CONTROL PHILOSOPHY FOR A SIMULATED PROSTHETIC HAND

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ABSTRACT

Multifingered robot hands can approximate human hand functionality, and it is possible to consider their use in prosthetics. The Belgrade/USC robot hand is used as a prototype prosthetic hand in order to evaluate a system, PRESHAPE, that translates user commands into motor signals using the virtual finger concept. This paper describes the control philosophy of PRESHAPE and presents simulation results.

BACKGROUND

The human hand is a complex and versatile system, both structurally and functionally. It is capable of shaping into a variety of forms, each specialized for the task at hand. For prehensile tasks, the hand preshapes into a posture suitable to grasp the object for the given task, and then encloses the object [Jeannerod 1981]. Prosthetic hands, which ideally should serve the wearer naturally, are largely an elusive dream, and most amputees are fitted with a dual hook. Recently, where cost and complexity have not been as large a constraint as in prosthetics, multifingered sensor-based robot hands have been built, e.g., the Utah/MIT hand [Jacobsen et al 1985] and the Belgrade/USC hand [Bekey et al 1990]. For control, techniques in artificial intelligence allow the development of intelligent controllers [Bekey et al, in press]. With the emergence of new light weight alloys, miniaturized components, and reduced voltage requirements, electrically powered prosthetic hands are also available (e.g., Steeper Electric Hand, Otto Bock System Electric Hand). In addition, multifunction sensor-based prosthetic hands are being built in research labs. For example, the Southampton hand [Chappell and Kyberd 1991] uses 4 motors to control a 5 fingered hand in 7 basic postures. Intelligent controllers are needed that will allow amputees to take advantage of these emerging robotic and prosthetic hand developments.

RESEARCH QUESTION

In order to develop an intelligent controller for using a multifingered sensor-based robotic prototype prosthetic hand in a versatile way, a minimum set of control variables is needed. The challenge faced here is that both a human and a robot controller are in the control loop. The human controller, at the minimum, controls the arm, addressing the planning and control concerns associated with object identification, location and orientation, grasping location. In addition, the human can select operation modes, choose parameters, and control finger movement. The robot controller performs the selected operation mode and uses sensory events as triggers and/or as control loop feedback. Thus, the planning and control problem for computer-controlled movements is simplified, and the problem of developing an intelligent controller is how to effectively partition control across multiple controllers.

This paper concentrates on that partitioning, leading to the development of a prosthetics control architecture using an existing anthropomorphic robotic hand as a vehicle. Arm positioning is not addressed, because the assumption is that the user is a below-elbow amputee.

METHOD

Hands carry out tasks which are part of the activities of daily living. A task database has been developed containing over 300 hand-related tasks [Iberall et al 1991]. Included are tasks from the Jebsen Hand Function Test [Jebsen et al 1969] which is used to evaluate restored human hand function and which includes tasks such as write with a pen and stack checkers.

The multifingered sensor-based robotic prototype being used is the Belgrade/USC hand [Bekey et al 1990]. Somewhat similar to the Southampton hand, it has 4 fingers with 3 joints each, each finger pair being driven by one motor. The motion of the 3 joints is not independent, but embodies a built-in synergy modeled on observations of human hands. The articulated thumb moves in an arc into opposition to one or more fingers; another motor flexes and extends it at its 2nd joint. Finger, thumb, and palm surfaces are covered with 23 pressure sensors. The digits are equipped with potentiometers for sensing finger rotation with respect to the palm.

Hand posturing is based on the concept of a **virtual finger (VF)**, which is a grouping of 1 or more real fingers (or the palm) working together to apply a functionally effective force within a task [Arbib et al 1985]. Prehensile postures are constrained by the way the hand can apply opposing forces around an object for a given task [Iberall and MacKenzie 1990]. From our analysis of the prehensile classification literature [Iberall 1987], these can be classified into 3 basic methods. Pad opposition occurs between the finger and thumb pads along an axis roughly parallel to the palm. Palm opposition, along an axis roughly normal to the palm, occurs between the digits and the palm. Finally, side opposition has an opposition axis occurring primarily along a transverse axis. What gives this language of oppositions its expressive power is that the hand is not limited to one opposition at a time. At least 21 different combinations of oppositions have been observed [Iberall et al 1991], creating a large repertoire of hand shapes for driving prosthetic hands, in contrast to the Southampton hand which is fixed to use 1 of 7 postures.

Figure 1: Preshape (a-d) and enclose (e-f) sequence for grasping checker, using Belgrade/USC hand simulation.

The system under development is called PRESHAPE (Programmable Robotic Experimental System for Hands and Prosthetics Evaluation). The system takes user commands and generates motor commands for the Belgrade/USC hand motors. Commands can either be task level commands that are decoded using the task database, or else opposition level commands that describe which oppositions and VFs to use for the task. We have successfully simulated the preshaping and enclosing of the chosen posture. A hand simulator, developed by J. Henz at the Technical University of Berlin, allows us to simulate a sequence of movements on the Macintosh computer. Control is in terms of normalized finger angle settings from 0 to 100. The control simulation was done in SIMULINK and MATLAB.

RESULTS

An opposition level command is used to shape the hand, by selecting normalized angles and coordinating fingers and thumb movements. For example, the opposition level command and normalized preshape angles for two sample tasks are:

Task	Opposition	Preshape angles
pick up checker	9 medium	20, 0, 20, 10
grasp hammer	12 medium	40, 40, 40, 10

Figure 1 shows a sequence of postures for preshaping to grasp a stack of checkers. This task calls up posture #9 with a medium-sized hand opening, involving only one opposition, namely pad opposition between the thumb (VF1) and index and middle fingers (VF2). The thumb first rotates slightly outwards (Fig 1a). The index and middle fingers then curl (Fig 1b-c) through intermediate steps while the thumb curls into a posture of opposition to the two fingers until the desired preshape posture is reached (Fig 1d). The motor settings at the end of the preshape are (20,0,20,10).

In the control simulation, the preshape movement is triggered by an EMG signal from the wrist flexor muscles. Electrical signals from surface electrodes positioned over muscles are amplified, rectified, and filtered before being used as a control input. Once the processed EMG signal reaches a specified threshold, the coordinated preshape movement begins. For the task of picking up a checker, the processed EMG signal (Fig 2a) triggers the preshape movement when the signal reaches a threshold of 1.5V. The joint motors are driven at a constant rate with the VF movement coordinated to resemble natural hand motion. Figs. 2b-2i show the normalized joint rates and angles for the motors. The thumb first rotates slightly outward (motor 4). The thumb then curls (motor 3) into a posture in opposition to the index and middle fingers while the index and middle fingers (motor 1) curl into the desired preshape position.

For prehensile tasks only, the Enclose Module must be triggered after the hand has been preshaped and the user has positioned his or her arm. The hand encloses the object, ending when the specified sensory feedback has been reached. For this phase, proportional myoelectric control has been chosen as the method of control. In proportional myoelectric control, the joint motor voltage varies proportionally to the EMG signal giving the user control over the speed of the enclose motion.

The enclose movement begins when the simulated EMG signal from the wrist flexor muscles reaches a small threshold. The rate at which the VFs are driven is then proportional to the EMG signal. Referring to Fig 2, the enclose motion for picking up a checker begins when the processed EMG signal (Fig 2a) reaches 0.3V. The VFs are driven at a rate proportional to the EMG signal with the movement coordinated to resemble natural hand motion. Figs. 2b-2i show the normalized joint rates and angles for the motors. The thumb first flexes (motor 3) and then the index and middle fingers (motor 1) curl until contact is made by both the thumb pad sensor and the index radial sensor. When contact is made, a signal to the user indicates that the enclose is complete. Sensory feedback to the computer controller is used to maintain a steady grasp during the actual task.

DISCUSSION

Multifingered mechanical hands are attempts at approximating human hand functionality. Our goal is to use one as a prototype prosthetic hand in order to evaluate a system that translates task-level commands into motor commands. Using the virtual finger concept, PRESHAPE consists of a series of modules that selects sensors, preshapes the hand, encloses it around objects if necessary, and performs task movements. Using a simulator, hand sequences for various tasks have been generated. The advantage of this approach is that a large repertoire of functions can be generated with a simple control language. The user has control over selecting postures, triggering movements, and speed during hand enclosing. The computer provides the lower level coordination of motors. The disadvantage is that, while it allows the computer to generate the more automatic motions, preshaping motions occur at a constant rate. Following the experimental evidence of Jeannerod [1981], an alternative is to preshape the hand in a more realistic way by coordinating it with wrist acceleration. As noted by Jeannerod, the hand is preshaped by the time the wrist reaches peak deceleration, and then the enclosing movement is synchronized to the wrist's deceleration. Under development are algorithms and accelerometer hardware for driving joint motors by monitoring the user's movements. By using intelligent

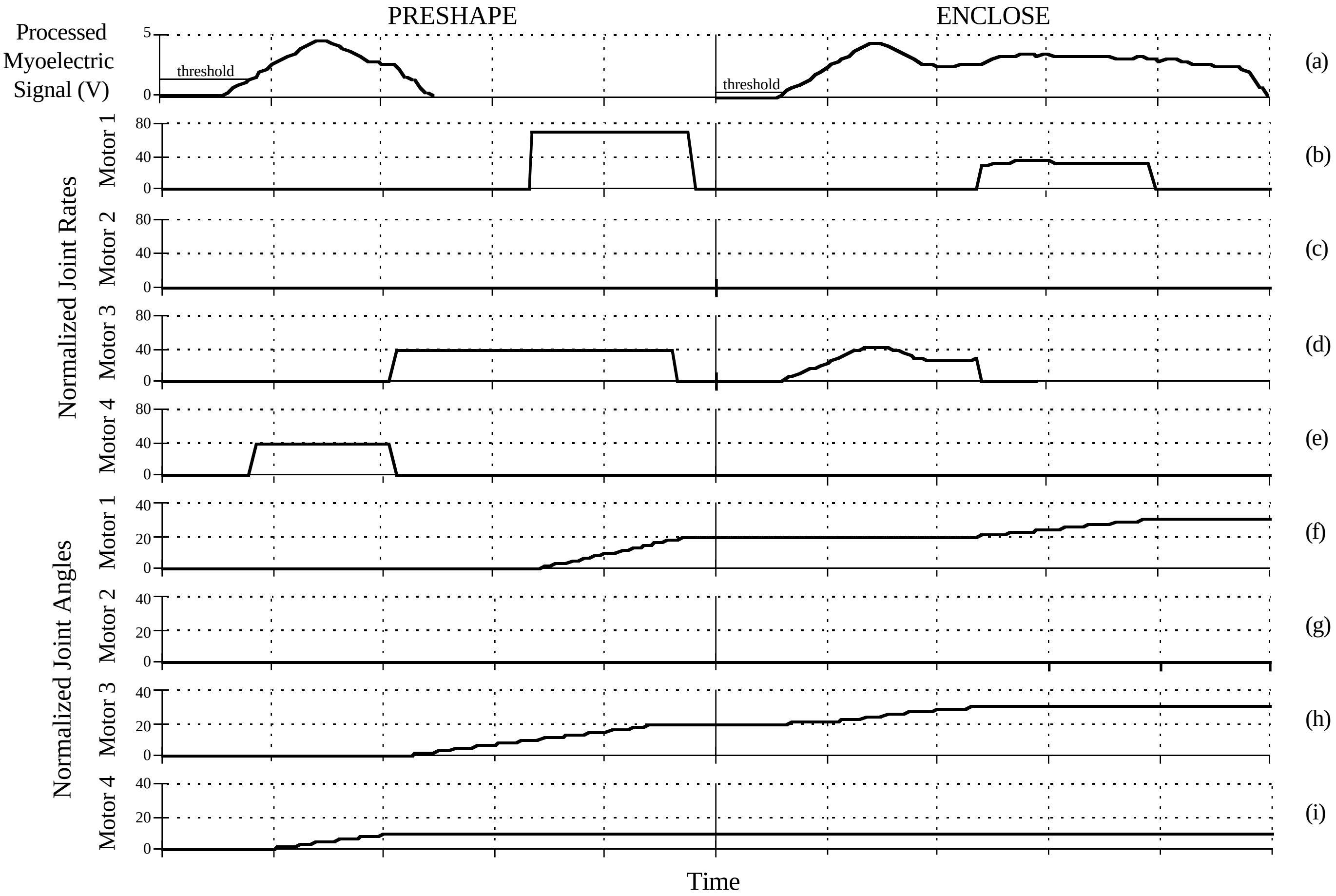

Figure 2: Simulated preshape and enclose sequence for grasping checker.

sensor-based robotics (within the constraint of what is possible to control), we believe that in the long term it will be possible to develop a new generation of sophisticated prosthetic hands.

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