FAULTS TOLERANT CONTROL APPLICATION USING NEURAL NETWORKS

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Abstract
In this work it is presented a fault tolerant control application using neural networks-based compensation schemes. The design consists of supervising the process possible faults using an observer that allows determining the present fault and its direction and then it will be used a classification neural network which will activate the appropriate controller according to the identified fault type. The plant to be controlled was the “Feedback Basic Process Rig 38-100”, a completely self-contained pipes circuit which drives the water contained in the inferior tank to a smaller dimension and double compartment superior tank, by means of the motor pumping located in the inferior deposit. In this work it is controlled the superior tank water level.

Key-Words: Artificial Neural Networks, Fault Detection, Fault Tolerance Systems, Fault-tolerant Control, Simulation, Matlab.

1 Introduction

The control engineering main advances are focus in dynamical systems behavior and control laws design, nevertheless in many occasions the implantation of these control laws in complex systems do not have the expected results, diminishing their levels of production. The control operation problems are connected to many factors, such as design errors, implantation problems, human operator faults, plants age or environment variations. Fault detection and isolation (FDI) systems are based on mechanisms designs that are able to detect the system operation errors in real time, find its cause and identify the components of the system that are outside the nominal operation rank [1]. On the other hand, Faults tolerance (FT) is related to the behavior of the system under fault situations, it analyzes the possibility of the system of reaching its objectives even when it is being exposed to a fault. The faults tolerant designs include the hardware and software architecture necessary for maintaining the systems with their normal operation parameters in anomalous situations. Therefore, the faults tolerance is defined considering one or several objectives and one or several faults.

Traditional control engineering considers two classes of objectives, those associated to the control systems and other associated to real time variables estimation. In general terms, each one of them are associated to a structural characteristic of the system: the controllability (the capacity of the system state of being controlled using the inputs) and the observability (the capacity of the system state of being estimated using the outputs). Therefore, the faults tolerance analysis and design are based on the Faults Tolerant Control (FTC) design where the interest is centered in the control objectives and as Faults Tolerant Estimation (FTE) where the estimation objectives are considered.

The automatic faults diagnosis in field devices actually is a research and development area that includes diverse disciplines as Control Engineering, Artificial Intelligence and Statistic, each one of them with diverse techniques (artificial neural networks, expert systems, cases-based reasoning, virtual sensors, observers, analytical redundancy equations, among others). In this work an active faults tolerant control system is designed and simulated, by means of *on line* fault diagnosis and immediate activation of the corrective action mechanism; using an

Artificial Neural Networks as control selector for the controller reconfiguration according to the fault presented in the system.

2 Theoretical Foundations

2.1 Faults Tolerant Control

The faults tolerant control (FTC) is based on faults diagnosis with control laws adjustment methods that allows the system for handling the faults, avoiding that a simple faults could become into a serious problem for the plant, Figure 1 illustrates the different regions that must be considered in the faults tolerant control design [3] (considering that the system is described by variables x_1 and x_2).

FTC includes actions for the fault diagnosis and for real time decision making in order to avoid unacceptable behaviors. In the FTC design, software is the intelligent component that generates the correctives actions, based on security, reliability and availability, being these characteristics fundamental for controlled systems and for control architectures.

FTC are used due to the high autonomy and reliability demand required by the systems, in order to guarantee a correct and constant operation in all possible situations.

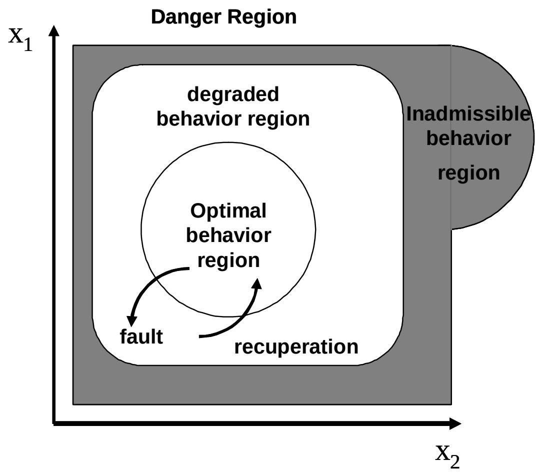

Figure 1. Behavior systems Regions

There exist two approaches for solving the faults tolerant control problem:

1. Passive fault-tolerant control systems: based on designing an unique control law that is able to reach their objectives in normal operation and in failure conditions, their characteristics are:
   - Robust fixed structure controller.
   - Faults have been considered at the controller design
   - Simple to implement
   - Difficult to account for large number of fault scenarios.
   - Unable to deal with unforeseen faults stage.
2. Active fault-tolerant control systems: a different control law is designed based on the system state (normal or failure) from the system restrictions and parameters estimation provided by the observer, their characteristics are:
   - Explicit fault detection/diagnosis schemes
   - Real-time decision-making and controller reconfiguration.
   - Potentially be able to deal with a large number of fault scenarios.
   - Can deal with certain number of unforeseen faults.
   - More complex to implement.
   - Real challenge is real-time decision making

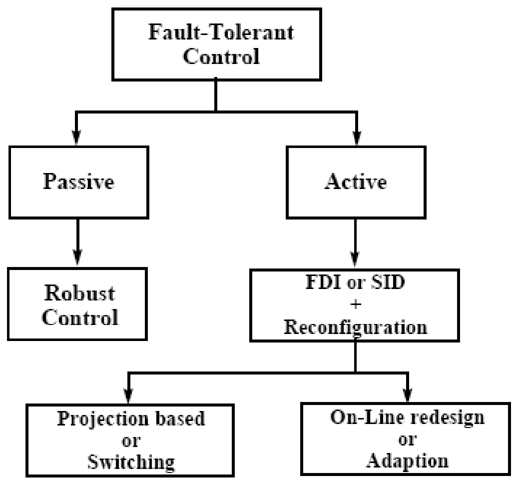

Figure 2. FTC Approaches

On the other hand, the active techniques for faults tolerant control consist of reshaping the control law based on the use of a "diagnoser" that provides automatically the necessary information for making the necessary adjustments in order to fulfil the control objectives.

The key aspect in faults tolerant control systems is the physical (actuators and sensors) or analytical (based on mathematical models) redundancy; for the first case the tolerance strategy consists of replacing the component that has failed by another one that works correctly; this strategy is expensive since it supposes to duplicate or to triplicate the controlled process critical components and this is not always possible to apply.

In case that physical redundancy does not exist, it is important to make a distinction between the components where the fault could happen. If the fault happens in the sensors usually they can be used virtual sensors for estimating the variable measured by the sensor that has failed using as inputs the measurements given by other sensors of the system. If the fault happens in the actuators and/or in the plant the controller redesign is proposed, being used, mainly, two mechanisms: adjustment to the fault and reconfiguration, according to changes in structure or control law, respectively [4].

2.2 Artificial Neural Networks

Artificial Neural Networks constitutes an Artificial Intelligence technique which tries to emulate the operation and capabilities of biological neural networks related to learning and information processing [5, 10]. ANN are based on biological behavior, and scientists are concerned in the brain organization, when they consider algorithms and configurations of ANN, but the total knowledge about the operation of the brain is so limited. For this reason, the designers of ANN should consider the current biological knowledge, looking for structures that execute useful functions.
Due to the advance in computer science, ANN can be trained using big lots of data, improve their performance and self organization capabilities, fault tolerance and real time operation. This have made that the field of application of the ANN has increased, being used in different tasks as: systems modeling and identification, simulation, processes control, prediction, fault handling, patterns recognition, medical diagnosis, virtual sensors design, etc.

ANN will be used in this work like part of the active FTC, since they will be in charge to select the suitable controller, according to the happened fault, for this, the ANN inputs will be the fault detection filter output and by means of its configuration it will generate the output that will activate the control signal.

3 Application Example

The design consists of supervising the process possible faults using an observer that allows determining the present fault and its direction, this information is given by a classification neural network that activates the corresponding controller for solving the fault, the block diagram is depicted in figure 3.

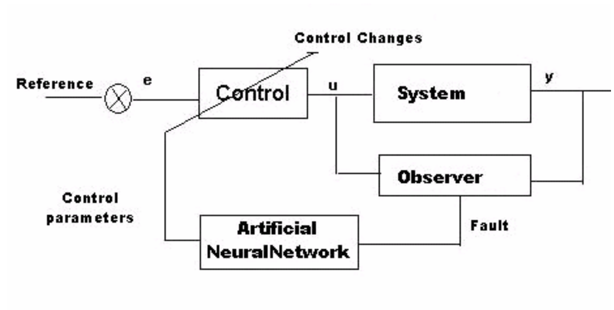

Figure 3 General Design Structure

The selected process is a scale plant of an industrial tanks system; "Feedback BASIC Process Rig 38-100" [6], is a simple loop easy model for level control and/or present water flow in the tanks. This process consists of a pipes circuit completely contained in it, composed of the following strategically located elements in the device: 4 manual valves, 3 solenoids valves, servovalve, flow visual ruler, flow transmitter, floating type level transmitter, two tanks and a signals handler device.

The system drives the water contained in the inferior tank to a smaller dimension and double compartment superior tank, by means of the motor pumping located in the inferior deposit. The water flows through the pipes network according to the opening or closing state of the manual valves and solenoids that the device has, as well as the servovalve opening that limits the flow level according to the user's wishes. The system is a simple loop model because the water-drainage pipes send again the water to the inferior tank, fulfilling an operation cycle [7]. For the controllers design it is used the tanks system model obtained by an identification process, which describes the dynamic behavior of the plant [7].

Obtained Transfer Function

$$G(s) = \frac{5.9717}{302s+1} e^{-10s}$$

The water level in the superior tank of the "Feedback Basic Process Rig 38-100" tanks system constitutes the variable to be controlled in the process, by means of the flow input regulation related to the opening of the servovalve. The objective of this control is to increase the process answer speed, to diminish the disturbances effects and to diminish the steady state error, establishing the following design specifications:

- Settling Time = 100 seconds
- Damping Ratio> 1 (Overdamped response)

These criteria can change depending on the designer, nevertheless the Settling Time must be defined greater than 52 seconds according to the servovalve limitations. From the raised requirements, the proportional - integral (PI) control law action is chosen because of its capacity for diminishing the steady state error and to provide robustness to the system.
In the controller's design the mathematical model time delay effect is not considered because it is smaller than the system's time constant and for being a first order model; in this type of processes the time delay effects are handled with the suitable adjustment of the proportional gain [8].

Closed Loop System:

$$Go(s) = \frac{5.9717\left(kps + ki\right)}{302\,s^2 + (5.9717\,kp + 1)s + 5.9717\,ki}$$

$$Go(s) = \frac{0.0198\left(kps + ki\right)}{s^2 + \dfrac{(5.9717\,kp + 1)}{302}s + 0.0198\,ki}$$

Equalling terms between the desired characteristic polynomial and the closed loop polynomial the proportional and integral constants values are obtained.

$$kp = 3.878$$
$$ki = 0.02$$

The control law parameters belong to an incremental controller, calculated from an identified plant model around an operation point. The system's closed loop answers are depicted in figures 4 and 5.
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Nevertheless, when the system is presenting faults in the input signal or the servovalve opening, it was observed that the system does not reach the steady state (see figure 6), reason why it is necessary to design a faults tolerant type control for stabilizing the system into a given reference, in this case, approximately 12 cm of height. Considering that the system is not able to support the faults presence, and when a fault occurs it changes to a new operation point, it is necessary to design a faults detection filter, by means of a complete order state observer, that indicates the fault direction for determining the type of controller to be used. Thus, when the system has any positive or negative direction fault, the filter will indicate it, by means of the error between the real and considered system.

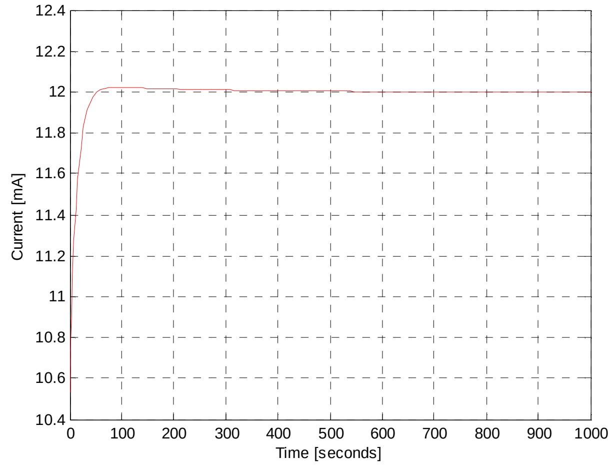

Figure 4. PI Controller's Systems Response

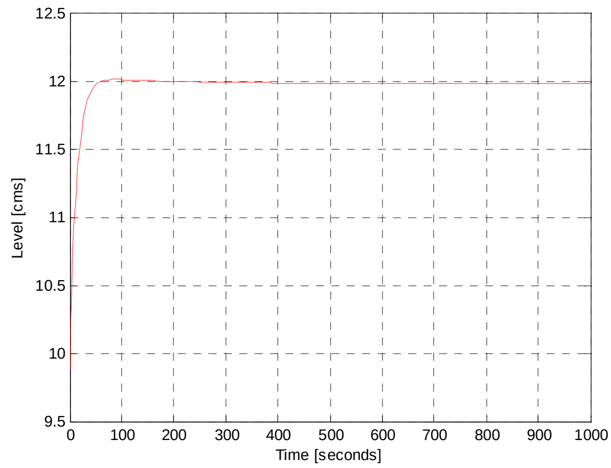

Figure 5. PI Controller's Water lever Response

Thus, for each fault direction, it is made the controllers design and tuning, having obtained that when the system has any fault it is necessary to use a PID controller with the appropriate parameters variation.

- Positive direction faults:
  PID Controller, with parameters

kp= 20, ki=0.3, kd=10

- Negative direction faults
  PID Controller, with parameters
  kp= 3.878, ki=0.08, kd=0.5
- Faults absence (it remains the original designed controller)
  PI Controller, with parameters
  kp= 3.878, ki=0.02

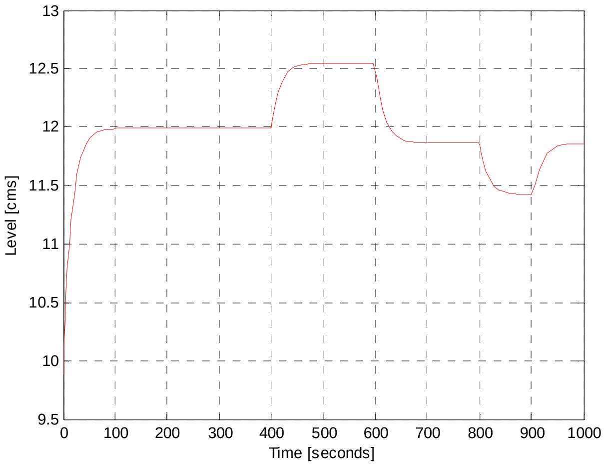

Figure 6 Controlled system's response with diverse faults

After designing the controllers for each possible type of fault, the artificial neural network (ANN) was designed in order to select the suitable controller, at every moment of time. The ANN was trained using the Matlab Neural Networks toolbox [9]; its final configuration was an input, three binary outputs and two neurons in the hidden layer. The neural network binary outputs allow carrying out the appropriate changes in the switch that activates the control law according to the detected fault; the input corresponds to the information given by the faults detection filter. The obtained results can be observed in figure 7.

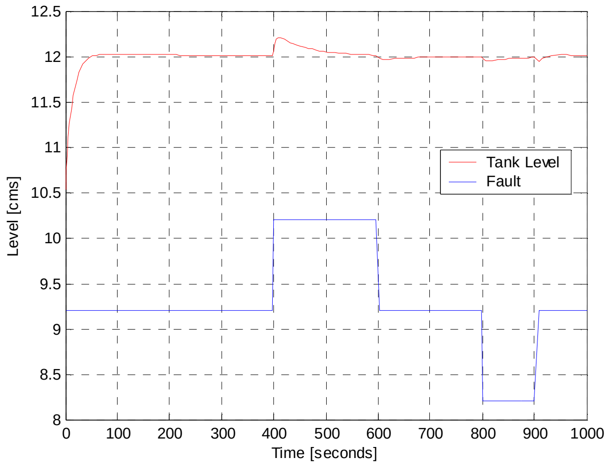

Figure 7 Controlled systems with diverse faults

4 Conclusions

The faults tolerant control involves detection, diagnosis and analytical redundancy techniques which are concepts with multiple studies and applications in the academic and industrial scope. The design presented in this works, allowed the technical hybrid use in the faults tolerant control development, mixing classic techniques for the residual generation by means of the state observer and intelligent techniques like Artificial Neural Network whose configuration and training let the commutation of the control according to the detected fault.

The presented design consists of supervising the process possible faults using an observer that allows determining the present fault and its direction and then it will be used a classification neural network which will activate the appropriate controller according to the identified fault type.

By means of the plant simulation, the proposed method operation could be verified, studying the controlled variable stabilization in the desired values even when diverse faults were present in the system, with appropriate response times according to the required parameters.

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