Robot Fault Diagnosis Part - I: A Retrospective Analysis

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ABSTRACT

Robot fault detection and identification captures an important role in robotics engineering. The retro analysis carried out in this paper shows the definitions and nomenclature used in the area of robot fault diagnosis systems, secondly we introduce brief history about robot fault diagnosis systems. The robot fault diagnosis systems were analysed and the motivation behind to select this area for research is addressed. The signal transformation phases of general robot are discussed. The general robot fault diagnostic frame work internal structure and the various source of fault in a robot control system were studied along with the necessary characteristics of robot diagnostics system. A brief classification about robot fault diagnostics algorithms is presented. Finally the paper ends up by presenting a comparative study of various robot fault diagnostic methods and necessary characteristics of robot fault diagnosis.
Keywords: Industrial Robot, Robot Fault Diagnosis, Robot Safety, Transformation, Decision Making.

Definitions and nomenclature used in the area of Robot fault Diagnosis systems:

Fault: A wrong route of any one property or parameter of the system going in an unacceptable way or condition.
Failure: An interruption of a system's ability to perform a required function under specified operating condition.
Malfunction: An off- and- on irregularity in the system's particular function.
Error: A mistake in a measured or computed value of an output variable and the true, specified or theoretically correct value.
Disturbance: An unknown uncontrolled input acing in a system.
Residual: An error signal found between measurements and model-equation based computations.
Symptom: A change in the normal behaviour of an observable quantity.
Fault detection: Finding of fault in a system and the time of detection.
Fault isolation: Verification of the kind, location and time of the location of a fault which follow full detection.
Fault identification: Finding of the size and time variation of a fault found after fault of isolation.
Monitoring: By recording information, recognizing and indicating anomalies in the behavior, the exact condition of the system is monitored.
Supervision: Having monitored a physical system, here appropriate action is taken on cases of fault.
Reliability: It is the ability of a system to do a required job under certain condition, scope, and period of time.
Safety: It is the efficiency of a system to perform well without causing any danger to person or equipment.
Availability: It is to make sure that the system or equipment will function well at any point of time.
Quantitative model: Here we describe a system's behaviour in qualitative terms of the static and dynamic relation.
Qualitative model: Here we describe systems behaviour in qualitative terms such as causalities and if-then rules.
Diagnostic model: it is a set of static or dynamic relation which links systems to faults.
Analytical redundancy: using of more than one method to determine a variable is seen under analytical redundancy.

1. INTRODUCTION

The discipline of Robot Fault Diagnosis (RFD) has made tremendous advances in the last two decades with the advent of computer control of complex robot with new technologies. With the progress in distributed control and model predictive robot systems, the benefits to various applications like aircraft, space, nuclear power plant and hazards environments have been enormous.

However, these robots are managed and controlled manually by human operators from the beginning to the end in real time applications. The expected task is that the robot should function normally based on the managing control by the human operators without any fault.

Robots are often used in inaccessible or hazardous environments in order to alleviate time, cost and risk involved in preparing humans to endure these conditions. In order to perform their expected tasks, the robots are often quite complex, thus increasing their potential for failures. However, if people are frequently sent into these environments to repair every component failure in the robot, the advantages of using the robot are quickly lost. Fault tolerant robots are needed which can effectively detect and adapt to software or hardware failures in order to allow the robots to continue working until repairs can be realistically scheduled (Ola Pettersson, 2005).

Motivation: However, the complete reliance on human operators to cope with such abnormal events and emergencies has become increasingly difficult due to several factors.

Unfortunately, faults in robots have been usual. In a research made by the Japanese Ministry of Labour, 28.7% of the industrial robots studied had a mean-time-between-failure of 100h or less; 60 % had mean-time-between failure less than 500h. Thus, there are good reasons to research RFD systems in robotic manipulators (Vamshi Krishna, 2011).

RFD is the task of responding to abnormal events in a robot. This involves the timely detection of an abnormal event due to malfunctioning in the robot, diagnosing its reason of malfunctioning and then taking appropriate control steps and actions to bring the process back to a normal, safe, operating mode based on RFD technologies.

Signal transformation phase of general RFD: A common autonomous robot control system consists of four distinct steps such as Monitoring, Analysis, Planning and Execution, as shown in Fig. 1. The function of the monitoring step is to monitor and measure the condition of different system components at different environment. In the analysis phase, the monitored data that is collected is compared with the modelled data which gives the deviation result. This called as residuals. The residuals that has occurred is because of sensor failures, motor failures, poor or failed communication links, low battery levels or poor quality of service due to overloaded communication links. The planning phase or the decision making phase makes the decision based on the residual evaluation. The final execution phase gives the appropriate voltage to the actuators to perform autonomously with the help of the RFD algorithm.

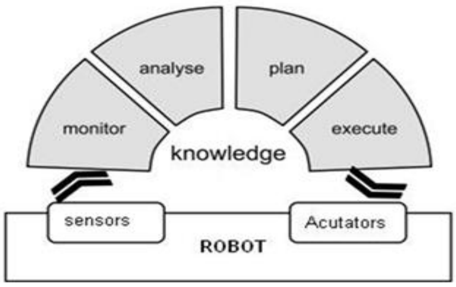

Fig.1. Robot Signal Transformation Phase of RFD

Robot Fault detection is difficult due to the broad area of the diagnostic activity that encompasses a variety of malfunctions because; it consists of a robot unit and a control unit (Microprocessor/ Microcontrollers). The robot unit represents the mechanical part, and the control unit represents the electronic part. The interface between the robot unit and the control unit includes sensors and A/D, D/A converters. The sensors work as follows, in real time all the physical parameters are in analogue in nature; the analogue signal is sampled with regular intervals with the help of Nquiest criteria, and given to the quantization process. It includes rounding and truncating operation, the output of quantized is given to the encoder, the encoder output will be a digital and given to the controller. The sensors failure may occur due to

- Not following the Nquiest criteria (fs>= 2fmax)
- Quantization errors (Rounding error, Truncation error)
- Encoding problems

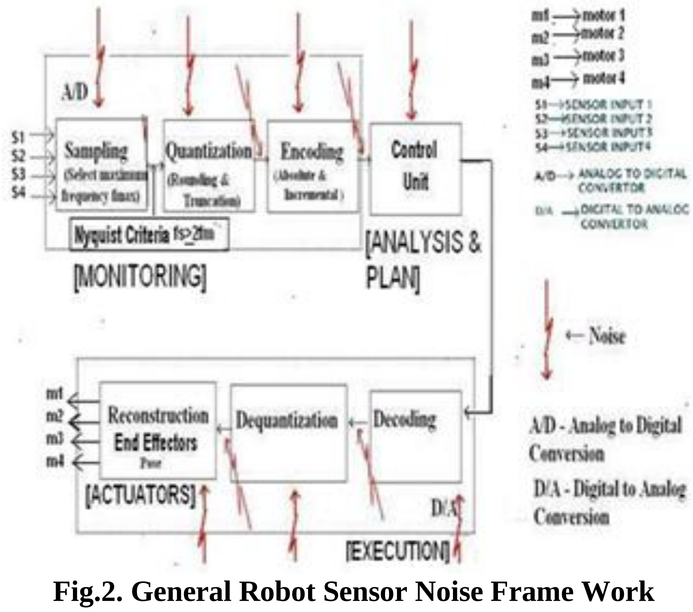

Fig.2. General Robot Sensor Noise Frame Work

The above Fig.2 shows the sensors noise in detail. The sensors sample the current position of the mechanical part and transform it to an analogue signal (voltage or current). The A/D converter converts the signal and sends it to the control unit. The desired trajectory and other control parameters are supplied by the user to the control unit. The control parameters describe the characteristics of the robot unit. The control unit collects data and calculates the needed force. The calculated value is converted to an analogue signal, and that signal drives the motor to move the robot (Themistoklis Bourdenas, 2011). The failures in robot unit degradation of mechanical parts due to ageing effect, parameter drifts and so on. It is further critical by the size and complexity of modern autonomous robot.

In addition, often the emphasis is on quick diagnosis which poses certain constraints and demands on the diagnostic activity. Furthermore, the task of fault diagnosis is made difficult by the fact that the sensor measurements may often be insufficient, incomplete and/or unreliable due to a variety of causes such as sensor bias or failures. Fault can be termed as any abnormal event that occurs in a robotic system when it is under operation.

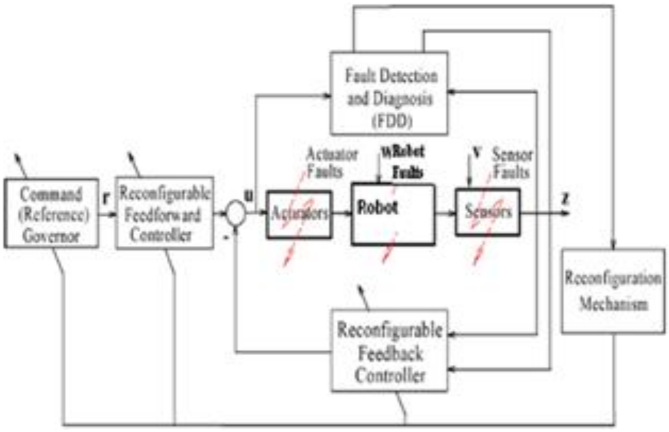

Fig.3. General Robot Fault Diagnostic Frameworks

The Fig. 3 shows a robot system and indicates the different sources of failures in it. In general, one has to deal with sources of failures or malfunctions as described below (Venkat Venkatasubramanian, 2003).

Gross Fault in a Robot Modelling: Gross error mainly occurs due to carelessness or lack of experience during modelling of robot by human being. These cover human mistakes in reading, recordings and calculating results. This fault also occurs due to in correct adjustments of instruments. These errors cannot be treated mathematically. This fault can be eliminated by carefully modelling of parameters or otherwise modelling the robot not based on one individual design but considering more than one design and optimizing them.

Systematic Fault: Systematic fault is mainly due to the shortcoming of the mechanical, electrical and electronic instruments in the robot. These errors depend upon the low quality and characteristics of the material such as defective or worn parts, aging effects. These effects can be avoided by selecting proper material based on the requirement and planning the proper procedure at the time of modelling. To handle such an error in a diagnostic system would require the removal of the corresponding model equations and restructuring the other equations according with the robot parts failed.

Misuse of Robot: A good robot if used in abnormal way gives misleading results, because of the poor initial adjustments and improper settings. Such things do not cause the permanent damage to the robot but definitely cause the serious fault. For example misusing the robot for another task rather than what it is designed to do. Loading effect occurs due to improper use of robot by applying more tasks or heavy weight more than what it is intended to work normally. For example pick and place robot handling weights more than what it is intended for.

Environmental Fault: These faults are due to the conditions of external surrounding to the robot. The various factors results this environmental fault includes temperature changes, pressure changes, magnetic field, electrical field, water, which is external in nature.

Malfunctioning Sensors: The sensors failure dues do a constant bias (positive or negative) or an out-of range failure in visual sensors. Some of the sensors provide feedback signals which are essential for the control of the robot.

Malfunctioning Actuators: Just like the sensor faults, even these can be classified into partial or complete actuators fault (loss of control action). When there is a breakage, burned or cut wires, then in-spite of the input applied to an actuator, no actuation is produced. This can be categorized under complete actuator fault. In case of partially failed actuator only part of the normal actuation is produced. It can be a result of hydraulic or pneumatic leakage, reduced input voltage or increased resistance (Dev Anand, 2010; Zhang and Jiang, 2008).

Necessary characteristics of RFD system: In this section we list some of the desirable characteristics that a diagnostic system should ideally possess to be effective. These are useful to benchmark various methodologies and can also aid in designing better diagnostic methods that meet most requirements. Though these characteristics will not usually be met by any single diagnostic method, they are useful to benchmark various methods in terms of the a priori information that needs to be provided, reliability of solution, generality and efficiency in computation etc. Resolution of a diagnostic classifier would require the fault set to be as minimal as possible. Thus, there is a trade-off between completeness and resolution. The trade-off is in the accuracy of predictions. These two concepts would recur whenever different classifier designs are compared. The following presents a set of desirable characteristics one would like the diagnostic system to possess.

Early Detection: When Robot goes awry, it is very essential that it be put to precise and on time diagnosis. But the dichotomy in the process of detecting is the quick response to failure diagnosis and the tolerable performance during normal operation. Such performance makes the system sensitive to noise. Moreover, it leads to incessant fault indication in due course of operation this can be problematic.

Isolativity: This diagnosis indicates the ability to differentiate between different failures. Higher resolution found in the hypothesis proposed for the failure is to say that detection method generates output which Orthogonal to faults yet to occur. Yet there lies trade-off question between isolativity and rejection of modelling uncertainties. The higher degree isolativity classifier would do rather a poor job in rejecting model uncertainties and vice versa.

Robustness: There occurs robustness to various noise and uncertainties. This means the performance degrades gracefully instead of total shut-off abruptly. Such graceful shut-off prevents deterministic isolativity tests when the thresholds are placed near minimum zero value. At the noise these thresholds may be selected minutely. Thus, the need for robustness to be put in a par with performance.

Novelty Identifiability: While diagnosing the system at the given current robotic condition, one needs to detect whether the robot is normal or abnormal. If not normal, it is due to known malfunction or unknown malfunction or a novel malfunction. Such detection is called novelty identifiability. As such the historical data method for abnormal regions is unavailable. So the need to concentrate on recognizing the occurrence of novel faults and classify them as known malfunction or as normal operation.

Multiple Fault Identifiability: When problem occur the need is to identify the fault in its entirety and complexity due to the interacting property of most faults. The non-linearity robotic process would result in synergistic interaction making it cumbersome to model the combined effects of the faults. Whereas detecting separately for multiple fault combination is computationally not possible for multi-robots.

Explanation Facility: It is a must to identify the source of malfunction. But greater focus must be on providing explanation about the source of fault which resulted in current malfunction. It needs to find out the reason, cause and effect relationship in its function. If a robot can help in this then it is rather easy for the operator to evaluate and find the exact fault by using his\her experience. Hence, we expect a robot not just too let us know why certain have proposed but why certain other theories were not proposed and found out.

Adaptability: On account of retrofitting the task of a robot may change and evolve in external input or structural change. Not just for disturbance the working c condition may change but the change may occur due to changing environmental condition, changes in products quality, quality of raw material etc. According to such and other in information available, the robot should adjust and develop its scope to function well.

Sufficient Storage and Computational Requirement: Computational complexity is in contrast with robot performance. Fast on-line decision requires Algorithms and implementations. There are not so complex but require high stage facility. Hence, a reasonable balance between computer operation and robotic performance is highly desirable.

Minimum Modeling Requirement: A minimum amount of modelling is required for a robot, at least for a fast real time diagnosis.

Classification Error Estimate: Another requirement essential for a robot is that it should be reliable. Consequently, the confidence of the user can increase. For this the robot must give the operator or user prior information about the fault. Only then prevention method can be adopted while the reliability of the robot may increase (Dash, 2000)

Brief classification of robot fault diagnostic systems: Due to the broad scope of the robot fault diagnosis problem and the difficulties in its real time

The below Fig.4 shows about robot Fault detection and diagnostic methods. This chart briefly classifies the fault finding system into a two different methods such as robot Model Based Method and Robot Data Based Method. As for the Model Based Method, it is further sharply divided into two methods: Quantitative Method and Qualitative Method. The Quantitative Method is further classified into State Estimation, Parameter Estimation, Simultaneous State / Parameter Estimation and finally Parity Space. Each of these four sub-methods explains what they are about: The State Estimation comprises of Observer Based and Kalman Filter Based. The Parameter Estimation comprises Least Square / Recursive Least Square and Regression Analysis. The Simultaneous Estimation includes Extended Kalman Filter and Two-Stage Kalman Filter. Whereas the last Parity Space contain State Space based and Input / Output based.

As for the Qualitative Method, it is further divided into Casual Model and Abstraction Hierarchy. While the Casual Models deal with Structural Graphs, Fault Trees and Qualitative Physics, the Abstraction Hierarchy deals with Structural and Functional aspect of the Hierarchy.

The Robot Data Base Method is classified into Quantitative and Qualitative Methods. Qualitative Method is further structured into two; Statistical and Neural Works. The statistical structure explains the Principal Component Analysis / Partial Least Squares and Statistical Classifiers.

The Qualitative Method explains various analysis such as Expert System, Fuzzy Logic, Pattern Recognition, Frequency and Time Frequency Analysis and Qualitative Trend Analysis.

These different approaches show how they are related to each other. Though each perspective is not clearly explained, one can very well understand how they are related with one another all leading to the fundamental Robot fault finding and diagnostic system.

The Fig. 4 Shows brief classification of robot fault detection and diagnosis methods. The basic aim of this four part series of papers is to provide a systematic and comparative study of various diagnostic methods from different perspectives. It has broadly classified fault diagnosis methods into three general categories and reviews them in three parts. They are robot Model Based Methods, Robot Quantitative Model Based Methods, Robot Qualitative Model Based Methods and Robot Data History Based Methods. Solution, various computer- aided approaches have been developed over the years. They cover a wide variety of techniques such as the early attempts using Fault Trees, Digraphs, Analytical Approaches, and Knowledge-Based Systems, Fuzzy systems, Neural Networks and Hybrid Intelligent Tools in more recent studies.

Based on the review these different approaches and attempt to present a perspective showing how these different methods relate to and differ from each other. While discussing these various methods it will also try to point out important assumptions, drawbacks as well as advantages that are not stated explicitly and are difficult to gather. Due to the broad nature of this exercise it is not possible to discuss every method in all its detail. Hence the intent is to provide the reader with the general concepts and lead him or her on to literature that will be a good entry point into this field.

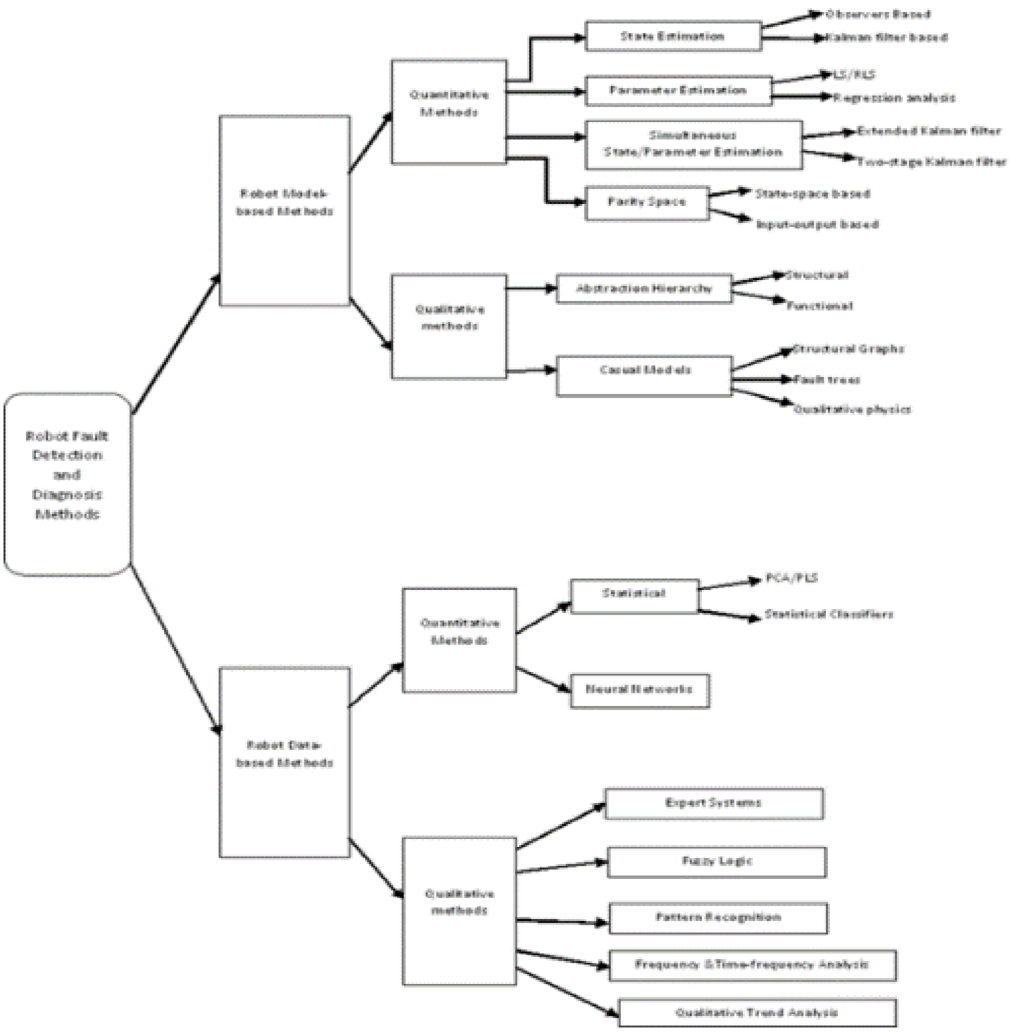

Fig.4. Robot fault detection and diagnosis algorithms

In the first part of the series, we give comparative analysis of different Robot fault diagnostic methods and necessary characteristic of Robot Fault Diagnostic Systems (Dash, 2000) shows the Table 1.

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Table.1. Comparison of various robot fault diagnostic methods based on the desirable characteristics

Table 1.Comparison of various Robot Fault Diagnostic Methods based on the desirable characteristics

ROBOT FAULT DEDUCTION AND DIAGNOSIS METHODS																					
	ROBOT MODEL BASED METHODS													ROBOT DATA BASED METHODS							
	QUANTITATIVE METHODS								QUALITATIVE METHODS					QUANTITATIVE METHODS			QUALITATIVE METHODS				
Method → / Criteria ↓	State Space estimation		Parameter estimation		Simultaneous State Parameter estimation		Parity Space		Causal Models			Abstraction Hierarchy		Statistical		Neural networks	Expert systems	Fuzzy logic	Pattern recognition	Frequency &time frequency analysis	Qualitative trend analysis
	Observer based	Kalman filters based	LS/RLS	Regression Analysis	Extended Kalman filter	Two stage Kalman filter	State space based	Input output based	Structural Graphs	Fault Tree	Qualitative Physics	Structural	Functional	PCA/PLS	Statistical classifiers						
Early Detection	√	√	X	X	√	√	√	√	X	X	X	√	√	√	√	√	√	√	√	√	√
Isolability	√	√	√	√	√	√	√	√	X	X	X	_	_	√	√	√	_	_	_	X	X
Robustness	√	?	?	?	√	√	√	√	X	X	X	_	_	√	√	?	_	_	_	X	X
Novelty Identifiability	√	√	X	X	√	√	√	√	X	X	X	_	_	X	X	?	_	_	_	√	√
Multiple Fault Identifiability	√	√	√	√	√	√	√	√	√	√	√	_	_	?	?	?	_	_	_	√	√
Explanation Facility	X	X	X	X	X	X	X	X	√	√	√	X	X	X	X	X	X	X	X	X	X
Adaptability	X	X	X	X	X	X	X	X	√	√	√	√	√	√	√	√	√	√	√	√	√
Storage Facility	X	√	X	X	√	√	X	X	X	X	X	√	√	√	√	√	√	√	√	√	√
Minimum Modeling	X	X	X	X	X	X	X	X	√	√	√	X	X	√	√	√	X	X	X	√	√
Classification error estimation	√	X	X	X	X	X	√	√	X	X	X	_	_	√	√	X	_	_	_	X	X
Additional Comments	Limited to few classes of robot models						Limited to few classes of robot models		High degree of ambiguity					Requires probability density estimate							

NOTE:(√)favorable; (*)less favorable;(×)not favorable;(+)applicable;(-)not applicable;(?) Situation dependent

2. CONCLUSIONS

In this first part of review, addressed retrospective analysis of robot fault diagnosis is carried out and discussed definitions and nomenclature used in the area of RFD, what are all the motivations behind to select this area for research and also discussed what are all signal transformation phases in general robot systems, what are all the sources of fault in a robot control systems. Also studied along with necessary characteristics of RFD and brief classification about robot fault diagnostics algorithms was presented finally the paper ends up by presenting a comparative study of various RFD methods and necessary characteristics of RFD. Thus according to retrospective analysis of robot fault diagnosis table each algorithms having strength and weakness, so need better fault diagnosis systems like hybrid tools/methods/techniques/algorithms. Further for forthcoming papers will discuss robot quantitative model based methods, robot qualitative model based methods and robot data history based in details.

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