# Analysis of Wireless and Internet Link Failure Effects on Open Loop Remote Control of Motors

Arpit Ainchwar, Jasmeet Singh Ladoiye, Dan Necsulescu
Department of Mechanical Engineering
University of Ottawa
Ottawa, Canada
Email: aainc092@uottawa.ca, jlado023@uottawa.ca, necsu@uottawa.ca

***Abstract*— In the era of the Internet of Things (IoT), it is crucial to study the real-time dependencies of the Web, its failures, and the time delays. Wireless links widen the domain of applications of mixed, engineered systems such that computer integration includes remote nodes that are not wired to a central station. System integration requires addressing, monitoring and control issues resulting from link uncertainty. The performance of a real-time control system depends not only on the reliability of the hardware and software used but also on the time delay in estimating the output, because of the effects of computing time delay on the control system performance. New solutions are required based on distributed model predictive control, inverse problem solutions, and fractional order modeling. Remote monitoring and control contain wireless sensors and actuator networks that are stand-alone or embedded in an Internet of Things system. The focus of the paper is on enhancing continuity of operation of remote nodes considering random link failures. This is illustrated by the simulation results of Model Predictive Control (MPC) and Proportional-Integral-Derivative (PID). Mechatronic systems control is illustrated for the case of data loss in a remote motor closed loop operation.**

***Keywords-wireless links; internet; motors; experimental study; model predictive control.***

## I. INTRODUCTION

Wireless links permit to expand the domain of applications of mixed, engineered systems such that computer integration includes remote nodes, which belong to a network that is partly not wired to a central station.

Wireless mechatronic system integration requires addressing monitoring and control issues resulting from link uncertainty [1]- [4]. Mechatronic systems for remote monitoring and control contain wireless sensors and actuators consisting of standing-alone nodes of networks that can be embedded in an Internet of Things system. Systems integrated using wireless links expand the applications of wired links between components of various physical types (mechanical, electrical, fluid, thermal etc.) but also introduce uncertainty due to inherent effects of the environment of wireless communications. Remote nodes considered in this paper are part of sensor and actuator networks. The focus is on enhancing continuity of operation of remote nodes considering the random failure of links [5] - [8]. The effects of random discontinuities of links will be addressed for remote monitoring and control by developing autonomous features. Some of the important application fields are the network of mobile sensors and of vehicle formations. In case of functioning wireless network links, a central control station will generate sequences of optimal commands from distributed control. During link interruption, the remote nodes will switch to autonomous operation using the finite sequence of the last pre-computed optimal commands from distributed model predictive control, until the link is recovered [9]-[13].

This paper is the extension of paper, [14] “Determination of Cycle Time Constraints in Case of Link Failure in Closed Loop Control in the Internet of Things”, which focused on the experimental setup for studying time delay and network losses in the open loop system. This paper analyses the data from a new experimental architecture and emphasizes on providing solutions for network interruption using MPC. A DC motor with an encoder is used as an actuator in our system for data analysis. A preliminary closed-loop solution for compensating for the time delay and losses in the recorded data is provided using MPC.

The paper is organized as follows: Section II describes the analysis of the delay components in detail. Section III presents the experimental setup and describes its various components. Section IV illustrates the experimental observations of our developed system implicating the rise in time delay and losses with an increase in the sampling intervals. Lastly, Section V shows preliminary results using MPC and a comparison is done with PID controller followed by discussion.

## II. TIME DELAY ANALYSIS

Time delay at a single node along its route from source to destination is composed of: nodal processing time + queueing delay + transmission delay + propagation delay as shown in Figure 1. Delays are usually short, but packets can be dropped in the communication network. For reliable links, in case of loss, packet resending is required. For this purpose, stable data transfer protocols were developed [4] [14].

 ISBN: 978-1-61208-621-7 

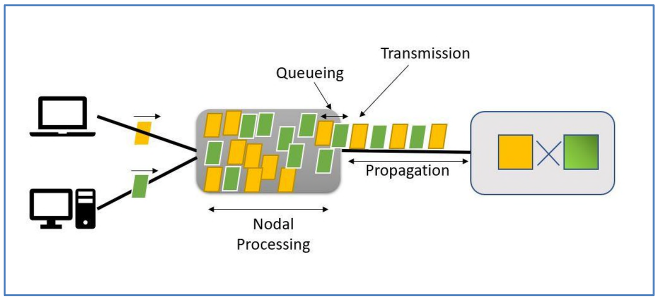


Figure 1. Delay components

The sampling rate must satisfy Shannon's sampling theorem [15] to accomplish the desired performance. A good example to confirm this is in [16] where series of robot control experiments were performed with different sampling rates. With the increase in the sampling rate time delay, computation becomes more evident. The effects of time delay cannot be neglected when the plant has a short time constant, and the order is high [17].

## III. Experimental System

### A. Experimental Setup

The configuration of the experimental setup of open loop control system for the study of time delay and data losses in the given wireless network is shown in Figure 2. It consists of two different parts communicating with each other. The first part of the system consists of (Arduino Uno™ + Wi-Fi Shield™ + DC Motor) and the second part contains (Arduino Uno™ + Wi-Fi Shield™ + Encoder). There is a physical wired connection between (DC Motor + Encoder) of the first part to the Wi-Fi Shield of the second part of the system. The DC Motor can be operated remotely using the port forward method, which allows devices in a local network to be operated in a global environment, using an assigned IP address. The DC Motor attached to the Arduino Uno can be operated (from turning ON and OFF) continuously for regular time interval using the program uploaded on the Arduino through IDE software. The Encoder connected to the other part of the system senses the variations in the speed and sends the speed of the DC motor to the attached server, where it gets recorded and stored, subject to its time constraint. The recorded data further can be studied for the data delays and the link failure statistics. The timing of each recorded data will give the time delay in execution of the loop. If the time delay is greater than that of the sampling interval, there is a loss of data, which can be observed from the experimentally recorded data.

### B. System Components

The experimental setup components consist of two sets of Arduinos Uno™ and Arduino Wi-Fi Shield 101™ connected with each other in two separate parts. First part containing (Arduino Uno + Arduino Wi-Fi Shield) connected to a DC Motor, while the other part is connected to the Encoder.

DC motor's speed can be controlled over a wide range. The rotary encoder converts the motion or angular position of a shaft or axle to an analog signal and eventually, in a binary form. The signal can be further processed for obtaining the position and speed of the motor shaft.

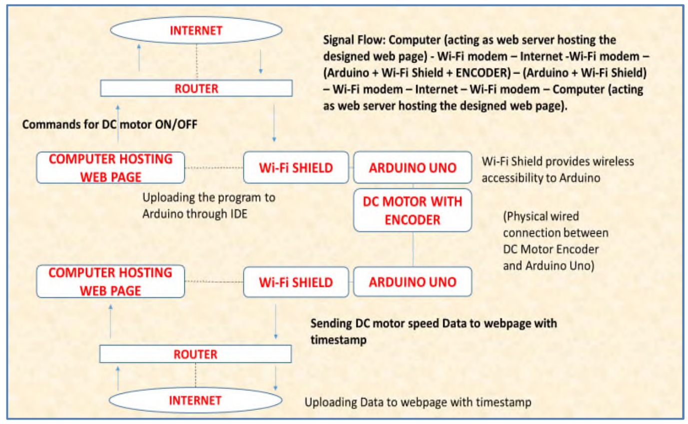


Figure 2. Experimental setup of open loop motor remote control

## IV. Experimental Results

The increasing implementation of IoT has made it crucial to thoroughly analyze the effects of time delay and data losses for the given wireless environment to study the link failures and find out its cycle time constraints. This computing time delay differs from system time delay resulting from the execution of control programs.

Consequences of computing time delay are categorized as the delay and loss problems which can be analyzed for cycle time to link failure. The experimental setup described in this article concentrates on the development of the practical approach to study the closed-loop link failure problems and eventually find its randomness characteristics and cycle time of link failure for different time intervals. This study will help in determining the suitable time interval or frequency for performing the closed loop control accounting for data losses and link failures.

Figure 3 depicts the recorded data from the preliminary experiment. Time constraint is associated with each registered data which ultimately helps to find the delay and data losses and can be used in determining the suitable time interval for performing the closed-loop control with reduced effects of failures. In the graphs, the x-axis represents the time of the data recorded while the y-axis denotes the DC motor speed. The short horizontal lines on the x-axis indicate data losses when there is no data recorded at that time constraint.

Recorded data in Figure 3 has its time constraint. The collected data for the sampling interval shows the randomness throughout the period. From this figure, it can be observed that sometimes the time constraint of two continuous data is greater than the fixed sampling interval which shows the time delay, while for certain consecutive

 ISBN: 978-1-61208-621-7 

readings the time difference is in multiples of sampling intervals that shows the loss of data.

Figure 4-6 illustrates the experimentally recorded data for the 2, 5 and 15 seconds time intervals of DC motor operating (turn ON to OFF) respectively, and each recorded data has its time constraint. As can be observed from these figures the data delay and data loss are more evident in case of 2 seconds' time interval as compared to the other two graphs. As we compare the results of 5 seconds' and 15 seconds' time interval, data delay and loss are more apparent in 5 seconds' graph than the graph that represents the 15 seconds' time interval. This shows that as the time interval for the control system increases there are lesser chances of data delay and data losses resulting in fewer failures of the system.


Figure 3. Experimental results with time constraints.

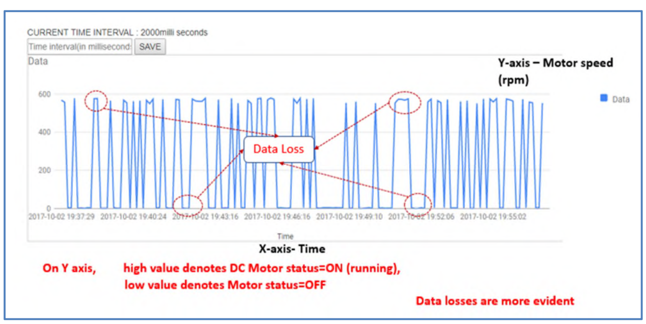


Figure 4. Experimental results for 2 seconds' time interval.

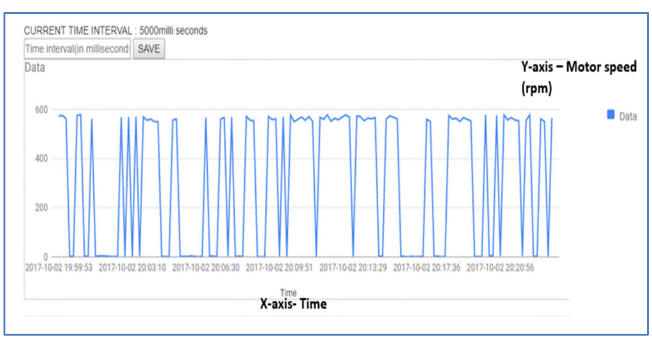


Figure 5. Experimental results for 5 seconds' time interval.

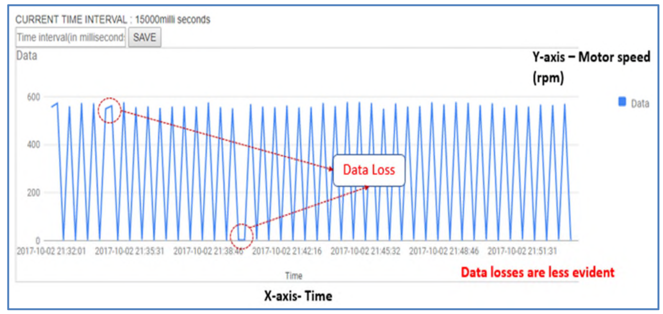


Figure 6. Experimental results for 15 seconds' time interval.

These experimental results show that, as the frequency of the open loop control system increases, more are the chances of failure of the system because of longer data delay and data loss as compared to the closed loop cycles of higher time intervals, i.e., lower frequency.

## V. Preliminary Results for Model Predictive Control

The wireless NCS (Network Control System) is a closed-loop system consisting of a plant consisting of an actuator and a sensor to provide feedback and a controller. The wireless input is communicating with the DC motor using the shared network. The wireless network is not a stable network as it always consists of delays and even data losses. To compensate the network latency and the data losses, Model Predictive Control (MPC) has been used, and the results are compared with the Proportional-Integral-Derivative (PID) controller. The property of the MPC to predict the future states will be exploited to compensate the losses in the network. In this system, as described in Figure 6, the delay is introduced when the Wi-Fi shield gets the signal from the webpage. Data packets also get lost when the latency exceeds a certain limit. We have introduced network delays and losses in the designed system imitating TCP/IP protocol considering average round trip delay of 70ms. The simulation results are produced and compared using MATLAB™ 2017b. Simulation results in Figure 7 show how MPC performs in case of network delays and losses.

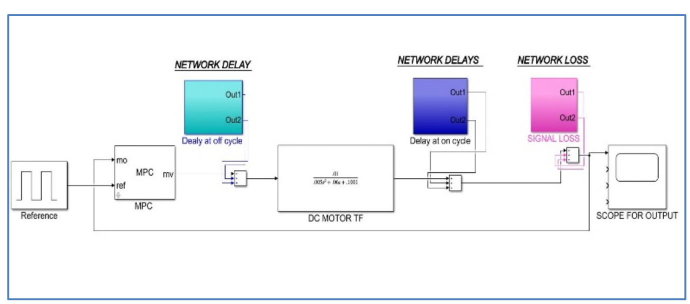


Figure 7. Closed loop network compensation using MPC

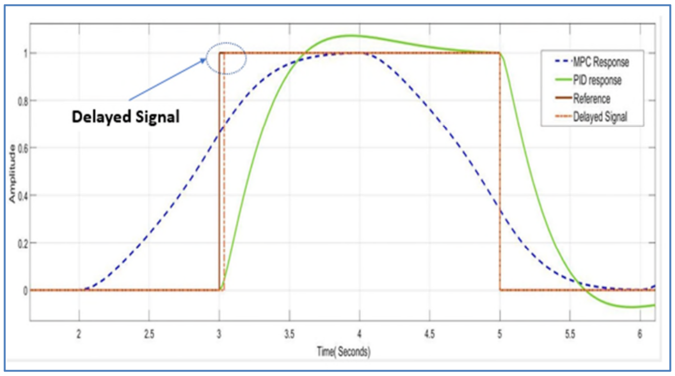

Figure 8. Closed loop delay compensation using MPC and PID.

Figure 8 describes the delay of 70ms during network interruptions. The network delays compensation was done using both MPC and PID stating the advantages of MPC over PID. MPC predicts the delay of its time as per its characteristic, unlike PID.

A sampling interval of 100ms was chosen for the simulation. Prediction horizon of 20 ms and control horizon as 3 ms were chosen such that the controller can look ahead at the behavior of the entire pulse. Reducing the sampling time will increase the performance of the system at the expense of the computational cost.

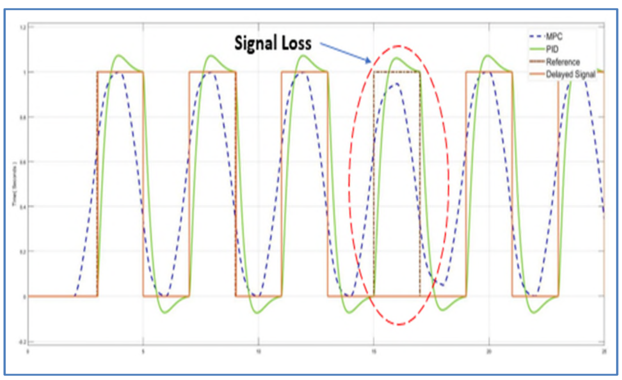

Figure 9. Simulation result for network compensation using MPC vs. PID.

The results obtained indicate that MPC can address the problems due to the delays and the losses such that in this initial investigation the output of the DC motor is unaffected by the network interruptions.

## VI. CONCLUSION AND FUTURE WORK

Wireless network control system depends heavily on the network protocol. The experimentally recorded data quantifies the randomness in the time delay and the data losses. Because of the time delays, wireless networks of sensors and actuators can become unstable. To stabilize the system, an appropriate controller must be used for the network delay and loss compensation.

In this paper, the various network delays and losses were verified using the custom-made experimental setup. The model predictive controller has been used to counter the effects of the time delay. MPC showed its robustness and prediction characteristics in the above results. The proposed scheme gives encouraging results and helps to operate remotely based sensor nodes and eventually record the sensor data accounting for the time delay and data loss problems.

In future work, the practical experimentation and evaluation with the constant and variable time delays will be done. Other delay compensation schemes can be applied and compared with the proposed ones. The future work will help present the intended experimental study of wireless networks of sensors and actuators for a remote velocity control, based on the approaches discussed in the paper.

## REFERENCES


[1] Y.-Q. Xia et al., Recent Progress in Networked Control Systems – A Survey, International Journal of Automation and Computing, Aug. 2015, pp. 343-367.

[2] I. F. Akyildiz and I. H. Kasimoglu, Wireless Sensor and Actor Network: Research Challenges. Ad-Hoc Networks, 2, 2004, pp. 351-367.

[3] I.F. Akyildiz et al., A Survey on Wireless Multimedia Sensor Networks, Computer Networks, 2006.10.002, pp. 1-40.

[4] C. Wang and K. Sohraby, A Survey of Transport Protocols for Wireless Sensor Networks, IEEE Network, May-June 2006, pp. 34-40.

[5] K. G. Shin and X. Cui. "Computing Time Delay and Its Effects on Real-Time Control Systems". IEEE transactions on control systems technology, vol. 3, no. 2, June 1995

[6] T. Strohmer and J. Tanner. "Implementations of Shannon's sampling theorem, a time-frequency approach." Vol. 4, No. 1, Jan. 2005, pp. 1-17 ISSN: 1530-6429.

[7] P. K. Khosla, "Choosing Sampling Rates for Robot Control," in front. IEEE Int. Conf 5 Robotics Automat., 1987, pp. 169-174.

[8] T. Mita, "Optimal digital feedback control systems counting computation time of control laws," IEEE Trans. Automat Contr., vol. AC-30, no. 6, pp. 542-547, June 1985

[9] S. Mansour, Using Model Predictive Control for Real-Time Control over the Internet, IEEE CCECE, Conf., Niagara Falls, May 2004, pp. 0827-0830.

[10] A. Fletcher et al., Estimation from Lossy Sensor Data: Jump Linear Modeling and Kalman Filtering, IEEE IPSN"04 Conf., Berkeley, Apr. 2004, pp. 251-258.

[11] A. Bemporad et al., Hybrid Model Predictive Control based on Wireless Sensor Feedback: An Experimental Study, Int. J. of Robust and Nonlinear Control, May, 2009, pp. 209-225.

[12] E. Henrikson, Predictive Control for Wireless Network Systems in Process Industry, Doctoral Thesis, KTH Royal Institute of Technology, 2014.

[13] W. Hu et al., Network Predictive Control over the Internet using Round-Trip Delay Measurement, IEEE Trans on I and M, no. 10, 2008, pp. 2231-2241.

[14] A. Ainchwar and D. Necsulescu. "Determination of cycle time constraints in case of link failure in closed loop control

in Internet of Things". Proceedings of the 4th International Conference of Control, Dynamic Systems, and Robotics (CDSR'17) Toronto, Canada – August 21 – 23, 2017 Paper No. 122 DOI: 10.11159/cdsr17.122.

[15] T. Strohmer and J. Tanner. "Implementations of Shannon's sampling theorem, a time frequency approach". Vol. 4, No. 1, Jan. 2005, pp. 1-17 ISSN: 1530-6429.

[16] P. K. Khosla, "Choosing Sampling Rates for Robot Control," in Proc. IEEE Int. Con. 5 Robotics Automat., 1987, pp. 169-174.

[17] T. Mita, "Optimal digital feedback control systems counting computation time of control laws," IEEE Trans. Automat. Contr., vol. AC-30, no. 6, pp. 542-547, June 1985.