MODEL BASED DATA COMPRESSION FOR 3D VIRTUAL HAPTIC TELEINTERACTION

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ABSTRACT

This paper presents a model based prediction of haptic data signals for data compression purposes in virtual haptic teleinteraction environments. The proposed data reduction itself is based on psychophysical properties of human perception. This scheme can be used for Internet-based multimedia applications like haptics-supported games or virtual haptic explorations. Using our approach haptic data packet rate reduction of up to 95% without impairing immersiveness is achieved.

1. INTRODUCTION

Apart from nowadays quite common media like video or audio the haptic modality is gaining more and more interest. Haptics, this means basically the perception of touch and feel, is already used in some types of popular applications like force feedback supporting computer games. With the emerging availability of better and cheaper haptic display devices, the haptic modality will gain more interest in a variety of different consumer applications.

To make haptic teleinteraction, e.g., for haptic exploration of a virtual museum [1], possible over the Internet a couple of criteria have to be fulfilled. One criterion is low network latency, another is the ability of sending and receiving packets at a very high rate. Because stability problems arise in haptic teleinteraction across networks as described in [2, 3, 4], it is necessary to optimize the communication between user and virtual environment. One approach in this direction is the herein proposed packet rate reduction by usage of a signal prediction model in combination with an already published psychophysically motivated deadband approach [3].

2. HAPTIC TELEINTERACTION

A haptic teleinteraction system consists of three main components. The Human System Interface (HSI) is operated by a human being, the so called Operator (OP). This HSI is some kind of haptic display device like a force feedback joystick or a more sophisticated device with more Degrees of Freedom (DoF) like the one we use in this paper. The operator usually commands target positions for the so called Teleoperator (TOP) in a Virtual Environment (VE) by sending position and velocity information acquired from the display sensors at a rate of usually 1000Hz. The TOP can be any kind of tool or even just a point within the VE which is used to interact with the VE by touching or moving virtual objects. The forces generated during haptic interaction with objects are calculated from object properties like surface stiffness and mass and are sent back to the HSI and displayed to the OP. Due to the fact that the VE and the TOP are usually located in the Internet to offer as many users as possible the opportunity to use its services, a network connection between OP and VE has to be used for communication of the involved haptic and other data.

3. DEADBAND TRANSMISSION

Psychophysically motivated deadband transmission is based on Weber's Law which states that change in a stimulus can only be felt by a human being if it exceeds the so called Just Noticeable Difference (JND). This JND is linearly related to the magnitude of the original stimulus. For example, you can sense the difference between two weights of 100g and 110g, but you cannot, respectively, sense the difference if they weigh 1000g and 1010g, although the absolute weight difference is the same. In the latter case you will sense it again at 1100g at a given JND of 10%. Typical JNDs for human haptic perception vary between 5% and 15%[5].

Deadband transmission as introduced in [3] works with this notion of JND by only sending new sample values over the network if the value differs from the most recently transmitted value by at least a JND. So only changes a human being is able to sense are transmitted.

4. MODEL BASED PREDICTION

Psychophisically motivated deadband transmission itself has already been the topic of our previous work [3]. In order to further reduce the amount of transmitted packets over the network a signal prediction model is used in this work on both sides of the system. On the OP side a force predictor is used to estimate future force values from the incoming force values from the TOP side. On the TOP side exactly the same predictor is running in parallel which is fed with the values sent to the OP side, i.e. exactly the same values as are used on the OP side. So the fact that the predictors on OP and TOP side are strictly coherent enables us to only send packets over the network if the current actual signal differs from the predicted signal by a JND. This enables us to implement different kinds of predictors which try to estimate upcoming signal characteristics.

Of course the same which is described for force values is also applicable to velocity values, which are transmitted in the opposite direction.

5. LINEAR PREDICTION

To demonstrate the potential of such a real time signal prediction a relatively simple linear predictor is implemented and experimentally analysed. It works as follows.

$$v_i = \begin{cases} v_{new} & \text{new value arrived} \\ v_{i-1} + \frac{v_{new-1} - v_{new-2}}{t_{new-1} - t_{new-2}}(t_i - t_{i-1}) & \text{else} \end{cases}$$

where $\{v_i, v_{i-1}, v_{i-2}, \dots\}$ are the most current values given out by the model (to use it as current force in the haptic display or as current velocity in the VE) and $\{t_i, t_{i-1}, t_{i-2}, \dots\}$ are the corresponding time instances. $\{v_{new}, v_{new-1}, v_{new-2}, \dots\}$ and $\{t_{new}, t_{new-1}, t_{new-2}, \dots\}$ are the last received values and the corresponding time instances.

So the signal is estimated by following the slope given by the last two received signal values. Once the so predicted signal differs too much, in our case one JND, from the actual signal, a new correct value is transmitted and the new prediction starts from there.

6. PSYCHOPHYSICAL EXPERIMENT

A psychophysical experiment was conducted where test subjects had to touch and feel a virtual sphere over a network using a haptic display device[1]. The used deadband for the transmission (see Section 3) was chosen out of the following discrete values: 0%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 20%, 25%, 30%, 35%, and 40%. The subjects should give a rating from 0 to 10 points according to the quality of the displayed haptic sensations. Therefore they were shown at the beginning how optimal feedback (0% deadband, 10 points) and worst case feedback (40% deadband, 0 points) feels like. Then the deadband was randomly chosen out of the aforementioned values and the subjects should tell how real the system felt. This experiment was conducted four times. The cases force deadband only and velocity deadband only were combined with the cases with or without linear prediction model active.

Apart from the rating, the transmitted packets were counted and analyzed.

7. EXPERIMENTAL RESULTS

The average packet rates measured during the experiment can be seen in Figure 1. Please note that in comparison to [3] the haptic display device used in this work has three DoFs and therefore a three dimensional extension of the approach in [3] is employed.

We can see that even this simple linear prediction model helps to reduce the packet rates beyond the 3D extension of the approach in [3]. The average gain from the LP-model is 21% for velocity values and 25% for force values. For 20% velocity deadband and 5% force deadband we observe an improvent of 41% and 44%, respectively. These deadband settings have been classified by the test subjects as not disturbing the immersiveness of the experiment. The total savings in comparison to transmission without deadband are 81% and 93% for velocity and force packets, respectively.

So far only four test subjects underwent the test procedure. But still the main tendencies are observable. The average ratings given by the test subjects were in average 14% higher for velocity and 40% higher for force when the linear prediction model was active. The exact ratings will of course be shown in the final paper along with the results of up to 20 subjects.

[1] SensAble PHANTOM Omni

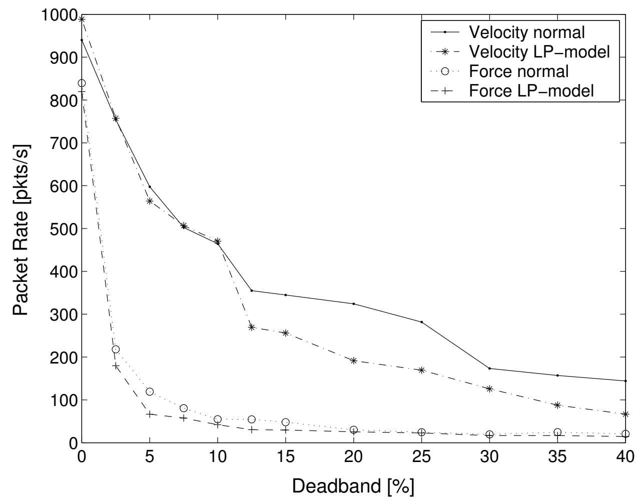

Fig. 1. Average packet rates for velocity and force signals with and without the proposed model based prediction. *Velocity normal* and *Force normal* refer to a 3D extension of the approach in [3].

8. DISCUSSION AND FUTURE WORK

We presented a haptic data transmission that combines model-based prediction with a psychophysically motivated deadband transmission approach. Even the quite simple linear prediction model used in this paper shows a significant decrease in packet rate without deteriorating the immersiveness of the system. In future work we want to find more accurate prediction methods to further improve this scheme.

9. REFERENCES

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