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AN EXPERT SYSTEM FOR DIAGNOSTICS OF AGRICULTURAL MACHINES

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On the basis of the knowledge about agricultural machine exploitation a Diagnostic Expert System (DES) was developed which consists of the following modules: knowledge acquisition, knowledge representation, mechanism of inference, interface of controlling of the user interrogation and system of explanations. In this work the principles and development stages were described. With the sample data the procedure of knowledge acquisition and diagnostic principles were presented.

1. Introduction

From the point of view of exploitation agricultural machines of modern design belong to technical objects of complex functionality, used seasonally, with considerable output, which require qualified service.

To maintain and service these machines a waste technical knowledge is needed because in the structure of these machines mechanical, hydraulic, electrical, and electronic systems (Michalski *et al.*, 1988) are included. Therefore, use of an expert system in diagnostics of agricultural machines becomes an essential tool, which should facilitate servicing and improve the diagnostic quality.

Development of DES has the following aims (Ganltney *et al.*, 1989; Michalski *et al.*, 1992):

- to provide the up–to–date knowledge for servicing personal necessary to make a proper diagnosis of a machine,
- to indicate in the non–operational states on the basis of observed diagnostic symptoms,
- to indicate causes and remedies of a failure or a malfunction of the tested assemblies and machine arrangement.

The above mentioned DES incorporate some range of methodical and technical problems connected with applying of a computer to solving of complex diagnostic problems in agricultural machines on the basis of knowledge acquisition, forming of principles and procedures of logical inferences (Ganltney *et al.*, 1989; Michalski *et al.*, 1992).

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It may be assumed that operated machines reveal their performance (technical states) through sets of working and concomitant processes, for example: vibrations, noise, wear, thermodynamic processes. Direct or indirect evaluations of these processes enable an identification of the technical states identification, assuming that the observed symptoms or signals of the initial processes have univocal character in their nature, and have sufficient separation (detaining) ability of the signal parameters.

Therefore, the development of a diagnostic expert system includes the following stages (Bubnicki, 1990; Cholewa and Czogała, 1989):

- definition of the problem in the form of a general concept with allowance to their aim, tasks, and a way in which the diagnostic knowledge is presented,
- design of a diagnostic model of a machine,
- acquisition of knowledge from the experts,
- programming of DES as a shell (skeleton) of an expert system,
- input of a knowledge base into computer memory,
- testing and verification of DES on the example data.

2. Problem Definition

The object is given, which consists of n elements mutually joined by relations:

$$IE = \{e_i\}, \quad i = \overline{1,n} \tag{1}$$

Designing by $C_q(e_i)$ the feature named $q = 1,2,...,Q$ and values $a_q(e_i)$ assigned to the i–th element, then the set of values of features for all n elements of the object the $a_q(e_i) \in A_Q$ will characterise the technical state of the object at the t moment as

$$\underset{i \in n}{\forall} \; \underset{q \in Q}{\forall} \; a_q(e_i) \Rightarrow S_l(t,n) \in S, \qquad l = \overline{1,L} \tag{2}$$

where $S_l(t,n)$ denotes the l–th technical state of the object discriminated (distinguished) for q value set of the features for n elements, and S the set of discriminated technical states of the object. This means that i–th technical state is an element of the set of discriminated states of the object. In the set of states of the object S the following states may be distinguished:

- states of fitness for use (operational) S^Z, in which the ability to use the object according to its appropriation is ensured,
- non–operational states S^N, resulted from exceeding the values of $a_q(i) \ngtrless a_{q(\mathrm{dop.})}(i)$ for the i–th basic element beyond allowable limits.

Taking into account the application of the machine the subsets of functional circuits may be defined on the IE set

$$OF = \{of_k\}, \qquad k = \overline{1,K} \tag{3}$$

Each element e_i of this set (OF) is connected with realization of the basic function of the machine, and its failure causes disability to work of the whole machine. So, as it is evident from the formula (2) i–th non–operational state can be presented as follows:

$$\underset{e_i \in OF}{\forall} \quad \underset{a_q(i) \not\gtrless a_{q(\mathrm{dop}\,)}(i)}{\exists} \quad S_l(i) \in S^N \tag{4}$$

$$S^N \bigcup S^Z = S \qquad S^N \bigcap S^Z = \emptyset \tag{5}$$

This indicates that all machine states (S) form a set of discriminated states considering their affiliation to OF, in which the operational and non–operational states mutually exclude themselves.

The values, which describe the technical state of the machine have a character of a random variable depending on the design, manufacture conditions, and actual service conditions. In this case the technical states of a machine are determined on the base the results of observation of symptoms and measurements of the selected diagnostic signals. The analysis of this knowledge representation by utilization of DES should enable to formulate appropriate diagnosis and to choose a way of service and maintenance, at limited time and costs of diagnostic testing of the machine.

3. Diagnostic Model

The diagnostic model of a machine formulates the dependence between the technical states $S(t)$ and the observed symptoms X and the diagnostic signals $X(t)$ (Drożyner *et al.*, 1991):

$$F : S(t) \rightarrow X \vee X(t) \tag{6}$$

In such a situation the inference in the moment t can be represented as a vector function of the technical state and vectors of the symptoms or diagnostic signals.

The unknown variables here are the technical state of the machine dependent on value a_q of element $e_i \in OF$. In the same time from the results of the external observations of the object, the diagnostic symptoms X or resulting from measurements of the diagnostic signals $X(t)$ are known. The symptoms or signals obtained during the diagnostic process can be presented by the following formulas:

$$\begin{aligned}
X_1 &= L_1(S_1(t), S_2(t), ..., S_L(t)) \\
X_2 &= L_2(S_1(t), S_2(t), ..., S_L(t)) \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
X_j &= L_j(S_1(t), S_2(t), ..., S_L(t)) \\
X_{j+1} &= L_{j+1}(S_1(t), S_2(t), ..., S_L(t)) \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots
\end{aligned} \tag{7}$$

If the symptoms X_j or signals $X_j(t)$ are known the system of equations (7) enables the determination of the parameters of the state $S_l(t)$ supposing that the operator L is a linear transformation and the relationships between X and $S(t)$ are explicitly determined.

In reality, these conditions are not satisfied for the complex agricultural machines. Therefore, one of the possible solutions is application of DES for diagnosis of the states of this class of objects.

4. Structure of DES

The structure of the diagnostic expert system in its basic version is presented in Figure 1, which consists of four mutually connected modules (Edmunds, 1991; Goodball, 1987; Martin and Oxman, 1988):

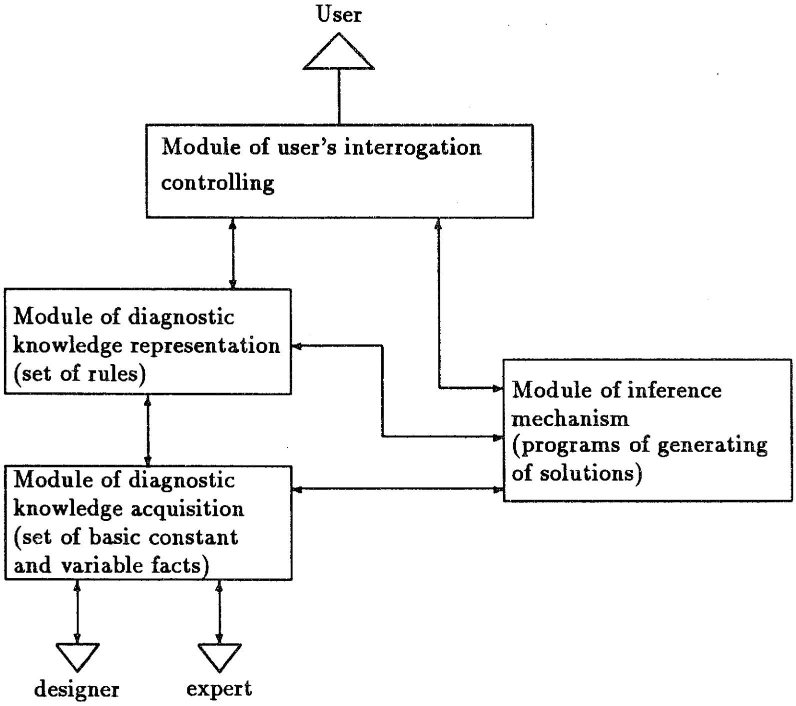

Fig. 1. The basic structure of the DES.

- knowledge acquisition (elicitation) and collecting by interviewing experts or gained from stand testing of the machine, classification of the gained knowledge and encoding it in the form of facts recognizable by a computer;
- knowledge representation is given in the form of inference rules: $RW = \langle V, F, CF \rangle$, where V is a set of facts, F is a logical structure, CF is a certainty factor, $CF \in [0,1]$;

- mechanism of inference (inference engine) is also used as an interpreter of the rules, which finds out the rules and facts connected with analysed diagnostic situation, and enables recognition of the technical states of the machine, and then designation of the proper servicing procedure;
- control of the user's interface in the form of instructions displayed and the user interrogation about the values or facts needed during inference process.

5. Acquisition and Representation of Diagnostic Knowledge

Acquisition of the diagnostic knowledge was executed by open questionnaires (Michalski *et al.*, 1992) with experts employed in the company which had manufactured the tested machine and in service shops. The choice of the experts was done with regard to the following criteria: knowledge and experience in designing and exploitation of the machine, knowledge about the physics of damage phenomena of machine elements during exploitation, knowledge about non-operational states of the machine and connected with them diagnostic symptoms, ability to independent evaluations and opinions and also psychical predisposition. People who satisfied the above criteria were interviewed according to the prepared questionnaire. The questionnaire included: the functional division of the machine on the third level of decomposition, the list of symptoms, types and causes of damages to elements, and also the knowledge representation card (Michalski *et al.*, 1992).

The knowledge acquired during the interviews was formulated by the experts in so called elementary facts. As an elementary fact the formula of logical structure was assumed in the form:

$$V_{ij} : X_j \Rightarrow US_{ij}$$

where V_{ij} is a fact given by the i-th expert connected with the j-th symptom of a non-operational state, i is expert's number; $i = 1, ...N$, where N is the total number of experts participating in the investigations, X_j is the j-th symptom of non-operational state, j-symptom number; $j = 1, ...J$, where J is the total number of discriminated symptoms, S_{ij} is a subset of non-operational states reported by the i-th expert and connected with the j-th symptom, and $S_{ij} \subset S$, where $S = \{S_1, S_2, ..., S_L\}$ is a set of non-operational states reported by all experts.

The collected elementary facts $(\underset{i}{\forall}\underset{j}{\forall})$ V_{ij} were submitted to the unitary inner verification, in order to evaluate their likelihood, and then were put together as a set of facts of the diagnostic knowledge $(V_{ij} \subset IV)$ in the form:

$$IV : \underset{i}{\forall}\underset{j}{\forall} X_{ij} \rightarrow S_j$$

where $S_j = S_{1j} \cup S_{2j} \cup ... \cup S_{Nj}$ indicate the type of non-operational states discriminated by N experts for the j-th symptom.

The diagnostic knowledge W accumulated in this way is presented in a form of the following table:

$$A = [a_{jl}]_{J \times L}$$

in which it was assumed that

$$a_{jl} = \begin{cases} X & \text{if} \quad S_l \in S_j \\ 0 & \text{if} \quad S_l \notin S_j \end{cases}$$

The task for experts was to assign ***the non-operational states of elements to their symptoms*** in the sequence from the most to the least probable. The remainder information provided by the experts was the causes of the disability to work, and also proposed which diagnostic parameters and in which places should be measured.

As an example the collected diagnostic information was presented in the power transmission system of the *Bizon* combine harvester in the form of a basic table of the diagnostic knowledge (Tabl. 1).

In the Table 1 the relationships were presented between the symptoms ($J = 18$) and the non-operational states ($L = 39$) pointed out by the experts from FMŻ (Factory of Harvesting Machines) in Płock and from the servicing network in relation to the power transmission system of a combine harvester.

Then, the diagnostic knowledge base of the power transmission system of a combine harvester (Tabl. 1) was applied to formulation of the diagnostic inference rules. The system of interference rules formulating as assumed here has the form:

Rule: IF $(X_1\ X_2\ ...\ X_J)$ THEN $(S_1\ S_2\ ...\ S_L)$

$X_1\ ...\ X_J$ represent ***premises*** of the type ***diagnostic symptoms*** and forms ternaries of the type $\langle$ object, attribute, value $\rangle$,

$S_1\ ...\ S_L$ represent ***conclusions*** in the form of diagnosis making and restoring the ability of state of elements as a indication of the way of technical servicing.

On the basis of presented in Table 1 the basic diagnostic knowledge supplemented by information from experimental investigations of the power transmission system, an example of the following inference rules was given:

Rule: (is the belt transmission usable?)

IF (belt is tight, $F = 100N$, deflection $\sphericalangle X1 > 2^\circ$)
THEN (the belt transmission is operational) $\wedge$ (carry out adjustment of the transmission)

Rule: (Is the chain wheel $Z = 52$ usable ?)

IF (chain wheel $Z = 52$, axial run out $X1 > 1.6mm$, radial run out $X2 < 2mm$)
THEN (chain wheel, exchange)

Rule: (Is the gearbox usable ?)

1. IF (Gearbox, knocks during forward running)
   THEN (The teeth of the final drive wheel are damaged $\vee$ the teeth of the wheel reduction gear are damaged)
2. IF (driving axle, total backlash $X3 \leqslant 9^{\circ}$ for I, II, III, and R speed)
   THEN (Gearbox is operational)

Rule: (Localization of non–operational points in the variable speed transmission)

1. IF (Variable speed transmission, excessive, unilateral wear of belts $j = 11$)
   THEN (Disk I, misalignment $l = 8$) $\vee$ (disk II, misalignment $l = 10$) $\vee$ (floating disk, excessive clearances $l = 11$)
2. IF (floating disk, excessive clearances)
   THEN (floating disk, exchange)

For designation, see Table 1.

Frequently, in a expert system as well as in the case of an diagnostic expert we are faced with deficiency and inaccurate observation and data. Diagnostic information is often subjective and difficult to interpret. Therefore, the inference mechanism should be equipped with some confidence factors (CF) referring to the facts reported by a user as well as the facts in the very reasoning process (*condition* X and *conclusion* S). General procedure in an uncertain condition of the diagnostic knowledge representation is as follow:

- choose the minimum CF for several X connected through *and* ($\cap$),
- choose the maximum CF for several X or S connected through *OR* ($\cup$),
- for existing more as one rule leading to this same conclusion, choose as final the maximal value from all the rules.

Let us consider two rules, which lead to the same conclusion C:
1. IF A(CF = 0.3) AND B(CF = 0.6) THEN C(CF = 0.5)
2. IF D(CF = 0.4) AND E(CF = 0.7) THEN C(CF = 0.9)

THEN:
$\mathrm{CF} = \max\ (\min\ (0.3;\ 0.6) \times 0.5;\ \ \min\ (0.4;\ 07) \times 0.9) = \max\ ((0.3 \times 0.5);\ (0.4 \times 0.9)) = \max\ (0.15;\ 0.36)$
$\mathrm{CF} = 0.36$ for C

6. Summary

DES was developed with the aim to assist diagnostic servicing of complex agricultural machines. The presented method of designing DES on the basis of identification of the investigated object, acquisition of the expert knowledge and the way of its utilization in the formulation of the inference rules is an original author's approach to the problem. This method is particulary useful, when only limited diagnostic knowledge is available and there aren't any possibilities of applying the automatic diagnostic means because of their cost and diagnostic time.

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Appendix

Symptoms of Non-Operational States of the Power Transmission System

1. Hindered engagement of the gears
2. Self–disengagement of the gears during running
3. Knocks or noisy running on one of the gear
4. Noisy work on idle gear and during operation

Tabl. 1. The basic table of the diagnostic knowledge of the power transmission system.

Symptoms of the non–operational states (j)																		
18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	LP
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			×			×												38
			×															39

(l) Non operational states

5. Excessive heating of the gearbox
6. After engagement one of the gears, the power is not transmitted to ground wheels
7. Periodical knocks during the forward running
8. During engagement of the gear the grind is heard
9. Noisy operation of the clutch during and after depressing of the clutch pedal
10. Vibration, knocks, noisy operation of the variable–speed V–belt transmission
11. One–sided excessive wear of the V–belts
12. After engagement the auger and finger feeder don't rotate
13. After engagement the reel doesn't rotate
14. The reel rotates non–uniformly
15. To frequent disengagement of the safety clutch during operation of the combine harvester
16. The undershot chain – belt elevator doesn't move at engaged drive (the shave of the elevator drive rotates)
17. The grain and broken ear elevator doesn't work
18. The V–belt slips

Non–Operational States of the Drive and Power Transmission System

1. V–belt HM2178 — excessive elongation
2. V–belt 25 x 16 x 2900 — excessive elongation
3. Chain 10B–92/PZ — break
4. V–belt HC2315 — break
5. Shaft 5040/20–001/1 — broken key of the shaft
6. Chain 12B–89WZ — break
7. Ring I 5040/27–016/0 — excessive play
8. Ring I 5040/27–016/0 — misalignment
9. Ring II 5040/27–017/0 — excessive play
10. Ring II 5040/27–017/0 — misalignment
11. Floating disk (variable–speed transmission of the driving mechanism) — excessive play
12. Bearing 6206 2RS (variable–speed transmission of the driving mechanism) — excessive play
13. V–belt HL 3242 (variable–speed transmission of the driving mechanism) — one sided wear
14. Clutch disk 303.18.212 — material wear
15. Clutch 303.18.221 — material wear
16. Thrust bearing of the clutch — excessive play
17. Right half-shaft 5040/24–169/0 — break
18. Left half-shaft 5040/24–168/0 — break
19. Big wheel reduction gear 5040/24–132/2 — break of a tooth or teeth

20. Sliding change gear of I and R speeds — break of a tooth or teeth
21. Sliding change gear of II and III speeds — break of a tooth or teeth
22. The first motion shaft 5040/24–083/2 — break of a tooth or teeth
23. Retaining ring in the driving axle 22 z — break
24. Idle wheel of II and R speed — break of a tooth or teeth
25. Differential gear planet wheel — break of a tooth or teeth
26. Bearing 3307 — excessive clearances
27. Bearing Na4905 — excessive clearances
28. Half shaft 5050/73–003/1 — break
29. Bearing 6313 — excessive clearances
30. Bearing 6220 — excessive clearances
31. Chain of the undershot chain–belt elevator — break
32. Constant disk 5040/03–031/0 — contaminations
33. Sliding disk 5040/03–051/0 — contaminations
34. V–belt of the driving mechanism of the reel HJ1300 — contaminations
35. Overload clutch of the driving mechanism of the undershot chain–belt elevator — excessive clearances
36. Overload clutch of the driving mechanism of the undershot chain–belt elevator — break of the clutch disk
37. Shaft of the driving mechanism of the undershot chain–belt elevator
38. Overload clutch of the driving mechanism of the header — excessive play
39. Overload clutch of the driving mechanism of the grain elevator — excessive play