Evaluating the Impact of Packet Delay and Loss on a Network Control System in DETERlab

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Abstract

The objective of my project was to analyze how adding time delay and packet loss will alter the second-order input signal after it has travelled from the digital controller across the wired control network system to the plant output. The study was conducted using the state-feedback UDP network control system that was created by using software implementation. The plant and controller programs were written with the use of socket programming in Java, and the programs were compiled and run by remote accessing into two nodes. The nodes were part of the network topologies that were created in experiments in the DETER Network Security Testbed at UC Berkeley. Using data that was collected from the experiments, the magnitude of the plant output was plotted over time, and the graph results that were obtained allowed for comparative analysis between the ideal plant output in an idealized network that had no added packet loss or time delay parameters with the plant output from an imperfect network that had additional network security vulnerabilities. The results from this paper contribute to data that is being collected in understanding how time delay and packet loss will affect a state-feedback signal of UDP packets that has gone through an internet communications network, and it reveals an efficient way for internet network security monitoring.

Introduction

Cyber-physical systems (CPS) research is a developing field that incorporates embedding computation into physical components in order to maintain the system's functionality[1]. The computations that are done are subsequently affected by interactions with the physical system[2]. For networked control systems (NCS), which are closed feedback loops with the data being transmitted through wired or wireless communication systems, the problems of instability in the network arise in the form of time delay, packet loss, and other network vulnerabilities when transmitting the data. The instabilities of the internet network become ever more apparent since the data being transferred is in the form of packets. With more research in this area, it can be better understood how the signal sent through a NCS by the method of packet transmission is affected as the result of the packets traversing through the network.

Method

The experiments that were run for this project required access to nodes and links of network topologies. These network topologies were created by using the DETER Network Security Testbed, with the bandwidth set to 100.0 Mb and the queue-type to be Drop-Tail..

The code that included the plant algorithm and the User Datagram Protocol (UDP) sender/receiver setup was compiled in node-0 while the code that included the controller algorithm and the UDP sender/receiver setup was compiled in node-1.

With the plant and controller programs installed in the nodes, experiments with the same two-node topology interconnected by a single link were run with different network settings.

The initial condition of the controller input $u_{controller}(t) = sin(\frac{2\pi t}{5})$ served as the reference input, having a period of $T = 5.0$ seconds.

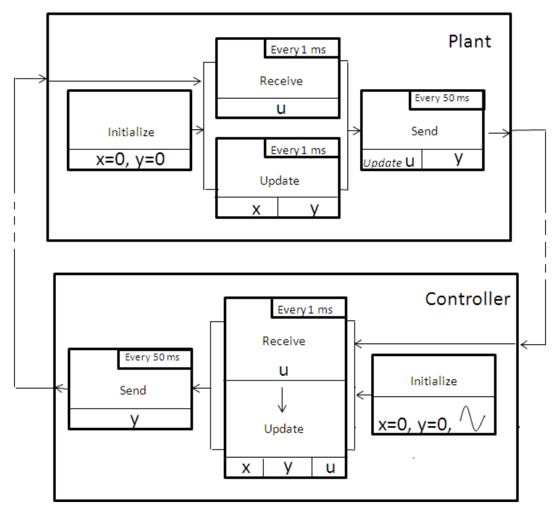

Figure 1: Flowchart of plant-controller code implementation

State-Space Equations

The plant with coefficients a=0.0, b=0.5, c=0.6826, and d=0.0, and Δt=1.0 millisecond can be described as:

$$x_p(k+1) = x_p(k) + [ax_p(k) + bu_p(k)]\Delta t$$
$$y_p(k) = cx_p(k) + du_p(k)$$

The discrete controller with coefficients a_c=1.0, b_c=0.05, c_c=24.9980, and d_c=7.994 can be described as:

$$x_c(k+1) = a_c x_c(k) + b_c u_c(k)$$
$$y_c(k) = c_c x_c(k) + d_c u_c(k)$$

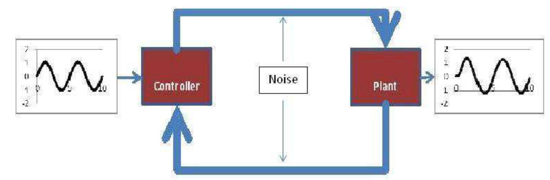

Figure 2: State-feedback model with the sinusoidal input and the output signal

Experiments- Time Delay

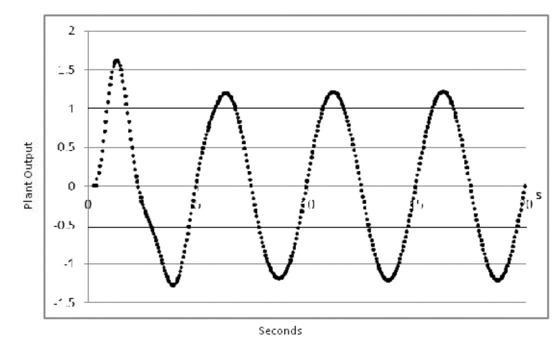

Figure 3: Plant Output vs. Time (s.) for 60.0-ms Delay Experiment

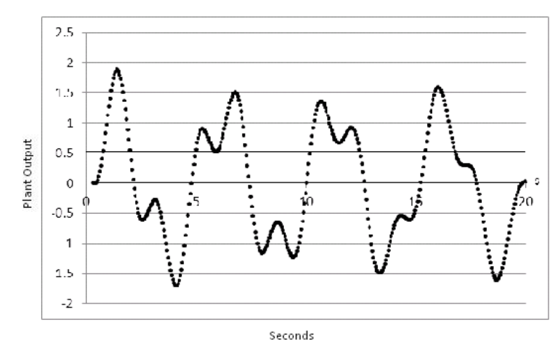

Figure 4: Plant Output vs. Time (s.) for 70.0-ms Delay Experiment

Conclusion

The results showed that this approach could remotely monitor the impact of changes due to packet loss and/or time delay if relevant parameters were well-defined. Further work can be done in learning about the underlying characteristics of how the network system will affect specific waveforms that are sending packets, using this research as foundation for building a viable model to collect and analyze network data.

Experiment Results

Four experiments were run that included network characteristics of time delay of 50.0 milliseconds, 60.0 milliseconds, 70.0 milliseconds, and 80.0 milliseconds, which are demonstrated in this paper. Four experiments were run with packet loss of 0.3, 0.4, 0.5, and 0.6.

Experiments- Packet Loss

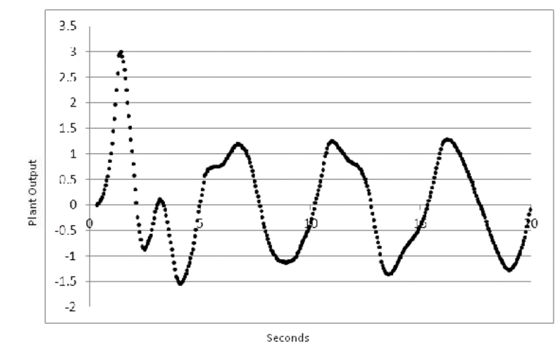

Figure 5: Plant Output vs. Time (s.) for 0.5 Packet Loss Experiment

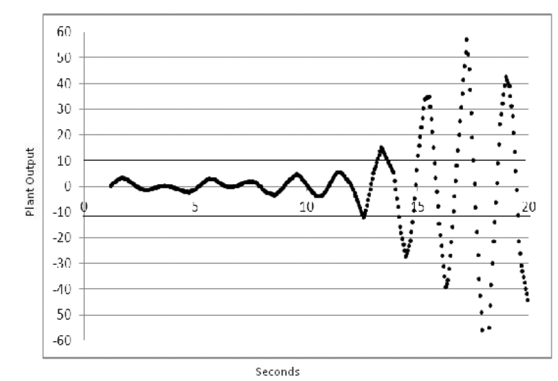

Figure 6: Plant Output vs. Time (s.) for 0.6 Packet Loss Experiment

References

[1] Tabuada, P. (2006, October). *Cyber-Physical Systems: Position Paper*. Symposium conducted at the NSF Workshop on Cyber-Physical Systems, Austin, TX.

[2] Lee, Edward A. (2006, October). *Cyber-Physical Systems - Are Computing Foundations Adequate?* Symposium conducted at the NSF Workshop on Cyber-Physical Systems, Austin, TX.