Predictive algorithms for distant touching

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Abstract

This paper focuses on the problems of networked gestures. The tele-gesture is the achievement of a remote gesture. To reach a good sensory perception of the distant scene, it is necessary to create a specific flow for the haptic data: position, orientations, and feedback forces. This flow presents intrinsically a bi-directional characteristic. Its quality is extremely dependent on the latency of the intermediary telecom network. In this paper we will present the predictive algorithms we have developed to avoid the delay.

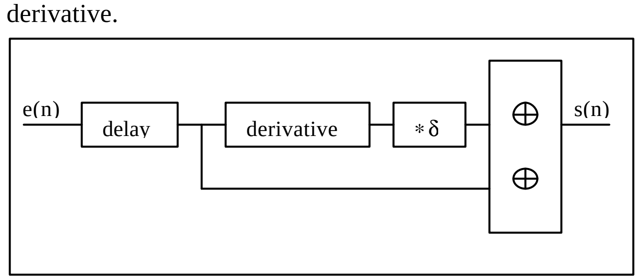
1. Introduction

This paper is about the transport of gestures through networks. The tele-gesture is the achievement of a remote gesture, i.e. to touch a distant object, that is real or virtual, for example, a human body, and to feel its mechanical characteristics, its sensitivity, specifically concerning bones, muscles, tendons and joints which give information about its static, balance and the motion of the body in space [1]. To reach a good sensory perception of the distant scene, it is necessary to create a specific flow for the haptic data: position, orientations, and feedback forces [2]. This flow presents intrinsically a bi-directional characteristic. We use a SensAble PHANToM haptic device. This device has 6 degrees of freedom and renders a 3D force information. It can track the position and orientation of the tool within a workspace of 16 cm wide, 13 cm high and 13 cm deep. The maximum force exerted is 6.4 Newton. To create a model of the gestures, we use a force feedback device (FFD). The gesture depends on the sampling frequency of the gesture signal. To have a smooth perception for the gesture, it is absolutely necessary that the haptic loop run at a frequency of 1 kHz. Below this frequency, the force returned by the force feedback device appears as discontinuous and as a result, the human hand sensors feel a strong unpleasant vibration. Current networks are unable to transmit data at a frequency of 1 kHz, which means that the message transmission delay is practically always longer than 1 ms. This delay is between 10 and 100 ms according to the type and length of network. We have to deal with an incompressible latency. The temporal variables of position and force, which represent the local model state, will only be able to update the distant model after a delay δ. Therefore, we want the distant model synchronous with the local model, in a real time application. Then, the prediction of the distant model's state at time t, with the history of the local model until date $t-\delta$, is an interesting solution, which we propose in order to avoid this delay.

We have analyzed different ways of prediction from the point of view of signal processing. The predictors are associated to filters so that the characteristics (magnitude response and phase) are evaluated from the predictor equations.

2. First order predictor

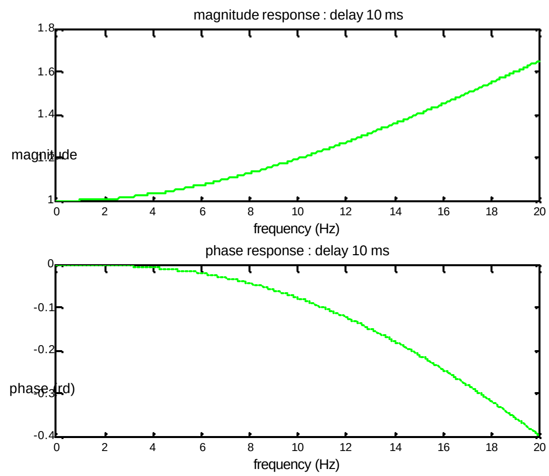
We studied three different types of predictors. The first one is the first order predictor that uses data contained in the first derived function of the signal (speed) that we want to predict. In this case, predicted signal is a function of delayed entered signal and her first derivative.



It is calculated by the following relation:

$$X\_predicted\ (t) = X(t-d) + d * \dot{X}(t-d) \quad \text{(EQ1)}$$

The magnitude and the phase response of this filter are illustred on the following figure.



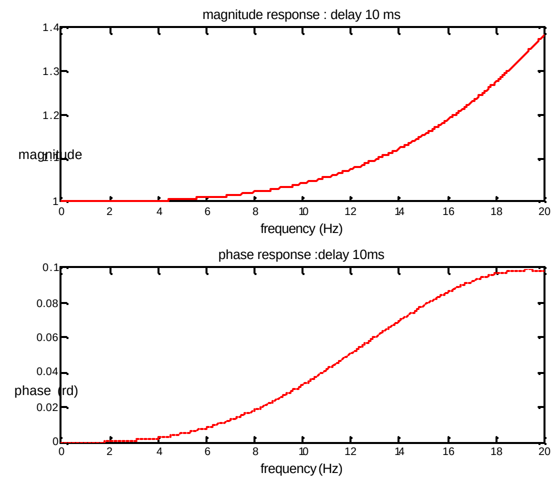
3. Second order predictor

The second one is the second order predictor that uses the data coming from the second derived function of the signal (acceleration).

This predictor is evaluated by the following equation:

$$X\_predicted\ (t) = X(t-d) + d * \dot{X}(t-d) + \frac{d^2}{2!} * \ddot{X}(t-d) \quad \text{(EQ2)}$$

The magnitude and the phase response of this filter are illustred on the following figure.



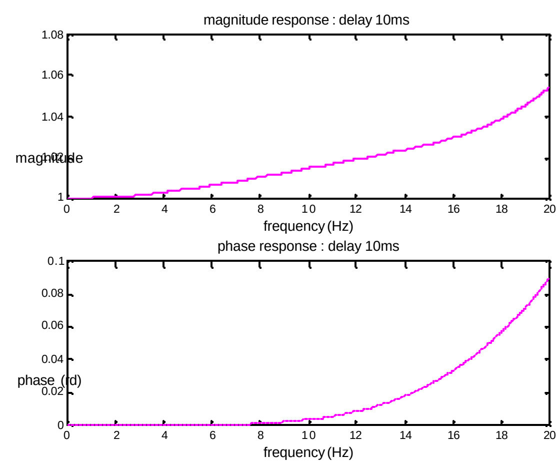
4. Third order predictor

The third one is the third order predictor that uses the data coming from the third derived function of the signal (jitter).

It is calculated by the following relation:

$$X\_predicted\ (t) = X(t-d) + d * \dot{X}(t-d) + \frac{d^2}{2!} * \ddot{X}(t-d) + \frac{d^3}{3!} * \dddot{X}(t-d) \quad \text{(EQ3)}$$

The magnitude and the phase response of this filter are illustred on the following figure.



4.The Noise of digitalization

By processing the first derived functions of the signal, representing the local model's state, we observed the apparition of an unpleasant noise directly depending on the noise resulting from the digital signal gesture quantification. The calculation of the derived function of the local model's state signal increases the high frequencies contained in this signal. Therefore, the quantification noise resulting from the gesture digitalization is a high frequency noise about of one kHz. This phenomenon dramatically increases when we use the second derived function or even more with the third derived function of the local model signal, see the Figure 1.

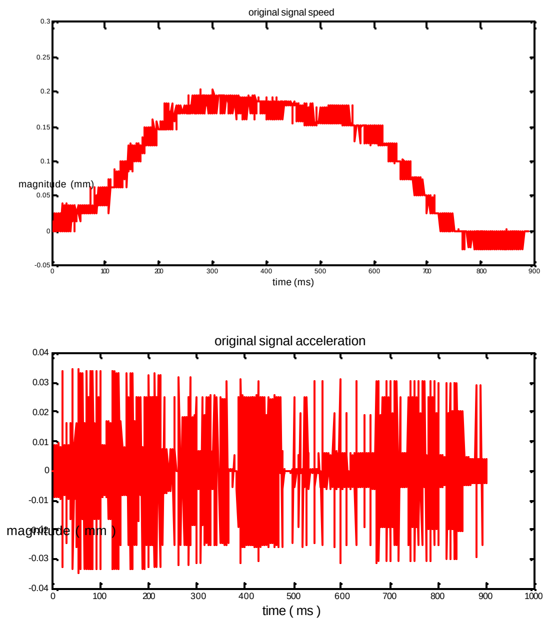


Figure 1 On top, the first derived function of the gesture signal x-component - Under, the second derived function of the gesture signal x-component

The noise created by the successive derived functions of the signal is all the more disadvantageous during the predictive signal construction, since the amplitude is multiplied by the delay and the factors function off the squared delay and the cubed delay. Thus, to minimize the disturbance coming from the successive derived functions, we decided to filter the noise created by each derived function with an elliptic low pass filter at various gauges depending on the derived order [5].

The predictor performances depend on the delay but also on the maximal frequency content in each axial component (x,y,z) of the gesture signal that we want to predict.
So we have evaluated the maximal frequencies on each signal component resulting from any gesture from several manipulators. The maximal frequency in each component does not reach 10 Hz, whereas for digital hand writing gestures the maximal frequency in each component is about 3 Hz.

5. Results

It was necessary to choose a criterion to extract the best predictive algorithm regarding delay, and the maximal frequency contained in each component (x,y,z) of a gesture.
We used, to evaluate our predictive algorithms, a criterion of mean square error :

$$E = \frac{\sum_{i=1}^{N} \left(X\_predicted(i) - X(i)\right)^2}{N} \quad \text{(EQ4)}$$

For a writing gesture, and a latency fixed to 10 ms, the one order predictive algorithm has got the least performance and the third order algorithm has got the best performance, see Figure 2.

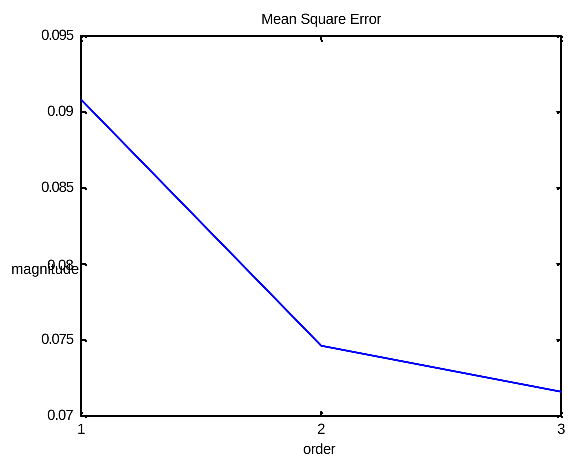


Figure 2 Mean square error for a writing gesture with time delay equal to 10 ms

In the second experiment, we fixed the time delay to 30 ms we observed the same phenomenon as the previous experience (with delay 10 ms). We can see that the magnitude of the error has been multiplied by 3 approximately, see figure 3.

Figure 3 Mean square error for a writing gesture with time delay equal to 10 ms

In the third experiment, the delay was fixed to 100 ms. We can observe that the best prediction's algorithm is now the second order, but the third order is better than the first order yet, see figure 4.

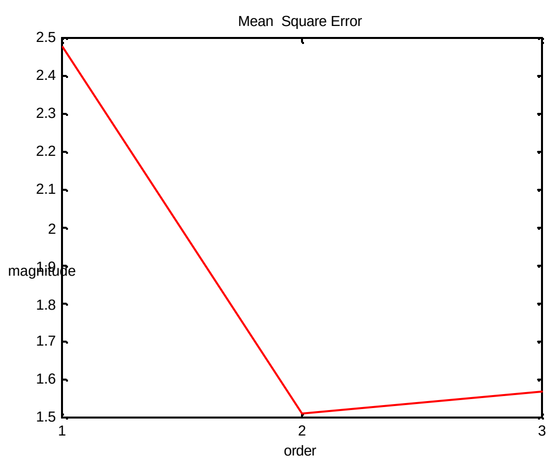


Figure 4 Mean square error for a writing gesture with time delay equal to 100 ms

6. Future works

In order to measure the perception due to the different predictors, and to verify their mathematical limits, we are testing them in the tele-hand-writing experimentation.

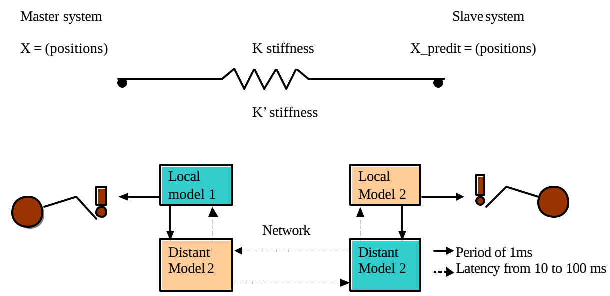


Figure 5 Distant control of the robot in position

We are developing an experiment of tele-hand-writing: Two FFDs are connected together through the local area network. One manipulator controls the master system, and the second manipulator follows the master order on the slave system. The master manipulator writes a word that is sent through the network to the FFD of the slave system, see figure 5.

We want also to compare our predictive algorithms with the approach of Anderson, the wave transform and the derivative work of Creare [3], [4] .

7. Conclusion

This approach of prediction, based on the successive derivatives of the original signal, is very interesting for delay about 10 until 100 ms. The prediction's error is very acceptable, and the third order algorithm is the best until 80 ms approximately, for gesture like writing. The algorithms are very sensitive to the maximal frequencies contained in each position's component of a gesture: the more the maximal frequency raises the more the prediction's error raises.

8. References

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