Exploring Dynamic Haptic Cues in Vehicle Teleoperation

Stephen Hughes, Ian Oakley, Andy Brady and Sile O'Modhrain

Palpable Machines Research Group, Media Lab Europe, Sugar House Lane, Bellevue, Dublin 8, Ireland
{steveh, ian, andy} @medialabeurope.ie, sile@mit.media.edu

Abstract. This paper briefly describes a system that captures the accelerations of a vehicle, and displays this information haptically to a remote user controlling that vehicle. The motivations for this system are that the haptic cues relating to the vehicle's experiences have the potential to provide the user with improved control over the vehicle, to more firmly place the user within the environment that it is encountering. This system is designed to support vehicular teleoperation. We then move on to discuss the possible mappings that can be applied to transform the raw data captured from the vehicle into information that is meaningful to the user controlling that vehicle. Finally, we speculate on other mappings and sensor inputs that may provide a user with useful haptic information in a vehicular teleoperation task.

Keywords: teleoperation, handheld haptic display, acceleration

1 Introduction

Teleoperation, the remote control of distant robotic devices, is a technique typically employed when physical interaction is required in a dangerous or environmentally hazardous situation. Vehicle teleoperation, a subset of this domain specifically focusing on remote driving or piloting, has been used for exploration deep under the ocean [2] and in space, and for high-risk operations such as bomb disposal. Both ground and air based vehicle teleoperation systems have also been extensively adopted by the military [3].

Despite its numerous applications, vehicle teleoperation remains a difficult task. A remote driver is required to pilot a craft in what are often challenging environmental conditions and using an interface that is substantially deprived when compared to the richness of driving in the real world. This fact is illustrated by the problems that have been observed with these systems. For example, users typically exhibit inadequate perception of the remote environment, and often fail to detect obstacles. One form of information that is lacking in current teleoperation systems is that relating to the physical experiences of controlled vehicle. This kind of information is extensively used in the control of a local vehicle. Drivers rely on the physical "feel" of their cars as they adjust the controls, or as external events influence them, to understand their environment and mediate their performance. Are they taking a corner to fast, have they begun to skid or slip, have they encountered an unusual, and potentially dangerous road surface? The tangible, physical changes in the properties of the car are often the first sign that such events are taking place.

2 System

The RELAY project [1] seeks to add this kind of dynamic haptic information, which is so important in real world scenarios, to a teleoperation system. Briefly, the system consists of the following components: a radio control car fitted with a sensor pack capable of monitoring accelerations in all three axes, and a custom built radio link connecting it to a wireless, handheld two degree of freedom haptic display. The haptic display consists of two parallel plates connected via a pivot joint at their center. Servomotors are positioned such that they can rotate the plates relative to one another. Holding the lower plate of this device in the fingertips, and the upper plate in the heels of the hands allows the display of ungrounded two degree of freedom displacements. This device is illustrated in Figure 1.

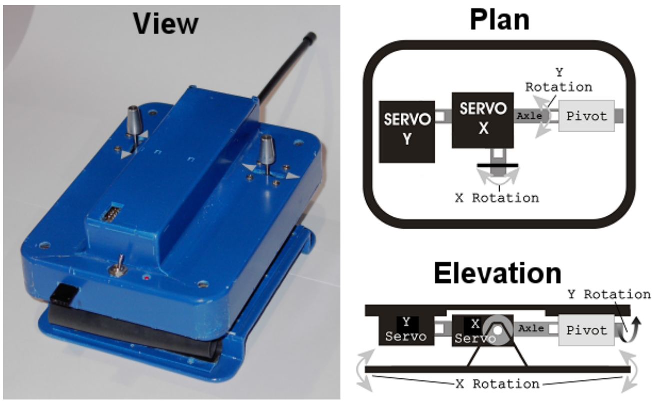

Fig. 1. View, plan and elevation of ungrounded haptic display used in Relay project.

3 Mappings

Having constructed this system, our attention turned to the next logical focus: we began to examine the various possible mappings between the raw data gathered from the car, and the displacements displayed on the handset. Initial experiences indicated that a linear mapping between vehicle acceleration and plate movement was often ineffective. This is partly due to the small amount of displacement possible with our device and partly due to limitations imposed by the speed of the servos we are using.

To facilitate our investigation of different mappings we sought a mechanism that would enable us to adjust these in real time; to allow us to dynamically alter how these data were being displayed and to immediately compare and contrast this with a previous mapping. To achieve this goal we altered our existing hardware setup to include an interceptor station operating in the radio link between the car and the handset. This station was connected to a PC, and operated by a GUI application that was able to alter the signals sent to and from the car and handset in real time. A screenshot of the interface to this application is shown in Figure 2.

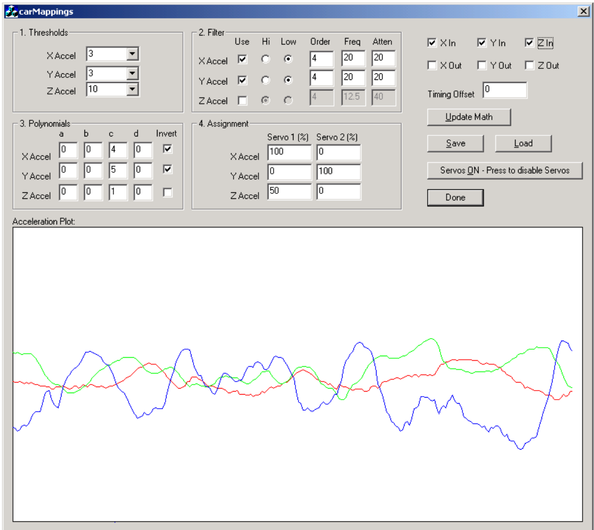

Fig. 2. Screenshot of the interface used to display and adjust data in the Relay project.

This application currently features a number of basic visualisations and manipulations, but as discussed in the future work section below, it will shortly be expanded to include more sophisticated functionality. Firstly, the application can graph the raw input data gathered from the car, and superimpose the output data sent to the handset on top of this. This basic tool visually and interactively illustrates the effect of experimenting with different mappings.

Beyond this display, the application supports four manipulations, each of which can be applied to the three axial data streams individually. The manipulations are thresholds, polynomials, basic filtering and assignment. The thresholds simply allow us to define a range of data around zero acceleration such that the output will not change until the input has exceeded this range. This enables us to easily screen out small-scale accelerations, such as those generated from moving over uneven surfaces, or due to vibrations in the engine itself.

The polynomials section allows us to apply a standard polynomial function to the input data as follows:

$$\text{Output}(t) = (a * \text{input}(t)^3) + (b * \text{input}(t)^2) + (b * \text{input}(t)) + d)$$

This allows us to experiment with a large range of different curves mapping input against output data. The filtering section supports applying either a high or low pass filter of varying order, frequency and attenuation to the input data. This functionality allows us to screen out aspects of the data that we are not interested in, and target specific types of change in the input data. Finally, the assignment section allows us to specify how we map the three individual axial inputs from the accelerometers to our two-degree of freedom display device. The most obvious mapping is to align the x and y axes of the car and the haptic device, but other more complex mappings may be more appropriate. For instance, this system allows us to add a percentage of the information from the car's z accelerometer to either the x or y axes of the haptic display. This explicitly provides information about the cars vertical movements to our 2 DOF display; it presents information related to the cars bouncing as it moves over terrain.

We have yet to carry out extensive user trials of our system. We are in the process of contacting groups of radio-control car racers – expert users in this domain - to gauge their responses and preferences for different mappings in multiple circumstances. However, this work is ongoing, and consequently, here we report our intuitions about what may make meaningful mappings derived from purely subjective experimentation with our software tool. The following is a brief account of this experimentation.

4 Initial exploration of mappings

For most mappings, the threshold effect was extremely useful for removing excess noise, which would manifest itself as seemingly uncorrelated vibrations in the hand-controller's fingerplate. The source of such noise includes vibration from the motor of the car and aliased components of that vibration due to an imperfect anti-aliasing filter. The threshold works such as to not to appreciably affect any larger scale events, and results in a much smoother experience, especially when driving in a straight line.

The low-pass filtering was found useful for the x and y data (left/right and forward/back) as it smoothed out bumps and motor induced noise. For example, when a fourth order filter with a cut-off frequency of 20Hz was applied to this data, the overall experience was much smoother, there was less jerkiness, and as such the sensation of temporally extended events such as turning and stopping was improved. The disadvantage to the filtering process was the increase in latency that it natively introduced. Including the filtering, latency in the system exceeded 70 ms, and the feedback began to feel sluggish.

As we speculated, the assignment operation performed the useful function of allowing us to incorporate a portion of the data from the z accelerometer (up/down) to that display in the x and y axes in the handset. We found it especially useful to map about 50% of the data to the x output alone, thus giving a sense of the terrain granularity over which the car was travelling. Finally, thus far we have done little with the polynomial section bar modify the c factor which essentially functions as a gain constant. Due to the higher magnitudes generated by events in the x axis (acceleration, deceleration) when compared to those in the y axis (turning), we found it beneficial to include a higher gain constant for the y-axis. This enabled us to clearly display forces relating to cornering without saturating the display when rendering forces relating to speeding up or slowing down.

5 Future Work

Building on our initial subjective work with the mapping software, we plan to implement a subsystem that will allow the detection and display of the degree to which the car is slipping or skidding. We believe that such a system would potentially increase the driver's control over the vehicle, especially if the terrain is slippery or otherwise treacherous, by giving a early warning that control is being lost, and hence provide an larger time window for this to be rectified. We intend to achieve this by measuring the degree to which the car does not follow a uniformly circular arc trajectory when turning. This will be achieved by mounting an additional accelerometer, equidistant from the car's centre of gravity as the main accelerometers, and parallel with and centred on the x-axis of the car, as illustrated in the Figure 3.

When the car is turning normally (or simply moving in a straight line), the y components of the measured accelerations will be equal ($\hat{A}1y = \hat{A}2\ y$).

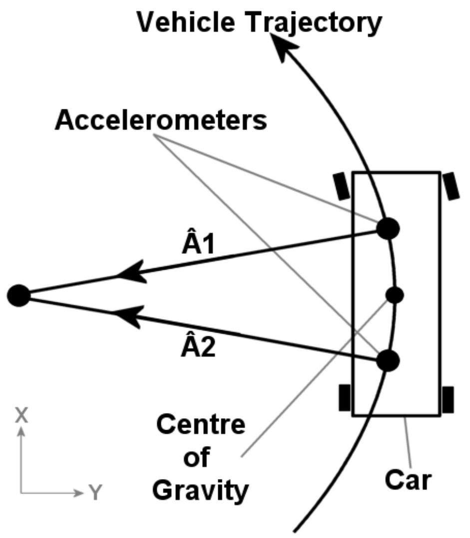

Fig. 3. Accelerations measured by two accelerometers mounted equidistant from the vehicle's center of gravity, supporting the measurement of slip.

If, however, the car loses traction, for example if the rear of the car is sliding while turning, these accelerations will no longer be equal. Thus by subtraction we can obtain a variable indicative of the degree and orientation of the car's slip. Initially, we plan to map this data to a vibration in the handset, with the amplitude of vibration being proportional to the degree of slip.

In parallel with this technical effort, we hope to move forward with trials of our system with expert users. We are in contact with groups of radio controlled car racers – who are highly skilled vehicular teleoperators – and hope to present information gathered from studies with these users in the final version of this paper.

6 Summary

We have briefly described the motivations for adding dynamic haptic cues (relating to accelerations) to vehicular teleoperation tasks, and described a system that enables this. Reflecting the complexity of this domain, we then spend the remainder of this paper discussing how these cues can best and most meaningfully be constructed from the raw data gathered from the car. We describe, with recommendations, various mappings we have tried, and speculate on improvements in the sensor system that we intend to implement shortly. Finally, we are beginning to consider evaluation of this system by looking at more real world scenarios, and groups of expert users experienced in related disciplines. This work is at a stage where we strongly feel that it will benefit from demonstration and discussion.

References

1. Brady, A., MacDonald, B., Oakley, I., Hughes, S., O'Modhrain, S. (2002). RELAY: A Futuristic Interface for Remote Driving. EuroHaptics 2002, Edinburgh, UK.
2. Dennerlein, J. T., E. Shahion, et al. (2000). Vibrotactile Feedback for an Underwater Teleoperated Robot. Internation Symposium on Robotics with Applications, Maui, Ha-waii.
3. Fong, T. T., C. (2001). Vehicle Teleoperation Interfaces. Autonomous Robots, Kulwer Academic Publishers.