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DESIGN OF A PROSTHETIC ELBOW FOR ELBOW DISARTICULATION AMPUTATIONS

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INTRODUCTION

Long above elbow and elbow disarticulation amputations pose a problem in fitting as the residual limb is nearly the same length as the upper arm on the sound side. Although these problems have been recognized for some time [2], no currently available elbows offer a complete solution. Conventional fittings, whether they employ an elbow system attached to the end of the socket or use outside hinges, either make the limb geometry unnatural or restrict the ability to provide humeral rotation and a powered joint (figure 1). The objective of the work described in this paper is to develop prosthetic elbows for long above elbow amputations which do not have these limitations. Our work, as described here, has focused on multi-link mechanisms much as are used for knee disarticulation prostheses. The additional challenge in the upper limb case is to provide active locking of the joint, which is not usually a requirement other than at full extension for the knee, and to provide for powered operation.

OBJECTIVES:

Design of the elbow system has three primary objectives:

1. That the elbow allow for a flexion range from full extension to at least 135° flexion with provision for humeral rotation over a range of at least 40° while at the same time maintaining the flexion axis as near as possible to its natural location.

2. That the elbow, when flexed to 90°, add minimal extra length to the upper arm. As a practical matter, the addition of 10-20 mm was considered to be acceptable.

3. That the elbow, including covers, locking system, etc. fit within the envelope of a normal arm for a child of eight or thereabouts.

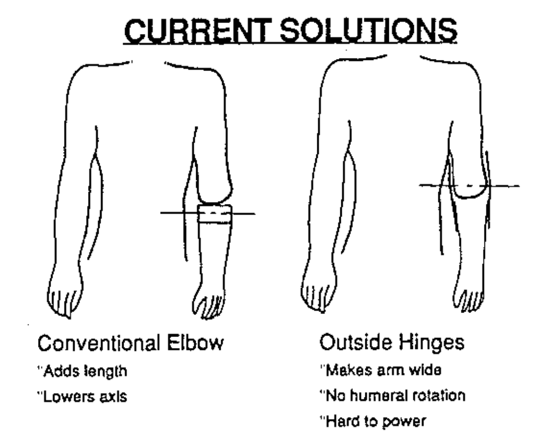


Figure 1:

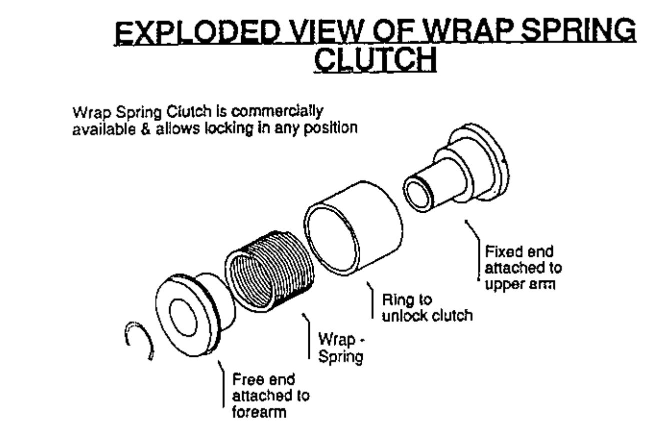


Figure 2:

SOLUTION METHODS:

Previous work in our own group [3,5] has shown that a four bar mechanism using a wrap spring clutch produces acceptable elbow configurations. In addition we have found [1] that inclining the humeral rotation axis of the elbow anteriorly relative to the long axis of the humerus has the effect of tilting the plane in which the forearm moves, thus bringing the prosthetic hand closer to midline. This has advantages in eating, dressing and other activities of daily living.

The wrap spring clutch consists of a double barrel arrangement (figure 2) joined by a coil spring wrapped loosely around both barrels. Rotation of one side relative to the other which "unwraps" the spring leaves the clutch unlocked, whereas rotation to wrap the spring tighter causes the spring to grip the barrels, locking them together. This type of clutch is inherently unidirectional. Our goal in the elbow design was to provide a "locked" state where the elbow would resist extension but still allow flexion, and an "unlocked" state where the elbow was completely free to swing.

Conventional synthesis techniques for mechanisms assume a base link and "driver" (figure 3) where the relative orientation of the two are known. The driven link and the coupler are then synthesized to produce a particular relative motion of the driver and driven links. In this case the objective is to specify, in general terms, the motion of the coupler relative to the base. In terms of the elbow, the base link will be mounted on the socket and the coupler will form part of the forearm.

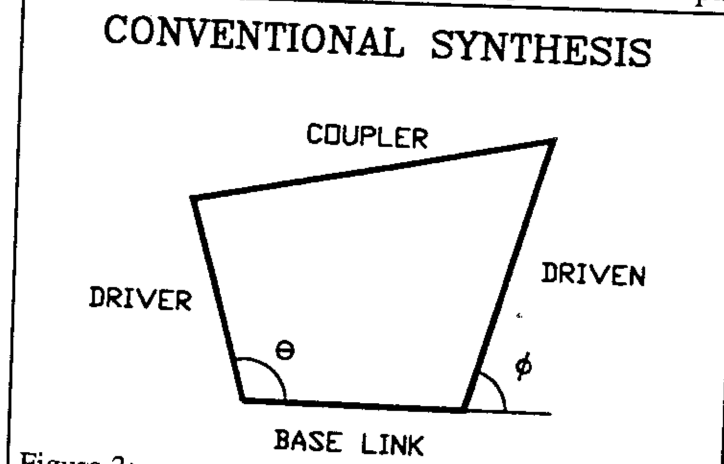


Figure 3:

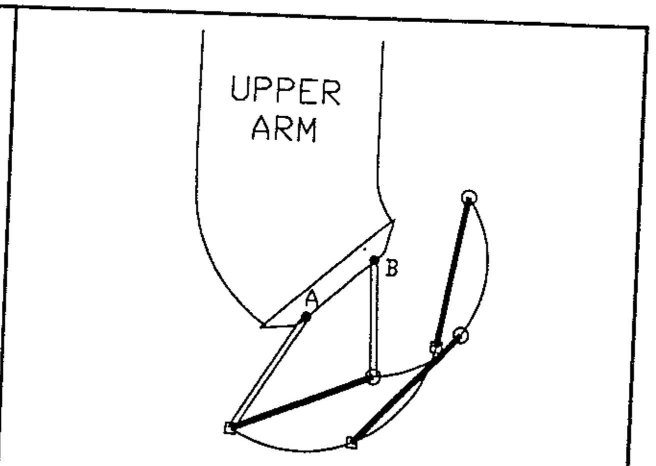
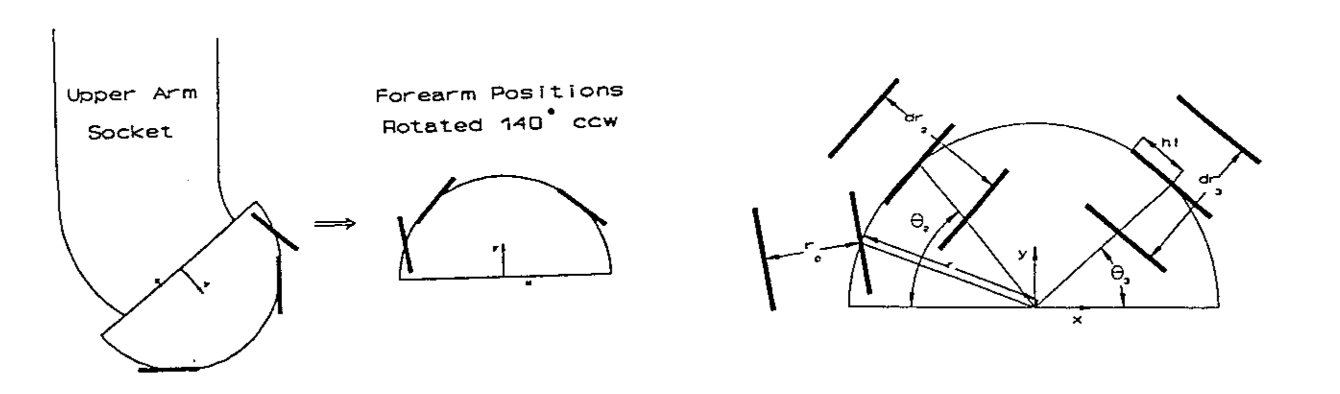


Figure 4:

To solve the synthesis problem we implement a closed form solution technique which, based on three known positions of the coupler, allows the location of the base link end points "A" and "B" to be found (figure 4). As implemented, we use an exhaustive search technique where the locations and orientations of the coupler are varied as shown in figure 5. From each set of three coupler positions, a linkage is generated by defining arcs through the path of the endpoints of the coupler (figure 4). The position of the arc centres corresponds to the endpoints (A and B in figure 4) of the base link. This method draws on the method of Rouleaux for finding instant centres and was proposed by Molian [4].

To simplify analysis, the base link was rotated so that it was horizontal, keeping the movement of the forearm in the positive Y quadrants as shown in figure 5. The actual orientation of the base link when the elbow is fitted is at 45° to the long axis of the humerus. Each combination tested includes a position of the coupler near the full flexion and full extension positions, as well as an intermediate position. The intermediate position corresponds to 90° flexion of the elbow. The solution method varies the location of the coupler as shown in figure 5. By doing this systematically, a large number of possible mechanisms can be evaluated.



Actual elbow position

elbow rotated for analysis

coupler position variations

Figure 5:

Four bar linkages generated by the technique were evaluated initially to ensure that the computed hinge points were in locations which did not intrude into the prosthetic socket. Mechanisms which met this criteria were analyzed with the coupler in nine positions from full extension to full flexion. The position of the clutch, the overall change in the distance from the elbow to the wrist, and loads in the links as well as on the clutch were evaluated. Each mechanism was then rated as to how well they met the overall design goals and a smaller selection of possible mechanisms were examined to determine the final design.

The final design incorporates a four bar mechanism and wrap spring clutch. The wrap spring clutch is provided with two states of operation by means of a two position latch. This allows the clutch to be in either an unlocked state with the elbow free to flex and extend, or locked, in which case the elbow will allow flexion, but will resist extension. The subject in our trials to date uses the elbow ballistically and does not have a cable and harness to provide controlled flexion.

The complete elbow is shown in figure 6. The elbow mechanism is arranged so that the clutch is mounted on the base. The base then attaches to a swivel which is mounted so the humeral axis is at approximately 45°. This elbow provides a range of flexion of over 140° and more or less unlimited humeral rotation. The elbow is covered with a corrugated material which expands and compresses around the elbow as flexion and extension occur.

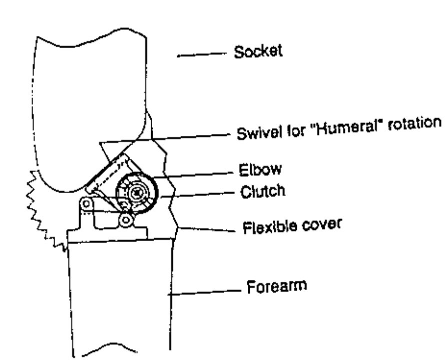


Figure 6:

Preliminary work with the system indicated two principal problems. The first of these was that to release the wrap spring clutch, one applies a force to "unwrap" the spring, which then detaches the spring from the barrels leaving them free to rotate. Very small movements of the spring will unlock the clutch, and the unlocking happens very quickly. This proved to be a problem because the wearer could inadvertently unlock the clutch, release the elbow and drop things. This problem was solved by redesigning the clutch activation mechanism so that it had 2-3 mm of initial travel against a spring resistance before it engaged and unlocked the clutch. This has proved a good solution.

The second problem has been somewhat less tractable. With the elbow mounted so that the humeral axis is at about 45°, the least amount of additional length added to the upper arm is about 70% of the combined diameter of the clutch and the thickness of the swivel mount. In practical terms, when mounting the system, the added length is accommodated by moving the clutch somewhat anteriorly, which then gives an anterior bulge at the elbow when the elbow is fully extended. Our current efforts are directed to solving this problem, and to adding the ability to power the joint.

DISCUSSION:

This project has produced an elbow which in field trials meets most of the initial goals. In particular, the elbow achieves the desired objectives in terms of flexion range, humeral rotation and overall length limitations for the upper arm. The primary difficulty has been provision of locking while maintaining a compact design. Further work is underway to solve this problem and to add a powered, as well as a friction version of the device.

SUPPORT:

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REFERENCES:

1. Bertolucci, M., Optimal Orientation of the Humeral Rotation Axis for a Prosthetic Elbow, Senior Report, Department of Mechanical Engineering, University of New Brunswick, 1992

2. Childress, D., Et Al, Report: Panel of Upper Limb Prosthetics, Orthotics and Prosthetics, 31(4), 47-53, 1977.

3. Hughes, G., Et Al, Prosthetic Elbow for Amputees with Elbow Disarticulation Amputations, Proceedings of the CMBES, May 1993.

4. Molian, S., Mechanism Design: an Introductory Text, Cambridge University Press, Cambridge, 1982.

5. Mullin, S., Development of a Prosthetic Elbow for Use in Cases of Long Residual Limb Above Elbow Amputations, Senior Report, Department of Mechanical Engineering, University of New Brunswick, 1977.