EVENT DRIVEN MPC FOR NETWORKED CONTROL SYSTEMS

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Abstract: Because of variable delays and stochastic data packets loss networked control systems require suitable algorithms to ensure stability of the control system and guarantee desired control performance. This paper presents the idea of an event driven approach with MPC controller. In opposition to network compensation, where standard regulators are used, the presented solution integrates network with plant. A MPC based controller is applied to extended plant that consists of plant and communication network. In order to reduce network influence on control quality, control signal computation and control signal application are done, when a data receive event occurs.

Keywords: Control system design, Predictive control, Networked control system, Dynamic models, Networks, Event driven dynamics

1. INTRODUCTION

Many modern industrial systems use distributed sensors and actuators. As the complexity and size of a systems grows, there is a need of communication networks, to reduce expensive and complex wiring. Using standard networks with standard protocols leads to low installation and parts costs, ease of reconfiguration and ease of maintenance.

Control systems, where measured and/or control signals are transmitted trough a network fall into a group called networked control systems (NCS). General schema of a NCS is presented in the Fig. 1. Signals y and u are the original signals: measured output and control value. Signals $\tilde{y}$ and $\tilde{u}$ are control and measured signals respectively, modified by the network.

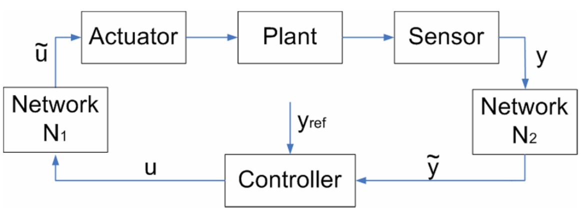

Fig. 1. Networked control system diagram

As the network is a shared link, transmission delays in signals become variable because of limited capacity of a transmission medium. Moreover, in many cases, because of media access protocol data rejection or a packet dropout may occur.

When a NCS is used to control plant with slow dynamics, where control system is oversampled, the network influence on control performance can be omitted. In order to improve control quality the network can be modeled as a constant transport delay.

In case of plants with fast internal dynamics, a suitable control algorithm must be used. For simple plants Smith's predictor may be used (Grega, 2005). If better control performance is required, a model predictive control (MPC) based solutions are often used (Yu *et al.,* 2004; Gang *et al.,* 2004; LoonTang and Silva, 2006).

In the NCS design process two main approaches are used. The first one is based on a compensation. In the approach the network influence (delays and data dropout) on the control performance is compensated with a suitable algorithm (based on compensator or predictor) and non-networked controller is applied to the plant (Beldiman *et al.*, 2000; Mu *et al.*, 2005).

The second approach incorporates network influence in the controller design process (Yoo and Kwon, 2005; LoonTang and Silva, 2006). In such a control system, the controller as to controls a new plant, which consists of the plant and communication channels.

This paper presents the MPC-based approach, where network influence on the control quality is taken into consideration in a controller design process. Moreover, presented approach is event-driven. The control signals are computed when measured data are received. Similarly, the control signals are applied to the controlled plant, when the actuator registers a new data receive event.

2. NETWORK – PROBLEM DESCRIPTION

Communication networks are shared links, where data are transmitted serially. As many devices use the same link, data to be sent is kept in buffers of the transmitters, waiting for free transmission medium.

Limited capacity of the communication channel is the main source of delays in data transmission – data placed in the transmission buffer waits until the communication channel is available. Data transmission over the medium is also the source of slight delays. The other source of transmission delays is data packet handling. The process of packing and unpacking data from packets is more important, if a standardized network architecture with a standard protocol is used.

In this work, the transmission delay term refers to the summarized delay in the data transmission process, without considering its components.

It should be remembered, that without clock synchronization, it is impossible to measure transmission delay of single data packet. On the other hand, it is possible to measure time of packet roundtrip time. Half of this value can be used as an estimation of a single packet transmission delay.

Besides data transmission delay, network communication inducts one another communication problem: data packet loss. Communication issues or high computational load of mediating devices may cause the situation, where sent data would not be received. Moreover, as the transmission medium has limited capacity, new data is kept in the transmission buffers. Those buffers have also limited capacity, so if the buffer is full, no more data can be put inside.

Values of the transport delay and probability of a packet loss depends mostly on the network load. If the network is heavily loaded, delays have bigger values and more packets are lost.

Many communication protocols handle the data loss by resending data, if an acknowledgment message from the packet destination has not been received. In case of the control systems, it would be better if the lost data were not resent. Sending additional messages and resending data, raises network load, what affects on the transmission delays and packet loss ratio. In case of a NCS, each packet should be send only once and it should be deleted from the transmission buffer, even if it was not received properly. Therefore, it is important to choose proper communication protocol to avoid high network load.

On the other hand, it would be better for the diagnostics purposes, if the number of lost data packets or its estimation was known. In such a case a suitable action could be taken, especially in case of a communication link failure.

To analyze network issues described above, an experiment has been performed. Investigated network was an office network, based on the Fast Ethernet standard. Basing on the ICPM protocol‘s echo command (the “ping” command) three computers were asked to send back packets to the data collecting unit. Investigated units were placed in different parts of the building and were connected to different sub-networks. Unit “Host 1” was connected to different sub-network. Communication was possible only trough the routing unit. Unit called “Host 2” was in the same network. Moreover, it was connected to the same network switch, as the data collecting unit. “Host 3” is one of the high performance servers, connected to the router’s sub-network. Units were sending back packets of size 1024 bytes every minute. The experiment lasted for one weak, to allow identifying any network traffic patterns.

In the Fig. 2 results of the experiment are presented. No patterns in the network load were observed. Delay values were usually in the bounded range, except single situations, when high delay values were observed. Periods of high delay values for each unit are probably dependent on the high computational load of the units. A temporary transmission disturbances can be the other source of a high delay values.

As the Fig. 2 presents packet roundtrip time, it is hard to determine true single transmission delay values. A half of a value is only an estimate of a single packet transmission delay. If a transmission disruption was short, one way transmission could take most of the measured time. Moreover, in case of a complex network, i.e. internet, there can be more than one route connecting two network endpoints, thus measured round-trip time will consist of two route-dependent transmission times.