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REAL-TIME COMPUTER MODELING OF A PROSTHESIS CONTROLLER BASED ON EXTENDED PHYSIOLOGICAL PROPRIOCEPTION (EPP)

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INTRODUCTION AND BACKGROUND

Extended Physiological Proprioception (EPP)

Proprioception utilizes the physiological components of the nervous and musculoskeletal systems to allow an individual to sense the position of their limbs subconsciously. By providing a rigid connection to an object this proprioceptive ability can be extended to the object and allow the user to sense the spatial location and orientation of these objects with respect to his or her body. This concept explains how a person can use a tennis racquet to hit a tennis ball without having to observe the position of the racquet during their swing or the way a blind person uses a long cane to ‘feel’ the location of objects in their surroundings.

Body-powered prostheses take advantage of this proprioceptive ability by relating the motion and position of the prosthesis to the motion and position of an intact joint of the amputee via the control cable. However, most externally powered prostheses do not have any mechanism with which to provide feedback regarding the state of the prosthesis to the proprioceptive system of the amputee. In these cases the amputee must rely on vision and other incidental sources of feedback such as motor whine and socket pressure to control their prostheses and this may place a significant cognitive load on the user.

Simpson suggested that the concept of “extended-physiological proprioception” (EPP) could be applied to externally powered prostheses [1]. He stated that, by mechanically linking the movements of an externally powered prosthetic joint (e.g., an elbow) directly to the movements of a physiological joint (e.g., the shoulder), the amputee could ‘feel’ the position of the prosthetic joint by using the proprioception inherent in the anatomical joint. Much like a body-powered prosthesis, the linkage between the two joints is able to provide feedback about the position and velocity of the prosthetic joint as well as loads that are applied to the prosthesis. The theory behind EPP control is that by directly relating the movements of the prosthetic joint to those of the anatomical joint, a prosthesis will be able to provide feedback regarding the state of the prosthesis in a manner that is physiologically appropriate in order to utilize subconscious pathways and therefore reduce the mental loading placed on the user.

Uni-directional vs. Bi-directional EPP Configurations

Two configurations exist for the implementation of EPP in an electric powered device. These configurations allow the user to control a single degree of freedom prosthetic component with either one or two control sources. Uni-directional EPP control requires only a single control source but this configuration constrains the prosthetic and anatomical joints to directly follow each other in one direction only (e.g., glenohumeral flexion as seen in figure 1). The two joints are only constrained to move with each other in one direction because the control cable only acts in one direction. It is possible for the anatomical joint to move more quickly than (or to beat) the prosthetic joint in the antagonistic direction (e.g., glenohumeral extension in figure 1). This condition can create slack in the control cable, which creates a situation in which EPP does not exist and feedback is no longer being presented to the user.

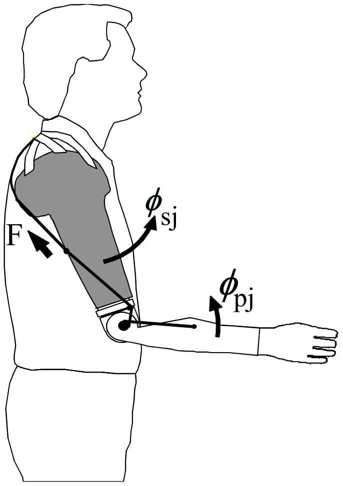

Figure 1: Uni-directional EPP control of a powered elbow using flexion of the residual limb.

Full or bi-directional EPP control requires that the prosthesis is directly linked to the anatomical joint in a manner that produces an unbeatable position servo-mechanism in both directions and thus preserves extended physiological proprioception for all movements of the anatomical joint. An example of a bi-directional EPP system is the Fitch elbow (figure 2). This cable-operated elbow is configured so that humeral flexion results in prosthetic elbow flexion and humeral extension results in prosthetic elbow extension. Due to the fact that bi-directional EPP control preserves EPP at all times and thus creates a more intimate interface with the amputee, it should theoretically be superior to that of uni-directional EPP control. However, the uni-directional configuration has been more frequently utilized because of its simplicity and similarity to body-powered systems.

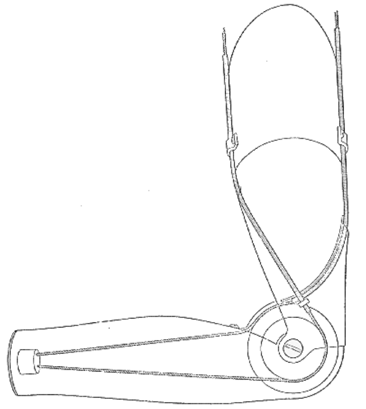

Figure 2: The Fitch elbow, an example bi-directional EPP control.
(From Orthopaedic Appliances Atlas, Volume 2, 1960, p.51)

Weir [2] attributes the current lack of application of EPP in externally powered prostheses to the fact that currently available prosthetic components do not posses a sufficient bandwidth to allow the user to have subconscious control of the device. In other words, due to the slow response of currently available prosthetic components users feel as if they have to constantly pull on the control cables to achieve the position they desire. This results in the operator using the prosthesis in a ‘bang-bang’ approach. Weir feels that the sluggish response of currently available powered components causes EPP to have the opposite effect than that for which it was intended. Instead of providing subconscious control of the prosthesis, the amputee has their attention continuously drawn to the control of their prosthesis.

Purpose

While the concept of EPP control seems credible and was demonstrated by Simpson ([3], [4]), implementation of such devices has been problematic. Our laboratory has developed an analog EPP controller [5] and two microprocessor based EPP controllers ([6], [7]), but only the analog controller has been clinically fitted to amputees. When mounted on the laboratory bench and set to high gains, the controllers exhibit smooth operation of an electric elbow in flexion and a 'jerky' behavior in extension. The goal of this study was to attempt to characterize our EPP controller and identify the factors that are contributing to this behavior in order to understand the nuances of EPP control and allow for the development of a clinically viable prosthesis that utilizes EPP principles.

METHODS

To investigate EPP control, a simulator has been developed using Matlab's Real Time and XPC Target toolboxes (Mathworks, Natick, MA). This simulator allows a controller to be designed in Mathworks' Simulink and then converted into C code on what is referred to as a 'host' computer. This code is then downloaded to a separate computer, referred to as the 'target' computer, using the XPC Target toolbox (figure 3). The target computer mimics a hardware controller while allowing the controller parameters to be easily changed from the host. The target computer houses a data acquisition card that enables the target computer to transmit drive signals to the prosthetic joint and allows for data collection.

To examine the capabilities of these controllers, an EPP controlled elbow system has been created using a Hosmer (Hosmer Dorrance Corporation, Campbell, CA) powered elbow. Operational amplifier circuits were constructed to allow for the collection of the elbow's angular position using a Helipot potentiometer (Helipot, Fullerton, CA) as well as collection of the force input control signal from a 25 lb. Flexiforce (Tekscan, S. Boston, MA) force-sensitive resistor (figure 3).

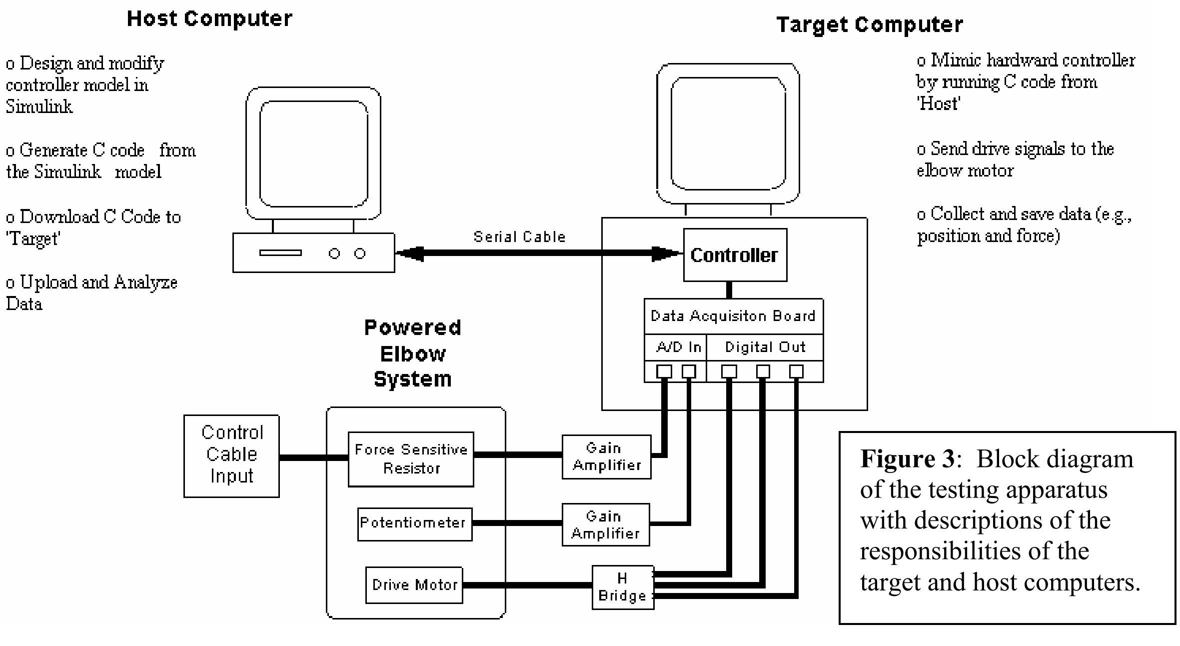

Figure 3: Block diagram of the testing apparatus with descriptions of the responsibilities of the target and host computers.

DISCUSSION

Mathworks' Real Time and XPC Target toolboxes permit considerable system versatility. It has allowed us to easily examine the effects of adding time delays as well as filters of different orders and cutoff frequencies to our system. It has also allowed us to easily assess the effects of varying the update rate and precision of the pulse width modulation of the drive motor signal.

We have spent considerable time using this system to examine the cable interface that exists between the human and the transducer. At present we have limited ourselves to examining a configuration in which a uni-directional EPP controller is implemented on a Hosmer powered elbow. We theorize that the behavior of the EPP system is affected, in part, by non-linearities in the uni-directional EPP configuration related to the control cable. However, the results that have been observed to this point are problematic due to the slow response of the elbow mechanism we are employing.

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REFERENCES

1. Simpson, D. C., (1974): "The Choice of Control System for the Multimovement Prosthesis: Extended Physiological Proprioception (e.p.p.)" In: The Control of Upper-Extremity Prostheses and Orthoses, Proceedings of the Conference on the Control of Upper-Extremity Prostheses and Orthoses, Göteborg, Sweden, Herberts, P., Kadefors, R., Magnusson, R.I., and Petersén, I., (Editors), Charles C. Thomas, Springfield, Illinois, pp. 146-150, October 6th-8th, 1971.

2. Weir, R.F. *ff*., (1995): "Direct Muscle Attachment as a Control Input for a Position Servo Prosthesis Controller", Ph. D Dissertation, Northwestern University Evanston, IL.

3. Simpson, D.C., (1969): "An Externally Powered Prosthesis for the Complete Arm," in Basic Problems of Prehension Movement and Control of Artificial Limbs, The Institution of Mechanical Engineers, Proceedings 1968-69, 183(3j), pp. 11-17.

4. Simpson, D.C. and G. Kenworthy, (1973): "The Design of a Complete Arm Prosthesis," Biomedical Engineering, 8(2), pp. 56-59.

5. Heckathorne, C.W., Strysik, J.S., and Grahn, E.C., (1989): "Design of a Modular Extended Physiological Proprioception Controller for Clinical Applications in Prosthesis Control," Proceedings of the 12th Annual RESNA Conference, pp. 226-227.

6. Bertos, Y.A., Heckathorne, C.W., Weir, R.F. and Childress, D.S. (1997) "Microprocessor Based E.P.P. Position Controller for Electric Powered Upper-Limb Prostheses", Proceedings of the 19th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS), Chicago, Illinois, Oct. 30-Nov. 2, 1997, pp. 2311-2314.

7. Al-Angari, H.M., (2001): "A Design of Two Degrees of Freedom Microprocessor-Based EPP Position Controller for Upper-limb Prostheses," Master of Science Thesis, Department of Biomedical Engineering, Northwestern University, Evanston, Illinois.