DESIGN OF A MODEL-BASED DIAGNOSIS SYSTEM FOR A THREE-TANK PLANT USING POSSIBLE CONFLICTS

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Abstract*

Continuous systems may exhibit disastrous consequences due to different kinds of faults. To reduce its consequences, systems must detect and identify these faults. The fault detection and isolation tasks can be carried out by means of model-based techniques. Among the model-based diagnosis techniques, consistency-based approach is the most used within the Artificial Intelligence community.

In this paper, we present the application of a consistency-based diagnosis technique, called Possible Conflicts, to a laboratory plant. Possible Conflicts can be computed using a specific software tool. The system and the Possible Conflicts have been implemented using the simulation software tool SIMULINK©. Finally, the system has been tested in a simulated benchmark.

Index Terms: FDI, model-based diagnosis, Possible Conflicts

I. INTRODUCTION

Our daily life depends on modern technology. Energy consumed by households, trains, and planes used for transportation or industrial purposes, strongly depends on technology. All these systems are made up of mechanical and electronic components. All these components may fail due to breakages and degradations. These faults can produce malfunctions, damage materials, generate economic losses, or been dangerous for people life.

For all these situations it is necessary to develop suitable techniques that detect and isolate faults. If the malfunctions can be detected and isolated just after the fault occurrence, they can be repaired, or at least the system can apply a security protocol, to minimize its effects.

Several fault detection and isolation approaches can be applied depending on the requirements, the environment, or the information available. Different disciplines study this problem. In this paper, a model-based diagnosis approach has been applied: consistency-based diagnosis (CBD). CBD is the most used approach to model-based diagnosis in the Artificial Intelligence community. Its main advantage is that it just requires correct-behavior models to perform fault detection and isolation. Within this approach there is no fault modes needed for fault isolation, and fault isolation is straight-forward. We have an estimation of the behavior of the system that compared with the observed behavior lead us to a conflict detection. The conflicts are computed on-line "recording" correctness assumptions for predictions. When a conflict is detected we proceed to generate the set of fault candidates, that will lead us to the fault detection and isolation results.

The FDI system has been tested in a three tanks benchmark described in [6].

The organization of this paper is as follows. First, we describe the Possible Conflicts technique. Then, we present the case study. Afterwards, we show the experimental results. Finally, we discuss the results and draw some conclusions.

II. POSSIBLE CONFLICTS APPROACH

Possible Conflicts, PCs for short [2], [4], are those subsystems capable to become conflicts within the Consistency Based Diagnosis framework [5], i.e. *minimal subsets of equations containing the analytical redundancy necessary to perform fault diagnosis* [3]. The main idea behind the *Possible Conflict* concept is that the set of subsystems capable to generate a conflict can be generated off-line. The PCs computation process is carried out in a three steps process:

– Create an abstract representation of the system, as an hypergraph. In this representation there is just qualitative information about constraints in the models, and their relationship to known and unknown variables in such models.

– Look for the over-constrained set of relations, that is, find all those subsystems with more number of constraints than unknown variables. These subsystems are called *Minimal Evaluation Chains*, or *MEC.* To find the Minimal Evaluation Chains, all the

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partial subhypergraphs in the system capable to generate an estimation of an observed variable or a double estimation over a non-observed variable, have to be found.

– Search for every possible way the system can be solved using local propagation. Each possible way is called a Minimal Evaluation Model, or MEM, and it can be used to predict the behavior of a subsystem.

Since conflicts will arise only when models are evaluated with available observations, the set of constraints in a Minimal Evaluation Model is called a Possible Conflict, PC. Each MEM describes an executable model, which can be used to perform fault detection. If there is a discrepancy between predictions from those models and current observations, the Possible Conflict would be responsible for such a discrepancy and should be confirmed as a real conflict. Afterwards, diagnosis candidates are obtained from conflicts following Reiter's theory [5].

As pointed out in [4], the set of MEMs generated with this approach is equivalent to the set of conflicts computed by the GDE.

III. CASE STUDY

A. Description of the system

The approach has been tested in a laboratory plant (fig. 1). A description of this plant can be found in [6].

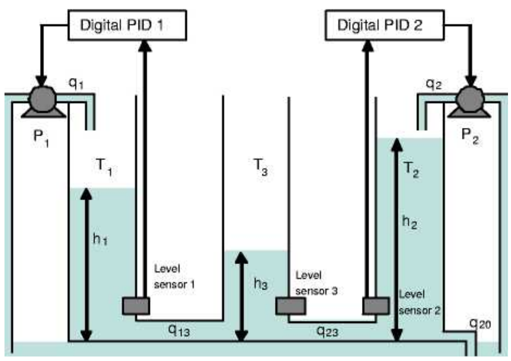

Fig. 1. Three-tank system

This plant is made up of three cylindrical tanks T_1, T_2 and T_3 with cross section A. The tanks are connected in series with one another by cylindrical pipes (q13 and q23) with a cross section S_n. In tank T_2 there is a outflow pipe. The outflowing liquid is collected in a big tank. This tank supplies the pumps P1 and P_2, which introduce liquid into tanks T1 and T_2 (q1 and q2). Each of the pumps are governed by a digital level controller. The three liquid levels h1, h_2 and h_3 are measured via physical sensors. The numerical values of physical parameters of the system are listed in the Appendix.

B. Mathematical model

A mathematical model can be developed describing the three-tank system dynamic behavior. The level of tanks can be calculated through mass balance:

$$c_1 : \dot{h}_1 = \frac{q_1 - q_{13}}{A} \quad (1)$$

$$c_2 : \dot{h}_3 = \frac{q_{13} - q_{32}}{A} \quad (2)$$

$$c_3 : \dot{h}_2 = \frac{q_2 - q_{32} - q_{20}}{A} \quad (3)$$

Using the Torricelli law, flows across the connecting and outlets pipes can be calculated:

$$c_4 : q_{13} = aS_n sign(h_1 - h_3)\sqrt{2g|h_1 - h_3|} \quad (4)$$

$$c_5 : q_{32} = aS_n sign(h_3 - h_2)\sqrt{2g|h_3 - h_2|} \quad (5)$$

$$c_6 : q_{20} = aS_n \sqrt{2gh_2}\ , \quad (6)$$

where a – is the scaling constant for the relation between the cross-section of the connecting and outlets pipes and the mass flow going thought them, g– is the gravity constant.

We also have to take into account the observational model of the system.

Levels can be read in sensors

$$c_7 : h_1 = yh_1\ , \quad (7)$$

$$c_8 : h_2 = yh_2\ , \quad (8)$$

$$c_9 : h_3 = yh_3\ , \quad (9)$$

where yh_i – is the level signal reading on sensors.

To take into account the temporal information, for practical reasons (i.e. the estimation of the derivative is a hard process), we decided to use integral causality in the equations modeling the dynamic information:

$$c_{10} : h_1 = \int \dot{h}_1 \quad (10)$$

$$c_{11} : h_2 = \int \dot{h}_2 \quad (11)$$

$$c_{12} : h_3 = \int \dot{h}_3 \quad (12)$$

C. Faults considered

The faults considered are listed in the following list:

– **fh1, fh$_2$** and **fh$_3$**: faults in level sensors.
– **ft1, ft$_2$** and **ft$_3$**: leakage in tanks T_1, T_2 and

T_3, respectively.

- **fb1$_3$, fb$_{32}$** and **fb$_{20}$**: blockage in pipes q_{13}, q_{32} and q_{20}

These faults have been simulated using SIMULINK© software tool too. User can introduce faults choosing the fault arising time and the fault magnitude.

IV. EXPERIMENTAL RESULTS

A. Design of the model-based diagnosis system

We carried out the PCs computation. They can be automatically generated using a software tool [1], called PCs. This tool uses a description of the physical system as input, and calculates the set of possible conflicts, moreover provides a text and graphic description about how the simulation model should be implemented. In fig. 2 a graphic description of these PCs is shown.

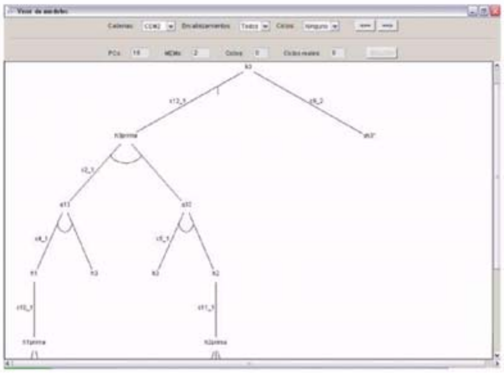

Fig. 2. Graphic representation of a Possible Conflict

Table 1
Possible Conflicts and equations found for the laboratory plant

PCs	cuations	Estimate
PC_1	$c_1, c_{10}, c_2, c_4, c_{12}, c_3, c_9, c_{11}, c_6, c_5$	h_1
PC_2	$c_1, c_{10}, c_2, c_7, c_{12}, c_3, c_4, c_{11}, c_6, c_5$	h_2
PC_3	$c_1, c_{10}, c_2, c_4, c_{12}, c_3, c_5, c_{11}, c_6, c_8$	h_3
PC_4	$c_1, c_{10}, c_4, c_7, c_9$	h_1
PC_5	$c_1, c_{10}, c_2, c_4\ c_{12}, c_5, c_9, c_8$	h_3
PC_6	$c_2, c_{12}, c_4, c_5, c_9, c_7, c_8$	h_3
PC_7	$c_1, c_{10}, c_2, c_7, c_{12}, c_5, c_4, c_8$	h_1
PC_8	$c_2, c_{12}, c_4, c_3, c_5, c_7, c_{11}, c_6, c_8$	h_2
PC_9	$c_2, c_{12}, c_4, c_3, c_9, c_7, c_{11}, c_6, c_5$	h_3
PC_{10}	$c_3, c_{11}, c_5, c_6, c_8, c_9$	h_2

We have found the set of possible conflicts shown in table 1. In the table, second column shows the set of constraints used in each possible conflict, which are minimal with respect to the set of constraints. Third column indicates the estimated variable for each possible conflict.

The last step is to generate the Fault Signature Matrix (FSM). This matrix is shown in table 2.

Table 2
Fault Signature Matrix (FSM)

	fh_1	fh_2	fh_3	ft_1	ft_2	ft_3	fb_{13}	fb_{32}	fb_{20}
PC_1	1	0	0	1	1	1	1	1	1
PC_2	0	1	0	1	1	1	1	1	1
PC_3	0	0	1	1	1	1	1	1	1
PC_4	1	0	1	1	0	0	1	0	0
PC_5	0	1	1	1	0	1	1	1	0
PC_6	1	1	1	0	0	1	1	1	0
PC_7	1	1	0	1	0	1	1	1	0
PC_8	1	1	0	0	1	1	1	1	1
PC_9	1	0	1	0	1	1	1	1	1
PC_{10}	0	1	1	0	1	0	0	1	1

B. SIMULINK implementation

To implement Possible Conflicts, first step is to build a simple model for each equation. Input variables (q_1, q_2, yh_1, yh_1 and yh_1) are connected to simulation model. Each equation is implemented using SIMULINK©blocks, and encapsulated in equation blocks. Figure 4 shows an example of equation c_4.

When the model of the system was implemented, we proceed to the Possible Conflicts implementation. These models are built connecting the equations blocks and taking care of the causality of the system shown in the graphic representation of a Possible Conflict generated with the tool PCs. All this Possible Conflicts generate a residual each one.

Residuals should be equal to zero in nominal situation and trigger off when the fault arises. As we consider noise in the measurements, we select a threshold to avoid false alarms produced by the noise. Comparing the residuals triggers with columns of faults signature matrix the faults can be isolated. Figure 5 shows the simulation results.

V. CONCLUSIONS

This paper has presented the design and implementation of a model-based diagnosis system for a three-tank plant using Possible Conflicts.

Possible Conflicts computation, and the implementation of the plant and the FDI system using SIMULINK©, has been described.

The Fault Signature Matrix (FSM) has been calculated using the approach presented and has been tested in a benchmark. The system has been able to detect and isolate the nine considered faults.

APPENDIX

Parameters of the three tank system:
$A = 0.0154\mathrm{m}^2$ $S_n = 5 \bullet \mathrm{Hr}^5\mathrm{m}^2$

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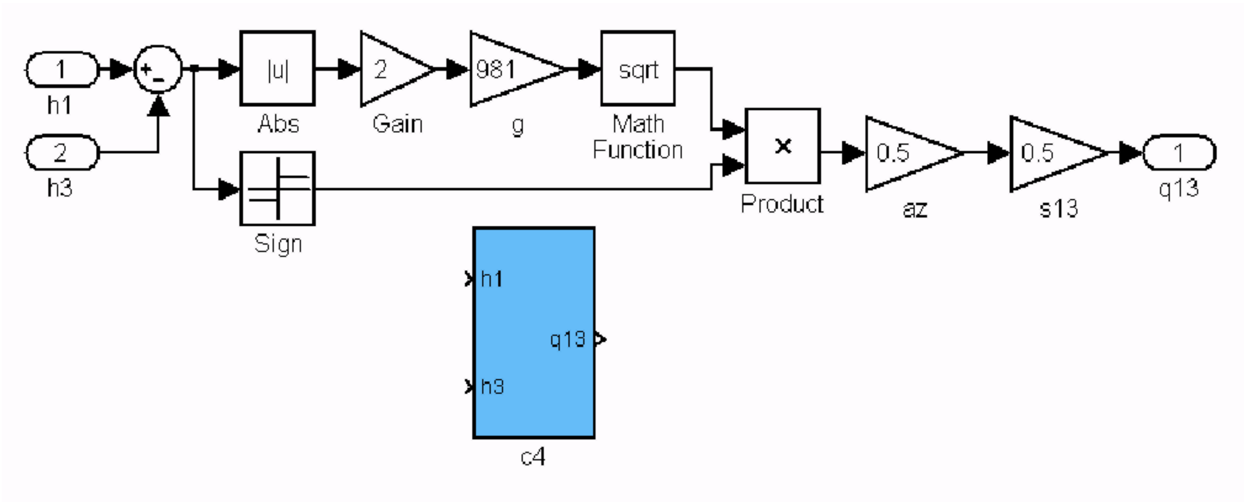

Fig. 3. Graphic representation of equation c4

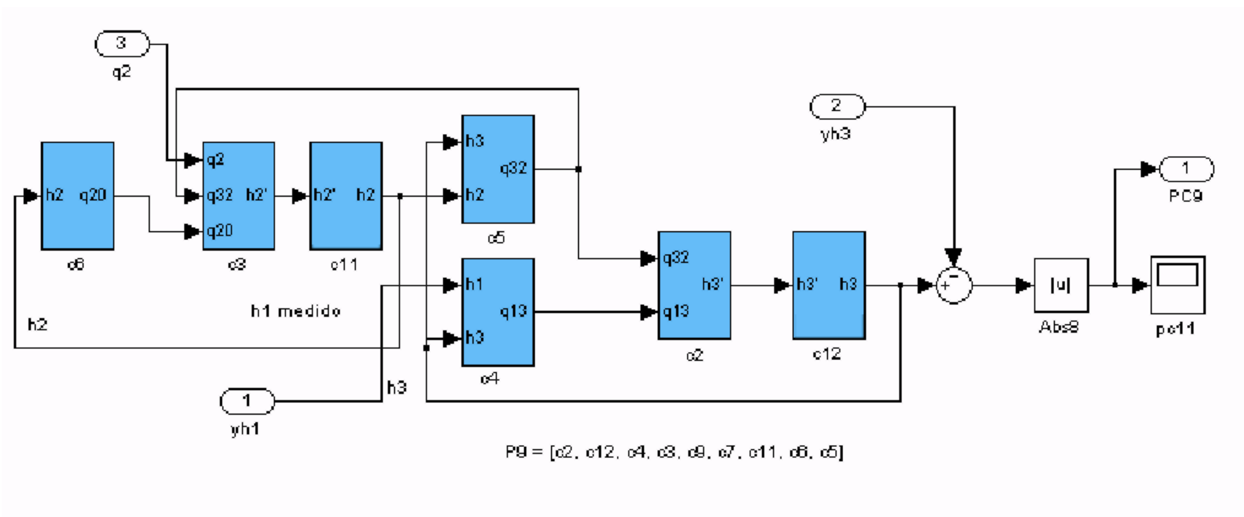

Fig. 4. Graphic representation of equation PC4

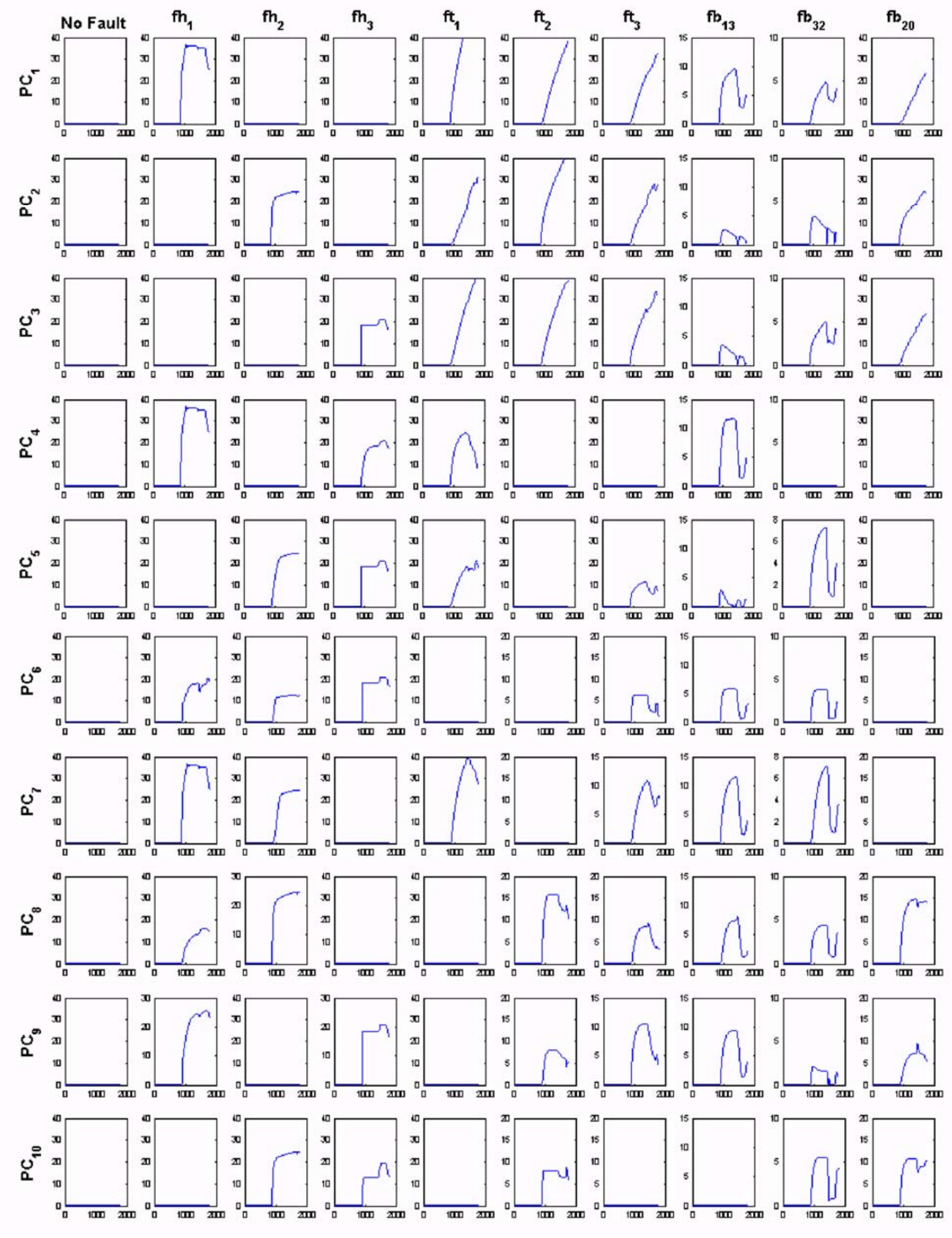

Fig. 5. Results of the simulations for all the nine faults considered