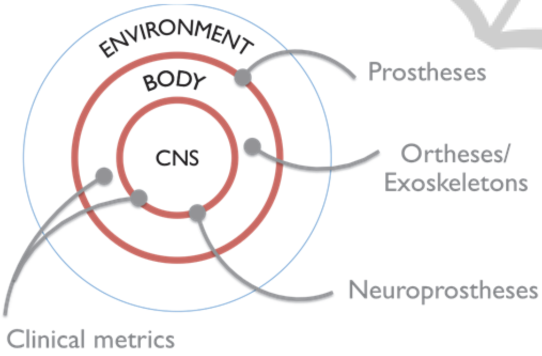

Figure 3: Interactions between elemental parts of a neurorobot are taken as inspiration for the development of rehabilitation devices.

From a technological point of view, the neurorobotic approach has two main advantages and one drwabacks. The first advantage is that most of the developmental phase does not involve experiments on patients. The second one is that a neurorobot not only is a tool for neuroscientific study, but also embodies technical solutions that may be directly transferred “as is” to the rehabilitative machine.

The main drawback is that this approach requires the availability of a real-life robot. Depending on biological principle considered, the process of design and development of a neurorobot can be very complex, time-consuming and costly.

In line with this last issue, the recently started European project H_2R “Integrated approach for the emergence of human-like locomotion” aims to develop a human-like neurorobot including the most relevant biological principles of walking and standing. If successful, this neurorobot can serve as testbed of the design procedures of innovative rehabilitative devices, as well as new clinical assessment methods, following the process above described.

4 THE H_2R PROJECT

The goal of H_2R project is to demonstrate that human-like gait and posture can emerge in a bipedal robot as a result of a combination of the most relevant biomechanical, neuromotor and cognitive mechanisms found in humans.

In order to achieve this goal, a threefold process will be adopted:

1. Understanding the key biological principles from human experiments.
2. Translating the formalized concepts into human-like bipedal robot.
3. Creating new benchmarking schemes for validating the robotic performance.

Regarding the first goal, three main biological principles will be object of investigation:

- The hypotheses of modular neuromuscular control of human movement, based on muscle synergies. This is a crucial step to understand how humans solve the problem of redundancy in the musculoskeletal system.
- The context-dependent sensor fusion process. Understanding the cognitive ability of predicting and estimating the typology of disturbances is one of the key points of human stability.
- The compliant principles of human joints and muscles. This aspect in strongly related to energy efficiency, computational burden, and natural looking motion.

Concerning the robotic development, the goal of H_2R project is to permit the inclusion in a real-life structure of the human-like neuromotor and biomechanical principles identified previously. For this reason, the neurorobot will present compliant elements in most of its degrees of freedom, and a neural-based hierarchical control architecture which permits the integration of feed-forward and feedback control strategies. The robot is expected to have human-like performance in terms of efficiency, stability and versatility.

The third goal of the project is to formalize a benchmarking scheme that can be used to assess and compare human-like skills of robotic humanoids.

We are particularly interested in testing:

- Stability during gait and posture, both in sagittal and frontal planes, during voluntary and perturbed conditions;
- Energy consumption during walking;
- Cognitive ability in predicting and anticipating disturbances, such as self-induced perturbations or unforeseen changes in the environment.

The threefold process described represents an example of the general neurorobotic process shown in Figure 1 for the case of human walking and standing. Once this process will be completed, the resulting neurorobot will be potentially made available for the design and development of new rehabilitative solutions as the ones depicted in Figure 3.

5 CONCLUSIONS

We presented the discipline of Neurorobotics as a promising approach to integrate Neuroscience, Artificial Intelligence and Robotics, to the aim of providing new tools for the study of motor control mechanisms and at the same time providing more intelligent solutions for rehabilitation.

The potential of the approach, based on the use on bio-inspired machines as test bed for neuroscientific studies, is twofold. On the one hand it permits generate evidences that may be difficult to achieve with direct experimentation on human subjects. On the other hand, the study of the interactions at different levels of a neurorobot can constitute a technological bridge between human needs and rehabilitation solutions.

As a first effort in this direction, we presented the European project H_2R, which aims at developing a neurorobot that includes the main biological principles of human locomotion and posture.

ACKNOWLEDGEMENTS

The ideas and concepts described in this paper result from the research activities of the project H_2R “Integrative Approach for the Emergence of Human-like Robot Locomotion”, Call FP7-ICT-2011-9. (ID: 60069).

REFERENCES

Encyclopaedia Britannica online, www.britannica.com / EBchecked / topic / 505818 / robot.

Merriam-Websteronline, www.merriam-webster.com / dictionary / robot.

Neisser, U., Boodoo, G., Bouchard Jr, T. J.; Boykin, A. W., Brody, N., Ceci, S. J., Halpern, D. F., Loehlin, J. C., Perloff, R., Sternberg, R. J., Others, (1998). "Intelligence: Knowns and Unknowns". *Annual Progress in Child Psychiatry and Child Development* 1997.

Albert C. Lo et al., Robot-Assisted Therapy for Long-Term Upper-Limb Impairment after Stroke. *N Engl J Med 2010*; 362:1772-1783.

Pons, J. L. (Ed.). (2008). Wearable robots: biomechatronic exoskeletons.

Rucci, M., Bullock, D., & Santini, F. (2007). Integrating robotics and neuroscience: brains for robots, bodies for brains. [Article]. *Advanced Robotics*, 21(10), 1115-1129.

Chiel, H. J., & Beer, R. D. (1997). The brain has a body: adaptive behavior emerges from interactions of nervous system, body and environment. *Trends in Neurosciences*, 20(12), 553-557.

Giszter, S. F., Moxon, K. A., Rybak, I. A., & Chapin, J. K. (2001). Neurobiological and neurorobotic approaches to control architectures for a humanoid motor system. *Robotics and Autonomous Systems*, 37(2-3), 219-235.

H2R project website, www.h2rproject.eu.