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Multilayer cognitive architecture for AUV control

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Аннотация Our abstract.

Keywords First keyword *·* Second keyword *·* More 1 Introduction

One of the obvious recent trends in science and technology nowadays is the rapid growth of the R&D areas related to Unmanned aerial vehicle design. UAVs themselves are becoming more cheap and thus more available both to scientists and general public day by day due to the following factors. First of all sensors which are needed in BIG NUMBERS to create any UAV are getting smaller, cheaper and more energy efficient while the quality of the output signal remains the same or even getting better (sensors become less noisy and more robust). Second, other components needed to build an UAV (rotors, carbon bodies etc.) are getting more widespread and cheap. Third, the computational efficiency of modern in-flight controllers has increased significantly. All these factors gave an impetus to the creation of the unified, moderately priced UAV platforms, such as Parrot AR.Drone [LINKS], mikrokopter [LINKS], 3DR IRIS [LINKS] to name a few, equipped with the sufficient amount of sensors, actuators, peripherals and in-flight controllers, coupled with the basic build-in software which automates the basic flight maneuvers and modes. This software typically provides easy and seamless integration of the third-party modules via the open data exchange protocols and APIs. Thus a lot of research is now focused on the development of models and methods which can be further implemented as software modules and plugged into the existing UAV platforms. As the tasks of performing basic flight maneuvers are considered to be solved and are automated with the build-in hard- and soft- ware researchers nowadays concentrate on automating such mid-level and high-level tasks as path and trajectory planning, contingency management, strategic (goal) planning, managing collaborations of the UAVs etc. Lots of research in these and other fields is done by numerous labs and research groups nowadays, see the survey [LINK] for example. Another direction of research which we are more interested in is creation models and frameworks which underlie all other methods and algorithms of the UAV control e.g. architectures of the control systems itself. Albus in [LINK] used the term intelligent control system to stress that the systems under design and development are capable of solving non-trivial, intelligent tasks (as opposed to the systems which are narrowly tailored to solve some peculiar tasks). In computational cognitive research the term cognitive architectures is widespread [LINK]. The main idea behind cognitive system is to model human cognitive activities and higher mental functions to solve such high-level tasks as goal-planning, role assignment and management (расширить, добавить, использовать правильные слова) etc.

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In our work we on the one hand deal with the non-abstract technical objects with complicated dynamics and kinematics – e.g. multirotor UAVs - and create architecture which takes it into account. In the other words, we are not interested in the architecture, which can not be further implemented as the software system which controls technical objects in real environments. On the other hand, we are not limiting ourselves to dealing only with low- and mid-level control tasks (such as UAV stabilizing, performing stand alone flight maneuvres, location and mapping, path-planning etc.) but also trying to automate high-level system’s functions (role management, group formation, goal generation and planning) using cognitive approach. As a result we present multi-layered cognitive architecture of the intelligent control system suitable of the ontrol automation fro the group of UAVs performing complicated tasks in wide range of scenarios.

1. Recent works

Numerous approaches to the creation of UAV intelligent control system and its underlying architecture exist. On the one extreme one can see ICS which uses simple, flat architecture based on functional decomposition. In that case, control system can be viewed as a bundle of modules without any hierarchy relations each of which is presumed to solve some specific task. Within this approach the following tasks are typically encapsulated: goal planning, interaction management, contingency management, situation awareness, communication management, navigation (including location, mapping and path planning) and others. One can see [LINK] as an example of such a system and architecture. On the other extreme sit unlimitly layered architectures based on abstract functional decomposition when each level of the architecture is composed of nodes which abstract different in-stances of controllable subjects (vehicle subsystems, vehicles, groups of vehicles, groups of groups of vehicles etc.) and each node is composed of fixed number of identical functional processes. The most YARKY example of such an architecture is 4D/RCS developed in NIST by the research group of professor Albus [LINKS]. In 4D/RCS the following 4 processes compromise each node of the architecture: behavior generation, world modeling, sensory processing, value judgment. In general one can think of the 4D/RCS functional process as of independent module with implicit specification: on the higher levels behavior generation is meant to be AI planning (e.g. planning in the context of actions, capabilities and high-level goals and constraints) while on the lower levels behavior generation becomes, say, path planning (planning in the context of spatial constraints) and more on the lower – control signal generation (planning in the space of UAV control inputs).

In between those two extremes lie a vast number of multi layered architectures with explicit module specification. Each module is considered to be in charge of solving some specified task(s) and the modules are grouped into levels which encapsulate the level of abstraction: the higher the level is the more abstract (and typically complicated) representation of input signals it uses to solve given task. The tasks being solved on top levels of the system are considered more sophisticated and complicated than the tasks on the bottom levels. Typically in the areas of robotics and unmanned vehicles 3 levels of control are distinguished and the corresponding 3 level architectures are proposed. Among the most widespread examples of such architectures one can name ATLANTIS [LINK], 3T [LINK], Aura [LINK] and others.

Semantics of

So “planning” or “target identification” or any other modules can not be encapsulated under

within this architecture but the corresponding functional is implemented within behavior generation and value judgment processes at some level of the hierarchy. As said before

1. General view of architecture

In the course of the project developed a conceptual diagram of the control system architecture consisting of three levels: strategic, tactical and reactive. Architecture describes (see. Fig. 1) core modules, selected in accordance with the functionality of each of the levels, as well as the interaction between them (type and direction of the transmitted data).

The main task of management at the strategic level is to build a plan of the behavior every member of the joint activity agreed upon by the members of the coalition. Each participant has its own world model, which is specific because of both the characteristic properties limiting the set of activities available to the control system and components of elements of the world model. Significant components ​of all elements of the world model for all members of the coalition are the same by definition. Plan of behaviour is constructed due to exchange messages with other members of the coalition. At each stage of the plan implementation is updated the description of the current situation, including with the information coming from the sensors. From the description of the current situation stands out temporal-spatial information, which forms the task supplied to the tactical control level and contained spatial description of the goal area and the time limits for its achievement.

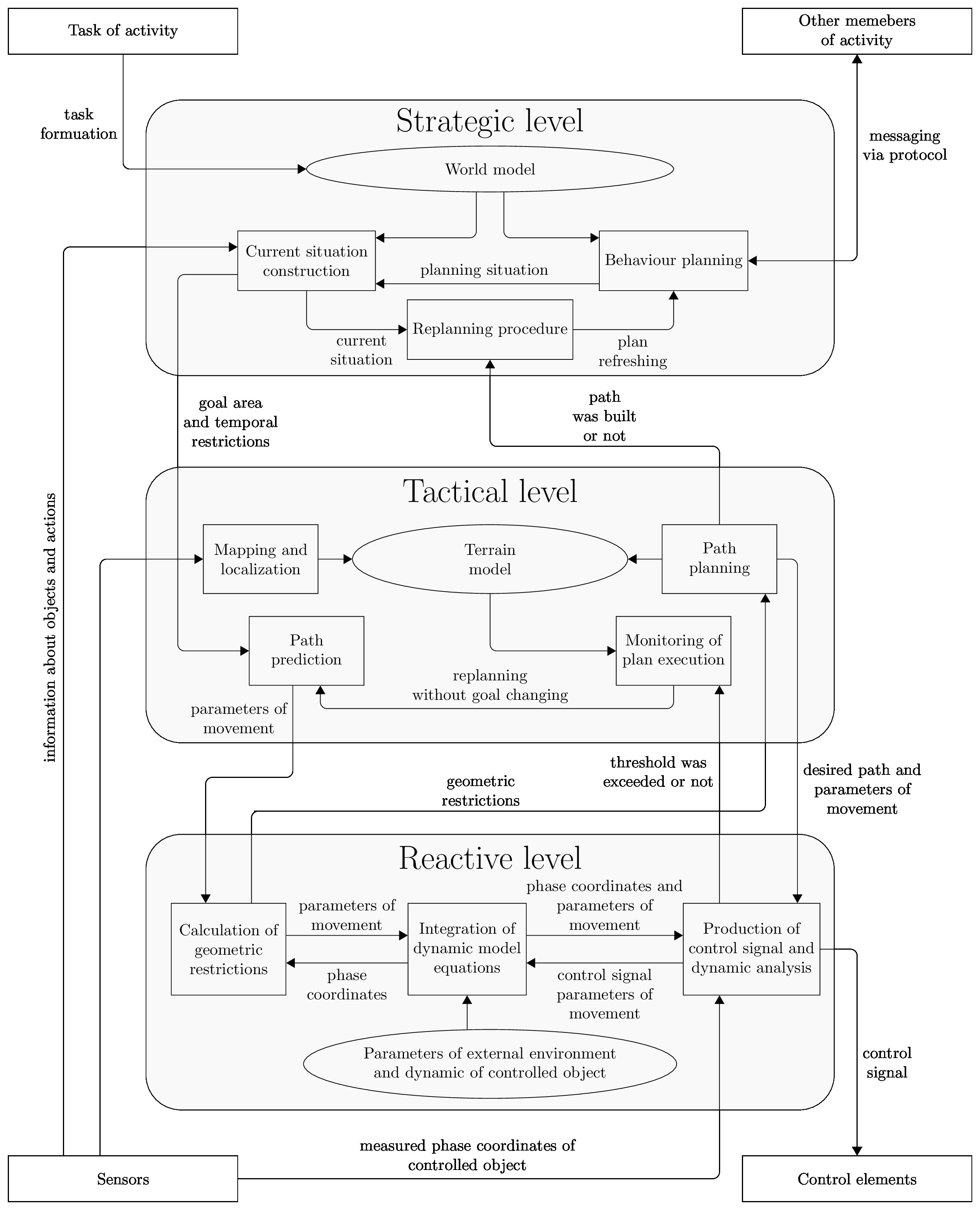


Fig. 1 Schema of proposed cognitive architecture.

Replanning procedure gets the result of the possibility or impossibility to perform the task of the movement with set restrictions and, if it's necessary, makes adjustments to the overall plan concerted with the other members of the coalition. Navigation tasks of control object in space are solved at the tactical level control, the main ones are: mapping (construction, updating, refinement of the model (map) area), localisation (binding of the control object to an existing map), and path planning. The final task is divided into 3 phases: prediction, plan construction and monitoring. Information of the goal space area and time limits on the achievement this area by control object is supplied from the strategic control level to the prediction unit, then a preliminary calculation of the necessary movement parameters (e.g. - speed) carried out to perform assigned tasks. The main difference between the prediction methods of the path and planning methods is the first one can ignore limits on the dynamics motion of control object and other limits. In this way the prediction of path is performed minimal costs of computing resources. Movement parameters calculated by prediction unit are transferred to the lower (reactive) control level, which is carried the registration of limits on movement dynamics of control object. As a result, geometric restrictions on the path form are formed, the observance of which guarantees the possibility of following through it at a fixed, previously calculated movement parameters (speed). Prediction unit constructs the path considering these geometric restrictions. The result of work is a constructed path (then a corresponding message is sent to the top level), or a signal about that task of path planning is impossible with specified restrictions (in the allotted time). In the final case, replanning request is transmitted to the strategy level, i.e. for selecting other goal area in space and / or other time limits. Thereby, the path planning is an iterative process with feedbacks from both the upper and the lower levels of control, which is a significant difference between the proposed architecture and the modern analogues. Supposed, that the use of an iterative loop "prediction - calculation of geometric restrictions - path planning - behavior planning" will significantly improve the quality of task solution of intelligent control complex technical objects, i.e. allow to solve such tasks, which can not be solved within the framework of existing approaches. The main task of control complex technical objects on the reactive level is ensuring the specified characteristics of the dynamic object via control influence by the feedback basis. For that into development procedure of the control signal desired path and desired movement parameters (for example, speed) are received from the tactical level. The level can operate in two modes: control of the real object and numerical modelling of the control. In the first case, the information about the current characteristics of the dynamic object (phase coordinates) comes from sensor and controlling is served on the control elements. In the second - information about the current characteristics of the dynamic object comes from the integration procedure equations of model of the flight dynamics, in procedure is also transmitted the current control action. At the reactive level also via the appropriate procedure is solved the task of determining the geometric restrictions on the acceptable path of movement. For that the desired movement parameters which are passed further to the procedure of integration equations of the model passed to this procedure from tactical level from the prediction unit. Based on the analysis of the received phase coordinates are determined geometric restrictions that are passed back at the tactical level to the path planning unit. In addition, at the tactical level, there is the analysis of control error, i.e. how the phase coordinates of the object (actually measured or obtained in the course of numerical modeling) differ from those specified. The error is compared with allowed threshold, the comparison result is transmitted to the tactical level in unit for monitoring the implementation of the plan.

1. Details of organization of strategic level
   1. Knowledge representation

As a basic psychological theories in which provides not only a qualitative description of the properties of cognitive functions, but also provides the structural description of the underlying mental formations were used cultural-historical approach of Vygotsky-Luria [1,2], the theory of activity Leontief [3] and the model of the psyche Artemieva [4]. According to these theories, the higher conscious cognitive functions are carried out within the framework of the so-called motivated objective activity when objects and processes are mediated by the external environment for the subject of special education, called signs. The process of engaging the sign in a particular cognitive function has three generators: an image, a significant and a personal meaning. Image component is responsible for playback and discernment mediated object or process during the activity. Significant component is a place of the sign in some overpsychological sign system that reflects in the functional sense the ways of using an mediated object or a process, which were gained of general historical practice collectivity - owner of the sign system. Finally, the personal meaning component carries its own experience of action between the subject and denotation of sign, which is expressed including in the integrated estimate of the role of denotation in its current activities: if the process or object satisfy current motive.

The three-component structure of individual knowledge, which, as mentioned above, in psychology called the sign, and confirmed by the work of neuroscientists, in which an attempt is made to construct a general theory of operation of the human brain. Thus, in the re-entry theory Edelmena [5] and Ivanitsky [6] is approved that the formation of conscious sensation or fixing input flow occurs only when the excitation activated by sensory input via the associative cortex from the hippocampus, and then from hypothalamus imposed on the sensory track on the projection cortex. This "circle of sensations" that passes over a characteristic time in the 150-300 ms, sequentially activates the three components of individual knowledge: the image (primary and sensory cortex), the significant component (hippocampus) and personal meaning (the hypothalamus). In addition, based on modern neurophysiological concepts structure of the cerebral cortex is almost uniform in its entirety (the existence of neocortical columns). Hereby the plurality of links between small enough areas of the cortex (the so-called connectome) clearly indicate its hierarchical structure and the presence of both uplink and back downlink. It follows that the components of individual knowledge element should have hierarchical homogeneous structure with ascending information flows and descending feedback. Furthermore, the significant component should have such recognition function, which except the categorization static objects and dynamic processes uses feedback signal for predicting of a sign at the next time.

To define the mathematical model of components of individual knowledge elements infinite Mili automation with variable structure and finite memory (recognizing automation or -automation):

where – the index of automation through the hierarchy, – the level of the hierarchy, – the set of input signals, – the set of output signals, – the set of control signals from the upper layer of the hierarchy, – the set of control signals to the lower layer of the hierarchy, – the set of states (Boolean of prediction matrices (see below)), – the transition function, – the vector-function of outputs. Input, output and control signals are vectors of real numbers. Each component of these vectors is a weight of recognizing or input feature.

As a recognition function of the th output feature in –automation convenient to use the set of bit prediction matrices . In these matrices each column is the prediction vector of input features in the moment , where is a start of the calculation circle (the moment of operation of the control signal ). The matrix specify the sequence of bit vectors where each bit indicates presence of a feature recognizing by the function . The algorithm that calculates the transition function and the vector-function of outputs by the initial moment , the control effect and the input effect is shown in fig. 1.

Introduction of that automation and several relationships on the set of –automata allows to define all components of the sign. The image of the sign corresponding to the feature is such subset of features where . Here the relationship is the relationship of absorption of one feature by another. If the set of columns of a prediction matrix is divided into two subsets: columns of conditions and columns of effects then each feature that has such prediction matrices is named as procedural feature. If is the feature corresponding to the sign , is procedural feature absorpted by in condition column () then is named as an element of significance of . If is the subset of features where each feature describes characteristics of the control system then the definition of personal meaning will be as follows: – the feature corresponding to the sign , – the procedural feature, , , is named as an element of personal meaning of .

* 1. Self-organized processes

On the sets of sign components specific relationships are occurred within the process of the actor activity. In its turn it leads to formation of world model of the actor. As a model of the actor’s world model three types of semantic networks were used. These are the network based on the set of sign image, the network based on the set of sign significance and the network based on the set of personal meanings. Self-organized processes on these networks involve as well the supplementation of the relationships’ collection as the formation of new nodes of the network which corresponds to the formation of a new element of individual knowledge.

Process of the formation of new sign includes the establishing connections between sign components and the naming generated structure. Until the name is not obtained this structure is called protosign and its components are called as percept evolved into sign image, functional significance evolved into sign significance and biological meaning evolved into personal meaning after sign formation completion. Common schema of the new sign formation [Osipov]:

1. The formation of percept.
2. Generation of the set of pairs “percept–functional significance” of the functional significance of the object based on earlier experience or precedents..
3. The actor obtains from the cultural environment accumulated in a natural language system the pair “sign name–significance” and evaluates the degree of closeness of the functional significance obtained in phase 2 to the significance obtained from the cultural environment. If these significances are not close enough, then the percept formation is continued by returning to phase 1.
4. Linking the name from the pair sign name–significance to the percept constructed after the completion of phases 1–3. At this time, the percept turns into an image.
5. Formation of personal meanings of the sign based on precedents of actions with the object.
6. Linking the name from the pair “sign name–significance” to each personal meaning. From this time on, the functional significance turns into the significance and the biological significance turns into the personal meaning.
7. Continuing the mapping biological significance–percept by including the personal meaning (formed in the preceding phase) in the domain and by including the image formed in phase 4 in the set of values.

Consideration of procedural features in the form of rules with defined sets of added and removal features allows construct the algorithm of the main iterative process (steps 1-3) of the described sign formation schema with -automation. To define conflictness and applicability properties of rules on the set of procedural features special operations are introduced. These are the cast of the column to the –automata () and the cast of the column to the –automata by the column ()...

1. Details of organization of tactic level
2. Details of organization of reactive level

As already noted, the main challenge for the reactive level is to provide specified dynamic object characteristics, got from tactical level, by the means of control signal generated by controller. In addition, at this level, using the appropriate procedure solves the problem of determining the geometric constraints on the admissible trajectory of movement. Let us describe the methods of controller synthesis and constraints determination which proposed in our architecture.

**6.1.** Method of controller synthesis**.**

One of the promising areas of research in the automatic control is investigations of Riccati equations with state-dependent coefficients (SDRE – State Depended Riccati Equation). Work in this area has been carrying out actively since the mid 90-ies of the last century [1,2]*.* Development and application of this technique provides a fairly general methodology for constructing suboptimal smooth nonlinear state depended controllers for nonlinear systems.

SDRE technique is based on the representation of the original nonlinear system in the quasi-linear form. This allows us to apply the procedure for stabilizing control constriction similar to procedure for optimal synthesis for linear systems by means of considering the corresponding algebraic Riccati equation, the coefficients of which are already dependent on the state variables of the original system.

Riccati equation, as in the linear case, is given by the linear quadratic quality functional, reflecting the quality requirements of the transition process by entering two weight matrices: for state and control. However, the elements of these matrices are also non-linear function of the state. This fact allows you to specify different requirements for the transition process, depending on the operating mode of the system (areas of phase space), as well as take into account the existing control constraints. For example, the requirements for trajectory accuracy is to be increased at the final stage of a missile flight or at aircraft landing, so values of the respective elements in the weighting matrix of system state is to be increased to modify the control law. In addition, the synthesized so controllers can compensate nonlinearity of control systems by means of SDRE numerical solution, take into account [2] constraints on control and system state. However, the essential issue here is a compromise between accuracy and computational complexity of method.

Originality of the proposed architecture is an approach to the construction of a nonlinear controller in numerical-analytical form. Traditional approaches for SDRE control use state space pointwise calculations, grid interpolation procedures, as well as various symbolic computation that may require a lot of computational resources in real tasks. Application of numerical-analytical form greatly reduces the computational complexity of control synthesis.

Let us consider the nonlinear control systems

|  |  |
| --- | --- |
|  | (1) |

where  – a positive constant, ,,  – a limited set in state space. Trajectory of (1) exist and is unique for any continuous control for .

***The problem***: It is required to construct a such control  for some change of , that closed system (1) is asymptotically stable, i.e.  for .

Presentation (1) has a number of advantages. It allows us to:

– deal with a wide spectrum of nonlinearity of the real system;

– construct a control on the basis of the nominal system model;

– make formal analysis and synthesis of control using asymptotic methods, based on small parameter technique.

– perform rigorous justification of stability by means of second method of Lyapunov.

Let us construct the control in the form

|  |  |
| --- | --- |
| , | (2) |

where , – some constant and variable matrices, respectively.

Let us construct the algorithm for determining the matrices in control (2). We introduce some conditions.

I.Let all the elements of the  matrices and their partial derivatives are smooth functions and uniformly bounded in a region  where is a positive constant.

Let the  matrix are controlled, namely following condition is hold

II. 

Suppose also that a positive definite matrix  is selected so that the pair of constant matrices  will be observable, ie, following condition is hold

III.

Let us consider the problem

|  |  |
| --- | --- |
|  | (3) |

It is obvious that under the conditions of II, III the zero approximation (- constant positive definite matrix, ) of this problem has a classical solution , where matrix  is a positive definite solution (let note it as ) of the matrix Riccati algebraic equation

|  |  |
| --- | --- |
|  | (4) |

Then, the zero equilibrium point in a closed system  is asymptotically stable in the Lyapunov sense, due to .

Arguing similarly in defining of the matrix  let chose it so that the final controller (2) be *formally* optimal in problem (3), where  is constant matrix and Q defines as

|  |  |
| --- | --- |
| , | (5) |

where , and the remaining terms are, generally speaking, positive semidefinite matrix. The formal solution leads us to the Riccati equation

|  |  |
| --- | --- |
| , | (6) |

where , ,

matrixes  will be chosen so that for and  equation (6) has a solution - a positive definite matrix

|  |  |
| --- | --- |
| . | (7) |

Now formally optimal controller in (3) can be found [2] in the following form of

|  |  |
| --- | --- |
| . | (8) |

By substituting (7) into (6) and taking into account (1), we obtain finite series of  due to the specifics of the operator in (6). Equating the first two terms of the expansion to zero, we obtain the equation (4) and following equations

|  |  |
| --- | --- |
|  | (9) |

Let us introduce the condition

IV.Matrix >0 for all .

If condition IV is held, then the matrix  is determined from (9) in a unique way by following analytical form

|  |  |
| --- | --- |
| . | (10) |

Thus, we obtain the following numerical-analytical algorithm for constructing suboptimal nonlinear control (8), (7) for the system (1):

1. Check the condition II, III for given constant positive semi-definite matrix .
2. Calculate positive definite solution  of the matrix equation (4)
3. Select, if possible, the matrixes ,  so that the matrix  from (9) is positive definite
4. Calculate  with a given accuracy by means (10).
5. Stabilizing control has the form (8),(7).

Let us note that for sufficiently small  defined control is solution for (6) and, in accordance with the general approach of SDRE synthesis, one may hope that it will be suboptimal for problem (3).

If the derivatives  of all coefficients of the matrix  are uniformly bounded for all  (it is a common assumption in SDRE approach) and the conditions I-IV are held, then using the Lyapunov function  it may be shown that the equilibrium  of closed system is asymptotically stable in the Lyapunov sense for all , where is sufficiently small constant, ie  for .

The controller (8),(7) can stabilize system (1) even if  is not small parameter. For local asymptotic stability it is sufficient to require additional condition

V. Pairs of matrices  and  are controllable and observable, respectively, for each pair  и .

Then under the conditions of I-V on may use the results of [3], according to which there is a local asymptotic stability of a closed system (1),(8), (7) even if  is not small parameter.

Thus, in our architecture we produce numerical-analytical algorithm for constructing nonlinear controller, which greatly reduce the amount of computation compared with traditional procedures of SDRE control approach.

**6.2. Method of constraints determination**

For the case of flight in a horizontal plane tactical level algorithms are trying to construct a trajectory in the form of such straight lines sequence that the angle between any adjacent lines of the sequence does not exceed (in absolute value) a fixed value α. It is assumed that satisfaction of this condition ensures the feasibility of the resulting trajectory, ie the possibility of constriction of a admissible control signals to follow trajectory with the specified error. Proposed method of geometric constraints determination is based on numerical analysis of attainability domain of dynamic system. The exact solution of this problem usually requires large computational cost. So confine ourselves to a simplified approach based on certain plausible assumptions. Nevertheless, the proposed approach is rather general for a lot of applications.

Our basic assumption is that the flight conditions and precise of control within its constraints are such that there is a possibility of constructing admissible control which guarantee that UAV is located in some admissible neighbourhood of desired *straight-line* trajectory. This neighborhood is defined by the "tube" with a radius *rd* (see. Fig. 6.1). The specific value of *rd* depends on the type of UAV, conditions and mode of flight and so on. It is assumed that values of we *rd* is known (e.g., based on the operating experience of the selected UAV).



Fig. 6.1. To the method of geometric constraints determination.

Obviously, for case of trajectory breaking shown on Fig. 1 the location of UAV at point *P* not belonged to “tube” is the worst challenge for control. Let us consider additional area defined by a circle *С* with a given radius *R*d and centered at point *P*. It is assumed that any point in *С* does not contain obstacles. It is assumed also that in the worst case, which is considered below, the velocity vector *Vg* of UAV is deflected from desired flight trajectory before breaking in point *P* through a maximum angle *α*v (see. Fig. 6.1). Then the problem of geometric constraints determination may be formulated as follows. It is required to find a such maximum angle α, that a UAV trajectory, without leaving the circle *С*, will return again in the admissible "tube" and no longer leave it, since the basis assumption above, there is always admissible control guaranteed it. Radius *R*d determines some maneuver area, which should not contain obstacles.

Next, it is assumed that *R*d value is given and the value of the velocity *Vg* is supplied as a parameter from the tactical level. Let axis Oxg, Ozg of Earth coordinate system Pxgygzg is oriented as shown in Fig. 6.1, and the axis Oyg is oriented vertically upward. Then the following algorithm for angle α determination is correct:

1. Make a numerical simulation of UAV dynamics, starting at the point *P* withvelocity *Vg*, up to the time  at which:
   1. trajectory crosses the circumference corresponding to circle *C* . Then go to step 2 of algorithm;
   2. or following inequalities are held:

,

where  – UAV coordinates in Pxgygzg at time . Then go to step 3 of the algorithm;

* 1. or the maximum simulation time is reached. Then go to step 3 of the algorithm.

1. Calculate angle α by the formula

**α()** .

The end of algorithm.

1. There are no restrictions on the geometry. The end of the algorithm.

Step 1.2 corresponds to the case when **α**, i.e. there are no restrictions on the geometry. Step 1.3 corresponds to the case when behavior UAV dynamics is rather complicated: the trajectory does not leave sectors IV, I of circle *C*. For sufficiently large simulation time it may be concluded that the restrictions on geometry of trajectory are also absent. It is obvious that if the condition 1.2 or 1.3 is held, then setted value of *R*d is too big for the selected UAV and flight conditions. Negative value of the angle α denotes too small setted *R*d value.

The proposed method was tested for the mathematical model of AscTec Hummingbird quadrocopter [24]. The maximum value of angle α for *Vg* = 7 m/s, *α*v = 45˚ was defined as 24.4˚.

Thus, a quite general method of geometric constraints determination is proposed. It’s based on model of flight dynamics, as well as some plausible assumptions.

1. 7 Conclusion

В последнее время наблюдается повышенный интерес к автономным летательным

аппаратам вертолетного типа. Исследователями было предложено множество архитектур систем управления такими аппаратами. Большая сложность реализа- ции автономных вертолетов приводит к тому, что двухкомпонентная архитектура систем управления, состоящая из делиберативного и реактивного уровней, стано- вится неэффективной и появляется необходимость явного выделения иерархичной трехуровневой архитектуры, содержащей стратегический, тактический уровни и уровень управления.

На стратегическом уровне осуществляется высокоуровневое планирование, в ходе которого стоится последовательность действий, решающих поставленную пе- ред автономным летательным аппаратом задачу. Этот уровень является наименее проработанным, и существующие подходы обладают существенными недостатка- ми. Преодоление основной трудности – проблемы автономного целеполагания – может быть достигнуто с помощью создания такого представление знаний, в ко- тором описание действий с понятием, связи этого понятия с другими понятиями и процедуры выделения этого понятия из сообщений с нижележащего уровня управ- ления представляли собой одну единицу знаний.

На тактическом уровне решаются задачи навигации БЛА и ключевой является задача построения траектории. Основная трудность, возникающая при решении последней, – громоздкость модели, описывающей трехмерную окружающую среду. Целесообразным способом преодоления указанной трудности является использо- вание эвристических и декомпозиционных алгоритмов планирования.

На уровне управления основной задачей является построение регуляторов и наиболее перспективно развитие методов синтеза нелинейных робастных регуля- торов с гладким управлением, обладающих строгим математическим обоснова- нием. Для улучшения работы полученных регуляторов возможно их совместное применение с механизмами адаптации (асимптотические наблюдатели, методы ИИ и др.), не нарушающих найденные условия устойчивости замкнутого контура.

Разработанная архитектура позволяет решать большой спектр задач управ- ления коалициями сложных технических объектов в динамической среде и будет использована для создания экспериментального образца программного обеспече- ния многоуровневой системы управления на следующих этапах работ по проекту.

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