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APPARATUS OF KNOWLEDGE FORMALIZATION FOR A SUPPORT SYSTEM OF DECISION MAKING BY OPERATORS OF AIR TRAFFIC AUTOMATED CONTROL SYSTEM

The article is devoted to the improvement of the information support system of decision-making processes by operators of the air traffic automated control system. The apparatus of knowledge base formalization of the subject domain was proposed, based on the basic factors of the categories theory and the existence calculus. It is proposed to present structures for description of objects with the help of objectives system. Axioms are formed based on the network model of tasks and objectives for each of the subtasks and the type of theory. The basis for their construction is the semantic network presentation of the object and the formulas of separate subobjects. Each presentation of the object in the theory of physical reality is mapped to the correspondence of the aggregate of information converters, which transform information about the original concepts that satisfy the initial conditions, into information about the resulting concepts that must meet the new conditions. As a result, the proposed formalization apparatus allows the synthesis of programs to solve decision-making support tasks.

Keywords: *potentially conflict situations, information model, operator activity, categorical knowledge model.*

Introduction

Formulation of the problem. Information support of decision-making processes by operators in air traffic automated control systems (AT ACS) should provide effective solution of a number of functional tasks that are characterized by highly dynamic changes in environment conditions and have unclear spatial and temporal characteristics.

With the formation of information models (IM) of situations in the airspace in the area of responsibility of the AT ACS on information display modes (IDM) of individual and collective use, along with the involvement of visual channel there is an urgent necessity to emphasize a number of problems and situations to improve the completeness of the initial information and speed of decision making.

Based on recent studies of the subject area, the most important problems and conditions of the situation, along with the formation of IM on IDM the following ones [1–2; 12] should be emphasized.

Potential conflicts between aircraft (ACFT), in which during the same flight regime, a dangerous near collision of aircraft may occur, such as the passage of the aircraft through a common point in the airspace, while moving of the aircraft on the common route section, while moving of the aircraft on intersecting routes.

Ensuring the minimum approach between aircraft in the airport area, namely security in space-time dimension between aircraft that are landing and coming to take off to prevent collisions between them and minimize the effect of falling into the vortex of aircraft that follows ahead.

For now, correlation dependence of performance evaluation of situations are proven, that occur in airspace from ergonomic properties of the information model. This IM is a primary source of data for solving problems to ensure the flight safety that AT ACS operators are faced with [3–4].

Based on the analysis of theoretical works and experience of ergonomic design it is necessary to improve AT ACS operators information support system, considering knowledge database structure and subject area database, with the formalization of forming process of messages of natural language.

Analysis of recent research and publications. A number of studies [5–12] directly address the improvement issue of information support of solving tasks of flight safety insurance by AT ACS operators. The authors proved the methods of individual elements designing of described IM system class and recommendations were made that are focusing on the improvement of their ergonomic qualities.

However, a number of fundamental points which were specific for tasks solving that AT ACS operators are faced with in potentially dangerous and conflict situations have not been discussed.

Examined papers are focused only on the design of such IM, where air situation changing in spatial-temporal section with the formation of IM for their visual perception is typical for. When forming the information models the internal structure of domain knowledge and uncertainty as to the dynamics of possible changes in the situations in the airspace are not considered, that lead to complications of the AT ACS operators' activity especially in the case of dangerous and conflict situations.

The purpose and objectives of the research. Previously developed methods of forming and controlling IM, that occur in air space do not include the issues of forming messages in AT ACS in a limited natural language interaction, and does not take into account the internal structure of the knowledge base and domain database.

Therefore, relevant and one that requires a solution is the task of developing a system of formalization of domain knowledge for decision system support by operators of air traffic automated control systems.

Main part

The need of structuring knowledge conditioned by the fact that the functional tasks of decisions making by AT ACS operators are characterized by complex structure. The experts who solve functional tasks usually can not clearly form the principles, heuristic rules and other knowledge used in solving problems in the operation of the system. So, to formalize expert knowledge it is necessary to develop a way of their structuring, taking into account the characteristics of the subject area.

It is proposed to use a sequence of stages of knowledge conceptual analysis.

1. Definition of input and output data. At this step, the data storage can be quite indistinct, and in the future, they must be specified.

2. Identification of objects, concepts, processes, events, features, etc., which are significant for the decision and important for creation of meaningful vocabulary. At this step, the basic systematic set of terms is formed that describe the subject area in different ways.

3. Identification of relationships between concepts. At this stage the construction of hierarchical "pyramid" of knowledge is performed with the help of which concepts may detect a higher level of generalization (metanotions) and specify them on a lower level.

4. Determination of relationships between concepts that should be identified both within each of the levels of "pyramid" and between levels. At this step, the names are given to those connections that were defined in the previous step and temporal, spatial, causal, linguistic and other relations are identified.

5. Determination of decision making strategies, i.e. identifying chains of reasoning linking the earlier formation of all concepts and relationships in a dynamic system of knowledge.

Methods of knowledge base formalization based on the theory of categories and existence calculus allows eventually synthesize program for solving tasks of decision making support.

This should provide the following levels: level of physical (abstract) objects; level of tasks of information conversion; data and software level. Taken together, these levels of knowledge are components of the knowledge of the problem area.

At the knowledge base of domain the following components [7] can be allocated:

$$\left\langle M_j, D_j, C_j, PM_j, T_j \right\rangle,$$

where M_j – set of descriptions of objects of domain ω_j; D_j – set of descriptions of the structures of output, intermediate and resulting data; C_j – a description of the set of target classes; PM_j – set of program modules descriptions; T_j – set of theory of domain and tasks that provide the necessary description of achieving the target states, the conditions of actualization of objectives, limits on the quality of problem solving, and others.

To form the set M_j the essential properties of concepts that are structured and summarized should be provided. For objects components sub-objects and their attributes and roles are defined. Each role is attributed to a unique morphism named α_n, the names of concepts and properties α_n are given to sub-objects and attributes.

Structure to describe objects in general may be presented in the form:

$$\left\langle i, \omega, T; \alpha_1 : \bar{\alpha}_1; \alpha_2 : \bar{\alpha}_2; \ \dots \ ; \alpha_n : \bar{\alpha}_n \right\rangle.$$

The set of target conditions is a combination of a description of the states of objects. Each of the possible states is presented as subobject of the object with a unique morphism name, which determines the ratio of inclusion (priority, subordination, etc.) of this subobject as condition of the object. Target states are formalized on the base of descriptions of targets (Tg) of the problem. This description of Tg may be presented in the form:

$$\left\langle C, V, \gamma 1 : C11, \dots Cln; \gamma 2 : C21, \dots C2p; \gamma 3 : C31, \dots C3k \right\rangle,$$

where C – the name of the Tg; V – type of Tg (disjunctive or conjunctive); γl, γ2, γ3 – forms of communication, therefore, priority, subordination, action.

To set the target the system must have the form:

$$\left\langle C, M; \nu_1 : \bar{y}_1; \nu_2 : \bar{y}_2; \ \dots \ ; \nu_n : \bar{y}_n \right\rangle,$$

where M – modality (usually deontic), with which the operator sets the task to the system to reach the target, $\nu_n : \bar{y}_n$ – parameters that vary.

Axioms are formed based on the tasks and Tg for each of the subtasks and the type of theory. The basis for their construction is the semantic network presentation of the object and the formulas of separate subobjects. Thus, differentials of existence are in correspondence with elementary actions of the aircraft or AT ACS in reality. The result is a set of theories that reveal the semantics of the concepts used to describe the state of objects in physical reality.

The structure of the object theory can be presented in the form of:

$$\langle TOb; StT \rangle,$$

where TOb – the name of the object or sub-object theory; StT – a description of the structure of the object or sub-object theory.

The name of the object theory can be presented in the form of:

$$TOb = \langle \mu(n, CEE) : i, \omega, T, S \rangle,$$

where μ – morphism, rising from the object; n – order of differential of existence of morphism; CEE – change in the evaluation of existence of morphism; i – the unique name of the object on which it can be recognized; ω – "possible world", which addresses the theory of the object; T – object theory type (process state space, time, etc.); S – service information (comments, existence evaluation, etc.).

The object theory structure includes syntactic constructions of subobjects theories, which are combined with each other by topological operations of Boolean algebra of the following form:

$$\langle \cap, \cup, \rightarrow, \neg, I, C \rangle,$$

where $\cap$ – connection as to the existence; $\cap$ – unexclusive "OR" according to the existence; $\cup$ – relevant logical implication; $\neg$ – addition as to the existence; I, C – taking back-ends and circling.

Rules of definition statement of correctly constructed formulas for the object structure theory.

1. Formula $\langle \mu(n, CEE) : i, \omega, T, S \rangle$ – is an elementary formula.

2. Any elementary formula is formula constructed correctly.

3. If A, B – formula, $A \cup B$, $A \cap B$, $\neg A$, $A \bullet B$, – these are also theory object formulas formed correctly.

In fig. 1 as an example, a semantic network presentation of the object X is presented. Conditions of morphism α existence includes the existence of morphisms ν_1, ν_2, ν_3 and morphisms ρ_1, ρ_2, expressing additional restrictions R1, R2 on components x_1, x_2, x_3.

Under the object X a following theory can be defined:

$$\langle \alpha(1, QP) : X, \omega; T, S \rangle$$

$$(\nu_1(1, PP) : x_1, \omega; T_1, S) \cap (\nu_2(1, PP) : x_2, \omega; T_2, S) \cap$$

$$\cap (\nu_3(1, PP) : x_3, \omega; T_3, S) \cap (\rho_1(1, PP) : R_1, \omega_1; T_4, S) \cap$$

$$\cap (\rho_2(1, PP) : R_2, \omega_1; T_4, S).$$

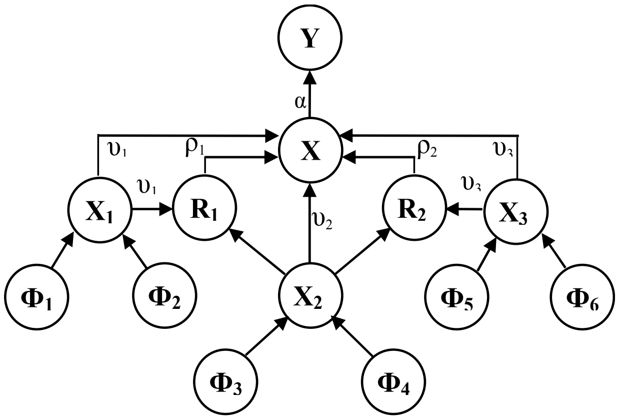

Fig. 1. The semantic network presentation of the object X

Each local object theory submitted by semantic network is associated with the theory of transformation of information that can be achieved by comparing each of the axioms from physical (abstract) object theory of the set of axioms in information theory. These theories are based on the descriptions of objects similar to the theories of physical reality.

Thus, each presentation of the object in the theory of physical reality is mapped to the correspondence of the aggregate of information converters, which transform information about the original concepts that satisfy the initial conditions, into information about the resulting concepts that must meet the new conditions (fig. 2).

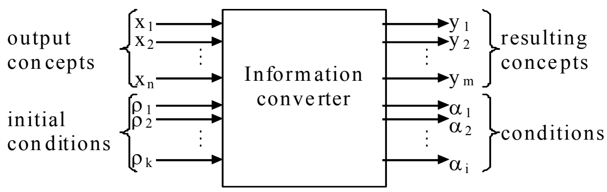

Fig. 2. Information converter

Later, information converters are to be replaced with compositions of data converters. Each of these converters serves as a component of knowledge on the order of of partial logical or computing tasks.

Each converter can be set in the following form:

$$\langle PM, \omega; \varsigma_1 : z_1, \dots, z_n; \varsigma_2 : y_1, \dots, y_m \rangle,$$

where PM – the name of the program module; ς_1, ς_2 – a list of structures of output and the resulting data.

Data structures z_n, y_m have the form:

$$\langle D, \omega, T; \mu_1, T_1 : \overline{g}_1; \mu_2, T_2 : \overline{g}_2; \dots; \mu_n, T_n : \overline{g}_n \rangle,$$

where D – the name of the data structure; $\mu_n, T_n : \overline{g}_n$ – accordingly, the name of the component of data structures, data types and data values that vary.

As the category may be used not only to describe concepts (concepts matched with the real class concepts, and examples of partial objects of reality), it is necessary to determine the structure for describing particular examples, which has the following form:

$$\langle i, \omega, T; \mu_1 : \bar{x}_1, val; \mu_2 : \bar{x}_2, val; ... ; \mu_n : \bar{x}_n, val \rangle ,$$

where i – the name of the concept for which partial examples are set, μ_n morphism that determines the type of connection (relationship) of the concept with a list of concepts (signs) $\bar{x}_n$, val – assessment of the existence of the signs that can take one of the values of the set $\{Pr, Ab, Un, Cn\}$.

The proposed designs for the description of the subject area based on the categorical model of knowledge are characterized by the following features.

Knowledge model constructions are rather generalized and require more detailed and accurate description of all components.

On the other hand, the proposed design of knowledge model is characterized by a significant complication for users who do not have formal logical device, which is the basis of categorical models of knowledge.

Concerning the features categorical knowledge models should also be noted that they have significant differences from other known models of knowledge, and this in turn requires the development of inner speech of decision making support system based on categorical knowledge model.

Conclusions

The proposed apparatus of formalization of domain knowledge allows taking into account the specific of air traffic control processes. Based on the theory of categories, each object of domain may be presented as a separate theory of object that connects according to the existence input and output descriptions as morphisms about the properties of objects. This ultimately combines descriptions of domain objects together. In the future it is possible to construct hierarchical theory of reality. Using topological Boolean algebra to construct inference theory allows going to the description of reality under uncertainty.

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АПАРАТ ФОРМАЛІЗАЦІЇ ЗНАНЬ ДЛЯ СИСТЕМИ ПІДТРИМКИ ПРИЙНЯТТЯ РІШЕНЬ ОПЕРАТОРАМИ АВТОМАТИЗОВАНОЇ СИСТЕМИ УПРАВЛІННЯ ПОВІТРЯНИМ РУХОМ

Ю.І. Полонський, С.Г. Шило, І.О. Борозенець, В.С. Мажаров

Робота спрямована на удосконалення системи інформаційного забезпечення процесів прийняття рішень операторами автоматизованої системи управління повітряним рухом. Запропоновано апарат формалізації бази знань предметної області, що базується на положеннях теорії категорій та счислення присутності. Пропонується подавати структури для опису об'єктів за допомогою системи цільових установок. На основі мережевої моделі задач і цільових установок для кожної з підзадач і типу теорії формуються аксіоми. В якості основи для їх побудови виступає семантичне мережеве подання об'єкту і формули окремих підоб'єктів. Кожному поданню об'єкта в теорії фізичної реальності співставляється у відповідність сукупність перетворювачів інформації, що трансформують інформацію про вихідні поняття, які задовольняють початкові умови, у інформацію про результуючі поняття, що мають відповідати новим умовам. В підсумку, запропонований апарат формалізації дозволяє синтезувати програми для вирішення задач підтримки прийняття рішень.

Ключові слова: *потенційно конфліктні ситуації, інформаційна модель, діяльність оператора, категорна модель знань.*

АППАРАТ ФОРМАЛИЗАЦИИ ЗНАНИЙ ДЛЯ СИСТЕМЫ ПОДДЕРЖКИ ПРИНЯТИЯ РЕШЕНИЙ ОПЕРАТОРАМИ АВТОМАТИЗИРОВАННОЙ СИСТЕМЫ УПРАВЛЕНИЯ ВОЗДУШНЫМ ДВИЖЕНИЕМ

Ю.И. Полонский, С.Г. Шило, И.А. Борозенец, В.С. Мажаров

Работа посвящена усовершенствованию системы информационного обеспечения процессов принятия решений операторами автоматизированной системы управления воздушным движением. Предложен аппарат формализации базы знаний предметной области, который базируется на положениях теории категорий и исчисления присутствия. Предлагается структуры для описания объектов представлять в виде системы целевых установок. На основе сетевой модели задач и целевых установок для каждой из подзадач, а также типа теории формируются аксиомы. В качестве основы для их построения выступает семантическое сетевое представление объекта и формулы отдельных подобъектов. Каждому представлению объекта в теории физической реальности сопоставляется в соответствие совокупность преобразователей информации, которые трансформируют информацию об исходных понятиях, которые удовлетворяют начальным условиям, в информацию о результирующих понятиях, которые должны отвечать новым условиям. В итоге, предложенный аппарат формализации позволяет синтезировать программы для решения задач поддержки принятия решений.

Ключевые слова: *потенциально конфликтные ситуации, информационная модель, деятельность оператора, категорная модель знаний.*