CAPTURING SHOULDER MOTION AS AN INPUT FOR EXTERNALLY-POWERED, SHOULDER DISARTICULATION PROSTHESES

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Prosthetists have been fitting externally-powered components to individuals with “shoulder disarticulation”, upper extremity amputations for decades. These components have ranged from momentary contact switches that permitted carbon-dioxide to pass through tubes in order to create an articulating motion, to force sensitive resistors (FSRs) that vary the amount of resistance between thin conductive plates in order to permit varied current to flow and provide input to an electrical motor. Activation of these types of inputs requires contact by the user with their remaining residual limb or, in the case of individuals with congenital deficiencies, phocomelic digits. A variety of pull switches have also been used to harness the body motions provided by the user, which activate an electro-mechanical switch used to drive a motor. With the use of coupled rotary potentiometers, the authors have chosen to investigate a unique approach to ipsilateral shoulder motion as a control source for two degrees of freedom.

Individuals with shoulder disarticulation amputations present major challenges for functional prosthetic restoration. Conventionally controlled, cable-driven prostheses for shoulder disarticulation and humeral neck amputations require the use of scapular or bi-scapular protraction. This requires that the individual have good shoulder and torso posture and maintain adequate range of motion within the prosthetic socket(s). The absence of scapulo-thoracic and sterno-clavicular motion in intra-scapulo-thoracic level amputations make individuals with said amputations inappropriate for the device being considered in this study. It is well know that 2 inches of excursion is required to fully open an adult, voluntary-opening, split-hook terminal device while another 2 ½ inches of excursion is required to fully flex a mechanical elbow (provided the elbow flexion attachment is placed in the original, “starting position”). Mechanical analysis of these systems can easily prove that changes to reduce the necessary excursion are possible by moving the location of the actuation lever or elbow flexion attachment; however, these changes are minimal and require a trade-off of increased force requirements. Components such as excursion amplifiers have traditionally been used to enable the users of such body-powered prostheses to have the necessary excursion to control the prosthesis with these aforementioned increases in force.

This being said, unless highly motivated, many individuals with these higher levels of amputation will discard their body-powered prostheses due to the limited tangible benefits of the device. Scapular protraction is being used to activate elbow flexion and/or terminal device operation. This gross body movement does not physiologically translate into the actions being performed by the prosthesis and compounds the drawback of increased force requirements. Although the motions used in this study are not completely physiological; they have closer ties to the functions for which the users intends the prosthesis to perform.

Due to the aforementioned limitations of completely, body-powered prostheses for individuals with shoulder disarticulation amputations, externally-powered or hybrid prostheses are often recommended. The use of externally-powered components decreases the necessary excursion and force requirements by the user and may provide benefit of increased joint range of motion and/or grip strength. For obvious reasons of epidemiology, the focus of externally-powered
components has been in the area of elbows, wrist rotators and terminal devices. There has been little focus on the development of externally powered humeral rotators or shoulder joints.

Humeral rotation, in upper extremity prostheses, has been provided primarily by means of passive pre-positioning. Turntables or other components permit motion via creation of an external moment of internal or external rotation with respect to the elbow axis in the transverse plane. This is usually performed with the contralateral hand or against the body or stationary object (in the case of individuals with bilateral upper extremity amputations). There exists a locking/free-motion, humeral rotator available that permits re-positioning of the elbow in the transverse plane through a sophisticated cabling and harnessing control. Although this is very effective in providing an increased independence to the prosthetic user, it requires significant motivation and training in order to perfect the control motions without expending large amounts of effort.

Mechanical shoulder joints of 0 through 3 degrees of freedom have existed for many years. Monolithic construct provides for an aesthetic appearance at the shoulder without function. Single-axis joints, usually set in the coronal plane for shoulder abduction and adduction provide the user the ability to more easily don clothing, etc. These are often reserved for individuals with humeral neck amputations to provide some motion without creating large asymmetries in hemi-shoulder widths from the midline of the body to the acromial region. The most popular shoulder joints are the bi-axial shoulders that have motions of flexion and abduction. They provide the same benefits as the single-axis joints and also provide for sagittal plane motion. This sagittal plane motion is a necessity for users to perform bimanual activities or reaching tasks either in front of the body or overhead. Although tri-axial shoulder joints exist, they are used infrequently. This is due to the fact that, as mentioned above; many of the elbow units that are used in conjunction with mechanical shoulder joints have transverse plane motion available passively through a turntable or other friction joint. A third plane of motion at the shoulder is; therefore, unnecessary. The tri-axial, or universal joints, are mainly used for passive prostheses when the user wishes to have free-swinging shoulders for aesthetic appearance at rest or during ambulation and are rarely used with mechanical friction settings that would enable stationary re-positioning or pre-positioning for use of distal components. Lastly, there exists a shoulder that has the ability to lock/free swing in one plane. This shoulder joint incorporates passive abduction with the locking and free-swing capabilities in the sagittal plane. Individuals with unilateral amputations use the free-swing feature because it permits comfort between the socket and limb interface during ambulation. Individuals with high, bilateral amputations will use these joints for re-positioning of the shoulder for a variety of activities. This re-positioning is performed by unlocking the shoulder joint, using gravity combined with forward trunk lean to place the shoulder joint in the desired location, re-locking of the shoulder joint and return to an upright, trunk posture. This shoulder joint has the ability to greatly enhance the functional abilities of the user, especially those with bilateral amputations. Drawbacks of this joint include the precise placement of the mechanical switch to lock and unlock the shoulder and the gross body movements that are necessary to re-position the joint, although the former may be remedied with an electronic lock/unlock strategy.

Limitations of mechanical shoulder joints were the impetus to investigate the use of a powered shoulder joint and corresponding control schemes. Three electromechanical control strategies
were tested: a pair of FSRs combined with a rocker switch, three linear transducers and a two-axis joystick. Initially, testing was performed on able-bodied individuals to determine the amount of available shoulder excursion during two antagonistic pairs, elevation/depression and protraction/retraction. Measurements were obtained with the use of an “oversized” shoulder cap mounted on an adjustable stand and a telescoping rod and sheave. The shoulder cap was placed around the subject and the rod was placed on strategic locations for measurement of these motions. Acromial travel for elevation and depression was measured using the telescoping rod placed laterally over the acromial area. Subjects were asked to first elevate and then depress their shoulder while measurements were taken between trials. The same procedures were performed anteriorly and posteriorly at the humeral head and distal scapula respectively. Each subject performed three trials of each motion and the data was recorded. Average amounts of travel were calculated for four subjects. These distances were used to determine how much travel could be applied to the joystick and where the attachment, along the axial distance of the joystick, had to be mounted. Although the amount of travel for the two antagonistic pairs was not symmetrical, this could be accounted for by altering thresholds and sensitivities in the programming software.

Bypass sockets were fabricated for three able-bodied individuals in order to test the three control strategies. The first strategy that was tested was a configuration that had been used clinically for several individuals with shoulder disarticulation amputations. Inside of the bypass socket was a combination of two FSRs mounted anteriorly and posteriorly on the lateral portion of the socket with a rocker switch mounted (upside-down) superiorly. (figure 1) The FSRs were used for control of internal and external rotation of a powered humeral rotator. The rocker switch, was used to control powered shoulder flexion and extension. The second strategy was designed with three linear transducers tethered to a mobile shoulder cap. Initially, the shoulder cap articulated with the socket with a urethane ankle joint. This configuration proved to be too rigid and thus the shoulder cap was loosely tethered by elastic webbing while the cords attached to the transducers themselves, along with the anatomical contour of the plastic, held the cap into place. (figure 2) Lastly, a two-axis joystick was mounted to the medial portion of the bypass socket while the loose cap was modified with an eyelet mounted superiorly to accept the extended rod of the joystick. It was essential that the eyelet permit the rod to slide in order to prevent binding and inadvertent signals.

Subjective feedback from the three strategies was obtained. Able-bodied individuals experienced similar problems, with the first strategy, to that worn by the individuals with shoulder disarticulations. Attempts to locate the FSRs and the position of the rocker switch with their lateral shoulder proved difficult. Additionally, the subjects often contacted FSRs
inadvertently while attempting to locate the rocker switch and vice versa. Balancing the three linear transducers proved the most challenging. Antagonistic pairs were set anteriorly and posteriorly for control of the humeral rotator while a single transducer was used for shoulder flexion and extension. A neutral location between end ranges of one transducer had to be found for a “resting state” so that elevation and depression could independently control the two powered shoulder motions. Joystick control proved the most effective as the subjects felt that it enabled them to move more naturally with motions that were somewhat intuitive to the powered motions of the shoulder and humeral rotator.

Following the able-bodied trials, two individuals with shoulder disarticulation amputations were able to utilize the joystick control in experimental fittings. Both of these individuals had undergone targeted muscle reinnervation and thus had independent, myoelectric control of elbow flexion/extension and terminal device open/close. The shoulder controller was added in order to provide inputs for externally powered shoulders and humeral rotators. Two styles of powered shoulder joints were used. One shoulder had powered flexion and extension only, while the other had the addition of powered abduction and adduction. Two, similarly designed, powered humeral rotators were tested as well. The first prosthetic design using the joystick incorporated shoulder elevation and depression for powered shoulder flexion and extension while shoulder protraction and retraction were used for powered humeral internal and external rotation. The second prosthetic design incorporated protraction and retraction for powered shoulder flexion and extension while shoulder elevation and depression controlled powered shoulder abduction and adduction. While the mobile, shoulder cap proved effective for the able-bodied subjects, hollow tubes mounted to form fitted shirts, on one subject, and a thin elastic band on the other (figure 3) proved even more effective in capturing the intended movements of the user. Furthermore, mounting of the joystick laterally created a mechanical excursion advantage which required less shoulder motion in order to drive the powered shoulder or humeral rotator.

While the subjective feedback from the able-bodied and shoulder disarticulation subjects proved very positive for the joystick design, it is yet to be utilized in clinical fitting. The experimental trials on subjects with shoulder disarticulation amputations were such that the commercially available components (i.e. elbow, wrist and hand) were controlled via EMG control. This is due to the fact that they had undergone targeted muscle reinnervation procedures. There should be little hesitation to preclude the use of this device for individuals with this level of amputation in order to provide control sources for commercially available and experimental components.