COMPUTER-AIDED IMPLEMENTATION OF THE "DUEL" AIRBORNE OPERATIONALLY CONSULTING EXPERT SYSTEM INVESTIGATIVE PROTOTYPE

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Introduction

The "Duel" airborne operationally-consulting expert system is designed for providing intellectual support to the pilot in one of the most intense operating modes.

The decision-making process requires a fast qualitative-quantitative analysis of a great amount of the available information, very often in the conditions when the data is imperfect and/or inaccurate. To carry out a thorough analysis without hardware support is highly problematic for the pilot in the conditions of time deficiency and superextremal psychological tense. This circumstance has led to the need for developing the "Duel" expert system.

The ultimate aim of the work on developing the "Duel" expert system is the implementation of an airborne expert system on board the aircraft. To achieve this goal it is necessary to develop a commuter-aided airborne expert system prototype, i.e. a investigative expert system. The investigative expert system can be used in two ways:

- as an instrument for updating (adjusting) data base and the knowledge base of the expert system;
- as a ground-based simulator for pilots.

For the investigative expert system to be able to solve these problems a commuter-aided simulation system is developed to include an expert system, an environment simulator and an onboard information environment simulator for the expert system. The simulation system incorporates models of objects, involved in the given operating mode, the objects interaction models, models of situations, characteristic of this mode and models of temporal development of the situations.

The paper discusses the commuter-aided implementation project of the investigative expert system which includes the onboard expert system structure, the object domain formalisation method and the logical-linguistical model of the object domain. The investigative expert system can operate in three modes:

- the standard (onboard) mode of displaying recommendations and prompts in the simulation system;
- the mode of step-by-step checking of the expert system operation, the contents of the data base and the knowledge base files, explanations, instructions etc.
- the data base and the knowledge base editing mode.

In the expert system prototype under development the data base and the knowledge base are deterministic in character. In the further updating of the expert system it is supposed to use a device of fuzzy knowledge.

The purpose of the expert system and a brief characteristic of the object domain

The "Duel" expert system is designed to provide the pilot with assistance in decision-making during the "pilot-airborne equipment" mode of the expert system operation. In its standard operational mode the expert system analyses the environment and the onboard systems state information, selects the best ways of solving the problems and provides the pilot with recommendations and prompts by means of the airborne data display system.

The "Duel" expert system belongs to operationally-consulting systems functioning in real time (the system reaction time to the environment changes must be largely less than 1 s).

The expert system-pilot interaction is based on the concept of passive (alarm-consulting) systems. Recommendations are only displayed on the indicator, there is no precise instruction to follow them. This fact ensures the **pilot's** priority in decision-making. The pilot can make decisions on his own without the expert system help or act according to its recommendations.

If necessary besides giving recommendations the expert system displays on one of the indicators a brief explanation (prompt) to the given recommendation and a temporary forecast of the following recommendations which may be given in case of regular evolution of the current situation.

The object domain of the "Duel" expert system is characterised in [1]. Its main characteristics are as follows:

- an acute shortage of time available to the pilot for decision-making;
- the availability of a set of objects interacting with the expert system carrier aircraft;
- the need for a fast change of the initially chosen plan of activity as some of the interacting objects actions may be varied and unpredictable;
- operation in life-threatening superextremal psychological tension;
- great amounts of information to be analysed by the pilot for decision-making.

The study of the object domain has shown that in terms of conditions and tasks to be solved by the pilot the object domain may be fractioned into a few fragments or stages to be described as scenarios. Each of the scenarios has a limited amount of cause-and-effect-related problem subsituations to be resolved by the "pilot-onboard equipment" system.

Each of the cause-and-effect-related problem subsituations is represented by its mathematical model, describing the spacing of the object domain member-objects, forecasting ts change in time and defining the moment of significant events (for the operational mode) occurrence. This stage is preceded by the mathematical study of the cause-and-effect-related problem subsituations ([2] describes the scheme of the fighter-aircrafts optimal defensive manoeuvre in the duel situation). Based on the optimal control mathematical theory, the game theory or selected as a result of mathematical simulation, the "rational solution of the cause-and-effect-related problem subsituations" is included into the mathematical model.

The mathematical models of all the cause-and-effect-related subsituations scenarios and the scenario-effective behaviour of the expert system carrier object and the enemy object form the scenario special-temporal framework [3]. The scenarios in their turn are characterised by cause-and-effect relations which make it possible in the changing external situation to fully describe the object domain by means of a transfer from one scenario to another and as a result to achieve the ultimate aim of the selected mode by reaching the aim of each of the scenarios.

The "Duel" expert system under development has the following five scenarios:
- the information supply scenario,
- the advantage insurance scenario,
- the active scenario,
- the passive scenario,
- the combined scenario.

The set of interacting objects being described comprises six objects:
- the SI object (the expert system carrier),
- the SC object,
- the RI1 object,
- the RI2 object,
- the RC1 object,
- the RC2 object.

<u>The expert system structure</u>

In figure 1 is given the structural scheme of the commuter-aided "Duel" expert system implementation. By thin arrow-shaped lines is shown the process of the expert system unit data exchange, by bold lines - the process of the units interactivisation

The expert system communicates with the outer world by means of two units:

- "the external environment",
- "the user input information".

The external environment unit is a file transferring information from the standard onboard information environment of the expert system carrier into the

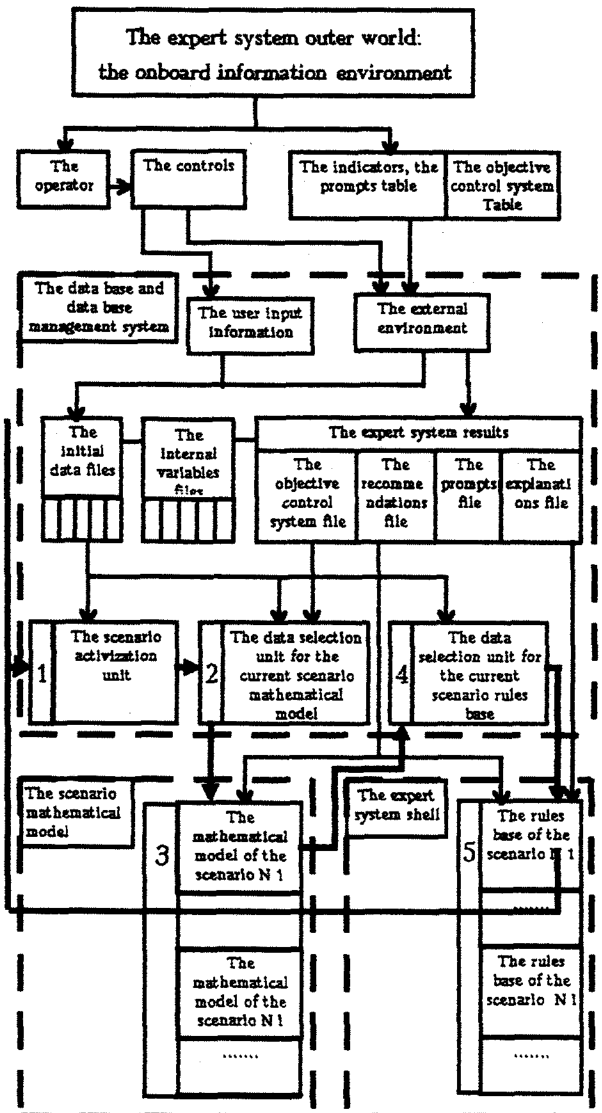

Figure 1. The expert system structure

data base and backward. The file contains information from the onboard sensors, the standard onboard algorithm, the cockpit controls (i.e. from the pilot), which is sent into the data base. The data base transfers into the external environment file the results of the expert system functioning:

- recommendations for the pilot,
- prompts,
- parameters to be registered in the onboard objective control system,

explanations to be presented in the non-standard (user's) mode of the expert system operation. The user input information unit serves for the expert system operational adjustment in specific operating conditions and makes it possible to change characteristics of interacting objects and their subsystems.

The expert system itself incorporates three functional units:

- the data base fitted with the data base management system,
- the mathematical models base,
- the expert system shell.

The data base and the data base management system contains a set of files which can be classified by their functional use into four groups:

1. the initial data files,
2. the internal variables files,
3. the expert system functioning results files,
4. the expert system functional (operating) units files.

The first group includes files containing objects information which comes from the external environment unit and the user input information unit. All the external information is systematised and allocated in these files. The specific object data may be stored in a few files (if the object is characterised by a great amount of information) and at the same time the specific file may store information characterising a few similar objects. The group includes 10 files.

The second group includes files storing information formulated or grouped in the expert system. This group has 5 files.

The third group includes files of the expert system functioning results to be transferred into the external environment unit and then on the indicators and into the onboard objective control system. The group has 4 files.

The fourth group is formed by the files storing the expert system functional ("operating") units texts, i.e. the knowledge base areas. These units are sorted sets of rules and can operate within the data base management system, without the expert system shell (the data base management system hardware makes it possible). The units are as follows:

a) the scenario activisation unit,
b) the data selection unit for the current scenario mathematical model,
c) the data selection unit for the current scenario rules base.

The expert system under development has an integrated knowledge base, i.e. the knowledge is represented in two ways:

- by the productions method (the "expert system shell" unit),
- by the traditional algorithms or mathematical models (the "mathematical models base" unit).

The mathematical models base has 15 algorithms, recorded in FORTRAN and grouped for the scenarios. For each scenario there is an algorithms system (the mathematical model of the scenario Ni, i=1-5). The algorithms are non-standard (internal for the expert system) unlike the standard onboard algorithms functioning on board the carrier aircraft regardless of the expert system needs. The airborne equipment and the standard onboard algorithms deliver to the expert system a great amount of information concerning the outer world and the onboard systems state by means of the "external environment" unit, but the data turns out to be insufficient to solve the arising problems and give recommendations to the pilot. However the amount of information allows for getting the missing knowledge by means of the non-standard algorithms within the expert system. It involves primarily the procedures simulating some outer world fragments by solving differential equations (Here we call them the mathematical models algorithms). The mathematical models forecast the current cause-and-effect-related problem subsituation in the given scenario before it terminates and estimate the occurrence time of the events being forecasted.

In addition to the knowledge base processing tools recommendations and prompts.

The expert system operation

The expert system prototype being developed implements the simplest functioning scheme: the cyclic (by turn) activisation of the expert system functional units. In figure 1 this process is shown by bold arrowed lines, in the left part of each functional unit there is a figure (from 1 to 5), indicating the ordinal number of the unit in a single operating cycle of the expert system. Before each cycle the data base and the data base management system read information out from the "external environment" unit and the "user input information" unit and allocate it in all the initial data files (information reading out from the "user input information" file is performed only once before the expert system start-up).

The expert system start-up is initialised in the scenario activisation unit where the current external environment data is analysed and one of the expert system scenarios is adequately selected (activated). The scenario activisation unit is located into the data base and the data base management system. The information for checking up the scenario activisation rules enters the scenario activisation unit from the group 1 file containing the external environment unit data required for the scenario activisation unit.

After one of the scenarios been activised the second unit, the data selection unit for the given scenario mathematical models base, starts up. In this unit information needed for the operation of the activized scenario mathematical models unit is selected out from the group 1 files of the data base and the data base management system and is sent to one of the group II files of the data base and the data base management system (the internal variables files). The data selection unit for the current scenario mathematical models is located into the data base and the data base management system.

The information selected in the data selection unit for the current scenario mathematical models is sent from the scenario i mathematical models data file into the knowledge base, the mathematical models base unit to be used in the current scenario mathematical model unit being activized. After the operation of the third unit, the mathematical models base unit, is completed the generated information is sent back into the data base and the data base management system and allocated in the group II files.

After that the fourth unit, the data selection unit for the current scenario rules base, starts up. As in the case with the second unit, the fourth unit is located into the data base and the data base management system. In this unit the information required for the operation of the current scenario rules of representing recommendations and prompts is selected out of the groups I, II files. The selected information is located into one of the group II files.

The information selected in the data selection unit for the current scenario rules base is then transferred from the data file for the current scenario i rules base into the knowledge base, the expert system shell unit, which is the fifth and the last operating unit of the cycle. The activated scenario rules unit (the rules base of the scenario Ni) starts up, formulating recommendations and prompts. After its operation is completed all the generated information enters the group III files of the data base and the data base management system, the "expert system results":

- the recommendations file,
- the prompts file,
- the explanations file,
- the onboard objective control system file.

At the same time the onboard objective control system file is filled up with information from the group II files (the mathematical model operation results), which is required for the subsequent (nonoperational) analysis of the expert system processes. After that the information is transferred from the group III files into the external environment unit.

At this stage the expert system working cycle completes and the next one begins (in the scenario activisation unit) to process the refreshed information in the initial data files.

The object domain logical linguistical model

Rules-productions construction in the scenario activisation unit and in the expert system shell unit is based on the object domain mathematical model [4]. The need for developing such a model for the investigative expert system prototype is accounted for mainly by two factors:

- the convenience of editing and extending the investigative expert system knowledge base at all stages of its life-cycle,
- the extension of the expert system users group by experts unfamiliar with the specific professional terminology and symbolism, used by the experts developing the investigative expert system.

The object domain logical-linguistical model structure is presented in figures 2, 3. The model uses three types of linguistical symbols:

- the notion,
- the variable,
- the relation.

In the logical-linguistical model the object domain dictionary is created (notions, relations, variables and their values) and the construction of the correctly formulated phrases and rules is declared.

In figure 2 the upper hierarchical level of the model is presented. By means of the "has" relation the key "system" notion (the expert system is implied) is related to the notions of "the SI object", ... , "the RC2 object" and the linguistical "scenario" variable, possessing one of the five possible values, for example, the scenario is combined.

By means of the "has" relation the "system" notion is related to the "recommendation" and the "prompt" variables, the values of which are the results of the expert system operation. The "prompt" variable value is the prompt text represented to the pilot.

The "recommendation" variable value is the notion of "the application of a means of influence ... ". There are complicated notions, that require ordering and classification since there are three types of a means of influence on the external environment (in figure 2: "the PH type", "the PK type", the MN type"). Each type has its subtypes and some of the subtypes have their varieties. Thus the notion of "the application of a means of influence ... " is made clear via the relation of "a part-the whole".

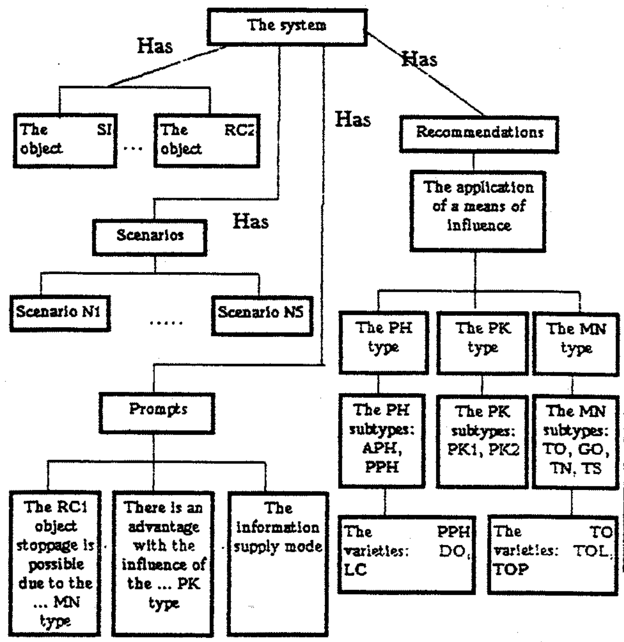

Figure 2. The logical-linguistical model upper level

So the "system" notion has the uppermost hierarchical level. On the next hierarchical level there are "the object ..." ("the SI object", ... , "the PC2 object") notions and the "scenario", the "recommendations", the "prompt" variables.

The "object ..." notions describe the doers (participants) of the object domain, they are characterised by the fact that they are related to other notions and variables by means of various relations. The SI object (fig. 3) has the most complicated relations structure. Here we are going to show what notions and variables the objects are related to by means of what relations, and the way the phrases describing the object are constructed in the developed logical-linguistical model.

In the left part of the scheme is shown the "has" relation with variables and their values. For example, the following phrase makes sense:

"the SI object has the most effective response - the application of a means of influence of the AP subtype from the PH type".

The notion of "the application of a means of influence ... " may be included both into the variable name and into its value.

In the right part of the scheme are shown the relations by which the SI object may be related to the notion of "the application of a means of influence ... " (executed/no executed, ready make/no ready make). For example,

"the SI object executed the application of a means of influence of the TO subtype from the MN type".

In figure 3 by the central line is shown the "has/has no" relation with a set of notions. Some of the notions are simple ("advantage", "effective response" etc.) .

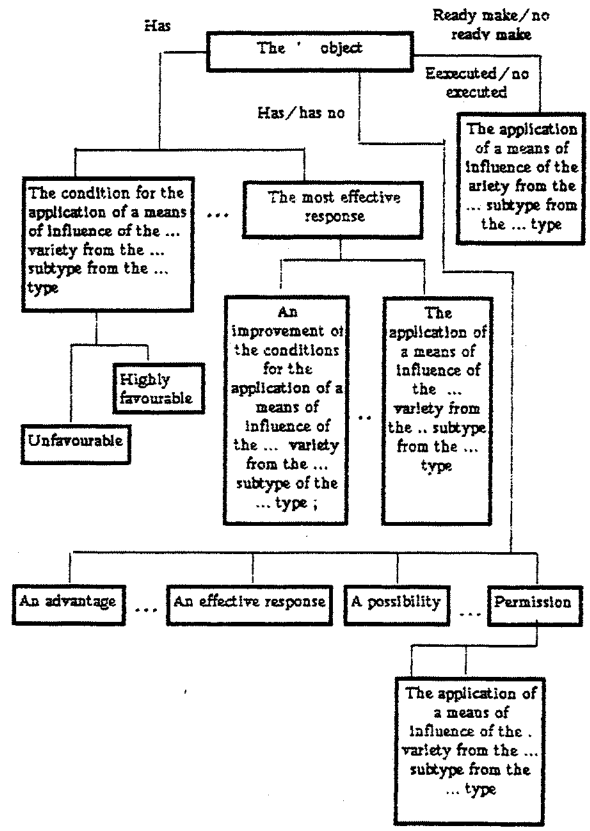

Figure 3. The logical-linguistical model lower level

A number of notions includes one of the basic notions of the object domain - "the application of a means of influence ...". These notions are different characteristics of the application of a means of influence, e.g. the possibility, the necessity, the effectiveness etc. The complete formulation of this class of notions is as follows:

"the limitation of the application of a means of influence of the ЦЛЪ type" etc.

When formulating a phrase making sense in the developed logical-linguistical model it is necessary to take into account the following:

- there are two types of a phrase construction:
1) the notion - the relation - the notion,
2) the notion - the relation - the variable - the variable value;

- the first place in a phrase may be occupied by notions of only two upper hierarchical levels: "the system", "the object...".

Example:

- the SI object has an advantage,
- the system has a scenario - passive.

And finally the rules in this model have the following construction:

IF - a correctly formulated phrase of a linguistical model
AND/OR - a correctly formulated phrase of a linguistical model
....

THEN - a correctly formulated phrase of a linguistical model
AND - a correctly formulated phrase of a linguistical model
....

In the left and the right parts of a rule-production there may be any number of "correctly formulated phrases of a linguistical model" (on the diagram it is shown by the dotted line). The phrases in the left part of a rule are connected by the "AND", "OR" conjunctions, in the right part - only by the "AND" conjunction.

Conclusion

The investigative prototype of the "Duel" onboard operationally-consulting system provides:

- the pilot with 30 recommendations concerning the selection of a means of influence on the external environment;
- about 50 prompts (a brief explanation to the current recommendation) outputted on the prompt table.

The investigative expert system object domain is described in the following way:

- by means of five scenarios,
- by means of 500 rules (each of the scenarios has from 20 to 200 rules),
- by means of 15 mathematical models ,
- by means of 15 data files storing about 300 parameters (200 of them enter from the external environment and about 100 - out of the mathematical models),
- by the logical-linguistical model, comprising:

a) a) a dictionary on a limited natural language (Russian) including about 150 notions and about 30 linguistical variables each of which possesses from 2 to 10 values,

b) five relations concerning notions and variables (the hierarchy, a part-the whole, has/has no, executed/no executed, ready make/no ready make).

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