TELEOPERATION OF A DEXTROUS ROBOTIC HAND USING VIBROTACTILE FEEDBACK

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ABSTRACT

The feasibility of providing vibrotactile information to humans in a teleoperated robotic system were investigated. Four channels of vibrotactile feedback were given to a human operator to relay force information from a teleoperated dextrous robotic hand. Significant advantage was seen when the operator was provided one or two channels of feedback.

INTRODUCTION

An important task in telerobotics is relaying information to the operator. Vibrotactile feedback has been suggested for such use as it does not interfere with vision [1]. Extensive studies have been performed using feedback for simple robotic manipulators, but not with high degree-of-freedom (DOF) manipulators [2]. Our research investigates the feasability of using multiple channel vibrotactile feedback to control a high DOF robotic manipulator.

METHODS

A NASA/Goddard dextrous robotic hand with sixteen DOF was used. Force sensors were placed on four of the finger tips of the hand. Each sensor relayed force information using vibrotactile stimulators placed on the fingertips of the human operator. A VPL DataGlove (VPL Inc., CA) read the finger angles of the operator; these values were used to control the robotic hand.

The experiment was then performed as follows: the subject was told to use the fingers of the robotic hand to press a push-button until a LED light turned on, which occurred at a preset target force. The test was performed using one, then two, then three, and finally four fingers simultaneously. The number of channels were defined as the number of fingers used in each test. The test was repeated five times for each finger, performed first with no feedback, and then with vibrotactile feedback. Five subjects participated in the experiments (2 male, 3 female, ages 18 $\pm$ 2 years) resulting in twenty-five tests. One trial was performed daily for four days. The error for each test was calculated:

$$error = 100\% \frac{F_s - F_t}{F_t} \qquad (1)$$

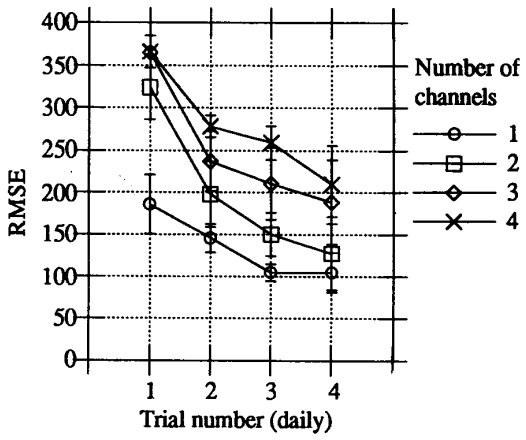
where Fs is the force recorded from the subject, and F_t is the target force. The root mean squared error (RMSE) for each trial was then calculated:

$$\mathrm{RMSE} = \frac{1}{25} \sum_{t=1}^{25} \sqrt{error^2} \qquad (2)$$

here t is the test number. The RMSE was calculated separately for each channel. The relative advantage of adding vibrotactile feedback (ADV) was then calculated:

$$\mathrm{ADV} = \frac{\mathrm{RMSE_{vf}} - \mathrm{RMSE_{nf}}}{\mathrm{RMSE_{nf}}} \qquad (3)$$

where RMSEvf is the RMSE while using vibrotactile feedback, and RMSEnf is the RMSE while using no feedback. The ADV was calculated for each channel, and averaged over the four trials.



(a)

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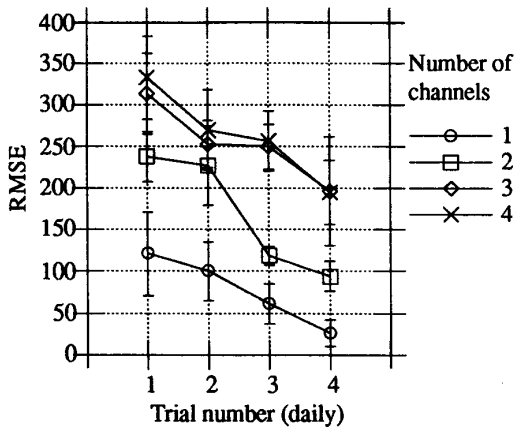

(b)

Figure 1: RMSE (root-mean-squared-error) over four daily trials (a) With no feedback (b) With vibrotactile feedback.

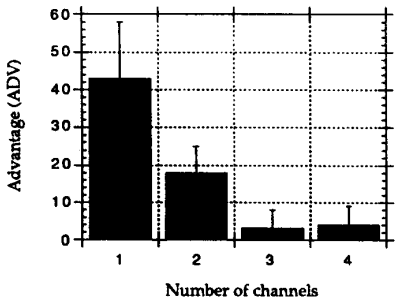

Figure 2: Average ADV (advantage of using vibrotactile feedback over no feedback) in percent per number of channels used.

RESULTS

Figure 1 shows the RMSE per trial results from the experiment. Lower RMSE indicates an improved achievement of target force levels. The RMSE increases significantly as the number of channels used increases. However the RMSE decreases significantly per trial. Averaged over the channels, the RMSE decreased per trial by an average of 12% with no feedback, and 11% with vibrotactile feedback.

Figure 2 shows the ADV from using vibrotactile feedback. Higher ADV indicates an improvement in RMSE from using vibrotactile feedback. The ADV is shown from using one to four channels. The results are averaged over the four trials from all subjects. One and two channels of vibrotactile feedback show a significant ADV of 46% and 15% respectively. The results from three and four channels of vibrotactile feedback were not statistically different from no feedback.

DISCUSSION

The results from ADV calculations showed that vibrotactile feedback reduced the RMSE. However, the differences were significant only when one or two channels of feedback were used. When three or four channels were used, the results were not statistically different from when no feedback was used.

Our results also show that increasing the number of feedback channels increased the RMSE. However the RMSE were also consistently lower per trial due to the effects of learning. These findings are consistent with earlier studies. Szeto reported that for tactile tracking experiments, the errors decreased per trial, with the largest decrease resulting after the first trial. He also showed that the tracking error increased as the number of channels increased [3].

CONCLUSION

There is an upper bound on the number of vibrotactile feedback channels that can be used for teleoperation. Our preliminary studies indicate a maximum of two channels. Using more than two channels of feedback did not show any significant improvement in performance over trials with no feedback. Further studies are required to investigate the benefits of multiple channels of vibrotactile feedback.

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