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HYBRID FDI ON CHEMICAL PLANTS

Ferreiro García, Ramón; Pardo Martínez, Xoán C. & Vidal Paz, José

Grupo de Enxeñeria de Sistemas e Control Automático.
Departamento de Electrónica e Sistemas. Universidade da Coruña.
E.S. da Mariña Civíl. Paseo de Ronda, 51. 15071, A Coruña. Spain.
Email: {ferreiro, pardo, vidal}@des.fi.udc.es

Abstract: This paper illustrates an alternative implementation to automatic protection and supervision task using the basic principles of model-based fault-detection and isolation associated to the rule-based FDI with subsequent appropriate corrective actions. Hybrid systems may be precisely described by sequential function charts (SFC). Operation supervision of hybrid systems may be carried out simultaneously on the basis of such SFC description. As discrete event and continuous processes operate simultaneously in close cooperation, a strategy to diagnose such hybrid system by means of a structured methodology under SFC description tool on the IEC-848 standard is developed. Copyright © 2005 IFAC

Keywords: Hybrid model based diagnosis, FDI by SFC, Parity equations, Supervisory control.

1. INTRODUCTION

The operation of technical processes requires increasingly advanced supervision and fault diagnosis to improve safety and production costs. With increasing process monitoring associated to an ever-higher level of automation to achieve desired quality, plants have become more vulnerable to faults in its instrumentation and consequently plant availability.

Most production plants operate as a combination of both discrete event and continuous processes (Blanke et all, 1997). Consequently, a structured methodology to solve the supervision task of hybrid processes is strongly demanded. The proposed methodology uses the association of plant operation description under SFC to the classical model-based approaches such as parameter estimation, state estimation (Gertler, 1997; Iserman, 1997) and a novel parity equation procedure (Patton and Chen, 1997). This work describes the basic approach for the engineering design of control systems or plants supervisor. It outlines how fault detection and isolation (FDI) can be associated to decision making procedures achieving a class of fault tolerant control by means of a hybrid process control system description and programming tool: the SFC according standard IEC-848.

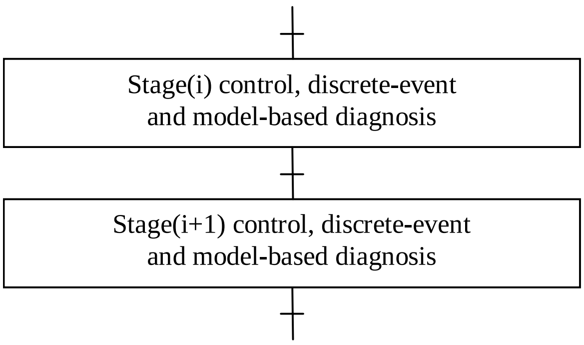

Fig. 1. Task description for control and supervision using SFC tools.

Figure 1 shows the basic approach of a partial sequential procedure illustrating a multitask structure as shown at (Blanke et all, 1997) with a difference that is, this implementation is carried out under the IEC-848 standard, in which both the control and supervision tasks are executed under the same tool.

Decisions on control sequence are taken by event following for plant degradation or fault detection and they depend on the state of plant and type of fault. Classically, the so-called diagnostic reasoning approach is performed by means of a rule base in which the single logical operations are state as IF THEN ELSE rules. SFC description tool contains all necessary knowledge and an inherent manager for its rule base capable to solve a discrete event control problem and consequently to solve any rule based control system. The major disadvantage of this approach has always been that binary logical decisions with Boolean operators do not reflect the gradual nature of many real world diagnostic problems. Fortunately SFC tool is capable to support both the discrete and the continuous event supervision under a unique representation frame

2. THE APPROACH TO DISCRETE EVENT DIAGNOSTICS

Such partial method consist in a control supervisor capable for evaluating, in any stage of the control process, the condition of the actuators (effectors), sensors and/or detectors involved on previous and present stage of the sequential control path, and consequently decides which action should be appropriate in order avoid system damages or system failure (Ferreiro, 1992). Let's consider part of a flow control sequence described by means of a SFC, where CT(i) is the condition for transition from stage S(i-1) to stage S(i) as shown in figure 2.

For every stage (i) of a discrete event control sequence the time to perform activities is a key in diagnostic tasks. There are stages for which such time is a constant, while for others time is a variable that depends on process characteristics.

For stages in which the time necessary to complete the activities is a constant, such as on-off valves, actuator cylinders at constant speed and many other periodic activities, the evidence of a fault in an activity is the time T(i) the action takes to reach the next condition for a normal transition. With such information available, the problem to be solved so as to validate the acquired data from detectors /or sensors and process supervision can be formulated by means of a true table shown at table 1. The application of true tables logic supply the same conclusions as rule bases.

From the knowledge stored in true table it must be remarked that:

Row 000, there is no evidence of fault,

Row 001, there is no evidence of fault

Row 010, there is at least one fault, but it will be required further analysis to conclude the search in the direction (symptom, event, and fault).

Row 011, the activity is performed perhaps with symptoms of degradation or overload, but extensive analysis is also necessary to conclude with a deterministic solution.

Row 100, suggest that detectors/sensors are set from last stage. Further analysis is necessary. Obviously in such discrete event analysis it is clear that do not reflect the gradual nature of real world diagnostic problems. More information can be achieved by adding to the true table another limit time To, that is a low limit time, for which an activity could never be performed under normal conditions.

Table 1 The basic FDI true table

t<To	t>T	CT	Case	The cause of fault
0	0	0		Normal operation
0	0	1		Normal operation
0	1	0	A	Detectors and/or Sensors, variables, process.
0	1	1	B	Slow actuation (degradation or load excess)
1	0	0	C	Detectors/Sensors set from last cycle (MBA required)

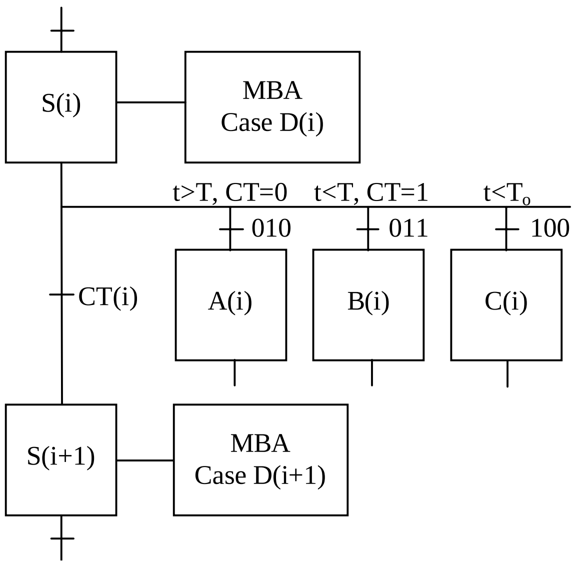

Fig. 2. The principle of hybrid supervision multitask.

It is clear that further effort is necessary to conclude the cause of faults. In this way discrete event search is useful as a management tool in scheduling model-based analysis. Figure 2 illustrates the diagnostic task added to a partial SFC control sequence.

Detection of the variable that do not satisfy the condition for transition is carried out by comparing the logic value of every actual variable involved in the transition function with the true value of same variable that satisfy the condition for transition. The conclusion is straightforward applied to a decision-making procedure. Decision-making through the conclusions given by the proposed true table, is to be implemented by SFC and depends on the desired action to be performed, which will be programmed by a human expert in the particular problem-solving task under the criteria of avoiding critical or ambiguous situations. In the case a condition for transition CT(i) fails, then SFC flow enter in supervision task as shown in figure 2. The result of supervision may be the detection of a single fault (non-critical fault) in one or more detectors involved in such transition function. If plant can operate or complete this operating cycle without forcing the control flow to a shutdown, then, flow should be transferred to next safety condition for transition by passing control flow to transition CT(i+1). In this case, the architecture belongs to fault tolerant control (FTC) for which SFC is able.

Generally, the time to complete an activity is not constant, it depends on process variables, internally coupled variables and process interrelated variables. Prediction of normal activity time may not be possible with required precision. Consequently, discrete analysis can not be carried out with a deterministic conclusion. The unique solution to this problem is to perform a model-based analysis for which if processes are well understood, dynamic models for fault detection and isolation using the well-established continuous-time modelling can be used. Such alternative is shown at figure 2 as case D.

3. HYBRID FDI

The most common case in FDI tasks is that one in which model based analysis must be associated to fault tree analysis to conclude and decide the required safe action.

Case A(i) in figure 2 is a poor or ambiguous conclusion if no further search were performed. The first conclusion is that at least a fault exists in one or both: detectors and/or process parameters and/or process variables.

In order to perform the isolation fault task for the case A(I), the worst case, a new fault tree analysis by means of a rule-based procedure is presented. Let's consider that if a fault is present in the case A(i) then A(i)=1 and if the fault is present in Model-Based Analysis (MBA), then MBA=1. Table 2 shows the sequence to be performed in the analysis approach.

Table 2 True table for analysis sequence

A(i)	**MBA**	**Detectors sensors**	**plant params.**	**plant vars.**	**state event**
0	0				
0	1		X	X	plant fault
1	0	X			
1	1	X	X	X	critic state

At above table, the cluster with X means that at least a fault is present. So that from row 2 in the above table it is concluded that plant parameters and/or plant variables state is abnormal. At this state an MBA task on plant parameters is useful to discriminate faults in plant variables. That means, if a after a MBA operation plant parameters are normal, then it is to be concluded that the fault is isolated in plant variables. Last row in table 2 indicates that a critic fault is present and normal sequence operation can not continue. Consequently, heuristic reasoning is strongly demanded for deciding under human inspection.

4. APPLICATION OF THE DIAGNOSTIC TASK ON A TANK LEVEL PROBLEM

Let's consider a subtask or fragment of a process based in the tank level control by means of an on-off control valve. In order to denote plant variables and parameters, it is shown in figure 3. The control sequence consists in open a valve when level is low limit, (CT1=1), and close the valve when level is at high limit, (CT2=1). The SFC for control and supervision is shown in figure 4.

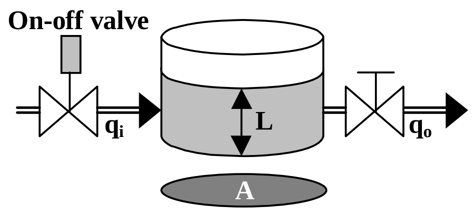

Fig. 3. The process to be supervised.

The supervision task or decision making procedure is carried out by processing MBA and true table logic with the conditions of table 1. If both results indicate plant faults, discrimination by means of another true table logic with the conditions of table 2 (tab2) is executed. Finally, a decision effector is activated to jump towards a safety stage. Figure 5 shows the sequence for decision making task.

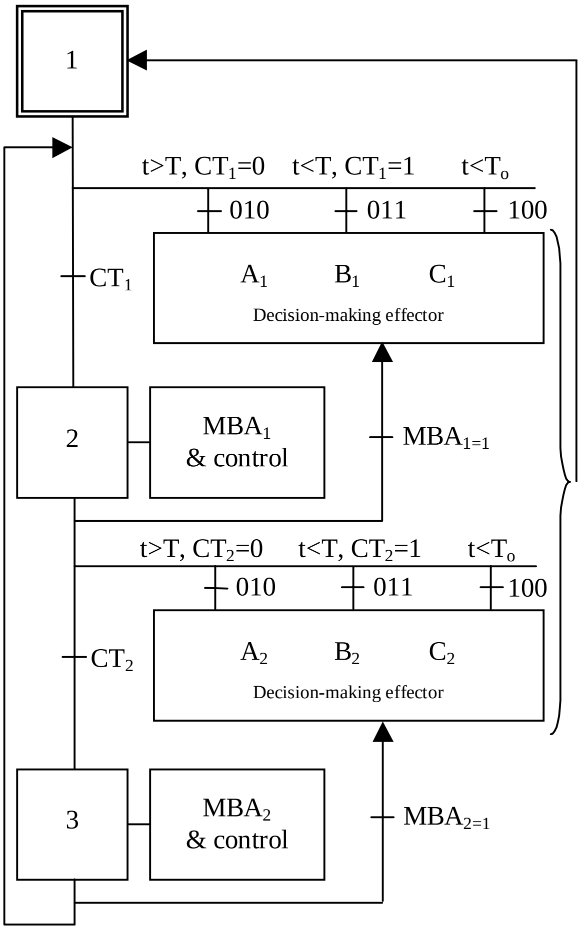

Fig. 4. The hybrid supervision multitask applied to level control sub-plant.

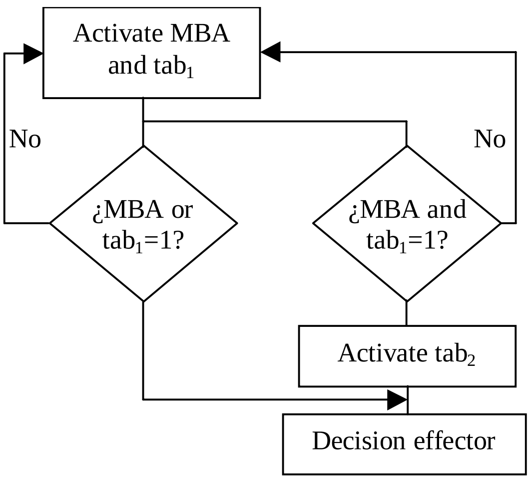

Fig. 5. The decision-making task sequence.

Such control system is implemented by means of a PLC programming language, the Pl7-Micro, a language of last generation, being applicable to several different PLC manufacturers such as Square-D, Modicon, AEG-Schneider and Telemecanique.

Model based diagnosis is restricted in this application to compare the actual tank filling velocity with a nominal value. That is, a time series function is compared with the actual measured level, which supply the necessary information to conclude that filling and discharge events are performing according desired models.

4.1. The model-based analysis for level tank dynamics with parity equations

The used models then,

$$q_i - q_o = A\frac{dL}{dt} \quad (1)$$

The transfer functions are

$$G_{ML} = \frac{L}{q_i - q_o} = \frac{1}{AS} \quad (2)$$

According residual generation models for level

$$r_L = G_{ML}\, f(q_i - q_o) + fL \quad (3)$$

4.2. Fault detection procedure

At least one fault exists if residuals are different from zero. It is possible also the existence of fault when for short periods of time the terms of right hand in equation (3) cancel each other. The detection of faults is straightforward from expression (3).

4.3. Isolation

The isolation of faults in the tank level process requires defining its time domain model, the model for plant parameters is

$$L(t) = \frac{1}{A}\int f(q_i - q_o)dt + fL \quad (4)$$

for application purposes it becomes

$$r_{L(t)} = \frac{1}{A} f(q_i - q_o)t + fL \quad (5)$$

Consequently, an equation system may be achieved

$$r_{L(t_1)} = \frac{1}{A} f(q_i - q_o)t_1 + fL \quad (6)$$

$$r_{L(t_2)} = \frac{1}{A} f(q_i - q_o)t_2 + fL \quad (7)$$

which in matrix form is

$$\begin{bmatrix} r_{L(t_1)} \\ r_{L(t_2)} \end{bmatrix} = \begin{bmatrix} \frac{1}{A}t_1 & 1 \\ \frac{1}{A}t_2 & 1 \end{bmatrix} \begin{bmatrix} f(q_i - q_o) \\ fL \end{bmatrix} \qquad (8)$$

whose solution for plant parameters is given as

$$\begin{bmatrix} f(q_i - q_o) \\ fL \end{bmatrix} = \begin{bmatrix} \frac{1}{A}t_1 & 1 \\ \frac{1}{A}t_2 & 1 \end{bmatrix}^{-1} \begin{bmatrix} r_{L(t_1)} \\ r_{L(t_2)} \end{bmatrix} \qquad (9)$$

The task of FDI requires plant simulation.

4.4. Rule-based diagnosis by Boolean Logic

Fault detection is based on a discrimination searching. It is considered that if measured velocities are outside the limits given by proposed plant operation safety limits (Low, High), then plant is running under normal conditions. That is,

$$VL_L < VL < VL_H \qquad (10)$$

VT_L, VT_H, VL_L, VL_H are defined from process models with safety tolerances

Isolation is concluded by means of heuristic reasoning as

$$\begin{aligned} VL < VL_L &\Rightarrow \text{Pump Efficiency} \\ VL > VL_H &\Rightarrow \text{Level Sensor} \end{aligned} \qquad (11)$$

5. CONCLUSION

Some particular characteristics distinguish the SFC based supervision system from others. The PLC exerts its computational effort on the stage in which process is operating. That means, is centred in the active stage for control and supervision. No inactive parts of plant overload the PLC with useless computations. The structured nature of SFC helps in supervision tasks as a straightforward application tool.

Logic and analog process supervision, can be performed simultaneously by means of the same PLC control program. The advantage of such procedure, is plant reliability and safety included its control system, avoiding ambiguity and dangerous actuations after some faults were detected. The indication of the stage in which the system fails, helps in minimise shut-downs, reducing maintenance cost and enlarging plant control system life.

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