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Design and implementation of a new fuzzy PID controller for networked control systems

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Abstract

This paper presents a practical network platform to design and implement a networked-based cascade control system linking a Smar Foundation Fieldbus (FF) controller (DFI-302) and a Siemens programmable logic controller (PLC-S7-315-2DP) through Industrial Ethernet to a laboratory pilot plant. In the presented network configuration, the Smar OPC tag browser and Siemens WinCC OPC Channel provide the communicating interface between the two controllers. The paper investigates the performance of a PID controller implemented in two different possible configurations of FF function block (FB) and networked control system (NCS) via a remote Siemens PLC. In the FB control system implementation, the desired set-point is provided by the Siemens Human-Machine Interface (HMI) software (i.e, WinCC) via an Ethernet Modbus link. While, in the NCS implementation, the cascade loop is realized in remote Siemens PLC station and the final element set-point is sent to the Smar FF station via Ethernet bus. A new fuzzy PID control strategy is then proposed to improve the control performances of the networked-based control systems due to an induced transmission delay degradation effect. The proposed strategy utilizes an innovative idea based on sectionalizing the error signal of the step response into three different functional zones. The supporting philosophy behind these three functional zones is to decompose the desired control objectives in terms of rising time, settling time and steady-state error measures maintained by an appropriate PID-type controller in each zone. Then, fuzzy membership factors are defined to configure the control signal on the basis of the fuzzy weighted PID outputs of all three zones. The obtained results illustrate the effectiveness of the proposed fuzzy PID control scheme in improving the performances of the implemented NCS for different transportation delays.

Keywords: Fuzzy PID; Networked control system

1. Introduction

Fieldbus is a new technology based on industrial communication networks which provides a reliable and efficient data exchange highway between field devices and fieldbus controllers. This new automation technology has many advantages such as reduced cabling, ease of system diagnosis and maintenance and also reduced commissioning time and cost for industrial plant. Various industrial networks have been developed by standard organizations since the late 1980s.

Foundation Fieldbus and Industrial Ethernet are two popular buses in industrial control. Industrial Ethernet is a suitable protocol in higher layers of automation for monitoring and supervisory due to its high speed data transmission capacity which can be used in large distances. Whereas, Foundation Fieldbus is a suitable protocol for data communication in the field layer. The most important capability of Foundation Fieldbus is due to the function block (FB) implementation that offers closing control loops in the field layer. In contrast, in the networked control system (NCS) implementation control loops are closed on the remote controllers that may be located far from the field. In the both implementations, serial data transmission is used for communicating between controllers and field elements. Transmission topology and traffic cause transmission delays which can degrade control performance. Therefore, the communication requirement should be passed as

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a critical concern to be properly addressed in the control and communication design procedure [1]. The maximum allowable transmission delay is another important issue on which researchers have recently focused [2]. In addition, different process model and uncertainty sources have encouraged many other researchers and practical engineers to explore the performance of candidate controller tuning methodologies [3,4].

To improve the control performance under the transmission delay degradation effect, appropriate control methods should be developed. Although considerable research interest has been paid to the implementation of advanced controllers, PID controllers are still being used in the majority of industrial processes. This is mainly due to the fact that the PID control schemes have a simple structure which can be easily understood and maintained by field engineer. However the tuning of conventional PID remains a difficult task due to lack of insufficient knowledge of the analytical process dynamics. Therefore many classical PID control loops suffer from poor tuning due to the nonlinear and time-varying nature of industrial process. As a consequence, a recourse to the automatic PID tuning approach is unavailable in most practical situations for maintaining a consistent performance in the presence of real process uncertainty. This is attracting recent attention from researchers and practicing engineers [5].

Currently, the fuzzy logic control technique has demonstrated great promise to provide a reasonable and effective alternative to the classical controllers in the face of proven model complexity and uncertainty. In this direction, fuzzy PID control type has been the subject of intense interest during the last two decades because of its ability to induce the familiar conventional PID control law on the basis of approximate fuzzy reasoning. Hence, it has received considerable attention in the field of process control to improve its performance in dealing with process model uncertainties compared to its alternative conventional PID counterparts [6].

In the fuzzy PID control approach, the fuzzy rules can be implemented either as an error driven direct control action type or a gain scheduling type [7]. The error driven type controllers constitute the majority in which the rules are expressed to produce the controller output. The gain scheduling type controllers are based on fuzzy tuning rules to adjust the PID gains. Different research attempts have been made to develop fuzzy PID controllers with automatic tuning concepts [8].

This paper proposes a new fuzzy PID control tuning methodologies in which the fuzzy PID control function is partitioned into three fuzzy regional-based PD, PID, PI whose contributions in derivation of the overall PID control output are adjusted on the basis of their fuzzy membership values. The paper is an attempt to undertake the demonstrations of how FB and NCS control strategies can be practically implemented on a real pilot plant. Then, the detrimental effects of different transmission delays will be investigated on the resulting control performances of proposed networked-based control architecture by inducing artificial time delays in a well-tuned conventional PID controller. Finally, the proposed new fuzzy PID control scheme will be evaluated practically to overcome the performance degradation of implemented networked-based control systems due to variable induced networked data transmission delays.

2. Basics of FB implementation

Implementation of Foundation Fieldbus FB can be carried out in the following two steps. First, the required hardware structure such as bridges (i.e., fieldbus controllers), transmitters and actuators are defined. Then, transmitters and actuators should be linked to the bridge. A bridge assigns a unique tag to each transmitter and actuator and communicates with them using the assigned tags as a master on the network. The master communicates with the slaves within a predefined time schedule. The second step is to define control strategies. A basic set of function blocks for analog and discrete inputs/outputs should be used for this purpose. Using this basic set of function blocks, the control applications may be defined in different options such as manual mode, single loop control (PID and PD), automatic mode, cascade control, over-ride control, ratio control, etc [9].

All field devices can be scheduled to execute the function blocks in a pre-determined sequence and publish the results at a pre-determined time. Function blocks, located in the other field devices, may use the results too. These function blocks will be executed only after the required inputs are scheduled to be available. To address the case, where a device providing an input becomes unavailable, the user can configure the number of consecutive communications that may be lost before the input status of the receiving device is set to the bad state and consequently the actual mode of the block using this input switches to manual [10,11].

3. Basics of NCS implementation

NCS implementation can be carried out in the following two steps. The first step consists of PLC hardware and software configuration. Hardware configuration means setting up the PLC modules physically and in the software. If this configuration is done properly, PLC's CPU can recognize other modules. Software configuration consists of PLC programming and also human machine interface (HMI) software configuration [12]. The second step includes network hardware and software configuration. Network hardware configuration means preparing the cables, hubs and other network devices for connecting PLC to the pilot plant. Network software configuration means defining the network characteristic in software for each device in a way such that each device can recognize other devices in the network in order to be able to communicate with them [13–16].

Master/slave communication is one of the common ways that transmitters and actuators can communicate with a controller on the bus. In the higher automation layers, other devices can only have access to the information of slaves via communication with the master. Sometimes, two different kinds of controllers must communicate with each other to receive information from the other's slaves. OPC servers provide the