A Review Robot Fault Diagnosis Part II Qualitative Models and Search Strategies

D. Sivasamy, M. Dev Anand, K. Anitha Sheela

Abstract--- In this part, we review qualitative model representations and search strategies used in industrial robot fault diagnostic systems. Fault diagnosis is increasingly important in modern autonomous or industrial robots. The ability to detect, isolate and tolerate failures allows robots to effectively cope with internal failures and continue performing designated tasks without the need for immediate human intervention. Qualitative models are usually developed based on some fundamental understanding of the applied physical science of the system. Various forms of qualitative models such as causal models and abstraction hierarchies are discussed. The relative advantages and disadvantages of these representations are highlighted. In terms of search strategies, we broadly classify them as topographic and symptomatic search techniques. Topographic searches perform malfunction analysis using a template of normal operation, whereas, symptomatic searches look for symptoms to direct the search to the fault location. Various forms of topographic and symptomatic search strategies are discussed. The important role of robot fault diagnosis in the broader context of operations is also outlined. We also discuss the technical challenges in research and development that need to be addressed for the successful design and implementation of practical new supervisory robot control systems.

Keywords--- Fault Diagnosis, Industrial Robot, Hybrid System, Qualitative Models and Search Strategies.

I. INTRODUCTION

Fault diagnostic activity comprises of two important components:a priori domain knowledge and search strategy.The basic a priori knowledge that is needed for faultdiagnosis is a set of failures and the relationship betweenthe observations (signal) and the failures. A diagnosticsystem may have them explicitly or it may be inferred from some source ofdomain knowledge. A priori domain knowledge may bedeveloped from a fundamental understanding of the system using first-principles knowledge. Such knowledgeis referred to as deep, causal or model-basedknowledge (Milne, 1987). On the other hand, it maybe gleaned from past experience with the system. Thisknowledge is referred to as shallow, compiled, evidential or history-based knowledge.

The model-based a priori knowledge can be broadlyclassified as qualitative or quantitative. The model isusually developed based on some fundamental understandingof the applied physics of the system. In quantitativemodels this understanding is expressed in terms ofmathematical functional relationships between the inputsand outputs of the system. In contrast, in qualitativemodels these relationships are expressed in terms ofqualitative functions centered on different units in a system. The qualitative models can be developed either as qualitative causal models or abstraction hierarchies.

Revised Manuscript Received on May 15, 2019.

D. Sivasamy*, Assistant Professor, SBMCET, Dindigul. (e-mail: sivasamy.d@gmail.com)

M. DevAnand, Professor and Research Director, Department of Mechanical Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, Thuckalay, Kanyakumari District, TamilNadu, India.

K. AnithaSheela, Professor& Head, ECE, Jawaharlal Nehru Technological University, Hyderabad-85, India.

II. QUALITATIVE MODELS

The development of knowledge-based expert systemswas the first attempt to capture knowledge to drawconclusions in a formal methodology. An expert/intelligent systemis a computer program that mimics the cognitivebehavior of a human expert solving problems in aparticular domain. It consists of a knowledge base, rules base, behavior base essentially a large set of if-then-else rules and aninference engine which searches through the knowledgebase to derive conclusions from given facts. Also, thetree of these if-then-else clauses grows rapidly with thebehavioral complexity of the system. The problem withthis kind of knowledge representation is that it does nothave any understanding of the underlying physics of thesystem, and therefore fails in cases where a newcondition is encountered that is not defined in theknowledge base.

2.1. Digraphs based Causal Models

Diagnosis is the inverse of simulation. Simulation isconcerned with the derivation of the behavior of the system given its structural and functional aspects.Diagnosis, on the other hand, is concerned with deducingstructure from the behavior. This kind of deductionneeds reasoning about the cause and effect relationshipsin the system. In the evidential reasoning approach todiagnosis, heuristic information in the form of productionrules is used. The underlying cause-effect relationshipsof the system are implicit in this form ofreasoning. In the first-principles model-based approach,one begins with a description of the system together withthe observations made from the malfunctioning process.The reasoning here is to identify functional changeswhich resulted in the malfunctioning of the control system (Davis, 1984; Rich &Venkatasubramanian, 1987;Venkatasubramanian& Rich, 1988). Now it is that qualitative causal models are very importantand are used extensively.

2.2. Fault Trees

Fault trees are used in analyzing the system reliabilityand safety. Fault tree analysis was originally developedat Bell Telephone Laboratories in 1961. Fault tree is alogic tree that propagates primary events or faults to thetop level event or a hazard. The tree usually has layers ofnodes. At each node different logic operations like ANDand OR are performed for propagation.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Fault-treeshave been used in a variety of risk assessment andreliability analysis studies (Ulerich and Powers, 1988). Ageneral fault tree analysis consists of the following foursteps:

(i) System definition
(ii) Fault tree construction
(iii) Qualitative evaluation
(iv) Quantitative evaluation

2.3. Qualitative Physics

Qualitative physics or common sense reasoning aboutphysical systems has been an area of major interest tothe artificial intelligence community. Qualitative physicsknowledge in fault diagnosis has been represented inmainly two ways. The first approach is to derivequalitative equations from the differential equationstermed as confluence equations. There is yet another method, called precedence ordering, that has been used to order the variables from the view point of information flow among them. Precedence ordering has been studied widely for solving sets of algebraic equations simultaneously (Soylemez&Seider, 1973).

2.4. Abstraction Hierarchy of System Knowledge

Another form of model knowledge is through thedevelopment of abstraction hierarchies based on decomposition.The idea of attributes is to be able todraw inferences about the behavior of the overall systemsolely from the laws governing the behavior of itssubsystems. In such decomposition, the no-function in structure principle is central: the laws of the subsystemmay not presume the functioning of the wholesystem (de Kleer& Brown, 1984).

III. TYPOLOGY OF DIAGNOSTIC SEARCH STRATEGIES

There are fundamentally two different approaches tosearch in fault diagnosis (Rasmussen, 1986): topographicsearch, and symptomatic search. Topographicsearches perform malfunction analysis using a templateof normal operation, whereas, symptomatic searcheslook for symptoms to direct the search to the faultlocation.

3.1. Topographic Search

Search can be performed in the mal-operating systemwith reference to a template representing normal orplanned operation. The fault will be found as amismatch and identified by its location in the system.This type of search is called topographic search.

3.1.1. Decomposition Techniques

All topographic strategies depend on search withreference to a model of normal function and aretherefore well suited for identification of disturbancesthat are not empirically known or that the designer hasnot foreseen. Consistency and correctness of the strategydoes not depend on models of malfunction and hence isless influenced by multiple unknown disturbances. Sincethe faults are not known a priori, topological searchhelps only narrowing the focus of fault diagnosis to asubsystem. Figure1 shows how one can use this approachto check the functionality of various subsystems in a robot system.

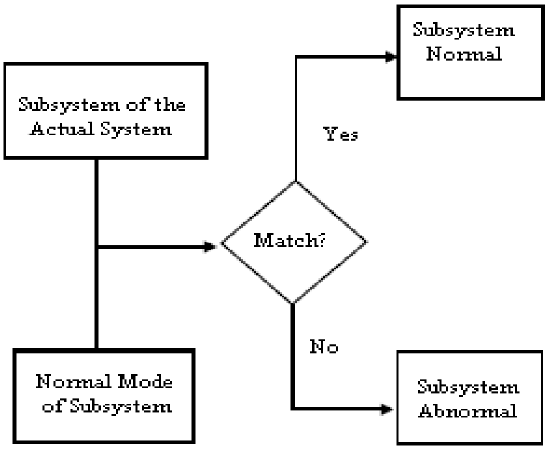

Figure 1: Topographic Search

3.2. Symptomatic Search

A set of observations representing the abnormal stateof the system can be used as a search template to find amatching set in a library of known symptoms related todifferent abnormal system conditions. This type ofsearch is called symptomatic search. The main featureof these methods is that their decisions are derived fromthe structure of data sets, their internal relationships,and not from the topological structure of systemproperties. Symptomatic search is advantageous fromthe view point of information economy.

3.2.1. Look-Up Tables

This is the simplest kind of symptomatic search. Atemplate of abnormal behavior and correspondingsymptoms are stored in the form of look-up tables.This kind of approach gets complicated and intractable for large systems. Hence one needs moresystematic approaches for solving the diagnosis problemsin the case of complicated systems.

3.2.2. Hypothesis and Test Search

Hypothesis and test search is a very popular symptomaticapproach to fault diagnosis. If a search is based onreference patterns generated on-line by modification of afunctional model, in correspondence with a hypotheticaldisturbance/fault, the search strategy is a hypothesis andtest search in the closed-loop form. The efficiency of this search depends onthe efficiency in generating hypotheses. Hypotheses aregenerated from topographic search or symptomaticsearch. In this approach, diagnosis proceeds in threesteps:

a) Hypothesis formulation;
b) Determination ofthe effects of the hypothesized fault on the system (faultsimulation); and
c) Comparison of the result to system data (hypothesis testing).

If the predicted symptoms arewholly or partially present in the system, the hypothesismay be retained, and the procedure repeated until nobetter hypothesis can be found. As the fault set would bevery large, the set has to be reduced before faultsimulations can be done.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Compiled or heuristic knowledgeis commonly used to reduce the fault set to give thehypothesis set.Figure 2 shows a schematic of the closed loop approach. In the closed loop approach, a candidate hypothesis is chosen and is tested if the reference matches the system. If the reference does not match the system, then a new reference is chosen for evaluation. In the closed loop approach, the information from the mismatch between the current reference and the system is used in the system of new hypothesis generation.

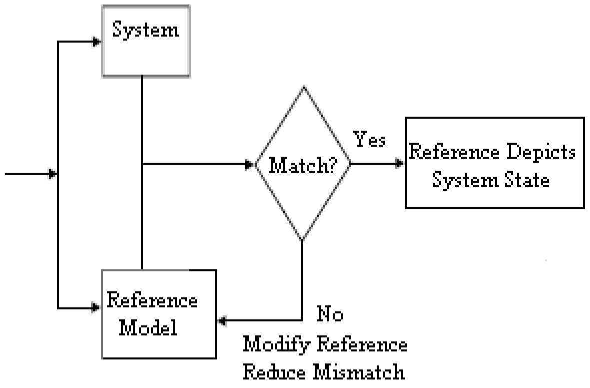

Figure 2: Symptomatic Search Closed Loop Approach

In the open loop approach, many reference models are used with different hypotheses. By comparing reference and the system the closest reference model is identified as the most representative of the process. Figure 3 shows a schematic of the approach.

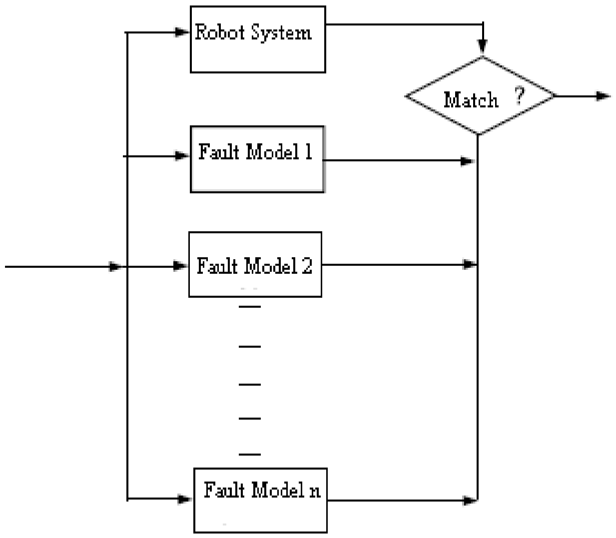

Figure 3: Symptomatic Search Open Loop Approach

IV. CONCLUSIONS

In this second part, of three parts, of review paper,various forms of qualitative models such as causalmodels and abstraction hierarchies were reviewed.Though qualitative models have a number of advantagesas discussed in this paper, the major disadvantageis the generation of spurious solutions. Considerableamount of work has been done in the reduction of thenumber of spurious solutions while reasoning withqualitative models. The search strategies were classified as either topographic or symptomatic search or the differencebetween these two types of search strategies werehighlighted.

REFERENCES

[1] Davis, R. (1984), Diagnosis Reasoning Based on Structure and Behavior, Artificial Intelligence 24 (1-3), 347-410

[2] de Kleer, J., & Brown, S. (1984), A Qualitative Physics Based on Confluences. Artificial Intelligence, 24 (1-3), 7-83.

[3] DevAnand,M., Selvaraj, T., Kumanan, S. &Ajitha, T., (2010) A Neuro Fuzzy Based Fault Detection and Fault Tolerance Methods for Industrial Robotic Manipulators, International Journal of Adaptive and Innovative Systems,1, 3/4, 334 – 371.

[4] Milne, R. (1987), Strategies for Diagnosis, IEEE Transactions on Systems, Man and Cybernetics 17 (3), 333-339.

[5] Rasmussen, J. (1986). Information Processing and Human-Machine Interaction, New York: North Holland.

[6] Rich, S. H., &Venkatasubramanian, V. (1987), Model-Based Reasoning in Diagnostic Expert Systems for Chemical Process Plants, Computers and Chemical Engineering 11 (2), 111-122.

[7] Soylemez, S., &Seider, W. D. (1973), A New Technique for Precedence Ordering Chemical Process Equation Sets. American Institute of Chemical Engineers Journal 19 (5), 934-942

[8] Venkatasubramanian, V., & Rich, S. H. (1988), An Object-Oriented Two-Tier Architecture for Integrating Compiled and Deep-Level Knowledge for Process Diagnosis. Computers and Chemical Engineering 12 (9-10), 903-921.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication