Model oriented system design on big-data

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Abstract

There are risks that any design hypotheses could be supported with big-data, when engineers focus on a particular part of the data intentionally or accidentally, for the reason that big-data include huge and various kinds of data to mislead the reasoning of the hypotheses. The design process of diagnosis system for vacuum pumps in semiconductor factories is picked up as a target of case study. Errors of the hypotheses in the design are clarified by visualizing reasoning process of the design. The visualization of the reasoning process guides the engineer to elaborate the proper design models on the correct hypothesis through cycles of deductive and inductive reasoning with both data and their domain knowledge. The diagnosis system is re-designed and implemented on the established design models and the accuracy of diagnosis of the system is confirmed through the field test. We emphasize that the design method led by the design model on the deep domain knowledge is indispensable for designing system on big-data in the paper.

Keywords: System Design Method; Cyber Physical System; Reasoning; Design Model; Visualization

1. Introduction

It is a basic mission for engineers, especially for the engineers in Cyber Physical Systems (CPS) domain, say advanced electric power grid and extreme-yield agriculture, to realize a useful system on big-data elicited from physical space. According to progress of CPS technologies, elicitation of the field data becomes easier markedly. However, there are growing risks that any design hypotheses could be supported with big-data, when engineers focus on a particular part of the data intentionally or accidentally, for the reason that big-data include huge and various kinds of data to mislead the reasoning of the hypotheses. As it turned out, the system on the invalid hypotheses cannot achieve their expected goals and the system development has failed.

In this paper, the design process of diagnosis system for the vacuum pumps in semiconductor factories is picked up as a target of case study. Errors of the hypotheses in the design are clarified by visualizing reasoning process of the design. The visualization of the reasoning process guides the engineer to elaborate the proper design models.
on the correct hypotheses through cycles of deductive and inductive reasoning with both big-data and their domain knowledge. The diagnosis system is re-designed and implemented on the established design models and the accuracy of diagnosis is confirmed through the field test. We emphasize that the design method led by the design models on the deep domain knowledge is indispensable for designing system on big-data in the paper.

The rest of the paper is organized as follows: In Section 2, a background and an overview of the target system are described. In Section 3, issues of reasoning process in the design are analyzed on the interview for the engineers. In Section 4, an experimental design process through cycles of deductive and inductive reasoning are presented. Section 5 concludes the paper.

2. Overview of target system

In this section, an overview of the target system and the results of the design activities are summarized.

2.1. Background

The semiconductor manufacturing equipment is obliged to work all day and night for improving productivity. Some devices in the equipment need preventive maintenances. A vacuum pump is one of typical devices requiring maintenance because it could be unless by abrasion in parts. The vacuum pump cools the equipment into cryogenic temperature with alternately process, compression and expansion process of refrigerants. Seals against leak of refrigerants and bearings for rotate mechanism are worn down through its continuous operation.

Generally, there are two major maintenance methods for the vacuum pump: periodical maintenance and ad-hoc maintenance. In the periodical maintenance, all the parts are exchanged at regular intervals on the statistical data. In the ad-hoc maintenance, parts are replaced when the device would warn for fault of its cooling performance. An optimization of the maintenance is strongly demanded for cutting down product cost against keen competition among semiconductor industries.

A business, which takes advantage of experiences and preserves statistical data for the pump maintenance, has started to develop a diagnosis system of the pump in response to requirements of a semiconductor factory. In the requirements, an expert engineer in the semiconductor factory insisted that operation sound of the pump might be utilized for diagnosis because the sound of the pump often changes at its terminal stage. Thus, the business decided that they adopted the sound measured by vibration sensors for diagnosis. The process of the development is shown in Fig. 1. They built an algorithm for diagnosis both by making full use of their statistical data and by conducting experiment in their laboratory, and installed the prototype of the diagnosis system (Fig. 1) in the semiconductor factory. They had been brushing up the algorithm on feedback from the field for two years. The system had never satisfied their goals, though the design process was seemed to be proper for the development of fault diagnosis systems.
2.2. Capability of the prototype for diagnosis

The prototype was designed to satisfy the Requests For Development (RFD) defined by the semiconductor factory (Table 1). The accuracy of the diagnosis stayed 60% during the field trial and had never satisfied 80% accuracy which was defined in RFD. Thus, the development have deadlocked though the process of development was quite appropriate.

| Design Constraints                       |
|------------------------------------------|
| Temperature is not stable because of gas injection required for product |
| Pump warns its fault when temperature of the equipment is over the prescribed temperature |
| Noise in the factory is big, it is difficult to use audible range of sound for diagnosis |

3. Analysis for faults in the system design process

We had interviews with system designers and visualized their reasoning process for analyzing faults in the design.

3.1. Visualizing reasoning process in design

Few attempts have so far been made at visualizing reasoning process in requirements engineering and argumentation scheme studies. In this paper, Toulmin’s graphical argument structure is introduced to describe reasoning process in the design (Fig. 2). Each element of Toulmin’s model is described with propositional network instead of natural language to avoid ambiguity. There are three reasoning methods in science or technology: deduction, induction and abduction. The deference among methods are explained as deferences of sequences of reasoning in Toulmin’s structure (Fig.2).

![Fig. 2. Visualization Method for Reasoning Process in Design](image)

3.1.1. Interview with engineers

For clarifying faults in the system design, interviews with engineers were conducted. The results are as followings:

1. Existing of reliable information from the experts in the semiconductor factory:
   The engineers heard that the pump occurs abnormal sound at their terminal stage from the experts in the semiconductor factory. The engineers themselves often heard the abnormal sound in the factory at maintenance and could reproduce the abnormal sound in their laboratory when the pump in errors worked.
2. Conviction from long experiences of maintenance and the preserved statistical data:
The engineers keep records for maintenance and store factors of these errors in their database for long time (Fig. 3), 90% of errors are originated from abrasion of seals and bearing and about 80% of the pumps at the final stage had lost grand seals (Fig. 3).

3. (Invalid) Domain Knowledge:
The engineers have a domain knowledge that errors in machines with rotating mechanism generates abnormal sound in general. Though they could not reproduce faults of the pump (fail of cooling performance) when they built the exhausted grand seal and bearing into the pump for evaluation, they discarded the results and explained the results as influences from complex conditions in the real field without doubting their domain knowledge.

3.1.2. Analyzing faults in reasoning
The reasoning process in the design is visualized on results of the interview (Fig. 4). The reasoning is performed in typical abduction sequences, Claim: Conclude(Pump in Abrasion, Fault in Pump) Warrant: Generate(Fault in Pump, Abnormal sound) Data: Generate(Pump in Abrasion, Abnormal sound).

The results of reasoning by abduction is not certainly valid because the abduction assumes affirming the consequent. However, the engineers have never suspected their hypothesis were invalid. In fact, the engineers considered issues for coming to the deadlock of their design as followings:

1. Lack of the signal synchronization detection technique
2. Lack of the sound diagnosis technology

The hypothesis changed involuntarily to their conviction in their reasoning process. The hypothesis that Generate (Fault in Pump, Abnormal sound) becomes their conviction by the testimony of the expert in semiconductor factory and their domain knowledge. The experiences and the database reinforced the conviction and prevented them from
reflecting truth of their hypotheses. These fallibilities are known as anchoring and clustering illusion\(^7\) in cognitive science.

4. **Trial for model oriented system design on big-data**

We have tried to improve the system with valid design models elaborated from cycles of deductive and inductive processes on big-data.

4.1. **Redefine issues and design process**

Peirce argued that the scientific reasoning should be performed as the followings processes\(^5\):

**Process 1** Clarify claim to solve

**Process 2** Elaborate hypotheses to prove the above claim (abduction)

**Process 3** Brush up warrant so as to improve validity on data elicited from experiments (induction)

Repetitions of process-2 with deductive thinking on deep domain knowledge and process-3 to prove validity with inductive thinking on data are important in the design process. In other words, only these repetitions are expected to lead the engineer to avoid these fallibilities. The reasoning process of the design are reconfigured on the above mentioned processes.

4.2. **Building error model and error progress model**

We tried to build the design models for error and error progress in time with deductive and inductive thinking on big-data.

4.2.1. **Error model**

From the RFD shown in Table 1, the fault in the pump is defined as deterioration of cooling performance in a narrow sense. The claim are re-defined as the system ought to diagnose and predict the deterioration of cooling performance. To build the warrant for validating: Data "Generate(Pump in Abrasion, Abnormal Sound)" Claim "Conclude(Pump in Abrasion, Deterioration of Cooling Performance)". we should confirm the following hypothesis:

- Some parts's abrasions give changes for its operation sound
- Some parts's abrasions affect cooling performance of the pump

The following experiments were conducted for confirming the above hypotheses:

1. Extract parts which may be worn based on the physical structure with engineer’s domain knowledge (deduction)
2. Build experimental pump where each abrasion part are build in and measure operation sounds and cooling performance for each experimental pump in the laboratory (induction)
3. Analyze characteristics of abnormal sounds for each abrasion parts (induction)

At first, the relations of sounds with abrasion parts are identified deductively. From the structure of the pump (Fig. 5), we can find out 2 significant parts (inlet and cylinder seals) to affect the cooling performance of the pump besides the grand seal (Fig. 3). Then, we built the experimental pumps in which each abrasion part were embedded, and measured operation sounds and cooling performance for each sample. The claim "Conclude(Pump in Abrasion, Deterioration of Cooling performance)" is confirmed with the experimental data inductively, because abrasions of parts affect deterioration of cooling performance (Fig. 5).

The relations between abrasion parts and their operation sounds are shown in Fig. 6. As each experimental pump generates unique sounds, both hypotheses: "Correlate(Abnormal Sound, Pump in Abrasion) and ""Indicate(Abnormal Sound, Deterioration of Cooling Performance) on the experimental data inductively.
As a result of these, the warrant that ”Affect(Abnormal Sound, Cooling performance)” is confirmed deductively (Fig. 7). The hypotheses defined in the previous design is partly valid. However, the hypotheses that the abnormal sound and the deterioration of cooling performance are due to the abrasion of grand seal is invalid. The operation sound and cooling performance are affected from abrasions of three kinds of parts (grand seal, inlet seal and cylinder seal) concurrently. The defectiveness of the design model explains why the previous systems did not satisfy its goal even if repeating field tests and brushing up algorithm.
4.2.2. Error progress model

For predicting faults in the pump, the error progress model that how abrasions does progress in terms of time is required. Long term and huge sound data are necessary to identify the error progress model inductively. The field data collection tool was developed to collect long-term and huge sound data from semiconductor factories. We has started to collect sound data for 100 pumps installed in a semiconductor factory for 1.5 years with the field data collection tool.

By using the huge field data, the hypothesis “Correlate(Operation Time, Abnormal Sound)” is inspected. The relation between operation time and abnormal sound level is shown in Fig. 8. As the abnormal sound increases in its operation time (coefficient of determination:0.57), the hypothesis ”Correlate(Operation Time, Abnormal Sound)” is confirmed inductively on the big-data. There are two clusters in Fig.8. Cluster-A has characteristics of sound when the grand seal is in abrasion and Cluster-B has characteristics when the cylinder seal is in abrasion. In the interphase of each cluster, the characteristics of sound when the inlet seal is in abrasion are included. These characteristics are mingled with at the terminal stage of the pump.

![Fig. 8. Relation between Operation Time and Level of Abnormal Sound](image)

The process of deductive and inductive thinking on deep domain knowledge and big-data described in 4.2.1 and 4.2.2 are succeeded in establishing the valid design models (Fig. 9).

![Fig. 9. Error Model and Error Progress Model for Abrasion in Pump](image)

5. Evaluation of the system

Based on the established design models, the prototype of the diagnosis system was re-designed and implemented (Fig. 10).
We have been started the field test of the prototype. The capability for diagnosis has not been confirmed enough because of short of field test period. The prototype achieves that the precision is 0.85 and the recall is 0.88 tentatively and is succeeded in predicting all the pumps in fault in coming six months, which are enough to satisfy the goal defined in Table 1.

6. Conclusions

There are growing risks that any hypotheses could be supported with the big-data, when the engineers focus on a particular part of the data intentionally or accidentally, for the reason that big-data include huge and various kinds of data to mislead the reasoning of the hypotheses. The diagnosis system for the vacuum pump was picked up in the paper as an example. The system designed on the proper process, however the hypothesis changed into conviction with the data preserved in their database and their rich experiences for the maintenance. As the results, the reasoning are misled by the hypothesis and the system could not satisfy the goal. We have constructed the error and error progress models through cycles of deductive and inductive thinking on domain knowledge and re-designed the prototype of the diagnosis system based on the models. Thus, we have confirmed that the prototype has high capability of diagnosis. We intend to emphasize that the design method led by the design model on the deep knowledge and data, which are established through deductive and inductive reasoning processes supported by visualization of the reasoning, is useful for the design of the system with big-data.

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