A FAULT DIAGNOSIS TOOL FOR HVAC SYSTEMS USING QUALITATIVE REASONING ALGORITHM

Junichi Shiozaki and Fusachika Miyasaka
Yamatake Corporation
1-12-2 Kawana, Fujisawa-shi, Kanagawa, 251-8522 Japan

ABSTRACT

A real-time fault diagnosis tool for HVAC systems has been developed. In the tool, we used the signed directed graph as a qualitative model of the system. By use of the signed directed graph, we could minimize engineering efforts for customizing a diagnosis system for a specific HVAC system. The signed directed graph model is so compact model, compared with the usual IF-THEN rule model, that the required man-hours are very small. A real-time fault diagnosis system for a specific HVAC system can be built very easily. It detects the symptoms of the fault and finds the cause candidates of the fault using the qualitative reasoning algorithm. It shows the symptom and the cause candidates to the users. The diagnostic results are saved into the database. Users can make the qualitative models of the HVAC systems graphically using the engineering tool.

INTRODUCTION

If you want to make an expert system to diagnose many types of failures, which occur in the HVAC system, considerable effort is needed to develop diagnostic rules in a tree structure format. You must derive large number of rules from complex cause-effect relationships of the HVAC system. This case is well suited to the use of the signed directed graph diagnostic algorithm [1,2,3]. It finds the cause of a failure by automatically searching tree structure subgraphs in the signed directed graph, which is a qualitative model of the HVAC system. Therefore you need not develop a large rule-base. Only you need to make a qualitative graph model, which can be made combining small graphs of each facility.

QUALITATIVE MODEL

We used an SDG (Signed Directed Graph) to represent the model of the system. SDG = (G, f) is the composite concept consisting of the directed graph G and a set f of signs of branches. The node of the SDG represents the state variable. The branch represents the direct influence between state variables, and its branch is assigned sign "+" if it represents positive influence (reinforcement) and sign "-" if it represents negative influence (suppression).

The value of the state variable being normal, higher than the normal value, or lower than the normal value is represented as "0", "+" or "-" respectively. The combination of the signs assigned to the nodes of the SDG is defined as a "pattern" and represents the state of the system.

In the tank system (Fig.1 (a)) F0, F1, and F2 represent the flow rate, and L1, L2 represent the liquid levels in the tanks. The SDG of this system is shown in Fig. 1(b). The arrow with the solid line represents the branch with "+" whereas the arrow with the broken line indicates the branch with "-". The branch with "+" from node F0 to node L1 indicates that when F0 is increased (decreased), L1 is also increased (decreased). The branch with "-" from node F1 to node L1 indicates that when F1 is increased (decreased), L1 is decreased (increased). For instance, if blockage occurs in the pipeline between Tank1 and Tank 2, it may generate the pattern that is shown in Fig.2.

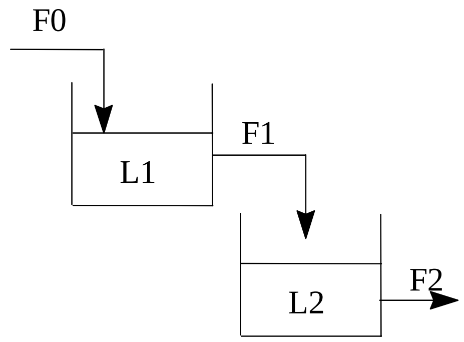

Fig. 1 Tank system

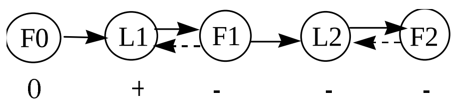

Fig. 2 Signed directed graph and pattern

QUALITATIVE REASONING

When an SDG and a pattern on it are given, a branch b is said to be consistent if its sign coincides with the product of signs of initial and terminal nodes, and a node whose sign is not "0" is called a valid node. The partial graph G consisting of all the valid nodes and all the consistent branches is called a CE-graph.
If a CE-graph is given, it is not difficult to find the cause of the failure. Iri [1] told, "There exists the cause of the failure in the most upstream nodes of the CE-graph." An example of CE-graph is shown in Fig.3. The most upstream node of the CE-graph is F1.

In the above explanation of CE-graph, we assumed all signs of nodes are given. However, there are few cases where all nodes with their signs. Usually, some nodes are measured by sensors, but the others are not measured. Iri [1] proposed an effective algorithm to find all candidate causes. The algorithm uses an assumption; "There is only one cause (origin) of the failure." This assumption is used in many fault diagnosis systems, because the probability that two (or more) causes occur simultaneously is very small.

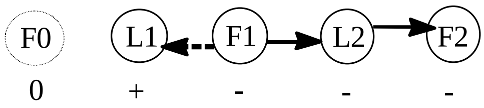

Fig. 3 CE-graph

SYMPTOM GENERATION

The sign of the measured node is determined by comparing the value of the state variable with corresponding thresholds. There are two types of thresholds.

Iri [1] used 3-range thresholds to generate the signs of observed nodes. A sign of a node corresponding to state variable x is determined to be "+" if x > a1, "0" if a2< x =< a1, and "-" if x < a1.

It is not easy to determine 3-range thresholds that distinguish the abnormal values from the normal values. Ill-suited thresholds make improper patterns, which bring about erroneous diagnoses. In order to overcome the problem, Shiozaki et al. [2] have proposed the concept of the 5-range pattern. They introduce four thresholds a1, a2, b1, b2, as shown in Fig.3. A sign of a node corresponding to state variable x is determined to be "+" if b1 < x, "+?" if a1< x =< b1, "0" if a2 <= x <= a1, "-?" if b2 <= x < a2, and "-" if x < b2.

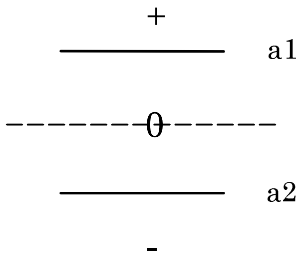

Fig.4 3-Range Thresholds

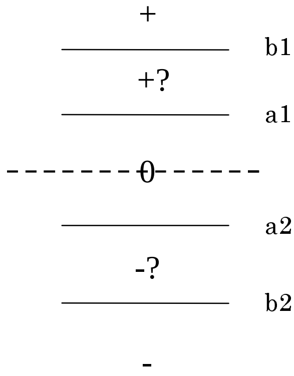

Fig.5 5-Range Thresholds

Signs thus determined are called 5-range signs, and a combination of them is called a five-range pattern. The sign "+?" means "+" or "0" and the sign "-?" means "-" or "0". Shiozaki at al. [2] have given an efficient algorithm to find all candidate causes.

DIAGNOSIS TOOL

We made a diagnosis tool using the qualitative reasoning algorithm. It consists of following five subsystems.
1) Data Gathering Subsystem
2) Symptom Generating Subsystem
3) Reasoning Subsystem
4) Man-Machine Interface Subsystem.
5) Engineering Subsystem.

We show you the two windows of the tool. The first one is the diagnostic result window shown in Fig. 6. The second one is the engineering window shown in Fig. 7.

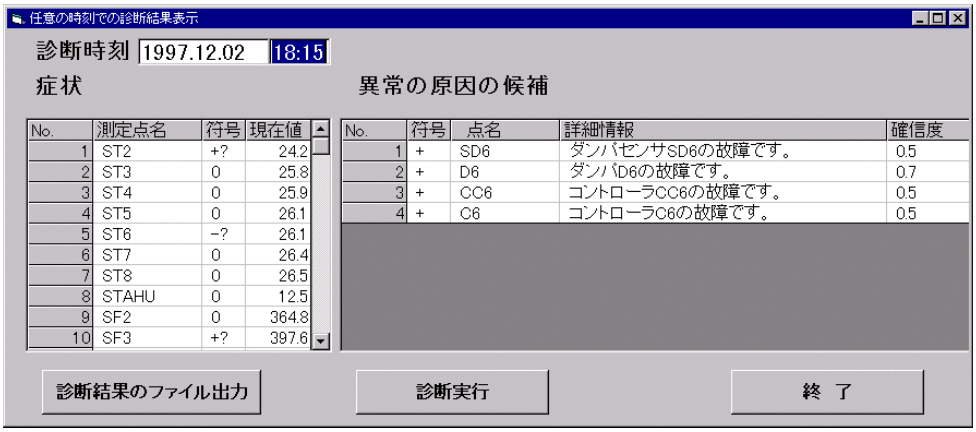

Fig.6 Diagnostic Results Window

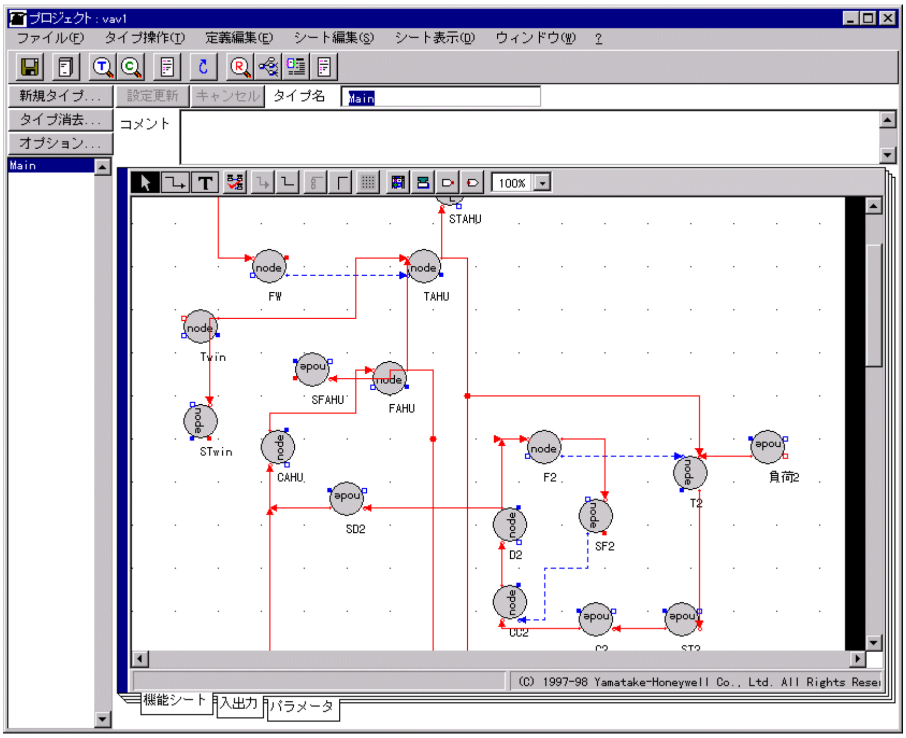

Fig.7 Engineering Window

EXPERIMENT

The T-Building VAV air conditioning system is shown schematically in Fig.8. The system has eight VAV units. Fig.9 shows the signed directed graph of the VAV air conditioning system. It has 83 nodes and 129 branches. The number of the preliminary registered causes is 132.

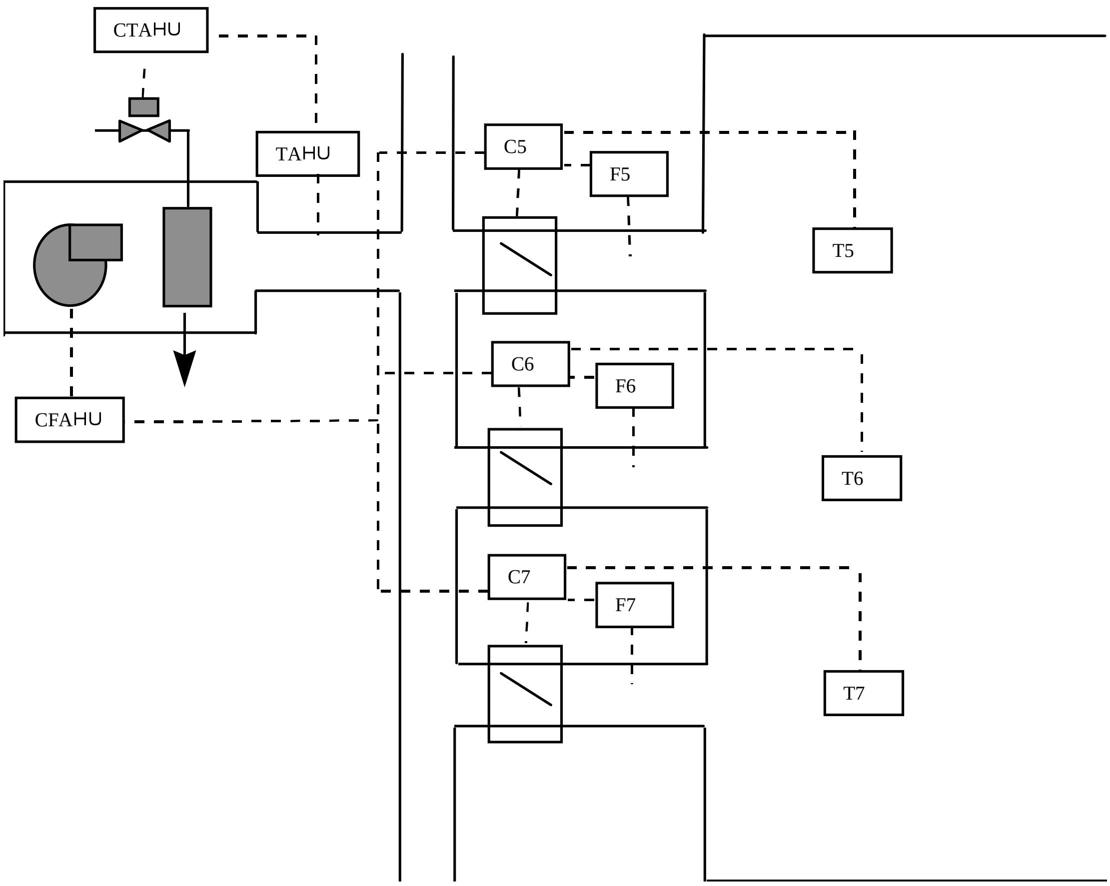

Fig. 8 T-Building VAV Air Conditioning System

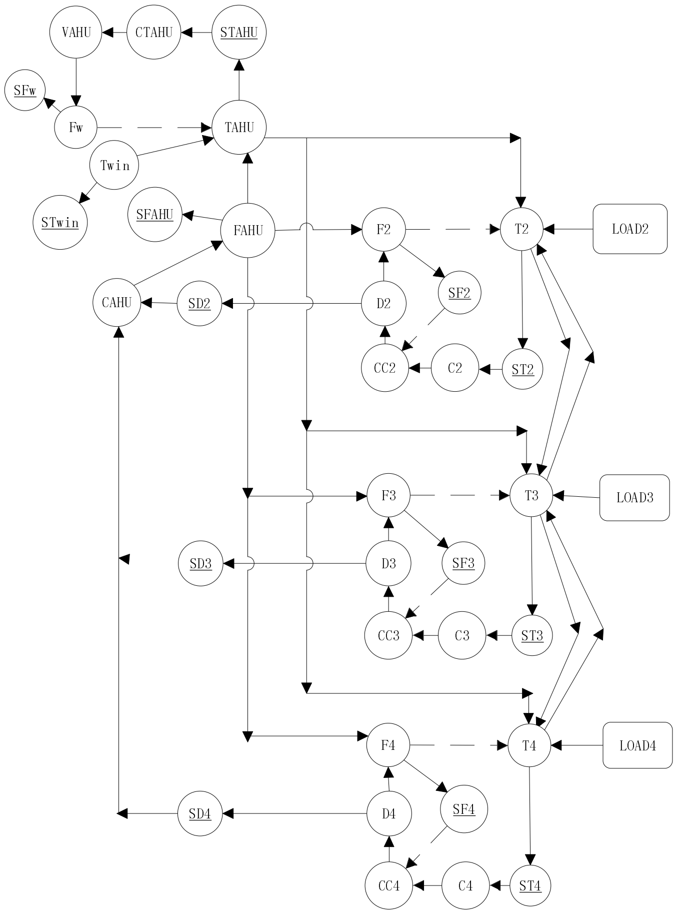

Fig.9 SDG of T-Building VAV Air Conditioning System

Table1 Nodes of the Signed Directed Graph

Fi	Air flow rate of VAV unit
SFi	Air flow rate sensor value of VAV unit
Ti	Temperature
STi	Temperature sensor value
Ci	Output of temperature controller
CCi	Output of flow rate controller
Di	Damper open rate
SDi	Damper open rate sensor value
FAHU	AHU air flow rate
SFAHU	AHU air flow rate sensor value
CAHU	AHU air flow rate controller output value
TAHU	AHU air temperature
STAHU	AHU air temperature sensor value
CTAHU	AHU air temperature controller output
VAHU	Valve open rate
FW	Water flow rate
SFW	Water flow rate sensor value
STWIN	Water temperature sensor value
TWIN	Water temperature

THRESHOLDS SETTING

Thresholds distinguish failure states from normal states. Thresholds' setting is very important. If thresholds are not set properly, the diagnosis system would make wrong diagnosis. For many diagnosis systems, threshold setting is difficult and time-consuming work. If thresholds are automatically adjusted, it is very convenient.

In the experiments, we adjusted 5-range thresholds from the average value μ and the standard deviation. The average value μ and the standard deviation σ are calculated from normal state data.

FAULTS GENERATION

We generated following four faults artificially in T-building.

Case1. VAV-6 damper is full opened manually.

Case2. VAV-6 damper is closed manually.

Case3. The air flow rate of the AHU fan decreased manually.

Case4. The water flow rate of the AHU coil decreased manually.

The experimental data are gathered from the network to a PC's hard disk and are used to diagnose these system faults.

DIAGNOSTIC RESULTS

(Showing Cause Candidates)

Case 1. + FAHU, + CAHU, ＋SD6, + D6 (true cause) , + CC6, + C6

Case 2. - D6 (true cause), - CC6, - C6

Case 3. - FAHU (true cause), - CAHU

Case 4. - FW (true cause), - VAHU, - CAHU

The number of cause candidates was from 3 to 6. The number of preliminaly registered causes is 132, therefore the output cause candidtates are from 2.3% to 4.5% of all registered candidates. The cause candidates included the true cause in all cases. Computing time of each diagnosis was less than one second.

CONCLUSIONS

We developed a fault diagnosis tool, which uses signed directed graphs to represent the causality model in the HVAC system. The signed directed graph model is so compact compared with IF-THEN rule model that the engineering effort can be minimized. Using the tool, a real-time fault diagnosis systems can be made very easily.

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