# 52. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCCEDINGS | 10 - 13 September 2007

## FACULTY OF COMPUTER SCIENCE AND AUTOMATION

## COMPUTER SCIENCE MEETS AUTOMATION

## VOLUME I

Session 1 - Systems Engineering and Intelligent Systems

Session 2 - Advances in Control Theory and Control Engineering

Session 3 - Optimisation and Management of Complex Systems and Networked Systems

Session 4 - Intelligent Vehicles and Mobile Systems

Session 5 - Robotics and Motion Systems

TECHNISCHE UNIVERSITÄT ILMENAU

**Bibliografische Information der Deutschen Bibliothek**
Die Deutsche Bibliothek verzeichnet diese Publikation in der deutschen Nationalbiografie; detaillierte bibliografische Daten sind im Internet über **http://dnb.ddb.de** abrufbar.

**ISBN 978-3-939473-17-6**

## Impressum

| | |
|---|---|
| Herausgeber: | Der Rektor der Technischen Universität Ilmenau<br>Univ.-Prof. Dr. rer. nat. habil. Peter Scharff |
| Redaktion: | Referat Marketing und Studentische Angelegenheiten<br>Kongressorganisation<br>Andrea Schneider<br>Tel.: +49 3677 69-2520<br>Fax: +49 3677 69-1743<br>e-mail: kongressorganisation@tu-ilmenau.de |
| Redaktionsschluss: | Juli 2007 |
| Verlag: | Technische Universität Ilmenau/Universitätsbibliothek<br>Universitätsverlag Ilmenau<br>Postfach 10 05 65<br>98684 Ilmenau<br>www.tu-ilmenau.de/universitaetsverlag |
| Herstellung und Auslieferung: | Verlagshaus Monsenstein und Vannerdat OHG<br>Am Hawerkamp 31<br>48155 Münster<br>www.mv-verlag.de |
| Layout Cover: | www.cey-x.de |
| Bezugsmöglichkeiten: | Universitätsbibliothek der TU Ilmenau<br>Tel.: +49 3677 69-4615<br>Fax: +49 3677 69-4602 |

## Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

Table of Contents

# C O N T E N T S

Page

## 1 Systems Engineering and Intelligent Systems

## Paper submitted after copy deadline

## 2 Advances in Control Theory and Control Engineering

O. Sokolov / M. Wagenknecht / U. Gocht

# Multiagent Intelligent Diagnostics of Arising Faults

### Decision Support Systems

This paper is devoted to fault diagnosis problems using decision making mechanism based on multiagent approach. We investigate dynamic systems which can be diagnosed by symptom-fault rule bases. The main question to be answered is what faults produce observable symptoms in the first moments of their appearance. To solve this task we propose to use a set of agents for making hypothesis about symptoms and coming to an agreement.

## 1 Symptom-fault model

We use $F = \{f_l\}_{l=1}^{N_F}$ and $S = \{s_m\}_{m=1}^{N_S}$ to denote the finite sets of all possible faults and symptoms, respectively. There is also multi valued mapping

$$\psi : S \to F \tag{1}$$

that can be presented as a ***binary diagnostic matrix*** like in Table 1. This matrix reflects the influence of relations between elements of sets $S$ and $F$ as numbers from $I = \{0,1\}$.

Table 1: Example of binary diagnostic matrix

| $S/F$ | $f_1$ | ... | $f_{N_F}$ |
|---|---|---|---|
| $s_1$ | 1 | ... | 0 |
| ... | 0 | ... | 1 |
| $s_{N_S}$ | 1 | ... | 1 |

Let a set of agents are responsible for observing of symptoms and making hypothesis about possible faults [2].
The main mission of agents in diagnostic task is to perceive the symptoms on first stages of their arising and recognize caused faults.
Let the set of agents given by $A = \{a_i\}_{i=1}^{N_A}$, $N_A \le N_F$ and let exists a map

$$\xi : A \to F \ . \tag{2}$$

Let each agent is responsible for seve-ral faults but one fault can be recognized by only one agent. The way in which the set $F$ is divided by agents from $A$ is a state of art of the subject diagnostic area. The natural manner is to divide faults according to subsystems of diagnos-tic objects [5].

## 2 Multi-agent diagnosis model

Let $S_O \subseteq S$ be a subset of symptoms observed by some management application. It reduces to the generation of an appropriate logical expression from (1) in Conjunctive Normal Form, i.e.
from $\psi|_{S_O} : S \to F$ we can get

$$\sigma = \mathop{\vee}_{i=1}^{D(S_O)} \left( \mathop{\wedge}_{j \in C_i(S_O)} f_j \right) \tag{3}$$

where $D(S_O)$ is a number of disjunctions in the formula, $C_i(S_O)$ is a set of indexes in the $i^{th}$ conjunction expression.
Formula (3) gives the *minimum number of disjunctions* of faults that cause the set of observed symptoms. It is a necessary condition for getting $S_O$ from diagnostic matrix.
Let $C = \{a_{1_C}, \ldots, a_{N_C}\}$ be a set of agents responsible for σ. For each agent $a_{j_C}$ there is a set of appropriate faults $Af_{j_C} = \{f_{1_{j_C}}, \ldots, f_{N_{j_C}}\} \subset F$.
We propose the following heuristic recurrent procedure for choosing the set of testing faults from each element of $F_C = \{Af_{1_C}, \ldots Af_{N_C}\}$.
Let $\sigma_0 = \mathop{\vee}_{i=1}^{D_0} \left( \mathop{\wedge}_{j \in C_i^0} f_j \right)$ be an initial formula (3) where $D_0 = D(S_O)$ is the number of disjunctions in the formula; $C_i^0 = C_i(S_O)$ is the set of indexes in the $i^{th}$ conjunction expression. Let $F_0 = \{F_{1_C}^0, \ldots F_{N_C}^0\} = F_C$ be the set of possible faults that caused the observed symptoms distributed on agents from $C$. Further we propose the procedure that performs by each agent $Ag$ from $C = \{a_{1_C}, \ldots, a_{N_C}\}$ at the $k^{th}$ step simultaneous-ly. We call this an $\alpha$ **-procedure**.

1. Refresh
$$\sigma_k = \mathop{\vee}_{i=1}^{D_k} \left( \mathop{\wedge}_{j \in C_i^k} f_j \right)$$
according to the result of faults checking at the previous step and abbreviate by cancellation excessive variables and false conjunctions (executed one time at each step).
2. ***If*** $F_{Ag}^k \neq \varnothing$ ***then*** choose one fault $f_{Ag}$ from $F_{Ag}^k$ that belongs to the conjunction in (3) with minimal length $\min card(C_i^k)$. If there are several conjunctions with the same length we apply a random choice. Set $F_{Ag}^{k+1} = F_{Ag}^k \setminus f_{Ag}$ ***else*** *stop* testing process for the current agent.
3. Check $f_{Ag}$ and set $f_{Ag} = \{true, false\}$.
4. Set global state $k = k + 1$.

The proposed algorithm is converging due to the reliable set of symptoms, the truthful binary dia-gnosis matrix and the step-by-step reducing of the set of possible faults.
It is possible to improve the procedure and do not consider all agents simultaneously but one after another. In cooperation logic such model is called $\beta$-coalition contrary to the $\alpha$-coalition for the case described above [5]. The $\beta$-coalition foresees the conditional coalition when the current decision strongly depends on the previous one.
The $\beta$ **-procedure** is as follows.

1. Determine
$$\sigma_k = \mathop{\vee}_{i=1}^{D_k} \left( \mathop{\wedge}_{j \in C_i^k} f_j \right)$$

   from the previous step or after modification at the current step.

2. ***If*** $F_{Ag}^{k} \neq \emptyset$ ***then*** choose one fault $f_{Ag}$ from the set $F_{Ag}^{k}$ that belongs to the conjunciton in (3) with minimal length $\min card\left(C_i^k\right)$. Set $F_{Ag}^{k+1} = F_{Ag}^{k} \setminus f_{Ag}$ ***else*** *stop* testing the process for the current agent.
3. ***If*** $\min card\left(C_i^k\right) = 1$ and $F_{Ag}^{k+1} = \emptyset$ ***then*** set $f_{Ag} = true$ without checking.
   ***else*** check $f_{Ag}$ and set the appropriate value
   $f_{Ag} = \{true,\ false\}$.
4. Refresh
   $$\sigma_k^{\mathrm{mod}_{Ag}} = \bigvee_{i=1}^{D_k} \left( \bigwedge_{j \in C_i^k} f_j \right)$$
   according to the value $f_{Ag} = \{true,\ false\}$
   and abbreviate by cancelling excessive va-riables and false conjunctions.
5. Send to the next agent (from $C = \{a_{1_C}, \ldots, a_{N_C}\}$) the modified formula $\sigma_k^{\mathrm{mod}_{Ag}}$. If this agent is last in the list then set $\sigma_{k+1} = \sigma_k^{\mathrm{mod}_{Ag}}$.
6. After testing (4.9) by the remaining agents set global state $k = k + 1$.

Step 5 demands to set the schedule of agents for sending information. This schedule may be organized by

- A list in $C = \{a_{1_C}, \ldots, a_{N_C}\}$;
- randomly;
- in inverted range of cardinality of elements in $F_k = \{F^k{}_{1_C}, \ldots F^k{}_{N_C}\}$.

**3 Example**

Let us consider the example of three-tank system (Fig.1).

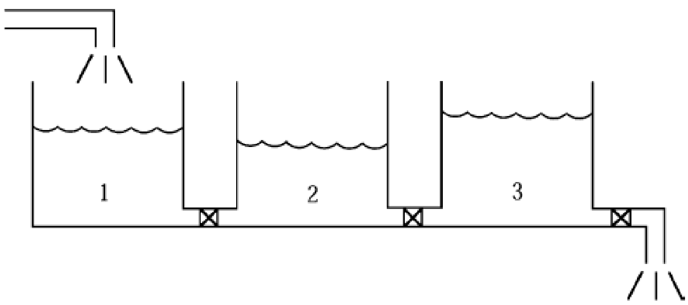


**Fig.1.** Three-tank system

The list of possible faults in this system is given in Table 2 [2].

Table 2: Set of faults of three-tank system

| $f_k$ | **Fault description** |
|---|---|
| $f_1$ | fault of the flow sensor $F$ |
| $f_2$ | fault of the level sensor $L_1$ |
| $f_3$ | fault of the level sensor $L_2$ |
| $f_4$ | fault of the level sensor $L_3$ |
| $f_5$ | fault of the control path $U$ |
| $f_6$ | fault of the control-valve |
| $f_7$ | fault of the pump |
| $f_8$ | lack of medium |

| | |
|---|---|
| $f_9$ | partial clogging of the channel between the tanks $Z_1$ and $Z_2$ |
| $f_{10}$ | partial clogging of the channel between the tanks $Z_2$ and $Z_3$ |
| $f_{11}$ | partial clogging of outlet |
| $f_{12}$ | leaking from the tank $Z_1$ |
| $f_{13}$ | leaking from the tank $Z_2$ |
| $f_{14}$ | leaking from the tank $Z_3$ |

Let us assume that fault detection is realized with the use of five residuals generated on the grounds of the physical equations of the system [2]. These residuals generate the symptoms $S = \{s_i\}_{i=1}^{N_S=5}$.

Let us represent symptom-fault mapping with following binary diagnostic matrix (Table 3) [2].

Table 3: Binary diagnostic matrix

| S/F | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $f_5$ | $f_6$ | $f_7$ | $f_8$ | $f_9$ | $f_{10}$ | $f_{11}$ | $f_{12}$ | $f_{13}$ | $f_{14}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $s_1$ | 1 | | | | 1 | 1 | 1 | 1 | | | | | | |
| $s_2$ | 1 | 1 | 1 | | | | | | 1 | | | 1 | | |
| $s_3$ | | 1 | 1 | 1 | | | | | 1 | 1 | | | 1 | |
| $s_4$ | | | 1 | 1 | | | | | | 1 | 1 | | | 1 |
| $s_5$ | 1 | 1 | 1 | 1 | | | | | | | 1 | 1 | 1 | 1 |

Let us create agents that are response for faults. The possible distribution of agents are presented in Table 5.3.

Table 4: Assignment of agents to faults

| **Unit** | **Agent** | **List of faults** |
|---|---|---|
| Tank $Z_1$ | $a_1$ | $f_2$, $f_9$, $f_{12}$ |
| Tank $Z_2$ | $a_2$ | $f_3$, $f_{10}$, $f_{13}$ |
| Tank $Z_3$ | $a_3$ | $f_4$, $f_{11}$, $f_{14}$ |
| Pump | $a_4$ | $f_1$, $f_5$, $f_6$, $f_7$, $f_8$ |

Our model has following body:

$A = \{a_1, a_2, a_3, a_4\}$, $F = \{f_1, \dots, f_{14}\}$, $Af_1 = \{f_2, f_9, f_{12}\}$, $Af_2 = \{f_3, f_{10}, f_{13}\}$, $Af_3 = \{f_4, f_{11}, f_{14}\}$, $Af_4 = \{f_1, f_5, f_6, f_7, f_8\}$,

Let the following event takes place – $S_O = \{s_2, s_3, s_5\}$.

Then we have $\sigma = f_2 \vee (f_9 \wedge f_{13}) \vee (f_9 \wedge f_{12}) \vee (f_{12} \wedge f_{13})$,

Let us apply $\alpha$ -procedure.

We have now two agents responsible for faults - $C = \{a_1, a_3\}$.

Besides, $F^0 = \{F_1^0, F_3^0\} = \{\{f_2, f_9, f_{12}\}, \{f_4, f_{11}, f_{14}\}\}$.

| **Step** | **Action** | |
|---|---|---|
| 0 | $\sigma_0 = f_2 \vee (f_9 \wedge f_{13}) \vee (f_9 \wedge f_{12}) \vee (f_{12} \wedge f_{13})$<br>$C_1^0 = \{2\}, C_2^0 = \{9,13\}, C_3^0 = \{9,12\}, C_4^0 = \{12,13\}$ | |
| 0 | $Ag = a_1$;<br>$\min card(C_i^0) = 1$ ;<br>$f_{Ag} = f_2$; | $Ag = a_3$;<br>$\min card(C_i^0) = 2$ ;<br>$f_{Ag} = f_{12}$; |
| 0 | **Checking**: $f_2 = false$ | **Checking**: $f_{12} = true$ |

| | | |
|---|---|---|
| 1 | $\sigma_1 = f_9 \vee f_{13}$<br>$C_1^1 = \{9\}, C_2^1 = \{13\}$ | |
| 1 | $Ag = a_1$;<br>$\min card(C_i^0) = 1$ ;<br>$f_{Ag} = f_9$; | $Ag = a_3$;<br>$\min card(C_i^0) = 1$ ;<br>$f_{Ag} = f_{13}$; |
| 1 | **Checking**: $f_9 = false$ | **Checking**: $f_{13} = true$ |

As it easy to see in this case we check all possible faults from the initial list and do not get a profit in compare with consecutive search except parallel calculation.
Let us apply $\beta$ **-** procedure now.

| Step | Action | |
|---|---|---|
| 0 | $\sigma_0 = f_2 \vee (f_9 \wedge f_{13}) \vee (f_9 \wedge f_{12}) \vee (f_{12} \wedge f_{13})$<br>$C_1^0 = \{2\}, C_2^0 = \{9,13\}, C_3^0 = \{9,12\}, C_4^0 = \{12,13\}$ | |
| 0 | $Ag = a_1$;<br>$\min card(C_i^0) = 1$ ;<br>$f_{Ag} = f_2$;<br>**Checking**: $f_2 = false$ | |
| 0 | $\sigma_0^{\mathrm{mod}_{a_1}} = (f_9 \wedge f_{13}) \vee (f_9 \wedge f_{12}) \vee (f_{12} \wedge f_{13})$<br>$C_1^{0\,\mathrm{mod}_{a_1}} = \{9,13\}, C_2^{0\,\mathrm{mod}_{a_1}} = \{9,12\}, C_3^{0\,\mathrm{mod}_{a_1}} = \{12,13\}$ | |
| 0 | | $Ag = a_3$;<br>$\min card(C_i^0) = 2$ ;<br>$f_{Ag} = f_{12}$;<br>**Checking**: $f_{12} = true$ |
| 1 | $\sigma_1 = f_9 \vee f_{13}$<br>$C_1^1 = \{9\}, C_2^1 = \{13\}$ | |
| 1 | $Ag = a_1$;<br>$\min card(C_i^0) = 1$ ;<br>$f_{Ag} = f_9$;<br>**Checking**: $f_9 = false$ | |
| 1 | $\sigma_1^{\mathrm{mod}_{a_1}} = f_{13}$ | |
| 1 | | $Ag = a_3$;<br>$\min card(C_i^0) = 1$ ;<br>$f_{Ag} = f_{13}$;<br>**Setting**: $f_{13} = true$ |

Using $\beta$ **-** procedure for this case reduce number of fault checking to three times and substitute checking process by setting.

**Remark.** We do not draw attention now on procedure of fault checking but we understand that this is some deeply investigation of symptoms dynamic contrary to identification of symptom to obtaining the set of observed symptoms $S_O$ . Moreover the checking procedure may include additional actions (like computational and even mechanical) to recognize suspected fault. That is why even ton big reduce of checking procedure is more than is required.

## Conclusion

Due to the distributional character of fault diagnosis and necessity of taking into account different uncertainties during the diagnosis process the multi-agent methodology has been proposed. We showed that the principle of assigning the agent to subsystems in this case is also useful. Then the local knowledge base of agents and rules for communications can precise the possible diagnosis in addition to the ordinary binary or fuzzy diagnostic matrix.

As a result of this investigation we could propose engineering methods for applying multi-agent methods to fault diagnosis problems.


## Acknowledgement

This research has partially been supported by the Saxon Ministry of Sciences and Art (Germany).


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