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FUZZY METHOD FOR FINDING THE FAULT PROPAGATION WAY IN INDUSTRIAL SYSTEMS

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ABSTRACT. The paper presents an effective method for finding the propagation structure of the real origin of a system malfunction. It uses a combined system model consisting of Structural Model (SM) in the form of Fuzzy Directed Graph and Behavior Model (BM) as a set of Fuzzy Relational Equations A o R = B. Here a specially proposed fuzzy inference technique is checked and investigated. Finally a test example for fault diagnosis of an industrial system is given and analyzed.

INTRODUCTION.

The complexity of industrial systems is mainly caused by the large number of interrelated process parameters. Therefore it is difficult even for an experienced operator to understand the real propagation way of the origin of the system malfunction. When a kind of fault occurs, it usually propagates throughout the system, thus "firing" a number of alarms for the measuring instruments (sensors). The root of this propagation structure shows the real cause (the origin) of the system malfunction.

In this paper the use of fuzzy relational models for representing the relationships between pairs of sensors is proposed. These are further used as a kind of standard patterns representing the different faulty states of the system. When a real system malfunction is observed the fault propagation structure consists of those branches in the total system structure having minimal fuzzy inference error.

PROBLEM FORMULATION.

Further we assume that the system status can be observed by a set of N measuring instruments (sensors) : $S = \{S_1, S_2, \ldots, S_N\}$. When a system abnormality occurs, a collection of L groups of measurements from the type $\{s_1, s_2, \ldots, s_N\}$ can be obtained through a fixed sampling interval dt The collected data should be further used in order to answer the following questions:

1. What is the structure of the real fault propagation throughout the system , i.e. which are the real relationships between the sensors $S_1, S_2, \ldots, S_N$?

2. Which sensor S_0 is the root of this structure ? It is the nearest sensor to the real acting fault (origin) of the system or coincides with it.

PREVIOUS SOLVING METHODS.

The answer of the above stated questions requires a kind of knowledge for the system behavior under different acting faults as well as a respective reasoning method for evaluation of the different system states.

In the crisp qualitative method [1] when the measured data are represented only by signs "+", "-" (alarm cases) or "0" (normal case), the knowledge base for the system is constructed in the form of Signed Directed graph (SDG). Then the real measured data (symptom pattern) are used to simplify the SDG (a kind of reasoning procedure) in order to show the fault propagation structure. However the diagnosis by this method becomes inexact or even faulty when the thresholds of alarms states are set improperly or in a subjective way.

For dealing with quantitative measurements in the fault diagnosis problems recently the application of different fuzzy modeling methods has been reported [3,4]. In [3] fuzzy rule based models have been used to save the so called trajectory between a pair of sensors. These models serve further as a key links for comparing the system behavior during the diagnostic procedure. The problem here is how to select the set of the most "re-presentative" links for a given system.

In [4] the knowledge of the system behavior under different acting faults have been saved in a graph structure (Structural Model) representing the immediate influence between the symptoms. Then the numerical data obtained in different system faults are used in order to create the so called Numerical Model in the form of fuzzy relation matrices for all branches of the graph and for all faults. The problem of real applicability here is the big computer memory needed to save all this information for a large scale system.

THE OUTLINE OF THE PROPOSED METHOD.

The new proposed method for finding the fault propagation structure combines the features of the methods in [3] and [4]. Here the total model of the system behavior also consists of 2 parts as follows: 1) **Structural Model** in the form of Fuzzy Directed Graph (FDG) and 2) **Behavior Model** in the form of set of Fuzzy Relational Models (FRM).

The structural model FDG is a directed graph including all **N** sensors (measured system parameters) $S_1, S_2, \ldots, S_N$. The branch (S_i, S_j) shows the early influence of S_i over S_j and means: "S_i has caused S_j". FDG is a kind of knowledge base for the system behavior and is created by an experienced operator, taking into account all possible direct links between the sensors.

The Behavior Model FRM is designed to "remember" the real patterns of the behavior between all pairs of symptoms $S_i \dashrightarrow S_j$ according to the structure of

FDG. Actually it utilizes the selection of data obtained for all faulty states when there was a real cause-effect relation $S_i \dashrightarrow S_j$. The step of creating the fuzzy relational model (FRM) for the pair (S_i, S_j) is a kind of training procedure for remembering the real relationships between S_i and S_j in all observed faulty cases.

Now if a kind of system fault occurs, it is reasonable to assume that all the branches in FDG which are trained for this kind of fault would have minimal fuzzy inference error in evaluating the real experimental data, comparing with other (not trained) branches. Then the set of all trained branches for this fault (called consistent branches) shows the fault propagation structure of the system with its root being the origin.

FUZZY RELATIONAL MODELS.

Here we propose a simplified fuzzy relational models for representing the one-dimensional relationship Y = **f**(X) between a pair of sensors (X,Y). In [2] and [4] a separate clustering of data for X and Y is made and then the elements of relation matrix R are created according to the **min** operation of their fuzzified values. Here we use the well known **Fuzzy C-means** technique for 2-dimensional fuzzy clustering and then each prototype's coordinates $V_{oi} = (X_{oi}, Y_{oi})$, i = 1,2,...,C fix just one **unit** element of R (the others are **zero**). The fuzzy reasoning is equal to solving the equation B = A o R [2], where A and B are the fuzzified values for X and Y. The defuzzification procedure uses weighted average method: $y = f_{yp} \cdot y_p + f_{yq} \cdot y_q$. Fig. 1. gives graphical representation of the above explained model construction.

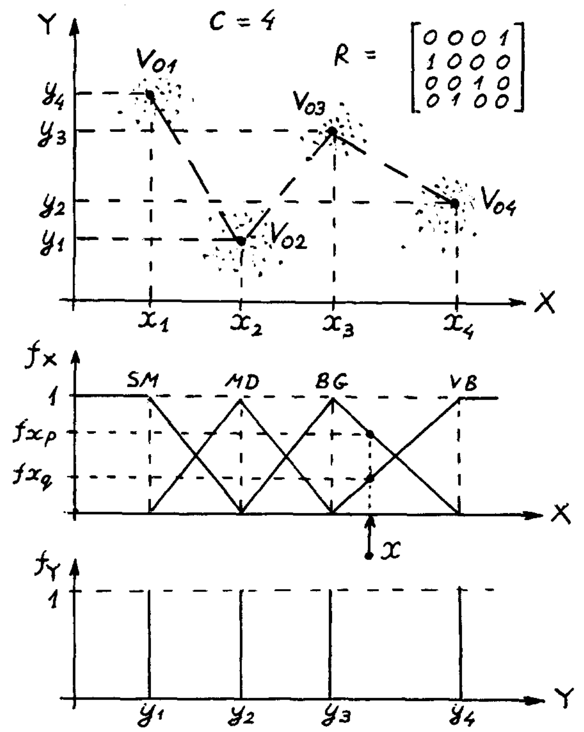

Fig. 1. Fuzzy Relational Model

EXPERIMENTAL RESULTS.

The above described method is illustrated on the test Heat-Exchanger System shown in Fig. 1. After computer simulation of different fault cases, relational models for each branch of the Fuzzy Directed Graph in Fig. 2. have been created. Then Fig. 3. shows the fault propagation structure when the fault "Abnormal Flowrate F_{13}" occurs.

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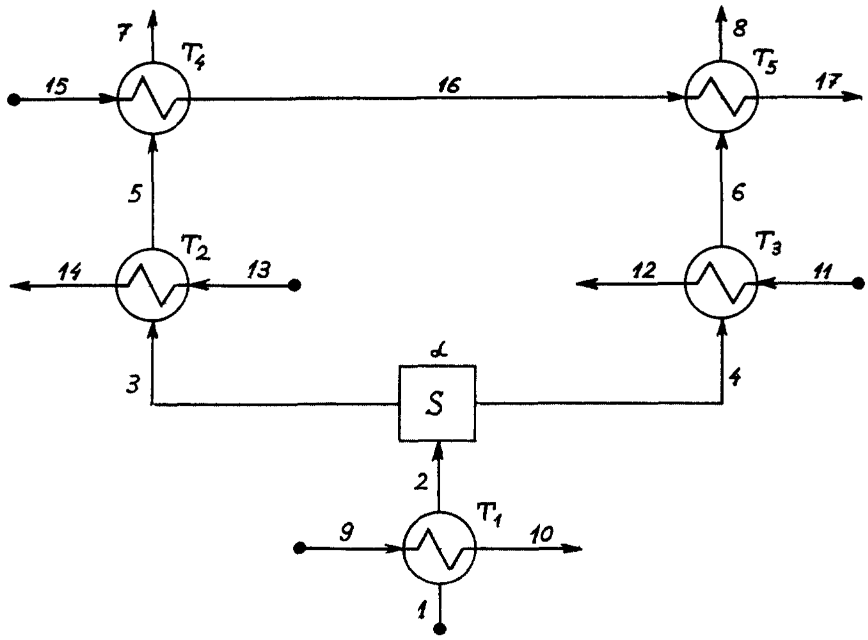

Fig. 2.

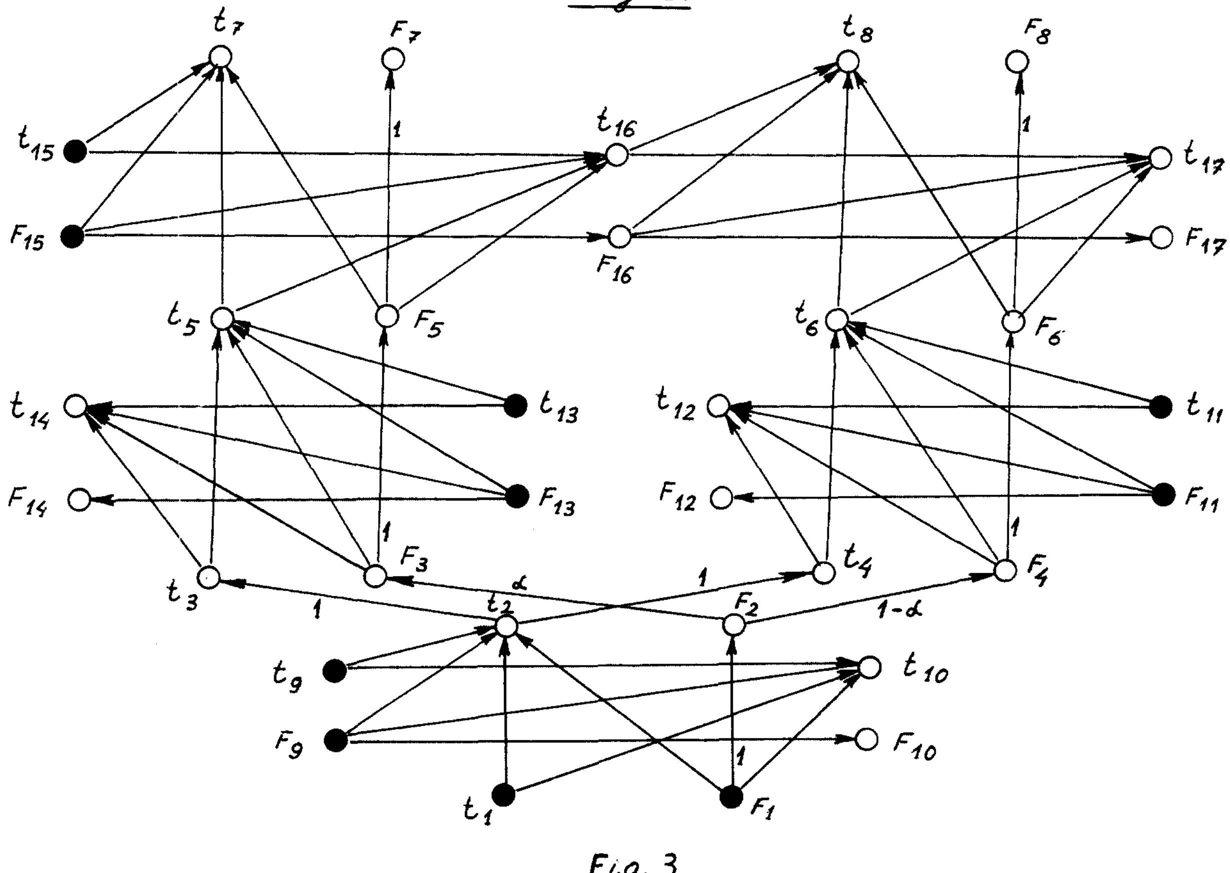

Fig. 3

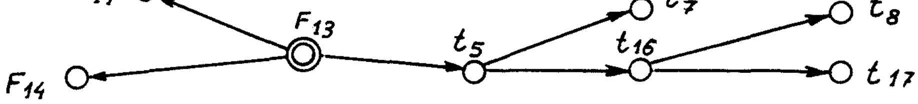

Fig. 4