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Evolution of microprocessor based control systems in upper extremity prosthetics

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Abstract. The recent emergence of microprocessor based prosthetic control for the individual with upper limb deficiency has significantly expanded the spectrum of treatment options and inclusion criteria for this patient population. Microprocessors can accept a wide variety of input devices and ranges enhancing an individual's prosthetic function allowing control options for individuals who were at one time not candidates for such prosthetic management. Additionally, myoelectric control parameters can be adjusted.

This paper will provide an overview of input and output devices to acquaint the rehabilitation professional with microprocessor augmentation of current upper limb control modalities. It represents the second paper in a series investigating commercially available microprocessor technology in the field of prosthetics.

Keywords: Upper limb prosthetics, upper limb deficiency, myoelectric control, upper extremity amputee, microprocessor

1. Introduction

1.1. Historical perspective

Many significant achievements are apparent as one examines the evolution of upper extremity prosthetics over the last thirty to forty years. The evolution of electronic upper extremity prostheses can be summarized into three distinct generations. First generation electronics, often referred to as digital systems, used an on and off control scheme to actuate electronic terminal devices, wrist rotators, and elbows. These digital systems exhibited a single speed or single rate type of actuation of prosthetic terminal devices. During the first generation there was limited sophistication of input devices. At that time, input devices consisted of myo-electrodes, servo type actuators as well and various switch technology often mounted in the prosthetic interface or attached to a control harness (Fig. 1).

Delineation between first and second generation was made at the introduction of the Utah Arm and later the ProControl I prosthetic controller (Fig. 2). Both systems allowed for large-scale threshold manipulation, gain or muscle amplification as well as adjustment of muscle contraction rate in an attempt to minimize effort in first generation co-contraction type switching. These systems lowered the microvolt requirement (by lowering the muscle thresholds) for terminal device, wrist, or elbow control allowing more individuals with upper limb deficiency to take advantage of prosthetic technology. Most importantly these systems introduced proportional control in a reliable electronics package.

Though more sophisticated than the first generation, second generation electronics exhibited challenges that affected the ability of the prosthetist to provide expeditious prosthetic management and interchangeability. Through the second generation, switch activated, single site or dual site control systems required different electronic packages. If, during the rehabilitation of the patient, it was noted that dual site type of control was too difficult and single site would be more appropriate, an entire new electronics package would need to be installed into the prosthesis creating additional expense and fabrication time at the point of rehabilitation where

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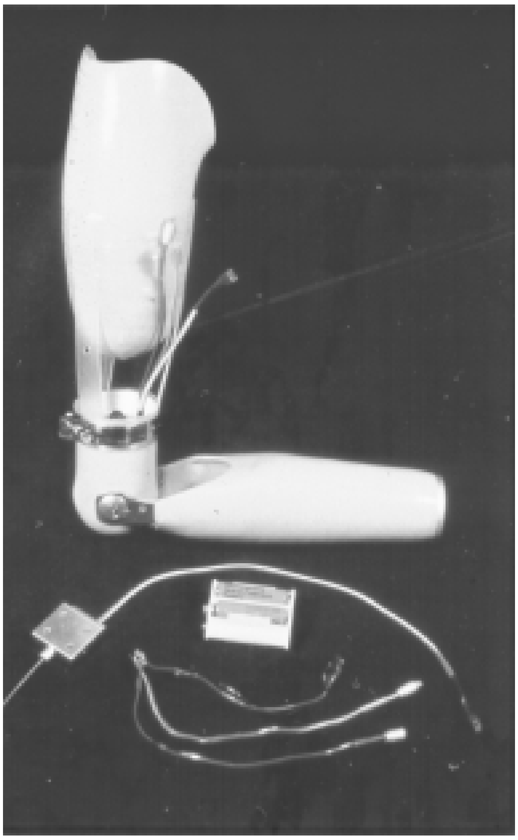

Fig. 1. Prosthesis Utilizing Switch Control.

timing and expeditious prosthetic function is so very critical.

The third and most current generation of prosthetic electronics incorporates programmable microprocessors. Third generation electronics are delineated by the acceptance of proportional control as the standard. Microprocessors of the third generation allow a larger range of adjustment of myoelectric characteristics for the enhancement as well as ease in prosthetic control.

The significant advantage of microprocessor use in upper limb prosthetics is to provide the ability to modify control options (without purchasing or changing components) and input characteristics during initial fitting quickly and easily within the clinical setting. Secondarily, microprocessors provide ease in changing control thresholds and sensitivity of the prosthesis as the user's strength and ability evolves. There are several microprocessor based control systems in the development stage (Southhampton Hand systems, Rutgers Hands, etc.). This article will focus solely on commercially available systems. Exciting work throughout the world on microprocessor prosthetic control systems is ongoing. As these systems become commercially available, future articles will address their benefits. While many related topics are discussed in the literature, there is a void in when one investigates commercially available microprocessor technology [1–9]. A significant portion of this paper is based on discussions with individual manufacturers as well as comparative microprocessor analysis performed by the authors [10,11].

1.2. Overview of microprocessors

Several benefits exist in the use of a microprocessor for the individual with upper limb deficiency. These benefits include: ease of modification of control parameters, reduction of expense and time during trial fitting period, increased user involvement and input during initial prosthetic management, and control type versatility. Currently, microprocessors control terminal devices, wrist and elbow functions as well as more esoteric control such as shoulder joint locking and unlocking, remote on and off and sensory feedback. Furthermore microprocessors illustrate an augmentation to current types of control, not necessarily a type of control to stand-alone. Such as the graphic equalizer in line with a sound system, the microprocessor delineates, filters and enhances input characteristics to produce the desired output – optimal prosthetic function and increased ease.

Currently four manufacturers provided programmable microprocessors at the transradial and hybrid type levels. These manufacturers are: Otto Bock – Sensor Hand, Motion Control – ProControl II, Liberating Technologies Incorporated – Programmable Vari-Grip III, and Animated Prosthetics System. Microprocessors are illustrated throughout the discussion of input and output characteristics.

2. Input characteristics

2.1. Types of control

Electric upper extremity prosthetics use three basic types of control:

Myoelectric

Single site – Single electrode that utilizes muscle characteristics such as the rate of the muscle contraction to control opening and closing of the terminal device or pronation and supination.

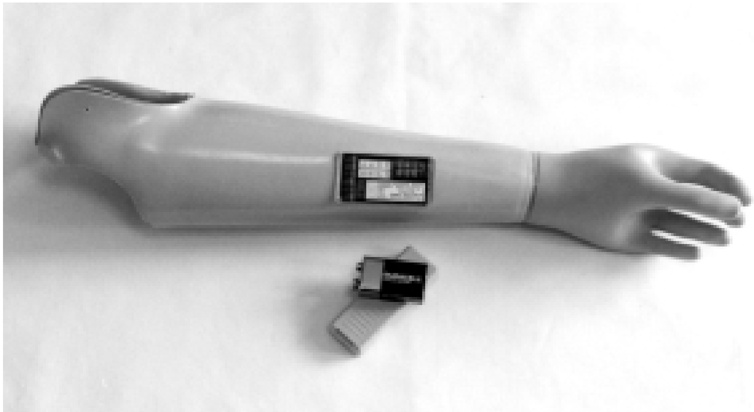

Fig. 2. The ProControl I Controller.

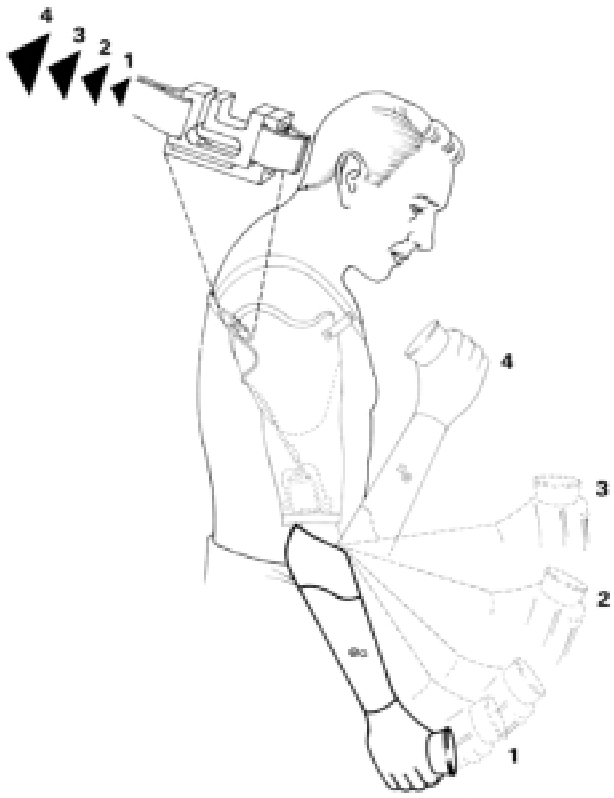

Fig. 3. Direct relationship of force to elbow positioning can be found in the Motion Control Servo Pro Force Sensor. (courtesy of Motion Control, Inc).

Dual site – The use of two electrodes to independently to control a terminal device, electronic wrist rotator or elbow. An example of this control scheme is one muscle/electrode controls opening of the terminal device while the second muscle/electrode controls closing of the terminal device

Switch

There are many types of switches. Some are activated by pulling a cable, while others are activated by depressing a lever. Some switches have multiple functions determined by the position of the switch.

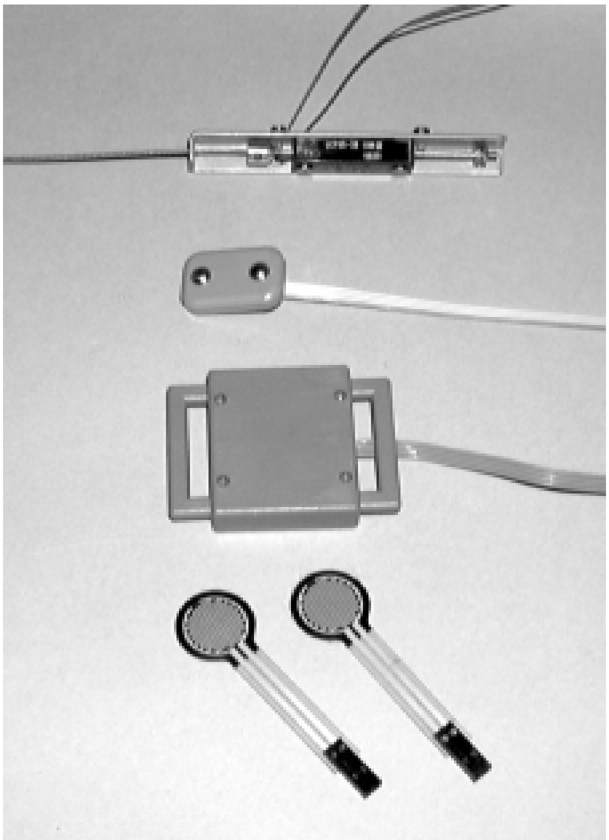

Fig. 4. Input Devices (from top) Linear Transducer – servo, myo-electrode, harness switch, force sensing reducer – touch pads.

Servo

A servo controller interprets excursion and/or force and translates this input into a proportional output. Feedback is utilized to enhance proprioception as illustrated in the direct force or linear relationship to elbow, wrist, or terminal device function (Fig. 3).

2.2. Input devices

Input devices (Fig. 4) for microprocessors include myo-electrodes, switches, Servo type actuators, force sensing resistors (FSRs). Myo control involves the collecting and filtering of surface EMG characteristics to actuate an electric motor. Myo-electrodes come in various sizes with compatibility limits among different commercially available systems. Myo-electrodes are further differentiated by the designation of remote or non-remote type of electrodes. Remote and non-remotes refer to the placement of the preamp electronics. Remote type electrodes are ones that do not have the preamp electronic housed within the electrode assembly. Examples of remote type electrodes are those used in the Motion Control type of electronics. Advantages of the remote type of electrodes include protection of electronics in the area of perspiration and environmental influences. Non-remote electrodes such as the Otto Bock type electrodes house the preamplifier and electrode in the same casing. Though there is risk of perspiration affecting the electronics, these types of electrodes reduce the amount of space needed to house electronics within the prosthesis or frame (Fig. 5).

Each type of electrode has its specific patient application. In the clinical setting, electrodes should be chosen taking into account factors such as soft tissue to bone ratio, presence of scar tissue as well as particular type of interface to be designed. It is important to note that the Motion Control style remote electrodes do allow the maintenance of a suction type socket fit as an airtight seal is created about the electrode. This type of negative pressure environment cannot be maintained in other types of electrodes and can be critical to prosthetic suspension and comfort.

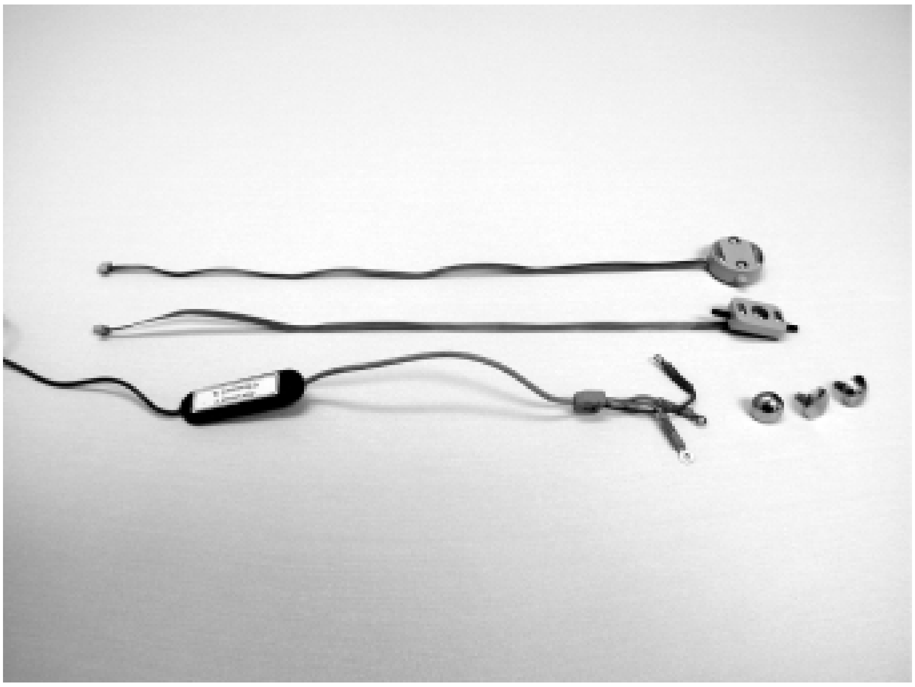

Fig. 5. Comparison of Otto Bock and Motion Control Style electrodes.

Fig. 6. Linear Transducer from Liberating Technology.

Switches come in a wide variety of presentations. Harness type switches are those that rely on excursion or some type of pull to actuate the switch. Another type of switch is known as a push or "nudge" switch. This type of switch is one that is merely pushed by a chin, phocomelic finger, residual limb or placed distal to the axilla and pushed when actuation is desired. More advanced switches are found in the multiple position type application. The typical type of application for multiple position switch would be one in which three positions are utilized. The first position is a resting position in which no function occurs. The second position allows for functions such as wrist pronation and third position allowing for wrist supination. Furthermore, switches can be momentary (provides brief actuation while the switch is activated) or latching (provides function until switch is fully actuated again). The use of microprocessors enables switches to be utilized in multiple applications though proportional control is absent in this input type.

Servo type actuators come in two varieties. The linear type potentiometer (Fig. 6) is a Servo input device that translates linear motion or excursion into proportional type function. Both types of Servos provide in-

Fig. 7. Tethered Cord Connection – ProControl (Top) – VariGrip (Bottom).

creased proprioception through the association of force or linear pull as it is related to proportional function. The second variety is the force sensing type Servo. The force-sensing Servo translates information gathered across a strain gauge and interprets this to proportionally actuate a device when programmed through a microprocessor or electronic system.

The force-sensing resistor (FSR) represents another type of input device applicable to the servo classification. These types of input devices consist of a force-sensing resistor matrix, which interprets pressure in a proportional type manner. FSRs are actuated by the acromion in the shoulder level amputee as well as a residual humeral neck or the phocomelic finger. These types of input devices represent a low profile solution providing an inexpensive proportional input device. Important to note is that FSR input devices require special care in their application in the prosthetic interface. Improper installation will result in premature failure and greater expense secondary to perspiration or moisture.

Fig. 8. Radio Wave Type Interface Communication utilizes a Prosthesis Configuration Unit (PCU) – (Top) to program the processor (Bottom) (courtesy of Animated Prosthetics, Inc).

2.3. *Programming method*

Programming the on-board microprocessor in a prosthesis to a specific user's requirements is currently accomplished using three different approaches. Adjustments to the electronics are made through a tethered cord connection, radio wave type interface communication, or coding plug method (Figs 7–9).

3. Output characteristics

Terminal devices are further divided into two classifications – those that have intrinsic or internal processors and those that use extrinsic processors (Fig. 10). Intrinsic processors have the advantage of reducing the amount of space distal to the interface and proximal to the terminal device to achieve a contralateral limb length match. Intrinsic processors are appropriate for individuals with longer residual limbs or those con-

Fig. 9. Otto Bock Coding Plug Interface Method (white plug inserted).

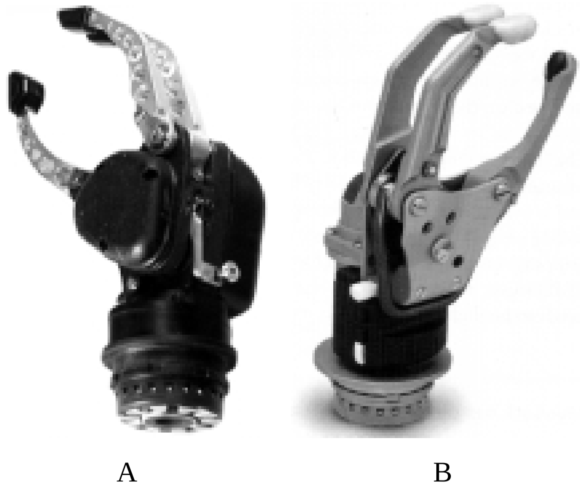

Fig. 10. (a) Motion Control Hand – controlled by extrinsic processor. (b) Otto Bock Sensor Hand – controlled by intrinsic processor (courtesy of both manufacturers).

cerned with the cosmetic contours of the prosthesis. Extrinsic processors on the other hand are located proximal to the terminal. These types of processors have advantages of extra protection about the prosthetic interface, ease of replacement, as well as the ability to control other functions beside the prosthetic terminal device. At this point, it is important to note that not all microprocessors are compatible with commercially available terminal devices and that referencing both microprocessor and terminal device manufacturer recommendations is necessary as to not compromise warranty guidelines. Often the challenging aspect of the third generation electronics is understanding system compatibility, reliability and appropriate control inputs.

Microprocessor control of the wrist allows for several control schemes to be incorporated to allow ease of switching between the terminal device and the wrist (Fig. 11). One of the most common types of switching is represented by the co-contraction or contraction and relaxation of two separate muscle groups simultaneously. Due to EMG signal differences secondary to muscle imbalances created by amputation surgery or general conditioning of the prosthetic user, proper co-contraction can be difficult for the amputee. Use of a microprocessor allows the prosthetist to manipulate muscle thresholds and/or rates to provide reliable co-contraction switching. Muscle thresholds represent the microvolt line that delineates function. When the EMG signal falls below the threshold, no function is realized. In contrast, when the EMG signal exceeds the threshold, proportional function is realized. Muscle rates represent the speed at which the muscle crosses the threshold. Manipulation of both of these characteristics allows the prosthetist to equalize muscle imbalances or weaknesses facilitating co-contraction switching.

The significant change between second generation and third generation electronic elbows is their ability to accept more input options and allow simultaneous control of elbow and terminal device. Microprocessor control for electronic elbows is at the developmental stage. The Boston III, Utah III, and Vasi-Pediatric type elbows are the first electronic elbows to utilize a microprocessor for on-board adjustments. A more popular type of elbow application includes the use of internal or external microprocessor in a hybrid type of situation most commonly seen with the use of the Otto Bock ErgoArm with the addition of a microprocessor (Fig. 12).

At the shoulder, microprocessor control is limited to joint locking and unlocking utilizing several different input options. Currently, electronically powered positioning shoulder units do not exist commercially (Fig. 13).

4. Conclusion

The recent emergence of microprocessor based prosthetic control for the individual with upper limb deficiency has significantly expanded the spectrum of treatment options and inclusion criteria for this patient pop-

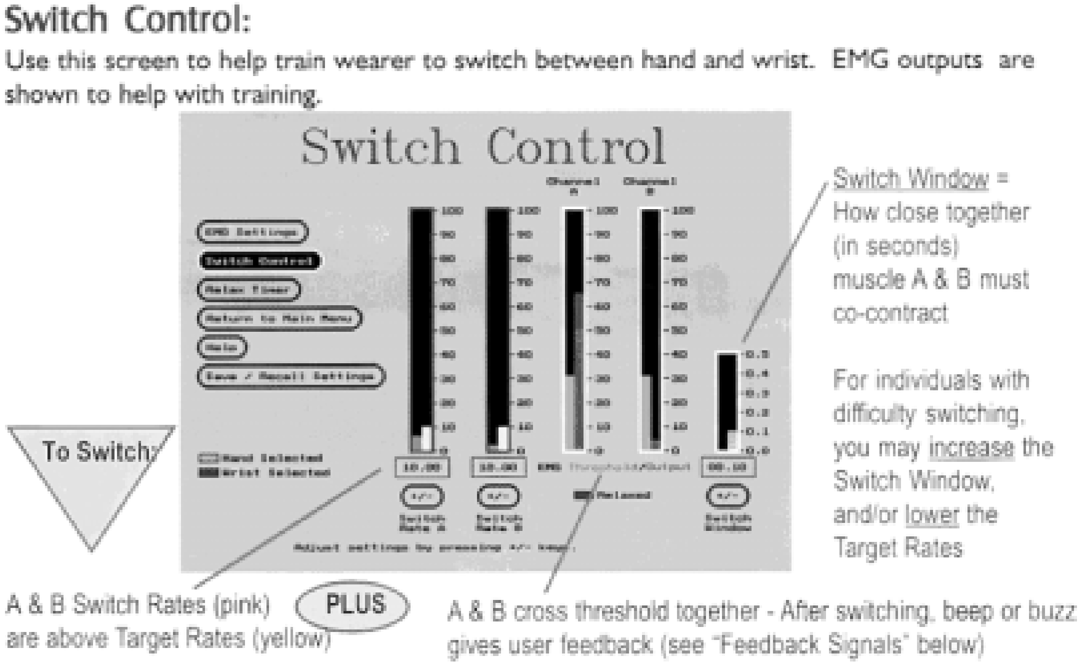

Fig. 11. Pro Control II Switch Control Window accessed for adjustment of co contraction switching between wrist and hand function. (courtesy of Motion Control, Inc).

Fig. 12. Hybrid Application of the Animated Prosthetics Controller and Otto Bock Ergo Elbow (courtesy of Animated Prosthetics, Inc).

ulation. Microprocessors provide the ability to modify control schemes and input characteristics quickly and easily throughout all phases of upper extremity prosthetic care. Microprocessors can accept a wide variety of input devices and ranges enhancing an individual's prosthetic function allowing control options for individuals who were at one time not candidates for such prosthetic management. With a myriad of control and component options available through microprocessor technology, patients have greater opportunities to maximize their rehab potential. Ultimately advances in technology can only be quantified by the enhancement of patient function.

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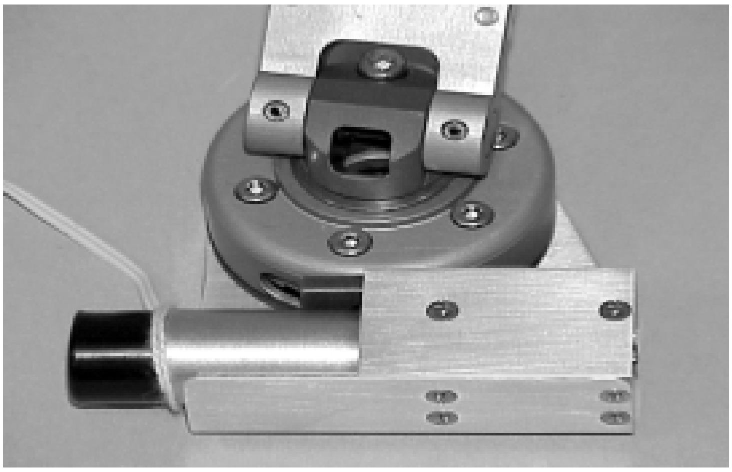

Fig. 13. Electronic Shoulder Lock from Liberating Technology used in conjunction with the Collier Shoulder Joint.

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