AN APPLICATION EXAMPLE OF A MULTIASPECT DIAGNOSTIC MODEL*

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Summary

The paper shows an application example of a multiaspect diagnostic model, i.e. a special kind of a model that consists of at least two submodels which are applied together but they can be identified separately most often by means of the different methods and criteria. In the presented example each submodel concerns the one in five predefined aspects (viewpoints). The example concerns a technical object which makes possible diagnostics of the continuous processes and exemplifies a physical miniaturization of an industrial installation used e.g. in chemical industry. The chosen results of diagnosis obtained from the multiaspect diagnostic model were shown and discussed.

Keywords: technical diagnostics, diagnostic model, multiaspect model.

PRZYKŁAD ZASTOSOWANIA WIELOASPEKTOWEGO MODELU DIAGNOSTYCZNEGO

Streszczenie

Artykuł przedstawia przykład zastosowania wieloaspektowego modelu diagnostycznego, który składa się z co najmniej dwóch stosowanych łącznie modeli składowych, przy czym modele te identyfikowane są oddzielnie najczęściej za pomocą różnych metod i kryteriów. W prezentowanym przykładzie każdy model składowy dotyczy jednego z pięciu zdefiniowanych wcześniej aspektów (punktów widzenia). Przykład dotyczy obiektu technicznego, dla którego możliwe jest diagnozowanie procesów ciągłych i stanowi fizyczną miniaturyzację instalacji przemysłowej stosowanej, np. w przemyśle chemicznym. Przedstawiono i przedyskutowano wybrane wyniki uzyskane z wieloaspektowego modelu diagnostycznego.

Słowa kluczowe: diagnostyka techniczna, model diagnostyczny, model wieloaspektowy.

1. INTRODUCTION

For many modern and complicated technical objects working out of a diagnostic model is uphill task. Identification of a single diagnostic model which would relate to the whole object, could be very difficult or even impossible. The practice shows that instead of using one global model better results are obtained by means of so-called local models (e.g. [Cholewa & Kiciński 1997]). If the outputs of local models are joined properly, e.g. by means of an aggregation operator, a multimodel will be built. Generally speaking the multimodel is a model that consists of at least two submodels which are applied together but they can be identified separately most often by means of the different methods and criteria [Wojtusik 2006].

In the presented example each submodel is designed on the basis of knowledge acquired from one point of view, i.e. taking into account one aspect. It means that a multiaspect approach consists in adoption at least two different points of view on the considered technical object. The set of aspects important from technical diagnostics point of view, the way of representation of the considered aspects and other details of the multiaspect approach were shown in [Skupnik 2008, Skupnik 2009b].

2. RESEARCH OBJECT

As a research object *FESTO S7 EduTrainer Compact Siemens S7-300 CPU313C* was chosen. This object exemplifies a physical miniaturization of an industrial installation used e.g. in chemical industry or food industry and makes possible diagnostics of the continuous processes.

2.1. The main elements of the object

Fig. 1 shows structure of the considered object. System control (not shown in the fig. 1) makes possible control one in four of process variables (i.e. temperature of water in the tank T1, level of water in the tank T2, pressure of air in the tank T3 and water flow intensity in the place where flow sensor FS is located) by suitable configuration of opening or closing manual valves Vi (i = 1, 3, 4, 5, 7, 8, 9, 10).

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2.2. Operation of the object

Operation of the object is controlled by the program developed by the author and executed by the programmable logic controller. After checking that the object is in the initial state the pump P is activated for 20 seconds and relative pressure of air in the tank T3 is increased to 200 mbar (atmospheric pressure is the level of reference). In order to achieve and stabilize the required pressure the proportional-integral-derivative controller was used (the values of tuning parameters were following: proportional gain k_p=1; integral gain t_i=1 s; derivative gain t_d=1 s). In the result of the operation the portion of water is pumped to the tank T3 from the tank T1 (fig. 2). Just before the 20th second the operator should close the valve V8. The pump P is turned off when time is up and the operation of the object is paused for 5 seconds. The operator should close the valve V3 during the break.

After the break the ball valve V2 is opened and the tank T1 is filled by water from the tank T2 (fig. 3).

The height of water pillar in the tank T2 is measured by the ultrasonic sensor US. The ball valve V2 is closed when the water pillar in the tank T2 equals 100 mm. Then the operation of the object is paused for 5 seconds. During the break the operator should open the manual valve V4. After the break the pump P is activated for 30 seconds and the water in the tank T1 is mixed (fig. 4). When time is up the pump P is turned off and the operation of the object is ended.

3. THE WORKED OUT MULTIASPECT DIAGNOSTIC MODEL (MDM)

The multiaspect diagnostic model was designed according to the method which had been presented in [Skupnik 2009a]. In the considered example all submodels were represented in the form of belief networks (Bayesian networks).

Generally speaking a belief network is a directed acyclic graph which nodes represent random variables and directed edges represent probabilistic relationships between the variables. The relationships are defined by means of conditional probability tables. The set of conditional probability tables makes possible calculating joint probability. Thus the whole network represents joint probability distribution for the all variables in an economical way [Jensen 2001].

Inference in a belief network consists in calculating unknown values of some variables on the basis of known values of remaining variables. If for example variables of a Bayesian network concern symptoms and technical states of an object then for given symptoms the network can be used to compute the probabilities of the presence of the considered technical states.

In the presented example each belief network represents the probabilistic relationships between technical states and symptoms in relation to one viewpoint (aspect). There are maximum five submodels for each functional state because according to the method presented in [Skupnik 2009a] should be enough to consider the following aspects:

- the functional state aspect (FSA);
- the elements activity aspect (EAA);
- the elements activity constraints aspect (EACA);
- the elements timing aspect (ETA);
- the elements history aspect (EHA).

In the operation of the research object one may distinguish three functional states. Thus in this case the multiaspect diagnostic model consists of the 15 submodels. Its structure and the idea of its application is shown in the fig. 5.

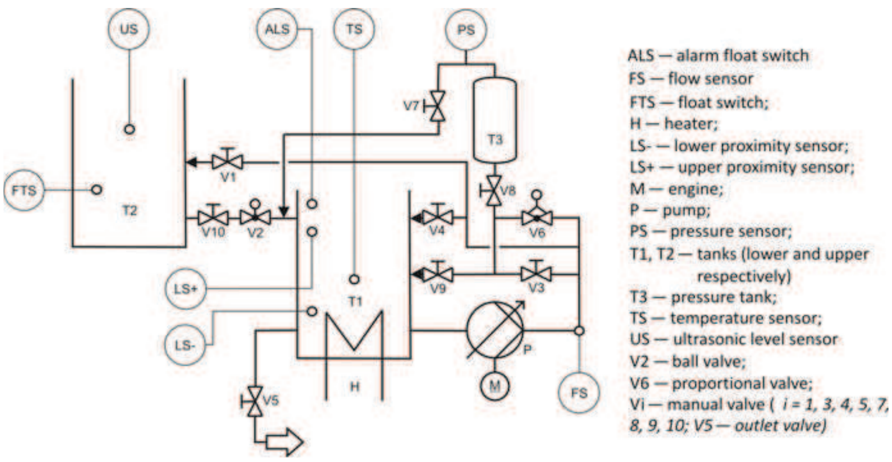

Fig. 1. Structure chart of the considered technical object

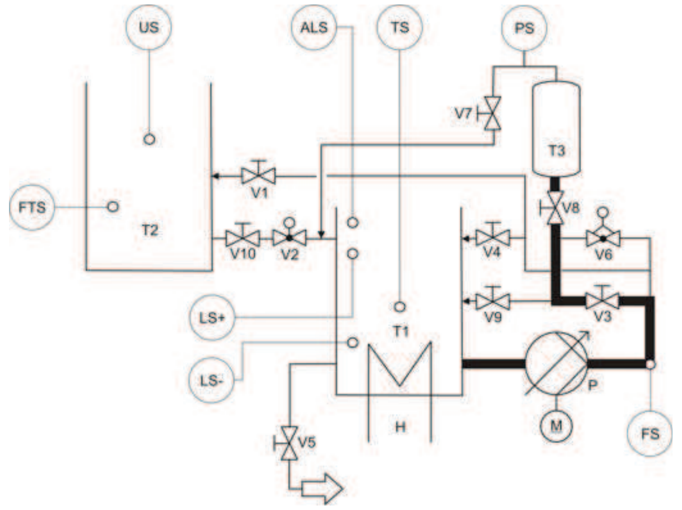

Fig. 2. Compression of air in the tank T3 by water flowing from the tank T1 to the tank T3 (bold curve shows the flow of water)

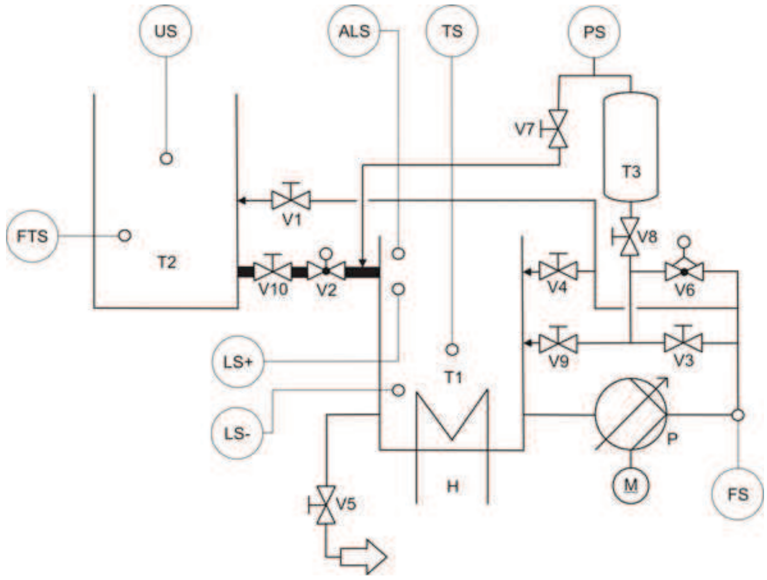

Fig. 3. Filling the tank T1 by water from the tank T2 (bold line shows the flow of water)

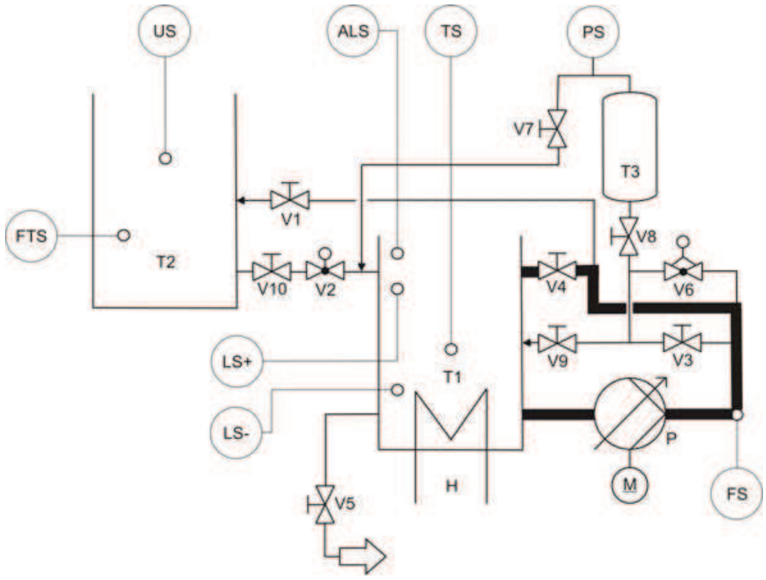

Fig. 4. Mixing the water in the tank T1 (bold curve shows the flow of water)

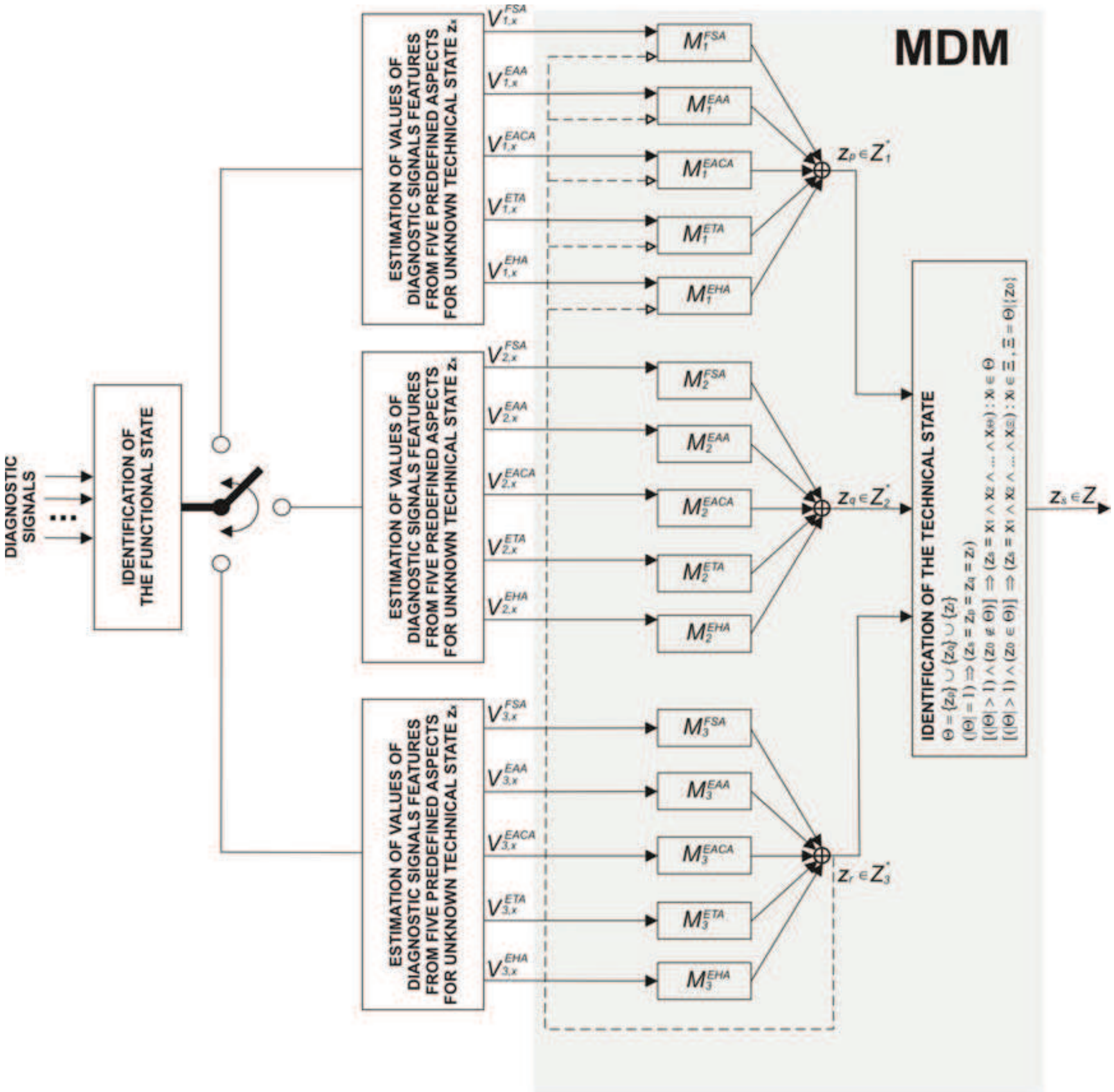

Fig. 5. The structure of the multiaspect diagnostic model (MDM)
and the idea of its application where:

- $V_{j,x}^{FSA}, V_{j,x}^{EAA}, V_{j,x}^{EACA}, V_{j,x}^{ETA}, V_{j,x}^{EHA}$ - subsets of values of diagnostic signal features which are calculated in the functional state aspect, elements activity aspect, elements activity constraints aspect, elements timing aspect, elements history aspect respectively, for the j functional state and unknown technical state z_x;
- $M_j^{FSA}, M_j^{EAA}, M_j^{EACA}, M_j^{ETA}, M_j^{EHA}$ - aspect diagnostic models (submodels) represented in the form of belief networks for the j functional state;
- Z_j^* - subset of the considered technical states for the j functional state;
- $Z = \bigcup_{j=1}^{3} Z_j^*$ - set of the all considered technical states.

The structures of the models $M_j^{FSA}, M_j^{EAA}, M_j^{ETA}$ were designed automatically by means of K2 algorithm and identification of the models was done with use of the junction tree algorithm. Both the structures and identified parameters were obtained on the basis of the set of data acquired in the result of active diagnostic experiments. The models M_j^{EACA}, M_j^{EHA} were designed by the author in the subjective way.

Taking into account the chosen form of the aspect diagnostic models, i.e. Bayesian networks, it was decided that as an aggregation operator ⊕ Dempster's rule of combination [Dempster 1967],

$m_{12}(\varnothing) = 0$

$$m_{12}(A) = m_1 \oplus m_2(A) = \frac{\sum_{B \cap C = A \neq \varnothing} m_1(B) m_2(C)}{1 - \sum_{B \cap C = \varnothing} m_1(B) m_2(C)} \quad (1)$$

can be used. Thanks to it, it is possible to compute output of the multiaspect diagnostic model but it should be emphasised that in some cases the rule may lead to irrational conclusions. Interesting discussion about this problem was published e.g. in [Zadeh 1986].

4. APPLICATION OF THE MULTIASPECT DIAGNOSTIC MODEL

Some results obtained from the multiaspect diagnostic model were presented in tab. 1÷8 (the last column called "**MDM**"). The first column of each table concerns the correct degrees of belief. The columns 2÷6 show degrees of belief obtained from the submodels, where: $M_j^{FSA}, M_j^{EAA}, M_j^{EACA}, M_j^{ETA}, M_j^{EHA}$ concern the functional state aspect, the elements activity aspect, the elements activity limitations aspect, the elements timing aspect the elements history aspect respectively in the *j* functional state.

4.1. Example 1 – leakiness of the tank T3

Tab. 1 contains degrees of belief about technical state of the tank T3 when it was leaky and remaining elements of the object were in usable technical state. One may notice that in this case only one submodel, i.e. M_1^{FSA}, gives useful information because it points unambiguously the right technical state. It is impossible to draw a conclusion about technical state of the tank T3 taking only into account the results obtained from the rest of the submodels. Application of Dempster's rule of combination in order to aggregate degrees of belief obtained from the all submodels makes possible computation, the output of the MDM. As it shown the result is completely consistent with the values of the correct beliefs.

4.2. Example 2 – partly blocked the canal between the tank T1 and T3

Tab. 2 contains degrees of belief about technical state of the canal between the tank T1 and T3 when it was partly blocked (the other elements of the object were in usable technical state). In this case there is a contradiction between results obtained from the submodels M_1^{FSA} and M_1^{EAA} or M_1^{EAA} and M_1^{ETA}. In spite of this fact the output of the MDM is again completely consistent with the values of the correct beliefs.

Tab. 1. Degrees of belief about the technical state of the tank T3 when it was leaky

Correct beliefs	M_1^{FSA}	M_1^{EAA}	M_1^{ETA}	M_1^{EALA}	M_1^{EHA}	**MDM**
0	0	0.4933	0.5156	0.5	0.5	**0**
1	1	0.5067	0.4844	0.5	0.5	**1**

Tab. 2. Degrees of belief about the technical state of the canal between the tank T1 and T3 when it was partly blocked

Correct beliefs	M_1^{FSA}	M_1^{EAA}	M_1^{ETA}	M_1^{EALA}	M_1^{EHA}	**MDM**
0	0	0.8235	0	0.2	0.2	0
1	1	0.1765	1	0.2	0.2	1
0	0	0	0	0.2	0.2	0
0	0	0	0	0.2	0.2	0
0	0	0	0	0.2	0.2	0

4.3. Example 3 – failure of the pump P

Tab. 3 contains degrees of belief about technical state of the pump P when it was faulty and the rest of the elements of the object were in usable technical state. As one can see this case is similar as in the example 2 but here none of the submodels point unambiguously the right technical state. Moreover there is a contradiction between results obtained from the some submodels. In consequence on the basis of degrees of belief obtained from the MDM one cannot draw a conclusion about technical state of the pump P without any doubts. However it should be noticed that the obtained result does not mislead.

4.4. Example 4 – completely blocked the canal between the tank T1 and T3

As it was mentioned above, in the operation of the research object one may distinguish three functional states. Lets consider the case when the canal between the tank T1 and T3 is completely blocked and the other elements of the object are in usable technical state.

On the basis of results obtained from the aspect models in the first functional state (tab. 4 and 5) one may draw a false conclusion that the pump P was probably faulty and the canal between the tank T1 and T3 was almost for sure in a good technical state.

However for the third functional state it was stated without any doubts that the pump P was in working order (tab. 6). Thus it was sensible to assume that the pump P had also been efficient in the first functional state.

The earlier conclusions for the first functional state were modified and accuracy of the diagnosis became higher after the information had been entered into the aspect models, which concerned the first functional state (tab. 7 and 8).

Tab. 3. Degrees of belief about the technical state obtained when the pump P was faulty

Correct beliefs	M_1^{FSA}	M_1^{EAA}	M_1^{ETA}	M_1^{EALA}	M_1^{EHA}	MDM
0	0.5451	0.1837	0.6770	0.5	0.5	0.3610
1	0.4549	0.8163	0.3230	0.5	0.5	0.6390

Tab. 4. Degrees of belief about the technical state of the canal between the tank T1 and T3 when it was completely blocked (before recalculation)

Correct beliefs	M_1^{FSA}	M_1^{EAA}	M_1^{ETA}	M_1^{EALA}	M_1^{EHA}	MDM
0	0.4618	0.5714	0.6178	0.2	0.2	0.9646
0	0.1865	0.1225	0.1324	0.2	0.2	0.0179
1	0.1137	0.2041	0.0808	0.2	0.2	0.0111
0	0.1243	0.0817	0.0882	0.2	0.2	0.0053
0	0.1137	0.0203	0.0808	0.2	0.2	0.0011

Tab. 5. Degrees of belief about the technical state of the pump P (before recalculation)

Correct beliefs	M_1^{FSA}	M_1^{EAA}	M_1^{ETA}	M_1^{EALA}	M_1^{EHA}	MDM
1	0.5451	0.1837	0.6770	0.5	0.5	0.3610
0	0.4549	0.8163	0.3230	0.5	0.5	0.6390

Tab. 6. Degrees of belief about the technical state of the pump P for the 3-rd functional state

Correct beliefs	M_3^{FSA}	M_3^{EAA}	M_3^{ETA}	M_3^{EALA}	M_3^{EHA}	MDM
1	1	1	1	0.5	0.5	1
0	0	0	0	0.5	0.5	0

Tab. 7. Degrees of belief about the technical state of the canal between the tank T1 and T3 when it was completely blocked (after recalculation)

Correct beliefs	M_1^{FSA}	M_1^{EAA}	M_1^{ETA}	M_1^{EALA}	M_1^{EHA}	MDM
0	0.2630	0.0001	0.5786	0.2	0.2	0.0002
0	0.2169	0	0.1240	0.2	0.2	0
1	0.1877	0.9999	0.1074	0.2	0.2	0.9998
0	0.1447	0	0.0826	0.2	0.2	0
0	0.1877	0	0.1074	0.2	0.2	0

Tab. 8. Degrees of belief about the technical state of the pump P (after recalculation)

Correct beliefs	M_1^{FSA}	M_1^{EAA}	M_1^{ETA}	M_1^{EALA}	M_1^{EHA}	**MDM**
1	1	1	1	0.5	0.5	1
0	0	0	0	0.5	0.5	0

The possibility of modification of the conclusions in the worked out multiaspect diagnostic model is represented in the fig. 5 by means of the broken lines.

5. SUMMARY

Many modern technical objects consist of several subsystems (e.g. mechanical, electric, control, etc.) and works according to the established procedures in changeable conditions. It seems that for this kind of objects an application of a multiaspect diagnostic model to recognize a technical state is a good idea. The main advantage of this approach is based on the fact that a change of a technical state observed from one point of view may be reflected, even more clearly, in the other point of view. Thus in that case the hard task of recognizing a technical state is solved by solving a few simpler tasks. Unfortunately, there is a serious difficulty which consists in aggregation the results obtained from the aspect models.

Even though, it seems that application of a multiaspect diagnostic model makes possible determination of new procedures connected with designing of supervision systems or improvement (simplification) of existing procedures, especially in relation to complicated technical objects. In other words a multiaspect approach may be used in formulating new methods intended for constructing diagnostic models or supplement of the methods which relate to analysis of residual processes (e.g. vibrations, noise etc.).

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