FAULT DETECTION USING NEURAL NETWORK

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ABSTRACT

This thesis is about the application of Artificial Neural Network (ANN) as fault detection in the chemical process plant. At the present time, the process and development in chemical plants are getting more complex and hard to control. Therefore, the needs for a system that can help to supervise and control the process in the plant have to be accomplished in order to achieve higher performance and profitability. As the emergence of Artificial Neural Network application nowadays had help to solve problems in various fields had given a great significant effect as the system are reliable to be adapted in the chemical plant. Furthermore, this thesis will be focusing more on the application of Artificial Neural Network as fault detection scheme in term of estimator and classifier in the chemical plant. Fault detection is popular in the present time as a mechanism to detect early malfunction and abnormal process or equipment in the plant. By implementing such system, we can boost up the production and the safety level of the plant. For this thesis, the Vinyl Acetate Plant had been chosen as the case study to provide the necessary data and information to run the research. Vinyl Acetate Plant process will provides a dependable source of data and an appropriate test for alternative control and optimization strategies for continuous chemical processes.

ABSTRAK

Thesis ini adalah berkenaan aplikasi Rangkaian Saraf Buatan *(Artificial Neural Network)* sebagai pengesan kesilapan pada kilang pemprosesan kimia. Pada masa kini, proses dan pembangunan dalam kilang kimia telah menjadi semakin kompleks dan susah untuk dikawal. Oleh itu, satu sistem yang dapat menyelia dan mengawal proses di kilang perlu diadakan untuk mencapai prestasi dan keuntungan yang lebih baik. Peningkatan penggunaan Rangkaian Saraf Buatan telah membantu dalam menyelesaikan masalah di pelbagai lapangan di zaman ini telah memberi kesan yang positif yang sistem tersebut yang turut dapat diaplikasikan di dalam kilang kimia. Selain itu, thesis ini akan lebih memfokuskan pengaplikasian Rangkaian Saraf Buatan sebagai pengesan kesilapan mekanisme dalam konteks peramal proses dan pengelasan kesilapan di dalam kilang kimia. Pengesan kesilapan adalah sangat popular pada masa sekarang sebagai alat untuk mengesan ketidakfungsian dan proses yang tidak normal atau kerosakan peralatan di dalam kilang. Dengan pengaplikasian sistem ini, tahap produktiviti dan keselamatan di kilang akan bertambah. Dalam thesis ini, kilang pemprosesan Vinyl Acetate telah dijadikan sebagai rujukan untuk mendapatkan maklumat dan data yang diperlukan untuk menjalankan kajian. Proses Vinyl Acetate akan memberikan sumber data yang tepat dan merupakan tempat yang sesuai untuk mengadakan kajian berkenaan pengawalan dan strategi pengoptimumtasi untuk proses kimia yang berterusan.

TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nowadays, technology of control system had achieved a tremendous impact on the engineering applications. Control system had been applied in various fields such as sensor data analysis, fault detection, nonlinear process identification, and pattern recognition, process modelling and plant wide control (Hussain, 1998) The purpose of plant wide control is to develop coordinated control of several important variables of a multi unit process, overall plant process system and sustain product quality. In the conventional way, the control problem that happen on the plant is divided into smaller parts according to the unit operation involved. For realizing the approach, the engineers would set up an appropriate inventory of items, equipments and man power. These units will consume a portion of space in the plant including the material compartment. This can increase the capital cost of the plant to support the process including the increasing of safety and environmental hazard. Therefore, the implementation of advance control system in industries is necessary in term of cost reduction and effective controlling system (Lyman and Georgakis, 1995).

Research of fault detection system had gain more interest lately not just only due to cost saving, yet more importantly; it serves as a safety mechanism. The disaster in Bhopal and Chernobyl is a good example why advance controller can plays a vital role in preventing the incident from happen in the first place. The implementation of advance controller in term of fault detection will help to reduce the probability of accident and loss as a result of human or mechanical error. The emergence of artificial intelligence (AI) also plays a role in the development of control system. The cognitive approach of AI is focusing on imitates the rational thinking of human (Lee, 2006). AI system such as fuzzy logic, neural network and genetic programming had been integrated with the conventional control system to produce an intelligent controller system. In this case, the intelligent controller will help the operator to handle and deal with various abnormal conditions or fault that happen with more reliable, efficient and faster.

Fault detection is essentially a pattern recognition problem, in which a functional mapping from the measurement space to a fault space is calculated A wide variety of techniques have been proposed to detect and diagnose faults. Generally, there are three different options available to approach a fault diagnosis problem: state estimation methods, statistical process control methods, and knowledge-based methods. A neural network, a type of knowledge-based system, possesses many desirable and preferred properties for chemical process fault diagnosis. These properties include its abilities to learn from example, extract salient features from data, reason in the presence of novel, imprecise or incomplete information, tolerate noisy and random data, and degrade gracefully in performance when encountering data beyond its range of training (Venkatasubramanian and Chan, 1989). Reviewing the development of neural network fault detection and diagnosis systems, the general trend in research is to increase the robustness of the system to unmodelled patterns, realise fast and reliable diagnosis in dynamic processes and dynamically filter noisy data used for detection (Hamid, 2004).

In this research, a model-based fault detection system proposed by Ahmad and Leong (2001) will be further developed. Figure 1.1 displays the overall structure of the system. Here, a model-based fault detection system consisting of a process predictor and a fault classifier is proposed. The process predictor is used to predict the normal fault free operating condition of a column in the Vinyl Acetate Plant. The deviation of the actual condition from the output of this predictor, termed the residual, is then fed to the classifier, which identifies the residual signal from the process predictor and classifies the cause of faults. The development of both models utilizes the nonlinear mapping capability of neural networks

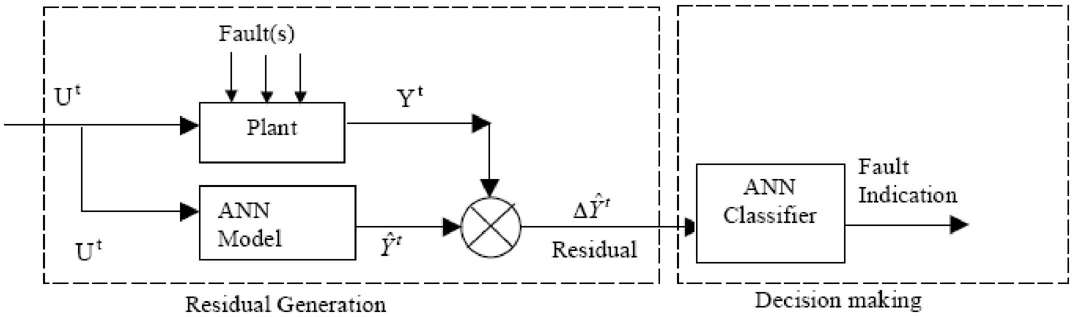

Figure 1.1 The proposed Model-Based Fault Detection

The hierarchical approach is advantageous because it lessen the chances of misidentification of normal operation trend that is due to the manipulation of the feeds condition. In practice, there are always possibilities that the manipulation of feeds will produce process conditions that coincidentally match the fault pattern and the classifier will tend to misinterpret the situation. The use of residuals provides some protection to the system

In this thesis, the implementations of Neural Network for fault detection in Vinyl Acetate plant are proposed. Fault diagnosis system can provides fault information to operate and schedule levels that can improve product quality, facilitate active scheduling, and reduce risk of accidents (Ricker, 1995). Therefore the implementation of Neural Network will help engineers to design a more effective control and monitoring system in the plant to achieve zero lost time.

1.2 Problem Statement

As we are heading towards the future, the advance knowledge and technology had contributing to the improvement on reability, safety and efficiency of fault detection and diagnosis system. This system is very important as it will prevent accident, failure and disaster from happen and save many life. Today, safety and health has becoming a main agenda in developing and managing technical processes. Consequently, the development of Neural Network in various fields especially in fault detecting has shown great progress. Neural Network has the potential to be developed further to be applied in chemical plant such as Vinyl Acetate Process Plant as the process control mechanism. Furthermore, Matlab 7.0 had been used to model and stimulate the Neural Network in terms of monitoring and supervising the Vinyl Acetate Process route. Matlab is a high-performance language for technical computing software that had in been used widely in the engineering field to calculate and solve many mathematical and technical problems. Thus, this research will be focusing on fault detection on Vinyl Acetate Process Plant by using Neural Network. These researches will emphasis on how and how far Neural Network can contribute to overcome Vinyl Acetate Process Plant failure and fault problems.

1.3 Objective and Scope of Research

The main aim of this research is to develop a fault detection system using neural network. By using the Vinyl Acetate Plant as the case study, the implementation of neural network will help the controller to detect fault more efficient. The work covered the following scope:

i. Simulation of case study : Vinyl Acetate Plant
Simulation of the plant was carried out within Matlab 7.0 based on a research developed by Luyben and Tyreus (1998). The simulation is done in order to generate the base data for the neural network

ii. Development of process predictor.
Process predictor is used to predict the normal behavior of the process. The development of the process predictor involves selecting suitable artificial neural network (ANN) architecture to differentiate between the abnormal behaviors of the process with the normal condition. The difference between

the actual plant signal and the estimated normal plant signal is termed as residual. This process is done in Matlab.

iii. Development of fault classifier.

Fault classifier is a decision making system used to detect process faults. Residual signals generated from the process predictor serve as an input to the classifier. Structure selection and training method are the criteria that must be taken into consideration. The fault classifier is developed in Matlab.

iv. Implementation of the proposed fault detection strategy.

The proposed model-based fault detection strategy is implemented to detect faults in the column in the Vinyl Acetate plant.

1.4 Summary

Following this introductory chapter is Chapter 2 that will elaborates some of the fundamental theory and application of safety, fault detection and Neural Network. The architecture, learning, advantage and limitation of Neural Network will also be discussed. In Chapter 3, the chapter will cover about the Vinyl Acetate Process plant simulation. The process, equipments and condition of the simulated plant are also roofed in this chapter. Chapter 4 will shows the methodology and planning of this research. Chapter 5 will commence with the discussion on the description of Neural Network as process estimator with its architecture specification and training process. This is then followed by the result of the estimator with training and validation. Chapter 6 will discuss about the analysis on Neural Network reliability as process classifier and its results. Finally, Chapter 7 will summarize the thesis and concludes all the findings. In addition, this research had provided some recommendations for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the area of plant-wide control at the supervisory level, the process fault detection and system plays a key role. The fault detection usually includes the fault diagnosis and fault correction system. Fault diagnosis is the identification of the root causes of process upset. Meanwhile, fault correction is the provision of recommended corrective actions to restore the process to normal operating condition. In this regard, real-time appropriate actions must be taken in present chemical and petrochemical manufacturing plants. The technical personnel in most of these industries is responsible for process monitoring status, detecting abnormal events, diagnosing the source causes and administering proper intervention to bring the process to normal operation. Nevertheless, the complexity of the supervision tasks has increased considerably due to the high level of development in process design and control. A decision support system is needed to assist process operators in understanding and assessing process status, and responding quickly to abnormal events, thereby enabling processing plants to maintain operational integrity and improve product quality at a reduced cost (Ruiz, *et al.*, 2000). However, a very important control task in managing process plants still remains largely a manual activity, performed by human operators. This is the task of responding to abnormal events in a process. This involves the timely detection of an abnormal event, diagnosing its causal origins and then taking appropriate supervisory control decisions and action to bring the process back to a normal, safe, operating state. This entire activity has come to be called Abnormal Event Management (AEM), a key component of supervisory control.

2.2 Principle of Safety

Safety aspect is one of the most important aspects in operating a plant rather than profit and process route. The terminology of safety is the ability of a system not to cause danger to persons or equipment or the environment (Isermann and Ballè, 1997). According to America Institute of Chemical Engineering (AICHE) Code of Professional Ethics, one of its fundamental principles is to use the knowledge and skills to enhance the human welfare. Thus, the usage of the advance control system in the plant is one of a good effort towards achieving the highest level of safety. In the Layer of Protective Analysis (LOPA) Model, the priority step in analyzing and assessing risk of fault is of the process design and control system of the plant (Crowl and Louvar, 2002).

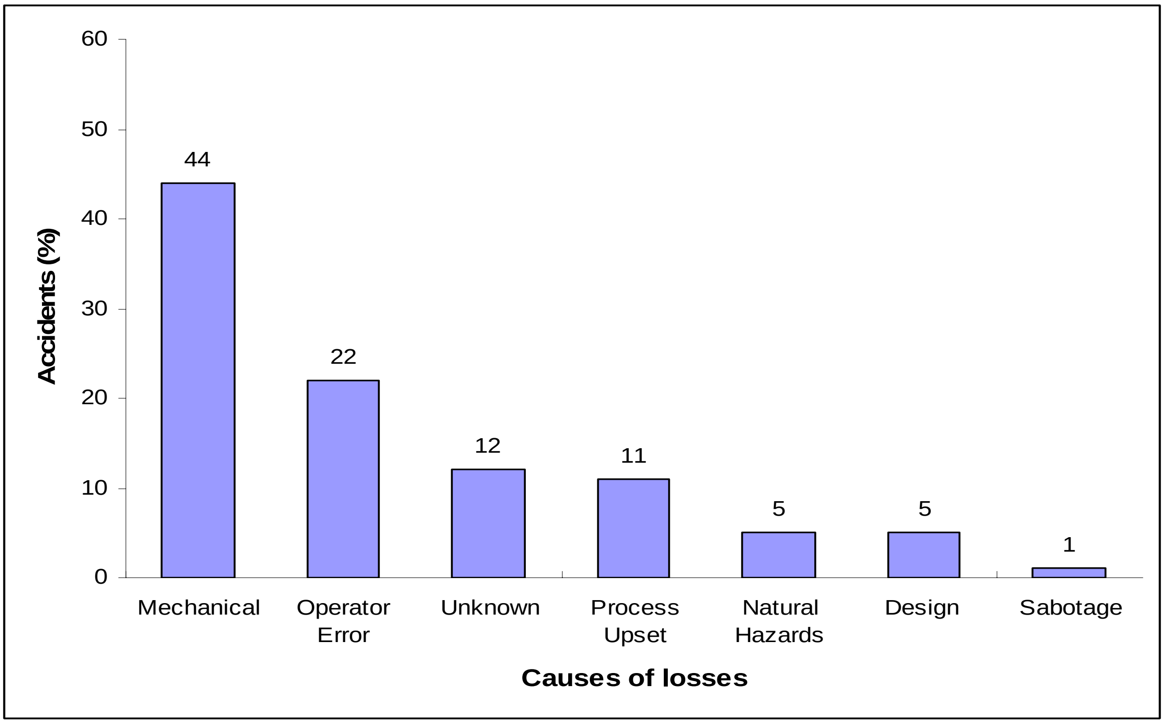

Figure 2.1 Causes of losses in the largest hydrocarbon-chemical plant accident (Crowl and Louvar, 2002)

From the figure 2.1 above, there are seven main causes of losses that occurred in a typical chemical plant. By far, the largest cause of losses is due to mechanical failure. Failure of this type is usually due to improper control system and maintenance service. The most damage can be caused by improper action or lack of awareness in safety is fatal casualties. Accident in Bhopal in 1984, which kills nearly 2000 people and injuring more than 20,000 people and catastrophic in Seveso in 1976, can be prevented if the plant involved had implemented the proper application of fundamental engineering safety principles for instance the fault detection system.

Moreover, based on this circumstance, the chemical plants had to setup a monitoring and supervising system to identify the fault or hazard effectively. This is to prevent losses in terms of profit, human resources, and product quality. Therefore, risk assessment or fault detecting in the chemical plant is one of significant studies that have to considerably taken for granted.

2.3 Principle of Fault

A fault is defined as an unpermitted deviation of at least one characteristic property of a variable from an acceptable behavior (Isermann and Ballé, 1997). In the meantime, Himmelblau in 1978 defines a fault as a process abnormality or symptom, such as high temperature in a reactor or low product quality. In general, fault is deviations from the normal operating behavior in the plant that are not due to disturbance change or set point change in the process, which may cause performance deteriorations, malfunctions or breakdowns in the monitored plant or in its instrumentation. Therefore, the fault is a state that may lead to a malfunction or failure of the system. The time dependency of faults can be distinguished, as shown in Figure 2.2, as abrupt fault such as overheating and overpressure, incipient fault such as continuing overflow, and intermittent fault such as fault in gear or valve.

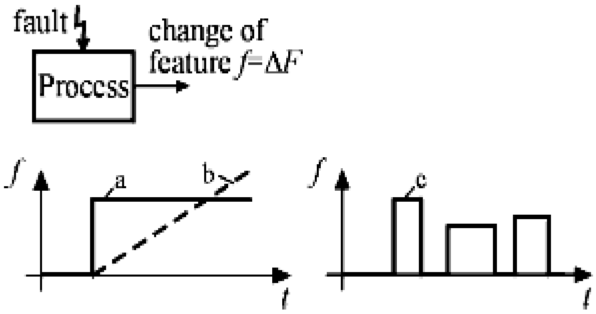

Figure 2.2 Time-dependency of faults: Abrupt (a), Incipient (b), and Intermittent(c) by Isermann (1997).

With regard to the process models, the faults can be further classified. According to Figure 2.3, additive faults influence a variable Y by an addition of the fault *f*, and multiplicative faults by the product of another variable U with *f*. Additive faults appear, for example offsets of sensors, whereas multiplicative faults are parameter changes within a process (Isermann, 2005).

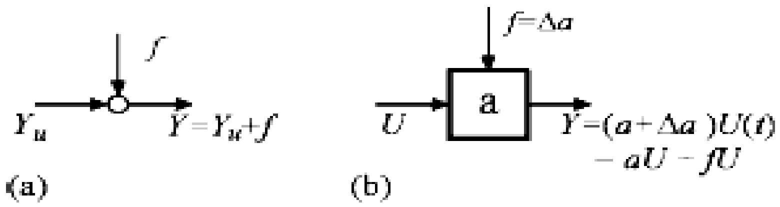

Figure 2.3 Basic models of faults: (a) Additive fault (b) Multiplicative faults (Isermann, 2005).

According to Gertler in 1998, faults can be categorized into the following categories:-

i. Additive process faults

   Unknown inputs acting on the plant, which are normally zero. They cause a change in the plant outputs independent of the known input. Such fault can be best described as plant leaks and load.

ii. Multiplicative process faults

These are gradual or abrupt changes in some plant parameters. They cause changes in the plant outputs, which also depend on the magnitude of the known inputs. Such faults can be best described as the deterioration of plant equipment, such as surface contamination, clogging, or the partial or total loss of power.

iii. Sensor faults

These are difference between the measured and actual values of individual plant variables. These faults are usually considered additive (independent of the measured magnitude), though some sensor faults (such as sticking or complete failure) may be better characterized as multiplicative.

iv. Actuator faults

These are difference between the input command of an actuator and its actual output. Actuator faults are usually handled as additive though, some kind (such as sticking or complete failure) may be described as multiplicative.

2.4 Fault Detection

Currently, the advance development of reliability, safety and intelligent of process control system has taken technical process especially chemical plant safety measurement to a new level. As the need for a better and safe plant as well as saving in cost, the advance control system would be a perfect solution. The traditional approach of control system is usually limited based upon the output variable and cannot give a deeper insight of the problems as well as not providing fault diagnosis. The new advance application of control system is analyzing the input and output by applying the dynamic process model. This can give a new view concerning the fault from different perspective. Furthermore, advance instrumentation can measure and evaluate hundreds of variables in just a few second to produce signatures in relation to the status of the process.

Fault detection is a monitoring process to determine the occurrence of an abnormal event in a process, whereas fault diagnosis is to identify its reason or sources. The detection performance is characterized by a number of important and quantifiable benchmarks namely (Harun, 2005):

i. Fault sensitivity: the ability of the technique to detect faults of reasonably small size.

ii. Reaction speed: the ability of the technique to detect faults with reasonably small delay after their occurrences.

iii. Robustness: the ability of the technique to operate in the presence of noise, disturbances and modeling errors, with few false alarms.

In general, one has to deal with three classes of failures or malfunctions as described below (Hamid, 2004):

i. Gross parameter changes in a model

In any modeling, there are processes occurring below the selected level of detail of the model. These processes which are not modeled are typically lumped as parameters and these include interactions across the system boundary. Parameter failures arise when there is a disturbance entering the process from the environment through one or more exogenous (independent) variables. An example of such a malfunction is a change in the concentration of the reactant from its normal or steady-state value in a reactor feed. Here, the concentration is an exogenous variable, a variable whose dynamics is not provided with that of the process. Another example is the change in the heat transfer coefficient due to fouling in a heat exchanger.

ii. Structural changes

Structural changes refer to changes in the process itself. They occur due to hard failures in equipment. Structural malfunctions result in a change in the information flow between various variables. To handle such a failure in a diagnostic system would require the removal of the appropriate model equations and restructuring the other equations in order to describe the current situation of the process. An example of a structural failure would be failure of a controller. Other examples include a stuck valve, a broken or leaking pipe.

iii. Malfunctioning sensors and actuators

Gross errors usually occur with actuators and sensors. These could be due to a fixed failure, a constant bias (positive and negative) or an out-of range failure. Some of the instruments provide feedback signals which are essential for the control of the plant. A failure in one of the instruments could cause the plant state variables to deviate beyond acceptable limits unless the failure is detected promptly and corrective actions are accomplished in time. It is the purpose of diagnosis to quickly detect any instrument fault which could seriously degrade the performance of the control system.

A large variety of techniques for fault detection had been proposed in the literature these days (Choudhury *et al.*, 2006, Thornhill and Horch, 2006 and Xia and Howell, 2005). Due to the broad scope of the process fault diagnosis problem and the difficulties in its real time solution, various computer-aided approaches have been developed over the years (Hamid, 2004). They cover a wide variety of techniques such as the early attempts using fault trees and diagraphs, analytical approaches, and knowledge-based systems and neural networks in more recent studies. From a modeling perspective, there are methods that require accurate process models, semi-quantitative models, or qualitative model. On the other hand, there are methods that do not assume any form of model information and rely only on process history information. These techniques can be classified as Model based methods and Historical data based methods (Detroja, *et al.*, 2007):

i. Model based methods: detect and isolate signals indicating abnormal (fault) operation for large scale system.

ii. Historical data based methods: attempt to synthesis utmost information from archive database and required minimum first principle knowledge of the plant.

The automatic control system can distinguish a fault from various parameters by using supervisory function to take appropriate action to maintain the process and to avoid any losses. There are three main elements in automatic control that can be classified as (Isermann, 2005):-

i. Monitoring: All related variables are supervised in regards to tolerances and alarms as identification instrument to the operators

ii. Automatic Protection: During abnormal, non linear or danger process state, the monitoring system will initiates an appropriated countermeasure.

iii. Supervision with fault diagnosis: Based on the measured variables, the current features are calculated, symptoms are generated via change detection, a fault diagnosis is performed and decision for counter action is permitted.

The advantage of the classical limit-value fault detection is their simplicity and reliability in handling monitoring process and automatic protection. However, fault can only be detected if there is a large change in the feature such as after either a large sudden fault or a long-lasting gradually increasing fault. Besides that, the system will not provide information regarding the fault diagnosis. The new advance method emphasis on the supervision and fault detection is needed to satisfy following requirement:-

i. Early detection of small faults with abrupt or incipient time behavior

ii. Diagnosis of faults in the actuator, process components or sensors

iii. Detection of faults in closed loops

iv. Supervision of processes in transient states

A general survey of supervision, fault-detection and diagnosis methods is given in (Isermann, 1997). In the following model-based fault-detection methods are considered, which allow a deep insight into the process behavior.

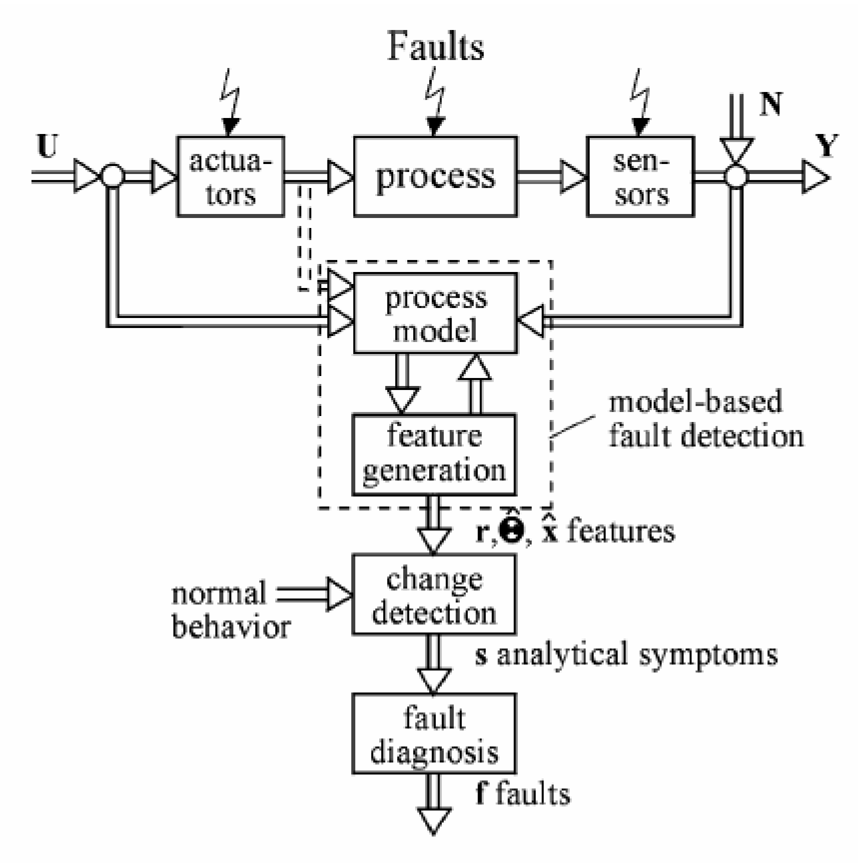

Figure 2.4 The general scheme of process model-based fault-detection and diagnosis (Isermann, 1997).

Different approaches for fault-detection using mathematical models have been developed in the last 20 years (Chen and Patton, 1999, Frank, 1990, Gertler, 1998, Himmelblau, 1978, Isermann, 1997, Patton *et al.*, 2000). The task consists of the detection of faults in the processes, actuators and sensors by using the dependencies between different measurable variables. These dependencies are