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Improving force feedback perception using low bandwidth teleoperation devices

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Abstract. **Operator perception could be improved by upgrading force feedback devices and adding more senses, such as audio and/or visual. This work is focused on multi-sensorial feedback such as vision, sound, and haptic. The main objective is to determine the most suitable manner to show proper information from the remote environment using devices with a bandwith lower than 30 Hz. The advantage of this device is its cost and simplicity. However, this constraint implies only to perceive contact forces. Information such as texture can not be displayed. This paper describes the results of an experiment about force feedback on telerobotics. The study concentrates on the evaluation of force perception affecting our senses such as haptic, audio and visual.**

1. INTRODUCTION

The first information lost on telemanipulation tasks is haptic force. Many researchers focus their work on control architecture of teleoperated systems, [1]. Others on teleoperation interface [2], and other researchers on depth or haptic perception [6]. This paper shows the integration of several results of operator interaction and teleoperated control system. Experiments have been focused on queries such as how audio and video devices can enhance haptic force feedback. One of the main consequence of a teleoperated task is the deterioration of forces and spatial location perceived by the human operator. Force perception needs to be improved. Improvements can be done by using higher bandwidth haptic devices, or by increasing the number of senses being excited. Force feedback could be used for applications, such as, haptic interface for disabled people. Virtual generated forces could be applied for new applications such as training operators, [2]. and [3]. Internet is an excellent medium to send information for teleoperated tasks [4].

The purpose of this study is to analyze the influence of an additional force display (audio or video) to improve the performance of a low cost operator haptic interface. Low cost interface allows this technology to be widely used. If force feedback devices could be applied on new applications, cost will be reduced and features be improved.

2. SENSORIAL SUBSTITUTION

Due to sensorial information loss, an alternative manner is to induce or provoke artificial sensation that are generated and controlled by application of the physical laws that govern movements or efforts to complete remote tasks. This sensorial substitution depends on the kind of sense being replaced replace, for example: in the case of the sight, because the operator and the telemanipulator are located in different places, it can be replaced by a dedicated monitor or a window that shows the task being executed. Moreover it also shows depth information which becomes useful on 3D techniques and stereo cameras [10].

For the audio channel, the simple use of a microphone or speaker to transmit sound from the remote environment to the operator and replace the loss information, other warning signals or alarms can also be used. One of the techniques widely used for sensorial substitution is haptic devices, which reflects the forces applied to and from the telemanipulator. Different studies show force reflection improves performance of teleoperation [10], [5] shows improvement in the execution time, [7] shows lower errors and peak forces with force reflection. [17] shows performance tendency in the operator with variation in force reflection control mode, [9] shows the effect that the operator can have in perception of details according to the magnitude levels of the reflected forces.

In multimedia and virtual reality areas, it is generally admitted that the use of several senses [8], besides sight, increases the integration of the user in virtual environments. Using this principle, [10] reflects forces through a haptic device and a 3D display. Auditory stimulus must be considered when designing teleoperation interfaces. The research concentrates on force reflection through visual, audio and touch senses.

3. EXPERIMENT DESCRIPTION

The experiment consists of tracing broken lines describing a Z figure in a paper with a marking pen held by the telemanipulator grip. Each paper contains 2 Z-figures which are placed on a board. A force-torque sensor is underneath the board to measure the applied force. It provides 50 force measurements per second. The master arm and the slave telemanipulator used is the Kraft Telerobotics GRIPS force reflection system. This is a poor haptic device; however it has an excellent anthropomorphic design.

A master-arm and a video image guide the teleoperated task execution. The experiment is designed to evaluate the influence of force feedback display on the task performance. Performance is evaluated by analyzing the exerted force while lines are being marked. Force data analysis responds to the operator's perception quality. Best result is achieved when a constant and adequate force is applied. Discontinuities, high forces and sudden changes of direction represent a poor operator perception during execution. Three force feedback displays are used: Kraft master-arm for haptic interface, a graph with a bar on a computer display for visual interface, and a speaker for the audio interface, as shown in figure 2. The graph shows two bars, a yellow bar that shows the reference force to be followed and a red bar that shows the

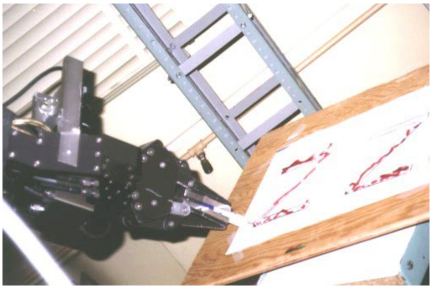

Fig. 1 View of the task done in the force reflection experiment

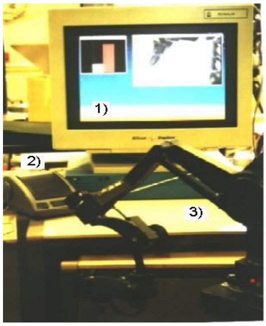

Fig. 2. Devices used for the experiments master-arm, speaker and graphics.

measurement of the force applied to the force-torque sensor. Consequently, the speaker emits a sound with variable amplitude and frequency depending on the force exerted on the board. The greater force applied, the higher frequency and amplitude of the sound is. A nice and soft sound can be heard when both yellow and red bars are in the same level and the force required is properly applied. Force sensor is updated on graph and speaker every 20 ms. Eight trials have been executed by each operator: Reflection using haptic device; Reflection using bar graph; Reflection using speaker; Reflection using haptic device and speaker; Reflection using haptic device and bar graph; Reflection using haptic device, bar graph and speaker; No force Reflection of any kind. The experiment was conducted by 12 operators tracing lines on 8 different conditions previously explained. Several tests have been done with different feedback devices before the actual experiment in order to be familiar with its operation. Operators, 20-30 years of age, were chosen from the department.

4. RESULTS

Result showed great difference among operators and conditions. The difference among operators is due to preferences each one has when tracing lines. Each operator has the tendency to apply a particular force. This discrepancy requires data transformation, so that different feedback interface can be compared. Using the transformation (1) the force is then expressed as a percentage of the maximum force applied by the operator on 8 conditions.

$$Transformed\_force(ope, Cond) = \frac{Mean\_force(ope, cond)}{Maximun\_force(ope)} \qquad (1)$$

After applying the transformation, the difference among operators dropped from 49% to 10%. Such transformation shows operators are similar. Then, it enhances difference among feedback conditions. The effect of the transformation strengthens operator’s preferences when tracing lines. The transformed data is use to build a level 3 factorial model. Such factorial model is represented graphically in fig. 3 Evaluations of interactions are relatively considered. As it can observe in figure 3, when the operator has no force reflection of any kind, more forces than needed are exerted. Any kind of force reflection reduces exerted forces significantly. First order interaction shows kinaesthetic force feedback as the best display, followed by auditory and visual. Second order interaction represents the combination of 2 displays. The best performance has occurred when haptic and auditory channels have been working at the same time. Worse results occurred on haptic and visual interaction and the worst on visual and audio. Finally, best results have not been obtained on the third order interaction.

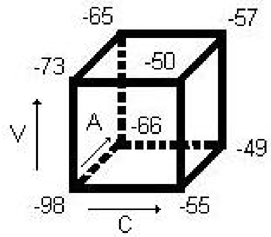

Fig. 3 Factorial Model

5. CONCLUSIONS

Haptic devices have constraints to provide all human capabilities in telemanipulation tasks. This work demonstrates the possibility to improve the operator's perception by using additional channel information. It represents a redundancy, but some criteria must be considered upon designing proper force feedback interfaces. Any kind of force reflection increase performance significantly. Best result is obtained via haptic interaction when exciting only one sense. It is possible to improve the operator's performance adding another sense. At the experiment described, the best results has been obtained when exciting haptic and auditory channels at the same time. Worst results have been obtained upon exciting haptic, auditory and visual senses as excessive redundant information.

This work demonstrates that not very complex devices have to be used for haptic applications. When no touch information is necessary, it is possible to use low bandwidth master arms and an audio channel to compensate for the loss of touch.

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