The Cybernetic can Improve the Quality of Life: An Intelligent Limb Prosthesis

R. Balvetti, M.L. Bargellini, M. Battaglia, A. Botticelli, G. Bozanceff, G.Brunetti, A.Chiapparelli, G. Casadei, A. Filippini, A. Guidoni, E. Pancotti, L. Puccia, L. Rubini, A.Tripodo, C. Zampetti.
ENEA and ENEA guest, 00044 Frascati, Italy
and
S.Brunelli, A.S.Delussu F.Paradisi, M.Traballesi
Fondazione Santa Lucia, 00100 Roma, Italy
and
A. Grandinetti
ARSEI, 84100 Salerno, Italy
and
E. Di Stanislao, R.Rosellini
ITOP, 00036 Palestrina,Italy

ABSTRACT

The paper will describe the basic elements of the cybernetic model of Synthetic Intelligence: GIASONE, and its implementation in the biomedical field, relatively to research and development of a synthetic intelligent prosthesis prototype, deepening the terms of the "dialogue" between the artificial component and the patient's intentional world.

Keywords
Cybernetic model, biological emulation, intelligent prosthesis, synthetic intelligence, artificial biomedical component.

1. INTRODUCTION

In people who use prosthesis, a considerable discomfort is generated by some physic events, as: peaks pressure; friction caused at the cellular tissue level, skin, muscle, and muscle-bone; temperature increasing; sweating increasing, etc. All this is causing a state of discomfort and consequences are an increased dropout rate which is estimated at 40% of cases. Starting with these observations we have been studying and researching for a trans-femoral prosthesis that dynamically adapts its volumetric shape to stump state in order to manage the dynamic of the pressures.

Once started the project, according to a cybernetic approach, we pushed our goal, as well, and we set out to design a prosthesis that works like a biological leg that is in dynamic continuity with the rest of the body system.

The project envisages a collaboration combining three kind of experiences: the cybernetic research in ENEA; the direct knowledge of the patient of the Fondazione Santa Lucia (Nationally renowned hospital for neuromotor rehabilitation); and the industrial competences of the ITOP (Orthopaedic Industry, which, since 1978, develops prostheses and tools for an improved quality of life).

2. PROSTHESES: STATE OF ART

Modern prosthetic devices are engineered with a modular structure so that each component can be modified separately from the others.

The main components of a standard modular prosthetic devices for AK amputations are:

- custom made socket, that realizes, in different ways depending on construction criteria, the interface between residual limb and device and may also contain liners to act as padding and/or provide suspension;
- adjustable joint, to couple and align socket with prosthetic knee joint;
- modular connection pipe to clamp knee joint with prosthetic foot;
- prosthetic foot that provides base of support, transfer weight to ground and relieve proper ankle motion during gate;
- exoskeletal finish, to improve prosthetic aesthetics, cover entire device and protect components from moisture, dust and dirt.

During 80’s and 90’s were developed a big variety of monocentric and polycentric mechanical knee joints with adjustable stance phase control developed to offer a present friction during knee flexion/extension coupled, at the end of eighties, with carbon spring foot to allow energy load and return during gait.

After development of microelectronics, bionic components got into prosthetics becoming the new technological landmark. The principle of bionic components is the perfect integration between sensors (accelerometers, load cells, gyroscopes), that relieves movements and position of the device in the space, computational algorithms that process data acquired by the sensors in order to produce an adequate response realized by the actuators (electric drives, hydraulic plungers and electro valves).

The objective of those mutual interrelationships between bionic components is to mimic the same sensorial information flow of human beings, involving central and peripheral nervous system and muscle-skeletal system.

Those principles were applied for the construction of the Ottobock C-leg (based on a linear hydraulic system as actuator) and Ossur Rheo Knee (that use a magnetorheologic system to modulate knee friction), two of the most widespread electronic prosthetic knee, and represents the base of the electronic prosthetic ankle Ossur Proprio Foot.
Nowadays prosthetic companies are working to develop and improve active motorized prosthetic articulations fighting against weight, noise and reliability of those components to offer the possibility of rise a stair or a ramp with the affected limb or step onto an obstacle in complete safety.

3. THE PROSTHESIS AND THE PATIENT

An optimal interaction between the socket of the prosthesis and the residual limb is one major determinant of mobility. Efforts should be made to minimize stump complications (Traballesi et al, 2007) and to avoid delayed prosthesis fitting, which is the main cause of increased costs of rehabilitation after amputation.
An “ideal” prosthesis should provide adequate setting not only to enable comfortable mobility, but also to ensure an adequate environment to the residual limb, thereby keeping it healthy and free of wounds to allow for a faster post-operative rehabilitation and healing process. The ideal prosthesis should reduce the pressure peaks and the shear stress on the residual limb to avoid pain and to reduce the risk of inducing or worsening skin lesions.
These mechanical insults are highly repetitive during locomotion and may damage the tissue by accumulating their individual effects. Besides, a longer exposure can likely reduce the threshold of mechanical load tolerance of the soft tissue, and high mechanical stress is the major cause of pain (Mak et al, 2001).
Gait instability may be caused also by shape and volume changes in the residual limb that leads to a poor adaptation to the socket, altering limb-socket interface pressure and increasing shear stress (Sanders 2005). These events occur even in a “mature” residual limb. This volume loss due to prosthetic use leads to an increased vertical movement of the stump within the socket named “pistoning”. This phenomenon should be minimized by a good prosthetic system that secures the socket to the amputee’s stump guaranteeing the prosthesis efficiency.

4. LIMITS OF CURRENT PROSTHESES

Despite the technological innovations in the field of bionics, currently there is a no commercial prosthetic device that simultaneously, have the knee and ankle joints, controlled by a single control system capable of processing organically all the perceptual data from the environment in order to implement, time to time, the best response for the action of movement which comes as close as possible to each physiological aspect.
Moreover, the electronics knee joints provide the only movement of flexion-extension on the sagittal plane, as well as the ankle does not allow active movements of pronation and supination or intra-extra rotation of the foot.
Besides to the inability of the prosthesis to simulate the normal biomechanics and joint function, it should be pointed also the transfer failure of intentionality by the patient, and the reception lack by the latter, of a proprioceptive feedback.
At present the electronic systems do not receive and not transmit any information to the subject.
The difference between voluntary action sought by the patient, and real action obtained through the use of prosthetic device creates a constant state of tension and dissatisfaction. The patient must adapt to the kinematic response of the external device, which exerts an action in a different manner if compared to 'healthy' limb.
Issues just described leading to a gradual reduction of ambulatory potential, until abandoning of use of the prosthesis.

5. THE PROJECT

The aim of the project is therefore to realize a prosthesis which takes into account the patient's discomfort, but also wake up the process of communication between volition and action and between action and proprioception, giving back the patient the broken cognitive relationship.
Realize a prosthesis that, autonomously, meets the intent of the individual, means to insert an artificial component in a physiological system, which constitutes a new harmonic system without discontinuity, and, as a result, to obtain a new continuity of interaction between the new system and the environment.
The final effect will be the recovery of the state of harmony before the amputation , the more the patient finds himself in the continuity of the system, the more he forgets he is wearing the prosthesis.
All of this, in the leg prosthesis, means to integrate the prosthesis into the movement cognitive process of the amputated patient, to be able to solicit and respond coherently to the context of environmental and intentional stimuli.
The continuity is achieved by restoring the previous skills, that are still present in the memory of the individual and even re-emerging into him, but not are able to trigger the movement process, because the new limb presents a solution of continuity with the rest of the body movement. This creates a sense of frustration and a following state of impotence.
To conceive the dynamics of the movement we should observe the genesis of the motor action.
A movement, a gesture of the body, before becoming the action in the environment, takes place at a level own, of the body system, as sequence of different pre-mimic shapes, that evolve as a screenplay in order to achieve the coincidence.
The body system is carried out by this scrolling of shapes and is oriented by the constant comparison between current shape and final shape.
Every shape is supported by a configuration of physic-chemical energetic field.
The difference between the current energetic configuration and the expected energetic state, creates a vectorial disequilibrium that becomes the engine to reach the coincidence.
These energetic gradients in sequence produce the thinner dynamic of movement.

The coincidence due to gradients dynamic produces the homeostasis of the system.
In order to design and generate emulation of the dynamic of the cognitive process, that oversees the movement of the leg and walking, we are employing our cybernetic model named GIASONE, already used at the research laboratories of ENEA Frascati and, with which many applications of synthetic intelligence have been made: machine tools and aids. This cybernetic approach allowed us to design and build intelligent modules. Our prosthesis will contain several intelligent modules that synergically will operate in the dynamic of the step.

6. THE PROTOTYPES FOR THE KINEMATIC OF THE MOVEMENT

The Fig. 1 shows the laboratory models built to study the kinematics of the step, analyzing in its active elements and functions: bones, joints, bearings, agonist and antagonist muscles, in order to rebuild from within the limb kinematic capabilities. A pre-existing prosthesis was equipped with the knee joint, we have designed.

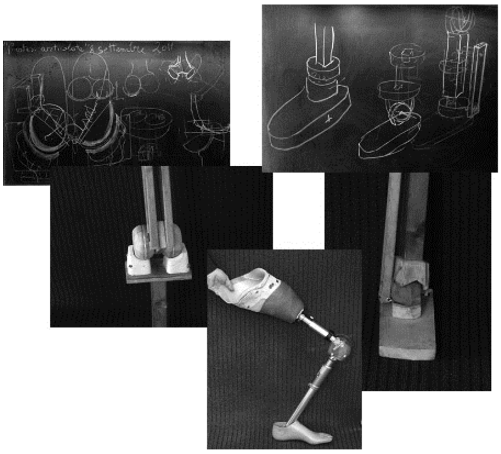

Fig.1 The prosthesis models and prototypes

The Fig. 2 shows the laboratory model which reproduces the dynamics of the fibula to the rotation of the ankle.

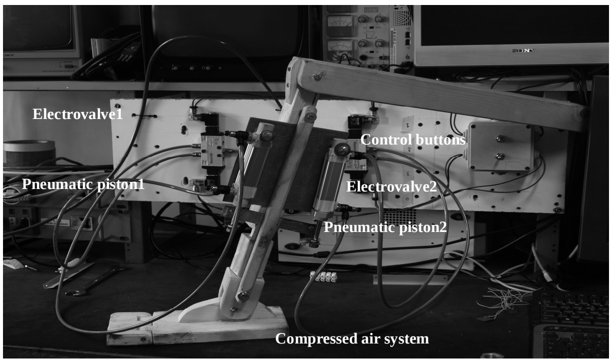

Fig.2 laboratory model for the ankle rotation

7. CONCLUSIONS

Certainly the cybernetic approach is making possible to create a bridge between the artificial parts inserted in the system to remedy any functional lack, and past memories of previous configurations. So we rely up on cybernetic approach to replace many physical disabilities.

8. REFERENCES

[1] R.F.Sup, A.Bohara, and M. GoldfarbInt, *Design and Control of a Powered Transfemoral Prosthesis,* J Rob Res. 2008 February 1; 27(2): 263–273

[2] G. Kielhofner, *Model Of Human Occupation:theory and application*, Lippincott Williams & Wilkins 2007

[3] Balvetti, M.L.Bargellini, M.Battaglia, A.Botticelli, G.Casadei, A.Filippini, A.Guidoni, E.Pancotti, L.Puccia, L.Rubini, C.Zampetti, F.Bernardo, A.Grandinetti, B.Mussi, G.Bozanceff, C.Iencenelli; *From Natural Intelligence To Synthetic Intelligence Through Cybernetic Model*, The International Symposium on Design and Research in the Artificialand the Natural Sciences: DRANS 2010 Orlando/Florida Jun.29

[4] R.Balvetti, M.L.Bargellini, M.Battaglia, A.Botticelli, G.Casadei, A.Filippini, A.Guidoni, E.Pancotti, L.Puccia, L. Rubini, C.Zampetti, F.Bernardo, A.Grandinetti, B.Mussi, G.Bozanceff, C.Iencenelli, *GIASONE:un modello cibernetico per l'autonomatica,* Società Italiana di Fisica, XCVI Congresso Nazionale (Bologna, Settembre, 2010).

[5] R.Balvetti, M.L.Bargellini, M.Battaglia, A.Botticelli, G.Bozanceff, G.Casadei, A.Filippini, A.Grandinetti, A.Guidoni, B.Mussi, E.Pancotti, L.Puccia, L.Rubini, A.Tripodo, C.Zampetti, *La visione è un processo mentale* Società Italiana di Fisica, XCVII Congresso Nazionale (L'Aquila, Settembre 2011)

[6] http://antonio.controluce.it/

[7] Robert Gailey, *Functional Value of Prosthetic Foot/Ankle Systems to the Amputee*. Journal of Prosthetics & Orthotics 2005;17(4):39-41.

[8] Martin J, Pollock A, Hettinger J. Microprocessor *Lower Limb Prothetics: Review of Current State of the Art*. Journal of Prosthetics & Orthotics 2010;22(3):183-193.

[9] Bellmann M, Schmalz T, Blumentritt S. *Comparative biomechanical analysis of current microprocessor-controlled prosthetic knee joints*. Arch Phys Med Rehabil 2010;91:644-52.

[10] Mak AF, Zhang M, Boone DA. *State-of-the-art research in lower-limb prosthetic biomechanics-socket interface: a review*. J Rehabil Res Dev. 2001; 38(2):161-74.

[11] Traballesi M, Porcacchia P, Averna T, Angioni C, Lubich S, Di Meo F, Brunelli S. *Prognostic factors in prosthetic rehabilitation of bilateral dysvascular above-knee amputee: is the stump condition an influencing factor?* Eur Med Phys.2007Mar;43(1):1-6.

[12] Sanders JE, Zachariah SG, Jacobsen AK, Fergason JR. *Changes in interface pressures and shear stresses over time on trans-tibial amputee subjects ambulating with prosthetic limbs: Comparison of diurnal and six-month differences*. J Biomech. 2005;38(8):1566-73.

ENEA: *Italian National Agency for New Technologies, Energy and Sustainable Economic Development. The Agency's activities are targeted to research, innovation technology and advanced services in the fields of energy. ENEA performs research activities and provides agency services in support to public administrations, public and private enterprises, and citizens.*

ITOP: *Orthopaedic Industry that has the mission to establish and develop tools for a better quality of life.*

Fondazione S.Lucia: *As a Scientific Institute for Hospitalisation and Treatment, the Santa Lucia Foundation carries out intensive research work in the fields of neuromotor rehabilitation and, more generally, of neuroscience.*

.