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DESIGN OF A HAND PROSTHESIS BASED ON KINEMATICS PRINCIPLES

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1 INTRODUCTION

Commercially available child hand prostheses prehensors usually have one degree of freedom (DOF) and one phalanx per finger. Such mechanism does not allow adequate encirclement of objects and its low compliance leads to instability of the object in presence of external perturbations. The goal of this research project is to modify an existing child hand prosthesis prehensor by adding an extra phalanx to each of the fingers. This new design should increase the number of possible grasps, their robustness and their compliance. The kinematics and dexterity of the mechanism, along with the static stability of the grasps are the selected design criteria. The objective is to design an actuating mechanism while respecting the reduced space available in the case of child prostheses.

2 ENVISAGED SOLUTION

A five-bar linkage, as shown in Figure 1, was first selected as the actuating mechanism because of three important points: there are two phalanges, the phalanges motion is coupled and sub-actuated. A two-phalanx finger provides a better encirclement of objects. The coupled motion of the phalanges depends on the particular dimensions of the mechanism segments and the presence of a spring at one of the joints. The mechanism is sub-actuated since only one actuator is located at joint O to produce finger motion. Sub-actuation is an important characteristic since only one myoelectric signal is required to control the 2 DOF finger. The spring is a key element to provide the adequate compliance to the prehensor.

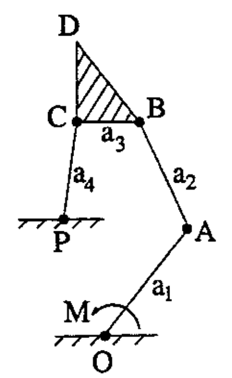

Figure 1: Five-bar linkage mechanism

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The five-bar linkage is particularly suitable to encircle objects. A moment M, applied at pivot point O, induces motion of the segments ai. If phalanx PC is blocked by an object along the motion (Figure 2a), phalanx DC keeps moving, rotating about point C until contact is made again with the object (Figure 2b). If phalanx DC first makes contact with the object, motion of both phalanges stops, as observed in median and distal phalanges of a non-amputated hand (Figure 2c). The particular dimensioning of the segments determines the kinematics of the mechanism, its dexterity and the distribution of contact forces on the phalanges.

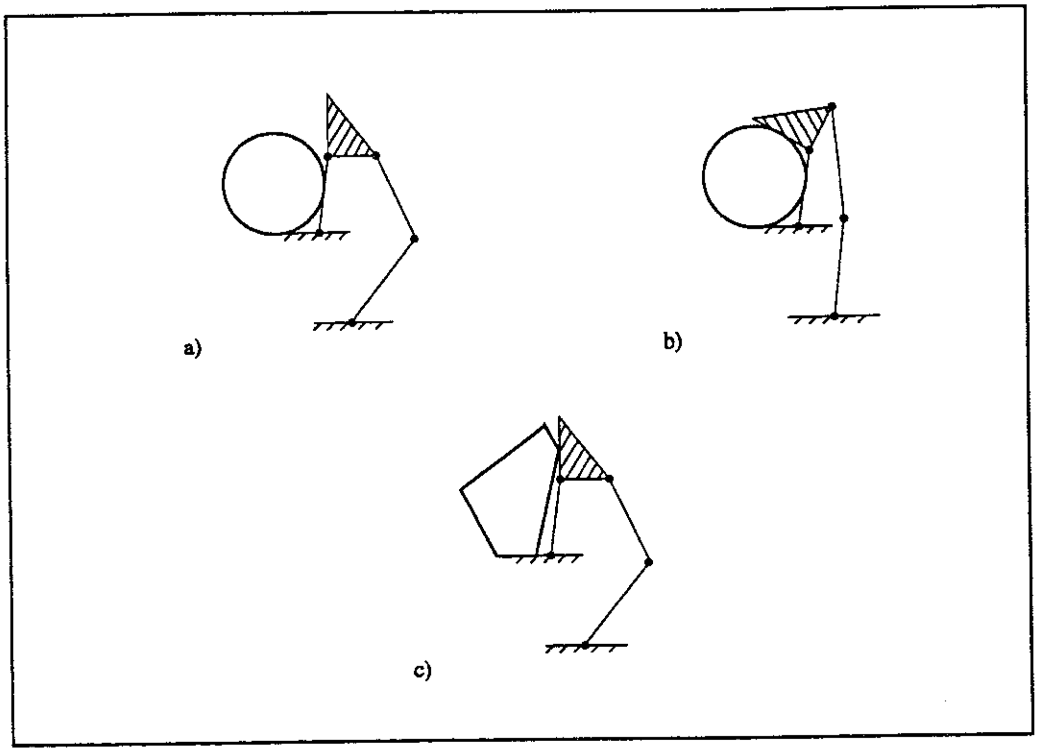

Figure 2: Blocking of phalanges a) proximal b) distal c) distal first

3 KINEMATIC ANALYSIS

An important criterion is to design the mechanism such that finger motion resembles to the kinematics of a non-amputated finger i.e. the coupled motion between the proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints. Buchner et al. [1] have suggested a dynamic model for the interphalangeal coordination. They expressed the relation between the DIP and PIP joints by:

(1)

where R'12 and R13 are anatomical parameters with respective values of 1.21 and 3.5. jpip and jdip are the flexion angles for joints PIP and DIP respectively. Experimental studies [2,3,4] suggested a nearly linear relationship between PIP and DIP joints. A similar coupling will be included in our hand prosthesis prehensor design.

4 DEXTERITY ANALYSIS

In addition to kinematic requirements, the five-bar linkage will be designed on the basis of dexterity

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issues. The dexterity of a mechanism with 1 DOF is obtained by deriving the prehensor finger opening with respect to time:

(2)

where and correspond respectively to the actuator velocity and finger closing/opening velocity. The dexterity, J, is a function of the input, the joint O rotation angle (motor angle), and various geometrical parameters k, such that:

(3)

It is clear, from equation (2), that J represents a ratio between the input and output velocities. In addition, based on the principle of virtual work, J also determines a relationship between the input and output generalized forces:

(4)

where Fi and Fo are respectively the input and output generalized forces. The mechanism dexterity is location dependent because finger configuration is involved. It characterizes the ability of a mechanism to produce fine movements. Equation (4) reveals the existence of a trade-off between velocity and force at the fingers: it is not possible to have a high velocity and high force at the finger tip or small velocity and small force at the same time.

4.1 EXAMPLE: VASI

To better illustrate the kinematic characteristics of a 1 DOF prehensor finger, the myoelectric VASI hand VV0-3 was modeled. The value of the dexterity J of the hand opening is given in Figure 3, as a function of the angle of rotation of the actuator. Figure 4 is a schematic of the VASI hand. A sensitivity analysis was performed to ensure that the errors involved in geometrical measurements of the hand did not have much influence on the results.

The dexterity obtained varies between 50 and 60 over a complete opening of the hand. This represents a 10% variation only and the dexterity can thus be considered constant. Hence, the closing/opening velocity and the available forces at the fingers are almost configuration independent.

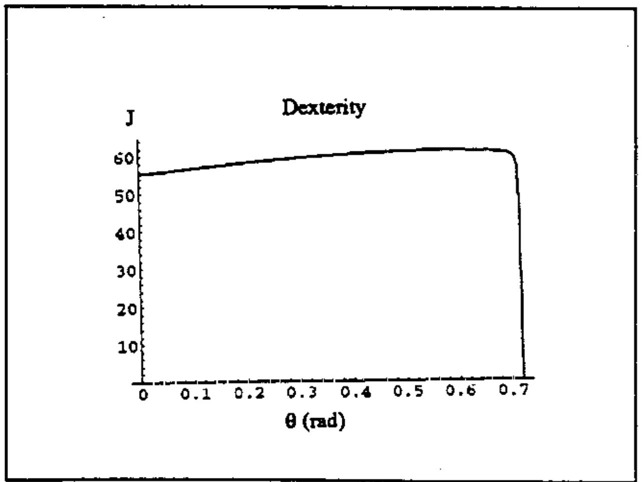

Figure 3: VASI dexterity

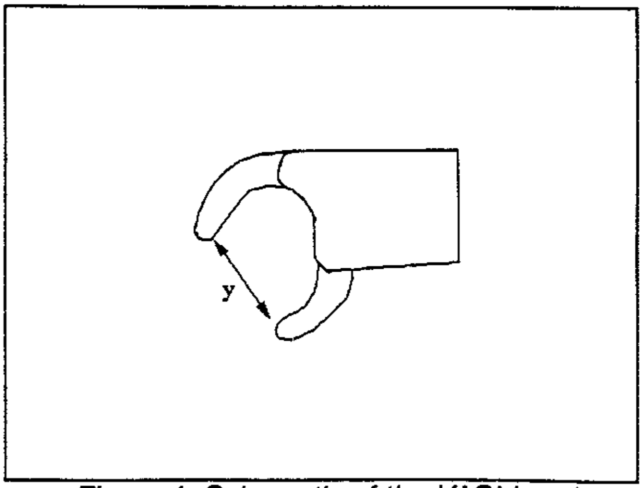

Figure 4: Schematic of the VASI hand

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4.2 ENVISAGED DEXTERITY

A preliminary experiment was performed with a VASI hand user in order to investigate whether a constant dexterity causes any manipulation problems. Current results did not reveal any particular problem. Yet, they do not tell us whether a different dexterity would be preferable. Based on engineering intuition, we plan to choose a five-bar linkage design such that the dexterity will increase with closing of the fingers. This is based on the fact that larger objects are usually heavier and thus, require higher finger forces for manipulation.

5 STABILITY ANALYSIS

Another important issue with the design of a prehensor is to ensure proper stability of the grip in presence of external perturbations. The forces generated on the object by the phalanges should not produce a resultant that would tend to push out the object. Since the force distribution of the phalanges on the object depends on the mechanism characteristics, we will develop software to simulate the static stability of mechanisms for different sizes of circular objects.

6 FUTURE WORK

A complete design of a five-bar linkage involves the determination of several parameters. Up to now, we have chosen three design criteria, i.e. kinematics, dexterity and stability, to help us in determining their values. Since there is no simple equation to find those, we plan to use a trial and error procedure to obtain a viable solution. Software for kinematic, dexterity and stability analyses will be developed to rapidly converge to the solution.

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