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Network Delay Regulator for Sampled Data-like Channels : A Feasibility

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Abstract: In time-delayed control systems such as haptics and teleoperation systems, handling an unknown time delay is always an issue. This paper proposes a technique to regulate the unknown time delay by converting it into a constant delay, considering the communication channel as a sampled-data system. Particularly, it regulates the data connected with the number of samples on equal interval based on maximum delay variation, provided that the sampling rate is known. The effectiveness of the proposed approach is shown via feasibility simulations on **MATLAB®** for any time delay.

Keywords: Predictive Control, Communication Channels, Regulator, Sample-data systems, **Teleoperation**

I. INTRODUCTION

Packed switching networks such as internet provides a convenient way to send and receive data from one part of the world to the other, in many applications including haptics and teleoperation systems. However, Internet as communication channels may offer severe amount of time delay, jitter and data losses [1-4]. In some applications of time-delayed control systems and haptic teleoperation systems, this unknown behavior of delay can cause unstable behavior which also degrades performance. There are some predictive control approaches that compensate the effect of time delay ([1, 5-8]), but most of them require accurate knowledge about the size and nature of time delay. Therefore, three types of time delays applied in their predictive controllers are: (1) Average value of RTT (T_{avg}) obtained from the time delay profile of packet-switching networks. (2) Estimated value of RTT. (3) Buffering RTT based on T_{max}.

Although the variable time delays are treated explicitly in some predictive control approaches (([1, 3, 5-7]), for example, by direct prediction of time varying delays (amount of delay, data losses, jitters, etc.) [2, 3], prediction of time delays directly is very difficult and is not reliable because of the random nature of the delays, especially in the packet-switched communication lines (e.g., Internet). Instead, most predictive control approaches ([1, 7] etc.) predict the maximum time delay because this prediction is relatively easy and is thought to be reliable for short time. Subsequently, they treat this maximum time delay as a constant time delay by making an arbitrary large time (T_{max}) delay by use of buffering techniques such as [4, 8]. These approaches do not completely consider the communication channel as sampled-data system and therefore are not able to address the issues such as packet disordering.

This proposed method is new and works for sample data like communication channel, and it will regulate the packet-data based on the number of samples equivalent to maximum delay provided sampling rate is known and fixed, regardless of time delay variations and data losses. The outline of subsequent sections of paper is as follows. In section II the proposed method and its details are given. Section III, shows simulations, and section IV concludes the approach.

II. PROPOSED METHOD

To accommodate artificial delay, a buffer is constructed which takes and stores data. The buffer then outputs the data based on the given time delay value (which is either *a priori* known or obtained online). Specifically, it also handles aperiodic signal (randomly-placed packets) by making it to a periodic signal (equally-placed packets based on maximum time delay value). In other words, it will regulate the packet-data based on the number of samples (n) equivalent to maximum delay ($T_{max} = n * \tau$), if τ is precisely known and fixed.

where T_{max} is the maximum value of time delay
n is the number of samples
τ is the sampling rate

The proposed scheme comprise on three steps.

1) Get packets appearing a-periodically at different samples (i.e., packets with variable time delay).

2) Place/push packets one by one in the buffer.

3) Then based on maximum value T_{max}, it periodically sends out/pops these packets one by one (based on T_{max}).

III. SIMULATIONS

To show the feasibility of the proposed regulator, simulations are performed using **MATLAB**. In this connection, data values at different samples have been hypothesized e.g., n = 30 sample values are considered as input. The data sampling rate is 0.001 sec.

Following assumptions and facts are as follows:

1) The buffer will not be required to delay the value

less than sampling rate.

2) For the feasibility, "T_{max}" delay is considered known, for example in real teleoperation, setting-up teleoperation phase for 1 min, can provide time-varying delay profile between packets. Predicting "T_{max}" is thus possible.

Furthermore, the following two scenarios in terms of data appearing in variable time delay and with disordered packet sequence are addressed as follows:

A. Making a variable time delay into a constant time delay

Figure 1, shows the results comparing real unbuffered data (upper plot) and constant delay buffer output (lower plot). Here it is assumed that the sequence of packets received is correct. It is evident from the lower plot that the data appearing with variable delay in upper plot is perfectly delayed to a constant time delay value (0.004 sec), which is the maximum interval between two data packets shown in the upper plot.

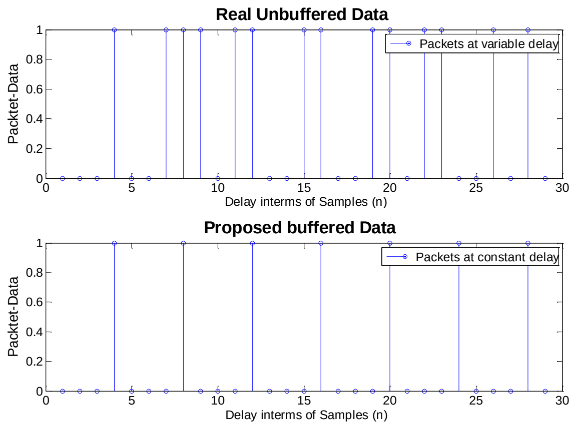

Fig. 1. Upper Plot: Packets-data received *a periodically*. Lowe Plot: Packets-Data placed periodically based on T_{max}.

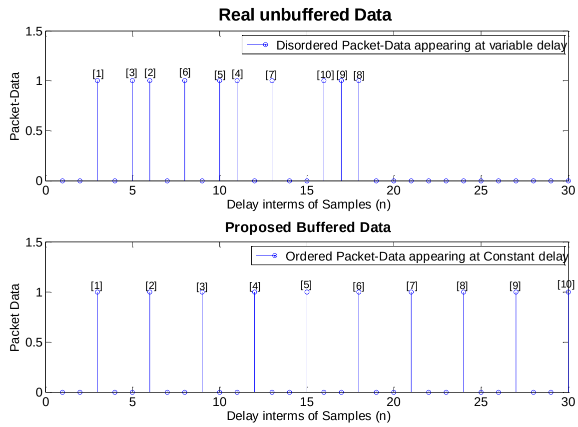

Fig. 1. Upper Plot: Data packets received *a periodically*. Lowe Plot: Data packets placed periodically based on T_{max}.

B. Compensating Packet Disordering

Figure 2, shows the case comparing disordered data at variable interval (upper plot) with the data through proposed buffer (lower plot). To reorder the packet sequence, time-stamped packets are considered. It is clearly evident from the lower plot that the data packets are place at 0.003 sec which is the maximum delay value in the unbuffered data (upper plot).

IV. CONCLUSION

The feasibility of constant time delay buffer is shown via MATLAB simulations. It is shown that in case of both variable time delay and disordered data packets, the proposed buffer regulates the time delay based on maximum delay variation. In future, real experimentation on a packet switching network such as Internet will be furnished.

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