Prediction-Based Diagnosis and Loss Prevention Using Model-Based Reasoning

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Abstract. A diagnostic expert system established on model-based reasoning for on-line diagnosis and loss prevention is described in the paper. Its diagnostic "cause-effect" rules and possible actions (suggestions) are extracted from the results of standard HAZOP analysis. Automatic focusing as well as "what-if" type reasoning for testing hypothetical actions have been also implemented. The diagnostic system is tested on a granulator drum of a fertilizer plant in a simulation test-bed.

1 Introduction

The importance of powerful and efficient fault detection and isolation methods and tools [1] for large-scale industrial plant cannot be overestimated. Prediction based diagnosis [7] is one of the most powerful approaches that utilizes a dynamic, quantitative and/or qualitative model of the plant.

Therefore, our aim has been to propose an expert system that is able to perform model-based on-line fault-detection, diagnosis and loss prevention [2] for large-scale process systems using a combination of model-based reasoning [6] and rule-base inference originating from a HAZOP (HAZard and OPerability) analysis, often available for large process plants.

2 The Knowledge Base and the Diagnostic Procedures

As dictated by the diversity of the knowledge sources, the methods and procedures used for diagnosis in our expert system are of two types. *Standard forward and backward reasoning on the rule-set derived from the HAZOP tables* is applied for cause-consequence analysis, and *model-based reasoning applied on dynamic engineering models* is used to predict the effect of faults and preventive actions.

Hierarchically Structured Dynamic Model. In fault detection and diagnosis, the prediction of a system's behaviour is used for deriving the consequences

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of a state of the system in time and it is usually done in process engineering by dynamic simulation. In the case of *prediction-based diagnosis* [7], however, the faulty mode of the system can also be detected based on the comparison between the real plant data and the predicted values generated by a suitable dynamic model.

The best solution for addressing computational complexity of multiple fault diagnosis [4] is abstraction [2], where the approaches are usually hierarchical and the problem is presented at multiple levels. Faults are then isolated on one level with further focus at more finer levels as required. The *multi-scale modelling* [3] approach of describing dynamic process models, that are composite mathematical models describing phenomena at different characteristic time and/or length scales fits well to abstraction. This is because a multi-scale model is an ordered hierarchical collection of partial models.

HAZOP Table. The operational experience about the faulty behaviour of the system together with the reasons and the ways of correction of malfunctions are described in the proposed diagnostic system in the form of diagnostic and preventive action rules constructed from a HAZOP table [5] consisting of standard columns. The column *Guide word* identifies a measurable or observable variable, the deviation of which is associated to the hazard. The column *Deviation* describes the difference from the "normal behaviour" of the *Guide word* by using guide expressions. In the column *Possible causes* are the real primary causes of the deviation. In the column *Consequeces* the potentially harmful consequences are listed. The last column *Action required* gives actions that are recommended for eliminating or mitigating the hazard that can be regarded as preventive actions.

Symptoms. Symptoms are identified deviations from design or operational intention described in the form of inequalities, such as $level_{low} = (h < 2\ m)$ which is defined by using measurable level h. Symptoms can be derived from the columns *Guide word* and *Deviation* of the HAZOP table. Symptoms are time-varying quantities and they are naturally connected to the process model through their associated measurable variable. Thus the rule-base associated with symptoms is also naturally modularized and driven by the structure of the hierarchical process model.

Rule-Base. We have mapped the knowledge of human expertise and operation collected in the HAZOP table to "if – then" rules of two types. *Diagnostic rules* describe the possible "cause – consequence" type relationships between the root causes and symptoms. *Preventive action rules* are "(cause, consequences) – action" type relationships between the (symptoms, root causes) pairs and preventive actions.

The Integration of Fault Detection, Diagnosis and Loss Prevention Steps. In our diagnostic expert system the model-based fault detection, diagnosis and loss prevention steps are organized in a cyclic process consisting of the following main steps:

1. *Performing measurements and symptom detection:* Using the measured signals from the system and the relationships among them, the possible symptoms are determined with pattern matching.
2. *Focusing and primary fault detection:* Focusing is applied to find the proper hierarchy level and/or part of the model (the dynamic model augmented with structured rules) connected to the detected symptoms by using the model and rule hierarchy. Thereafter, the possible causes are derived by backward reasoning. Multiple symptoms connected to a common cause or multiple causes connected to common symptoms are also taken into account together with possible preventive actions for the possible causes.
3. *Fault isolation:* Comparing the measured data with the predicted values of the variables the spurious (cause, preventive action) pairs can be removed from the list of the possible (cause, preventive action) pairs.
4. *Loss prevention:* Multiple prediction (what-if type reasoning) is performed for each applicable (cause, preventive action) pair and a preventive action is suggested which drives the system back to its normal operation mode.

The Granulator Diagnosis Expert System. A diagnostic expert system based on the above principles is implemented in G2 that is tested on a granulator drum of a fertilizer plant in a simulation test-bed.

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References

1. Blanke, M., Kinnaert, M., Junze, J., Staroswiecki, M., Schroder, J., Lunze, J., Eds.: Diagnosis and Fault-Tolerant Control. Springer-Verlag. (2003)
2. Console, W. H. L., Hamscher, de Kleer, J. Eds.: Readings in Model-Based Diagnosis. Morgan Kaufmann, San Mateo, CA. (1992)
3. Ingram, G. D., Cameron, I. T., Hangos, K. M.: Classification and analysis of integrating frameworks in multiscale modelling. Chemical Engineering Science **59** (2004) 2171–2187
4. de Kleen, J., Williams, B. C.: Diagnosing multiple faults. Artificial Intelligence **32** (1987) 97–130.
5. Knowlton, R. E.: Hazard and operability studies : the guide word approach. Vancouver: Chematics International Company (1989)
6. Russell, S., Norvig, P.: Artificial intelligence, A modern approach. Prentice-Hall (1995)
7. Venkatasubramanian, V., Rengaswamy, R., Kavuri, S. N.: A review of process fault detection and diagnosis Part II: Qualitative models and search strategies. Computers and Chemical Engineering **27** (2003) 313–326