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IMPROVED METHOD FOR USE OF NATURAL SENSORY FEEDBACK IN CONTROL OF GRASP FORCE FOR STIMULATED HAND MUSCLES.

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ABSTRACT

Functional electrical stimulation of paralyzed hands can provide the user with some basic hand function. To improve the grasp provided by this method it is being attempted to use information from natural cutaneous sensors as recorded by a nerve cuff electrode implanted around a peripheral nerve. Slips across the skin can be detected in the nerve signal. This can be used to provide automatic intervention if an object being held starts to slip. A method for estimating the proper intensity of the reaction to a slip is presented. The method is based on the assumption that the reaction intensity should increase with the velocity of the slip and that the velocity is reflected in the amplitude of the nerve signal.

INTRODUCTION

Functional electrical stimulation has been used in several applications for restoring hand function in spinal cord injured persons. So far they have been based mainly on feedforward control of the stimulation parameters. Due to the lack of good sensors to be mounted on/in hand and fingers it has been difficult to provide feedback to the stimulation system. It has earlier been proposed to use the signals from cutaneous sensors in one or more fingers to provide this feedback. It has been shown that it is possible to detect information about slips occurring across the skin from the signal recorded with a nerve cuff electrode on the nerve innervating the skin [1]. Further, it has been shown that it is possible for a stimulation system to successfully react to slips of an object being held in a lateral grasp, and rapidly increase the stimulation intensity and catch the object before it is lost [2].

However, several questions remain. One important question is: How strong a reaction is necessary to stop a given slip? This is the topic of the present paper.

The answer depends on a large number of parameters, e.g. the strength of the muscles, the weight and surface friction of the object and whatever the reason for the slip is. In the present paper we have limited ourselves to investigating a single situation: The pull force being constant, a surface structure of the object is fixed and the reason for the slip being a slow decrease in grasp force. Even for this "standardized" situation, there were still large variations in the course of the slips, caused by the immediate friction/sticktion between object and fingers. A descriptive parameter for a slip is the velocity of the object during the slip, which may also be a good indication of how much to increase the stimulation intensity in order to stop the slip. An object that slips fast needs a stronger reaction than one that slips slowly, simply because the momentum of the object is larger and because there is less time to catch it. It has been suggested [3] that the amplitude of the nerve signal reflects the velocity of an object sliding across the skin. The hypothesis for the present study was therefor that a reaction that increases with the amplitude of the nerve signal might give a better performance of the system, compared to using a fixed reaction.

METHODS

A spinal cord injured male subject was implanted with a tri-polar cuff, 2cm long and 2.6mm inner diameter, placed on the digital nerve innervating the radial side of the index finger (see figure 1). Further, percutaneous intramuscular stimulation electrodes (from NEC) were implanted in m. flexor pollicis brevis, m. adductor pollicis, m. extensor pollicis longus and m. flexor digitorum superficialis. At the time of recording the data presented here, the electrodes had been implanted for 26 months.

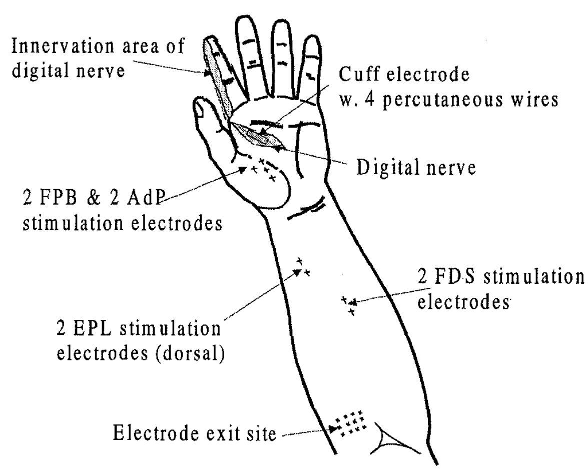

Figure 1. Implanted electrodes.

The lower arm of the subject was placed in a vacuum cast, providing support for elbow, wrist and the fingers from the 5'th to the medial half of the 2'nd finger (see figure 2). A grasp force sensor with an area of 4x4cm and 1cm thick was placed between the thumb and the flexed index finger of the subject. The surface was suede. A torque motor with a 10cm arm was used to apply a constant pull force of 2N at the end of a string attached to the force sensor. This pull force was measured with an in-line pull force transducer and the movement of the motor was measured with a high-resolution, low-friction potentiometer.

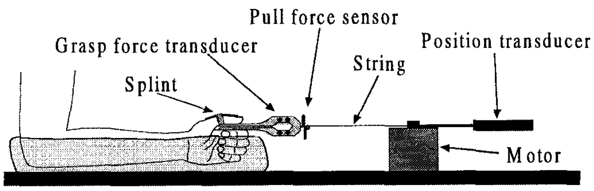

Figure 2. Experimental setup.

The implanted stimulation electrodes were connected to a stimulator that generated constant-current (10mA), charge-balanced pulses, whose duration (0.5-127μs) could be controlled from a PC. The stimulation frequency was 20 Hz. Activation patterns for the individual muscles were controlled by a template that used a value between 0 and 100 (points) as input and mapped this number into pulse widths for the pulses sent to the individual muscles. 0 points corresponded to an extended thumb and slightly flexed fingers and 100 points corresponded to fully flexed thumb and fingers. A relaxed thumb was obtained at 20 points.

A splint was taped onto the dorsal surface of the thumb. This stiffened the interphalangeal joint and allowed the force produced at the proximal phalanx of the thumb (by the FPB muscle) to be transferred to the distal phalanx, hereby improving the grasp.

The nerve signal was amplified (x100000), bandpass filtered (1-4 kHz) and sampled into a digital signal processor. Here it was rectified and integrated in bins that excluded the stimulation artifacts. This gave a signal that represented the overall activity in the nerve. The rectified and bin-integrated nerve signal was then band-pass filtered between 0.3Hz and 2.5Hz, to extract peaks in the signal. Slips could then be detected by comparing the resulting signal (the "slip signal") to a threshold value.

Results

To investigate if the nerve signal contained information about the velocity of the sliding object, a large number of slips (573) were produced experimentally. It was done by having the stimulated hand hold the object and reduce the stimulation intensity with 10 points per second until the grasp force became too small to hold the object. Each time the slip was detected and the system reacted correspondingly and stopped the slip. The value of the slip signal that caused the slip to be detected (i.e. the first value above threshold) was plotted against the velocity (=differentiated position signal) of the object at that time. This is shown in figure 3, left. It can be seen that there is some correlation between the slip signal and the velocity of the object. However, this correlation is more pronounced when the sample immediately after the first one is considered. This is shown in figure 3, right. The reason for the better correlation we attribute to the precise timing of the starting slip. For the first sample, the slip may have started at any time during the period in which the raw signal was integrated, giving rise to some variation and to a smaller amplitude of the signal. For the second sample, the slip is in progress during the whole integration period and a larger and more stable value for the slip-related nerve signal is obtained.

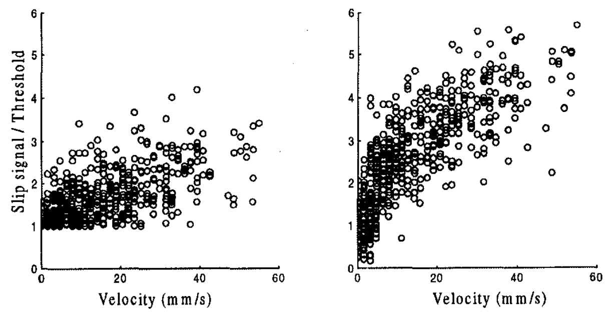

Figure 3. Slip signal amplitudes at (left) the first sample that crossed threshold and (right) the sample immediately after, related to the velocity of the sliding object at the same time.

It was decided to make the increase in stimulation intensity that was issued by the system depend linearly on the amplitude of the slip signal. Gain and offset of the relation was selected by trial and error, and the relation that was used is shown in figure 4. It is linear from a minimum reaction at threshold of 2 points and a maximum of 20 points at five times threshold.

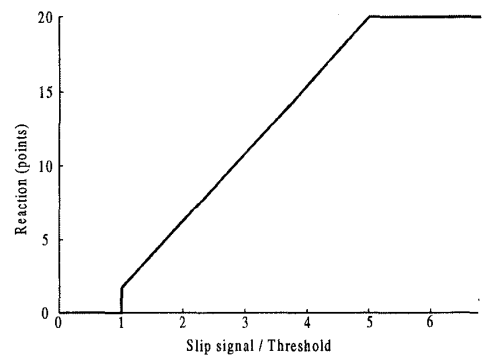

Figure 4. Relation between recorded nerve signal amplitude and the issued increase in stimulation intensity when slips were detected.

This "adaptive" method was then tested against a number of trials with fixed reactions. The results are illustrated in figure 5. Approximately 30 slips were produced and successfully compensated for, for each of ten different fixed reaction intensities. The average slip length for these slips are shown as o's, showing also the standard errors with vertical bars. It is obvious that larger reactions on average result in shorter slips. For comparison, single trials resulting from the adaptive method are shown with x's. The advantage of the adaptive method show as most of the points (26 of 36) are below the curve for the fixed reactions. This can be interpreted either as if it is possible to produce shorter slips for a given average reaction intensity, or as if a given average slip length can be obtained with lower stimulation intensities.

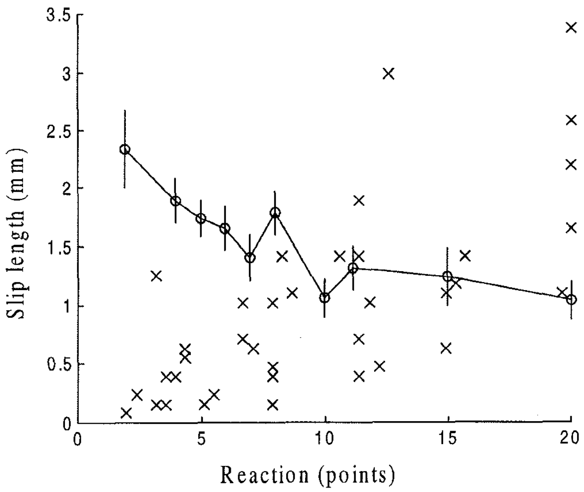

Figure 5. Average slip distances for different fixed reaction intensities (o) compared with slip distances for individual slips as resulting from the adaptive method (x). The bars show the standard error for the average values.

CONCLUSIONS

The method for estimating a proper reaction to a slip, based on the amplitude of the nerve signal, has been shown to give reactions that adapt to the velocity of the slipping object. This gives better performance with respect to either shorter slip length or lower stimulation intensity than any fixed reaction intensity can produce. However, these results have been obtained for one very specific situation, i.e. with no changes in surface of the object, no change in pull force. It still remains to be shown that the principle described here can be extended to a more natural environment.

FUTURE DIRECTIONS

Since these data were recorded, the subject has received a Freehand implantable stimulator (trademark of the Neuro Control Corporation). In the coming months we will start using this implant for control of the grasp and combine it with the slip-detection algorithm based on the neural signal. This should make it possible to perform more repeatable experiments and more functional tests than have been possible with the percutaneous electrodes.

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