FINAL PUBLISHABLE SUMMARY REPORT

1 Project Context and Objectives

Upper limb prostheses have made considerable scientific progress in the last 20 years. This progress though is based on velocity control, which is not the best option for subconscious control. Extended Physiological Proprioception (EPP) provides position control and has been proven to be better as a control methodology for upper-limb prostheses than velocity control. EPP is difficult to implement since it requires: (a) the use of a harness or a post-amputation cineplasty surgical procedure and (b) a direct mechanical linkage (Bowden cable) between the control site and the prosthesis. For the above disadvantages, EPP was abandoned in the later years. We propose a biomechatronics-based master/slave topology, which is going to provide an EPP-equivalent control but without the use of a harness, cineplasty, or Bowden cable, see Figure 1.

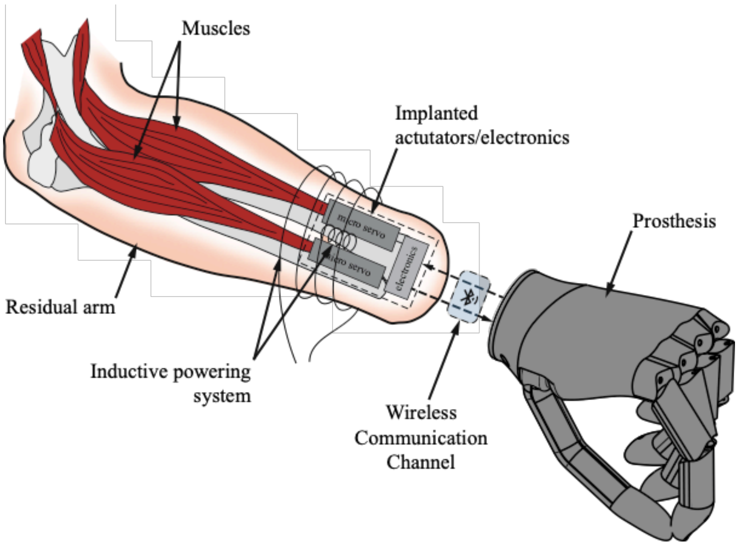

Figure 1. Biomechatronic EPP concept.

<u>Objective:</u> The objective of this project was *to develop a single DoF module of biomechatronic EPP-equivalent upper-limb prosthesis controller*. The proposed controller should not have the disadvantages of previous EPP implementations (post-amputation surgery, anaesthetic cineplasty, direct visible mechanical linkage). We believe that recent advances in robotic and sensing technology can lead us to the design and development of an EPP equivalent scheme but without the disadvantages of the post-amputation surgery, anaesthetic anchor points for control and the use of Bowden cables. We intend to use mechatronic designs in order to develop this EPP equivalent controller.

2 Work Performed

2.1 Theoretical Derivation of the Equivalent Biomechatronic EPP Model and Simulations.

Using Master / Slave teleoperation theory, the Biomechatronic EPP Controller Model was theoretically developed and was compared with the Classic EPP Controller Model (also theoretically derived). Both models were simulated using Matlab® and Simulink®.

2.2 Dspace Bench-Prototype of Biomechatronic EPP Controller

Using Matlab®, Simulink® and Dspace® fast prototyping, the Classic EPP and the proposed Biomechatronic EPP Controller along with the supported hardware and software were bench-prototyped.

2.3 Low Power Bluetooth Prototype of Biomechatronic EPP Controller

After derivation of the theoretical models, encouraging simulation results for transparency and encouraging bench-prototyped results, the standalone realization of a prototype of the proposed Biomechatronic EPP Controller using Bluetooth Low Power (BLE®) was decided and achieved. The transparency of the BLE® Biomechatronic EPP Controller was verified.

2.4 Experimental Verification & Validation

The performance of the Biomechatronic EPP Controller was compared to that of the following three other controllers including: (a) a “Classic EPP” controller, (b) an “unconnected” controller and (c) an “EMG” controller, see Figure 2. All these controllers were implemented using Matlab®, Simulink® and Dspace® fast prototyping and their performance was compared. The transparency of the Biomechatronic EPP Controller and the delays were verified and measured.

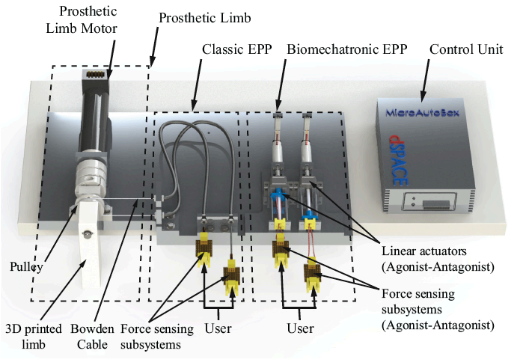

Fig. 10. Experimental setup for comparing Classic and Biomechatronic EPP.

Figure 2. Experimental setup comparing Classic and Biomechatronic EPP.

3 Significant Research Results

The transparency of the Biomechatronic EPP Controller was satisfactory at the Simulation, the Dspace® and the BLE® implementations. This means that the proposed Biomechatronic EPP Controller is *equivalent* to the Classic EPP Controller. Any additional delays introduced are under 50ms which are well under the time delays affecting reaching movements of humans.

In addition, the clinical comparison of the four Controllers: (a) a “Classic EPP” controller, (b) an “unconnected” controller and (c) an “EMG” controller, and (d) the Biomechatronic EPP controller, showed that the (d) is equivalent to (a) and even superior in some cases, see Figure 3.

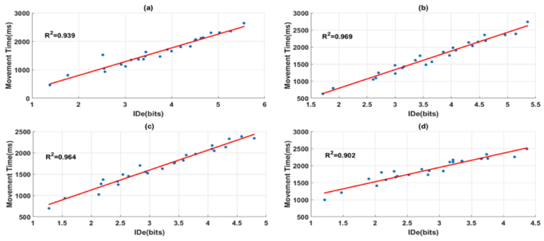

Fig. 8. The relationship between movement time (MT) and effective index of difficulty (IDe) for (a) “Biomechatronic EPP”, (b)”Classic EPP”, (c)”Unconnected” and (d) “EMG”.

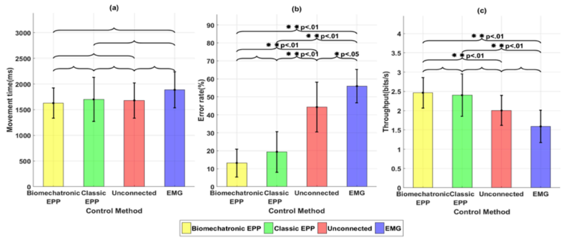

Fig. 9. Performance of control topologies across the various performance metrics (a) Movement time (b) Error rate (c) Throuhput. Pairwise comparisons are noted with brackets. Errorbars indicate standard deviations. Symbols * and ** denote a significant difference at .05 and .01 significance level, respectively.

Figure 3. Comparisons of control topologies.

Therefore, there is substantial engineering and clinical evidence that the proposed Biomechatronic EPP Controller maintains and augments the advantages of the EPP topology over EMG or unconnected controllers, while not having the disadvantages of using Bowden cables and harnesses (which was the main reason of the Classic EPP controller topology abandonment through history).

4 Potential Impact and Use

As we mentioned before, the EPP as a control scheme for upper-limb prostheses has advantages over myoelectric control in terms of proprioception (which is not supported only by previous literature but also from our validation clinical experiments), which is even more valuable for multi-DoF prosthetic controllers. It is in the best interest of the patients to revisit the proposed Biomechatronic EPP as a new alternative to myoelectric control since it provides better and subconscious control. The socioeconomic impact will be huge: better control schemas for upper-limb prostheses and therefore lower rejection rates of prosthesis adoption. This will lead with its turn to more amputees integrated into society, the ones that integrated will have better quality (subconscious) prostheses. Consequently, total lower costs for healthcare and increased economic efficiency will be an expected outcome.

5 Public Website of Project

http://csl-ep.mech.ntua.gr/index.php/projects/current-projects