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Rule-Based Supervisory Control System

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Abstract

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The thesis shows how fuzzy logic can be used as a supervisory controller. The application of fuzzy logic in control is illustrated by a case study, in which a Fuzzy Supervisory Control System (FSCS) is added to a fed-batch baker's yeast fermentation process. The FSCS was added as a layer above the conventional PI controller layer. The initial biomass concentration has an ideal initial value that leads to an ideal final biomass concentration. If this ideal initial value is degraded, the final value will also be degraded, which is a major problem in the fermentation process, because one of the main goals is to maximize the final biomass concentration as much as possible. The FSCS layer was able to solve this problem, without affecting the Respiratory Quotient (RQ) of the fermentation process, a problem that the conventional PI controller was not able to solve alone.

The proposed control scheme was simulated, verified and compared to the conventional control scheme alone. Simulation results show the power of the proposed algorithm to minimize control performance index like Integral Square Error (ISE).

Keywords

Fuzzy Logic, Intelligent Control, Adaptive Control, Rule-Based, Supervisory Control, Simulation, Nonlinear Process Control, Fermentation, Fed-Batch, Baker's Yeast

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Also, in memory of my grandma.

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Chapter 1: Introduction

1.1. Background to Research Work

The aim of the research is to introduce Fuzzy Logic as a supervisory controller layer, above the conventional PI controller layer. The Fuzzy Supervisory Control System (FSCS) layer was able to decrease the degradation in the performance, when the ideal input and operation conditions were not satisfied.

The application of fuzzy logic in control is illustrated by a case study, in which a Fuzzy Supervisory Control System (FSCS) is added to a fed-batch baker's yeast fermentation process. The FSCS was added as a layer above the conventional PI controller layer.

1.2. Thesis Challenge and Contribution

In this thesis, conventional and fuzzy control algorithms are studied and discussed. The thesis represents how Fuzzy Supervisory Control Systems, are used with conventional controllers to have better performance for control loops.

In order to improve the process final results; if this process was subjected to different non ideal initial values; a control scheme that integrates conventional PI controller with intelligent fuzzy controller is proposed. This fuzzy controller is tuned to minimize the error due to different initial values.

Concerning the fermentation process, the initial biomass concentration has an ideal initial value that leads to an ideal final biomass concentration. If this ideal initial value is degraded, the final value will also be degraded, which is a major problem in the fermentation process, because one of the main goals is to maximize the final biomass concentration as much as possible.

The FSCS layer was able to solve this problem, without affecting the Respiratory Quotient (RQ) of the fermentation process, a problem that the conventional PI controller was not able to solve alone.

The proposed control scheme was simulated, verified and compared to the conventional control scheme alone. Simulation results show the power of the proposed algorithm to minimize control performance index like Integral Square Error (ISE).

1.3. Thesis Layout

Chapter 2 presents the supervisory control theory and the supervisory controllers.

Chapter 3 discusses Fuzzy Logic basics including fuzzy sets and membership functions. The fuzzifiers and defuzzifiers are defined and explained. Also some fuzzy controllers are discussed. The chapter also presents different applications that use Fuzzy Logic.

Chapter 4 presents a detailed explanation of the process under study. The fed-batch baker's yeast fermentation process was chosen as a case study for this thesis. The chapter presents the fermentation process description and the details of each stage, besides its mathematical model. A practical experiment is also presented. A brief literature about the previous work done in the fermentation process control is finally presented.

Chapter 5 discusses how Fuzzy Logic was used as a supervisory control system on a fed-batch baker's yeast fermentation process, previously controlled by a conventional PI controller.

Chapter 6 concludes the thesis and represents future work.

Chapter 2: The Supervisory Control Theory

In This chapter, the Supervisory Control Theory and the Supervisory Controllers will be introduced.

2.1. Supervision

The supervision in the supervisory control theory is understood as the action of maintaining the closed-loop behavior, of a given process, within certain boundaries, by disabling the execution of controllable events. However, the execution of an operating procedure in a process plant involves not only the disabling of certain events, but actually the enforcement of others [1].

During manual operation, a human operator is normally responsible for assigning set points to regulatory controllers, performing discrete control actions, process monitoring and taking corrective measures when an abnormal situation is detected. These activities are collectively called 'supervision' or 'supervisory control' [2].

2.2. The Supervisory Control Theory

The supervisory control theory is a method for automatically synthesizing supervisors that restrict the behavior of a plant such that as much as possible of the given specifications are fulfilled. The plant is assumed to spontaneously generate events. The events are in either one of the following two categories **controllable** or **uncontrollable**. The supervisor observes the string of events generated by the plant and might prevent the plant from generating a subset of the controllable events. However, the supervisor has no means of forcing the plant to generate an event [3].

Supervisory control is a general term for control of many individual controllers or control loops, whether by a human or an automatic control system, although almost every real system is a combination of both. A more specific use of the term is for a SCADA system, or ***S***upervisory ***C***ontrol ***A***nd ***D***ata ***A***cquisition system, which refers to a specific class of systems that can be purchased, usually for use on fairly small remote locations [4].

Supervisory control often takes one of two forms. In one, the controlled machine or process continues autonomously. It is observed from time to time by a human who, when deeming it necessary, intervenes to modify the control algorithm in some way. In the other, the process accepts an instruction, carries it out autonomously, reports the results and awaits further commands. With manual control, the operator interacts directly with a controlled process or task using switches, levers, screws, valves etc, to control actuators. In contrast, with automatic control, the machine adapts to changing circumstances and makes decisions in pursuit of some goal which can be as simple as switching a heating system on and off to maintain a room temperature within a specified range [4].

2.3. The Supervisory Controller

A supervisory controller is a controller which operates only when some undesirable phenomena occurs. In other words, the supervisory controller evaluates whether local controllers satisfy prescribed performance criteria, diagnoses causes for deviation from the performance criteria, plans actions, and executes the planned actions. Typical goals for supervisory controllers are safe operation, highest product quality, and most economic operation. For example, when the state hits the boundary of constraint set, the supervisory controller begins operation to force the state back to the constraint set [5].

During plant running, the operator performs actions based on his knowledge of the components and how they interact. The operator actions can be categorized as follows [5]:

a. Binary Actions: change in the structure of the plant and switching to other plant configurations. Examples are on/off valves.
b. Prepare Actions: prepare the whole plant, or part of the plant, for closed loop control, with set points selected by the operators. An example is to

start a pump in order to obtain a minimum flow rate of steam before switching to automatic control.

c. Control Actions: closed loop control around proper set points. An example is control of steam flow rate by automatically adjusting pump speed.
d. Corrective Actions: take actions when malfunction occurs. An example is servo valve that does not function because it sticks.

A high level controller, like supervisory controller, works on the same level as the human operator. It takes over a part of, or the operator's entire job, of controlling the process [5].

2.4. Supervisory Control Schemes

Figure 1 shows the various schemes for the supervisory control systems. In this Figure, PID is an example of the conventional control scheme, while fuzzy refers to the supervisory control system. Often the conventional loops represent an existing control scheme, which has been controlling the process before installation of the supervisory control system [5].

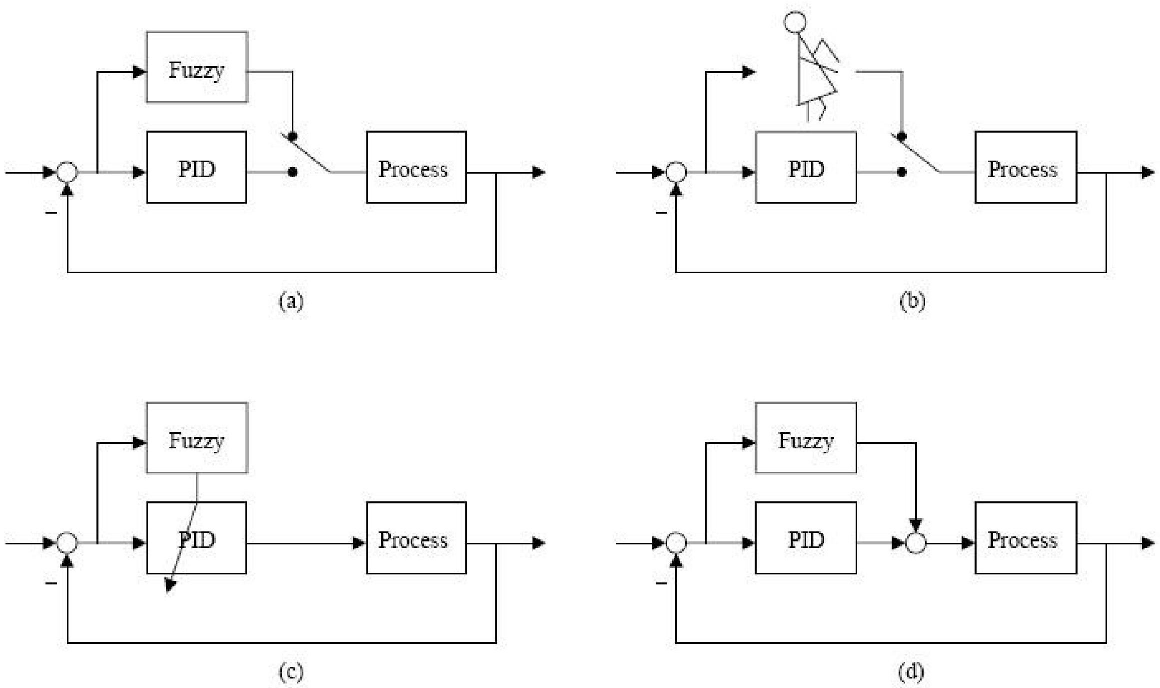

Figure 2-1 Fuzzy Supervisory Control System (FSCS) Configurations