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FUZZY CONTROL OF AUTONOMOUS QUAD-ROTOR

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ABSTRACT

This article is devoted to control of quad-rotor. of using optical system for correction movement of an aircraft during landing in area given by landmarks under conditions of adverse visibility. The algorithm founded on fuzzy logic is used in method of the image recognition. The problem of unmanned aircraft landing on signal objects is considered in the article. Suppose that there are two signal objects on direction of moving an aircraft. The problem is clearly to select these objects. The method of complex dynamic system such as quad-rotor control through the application of fuzzy controller is considered. Multiagent approach to control under conditions of uncertainty of environment is considered.

Index Terms - navigation, dynamic system, signal objects, landing, aircraft, vision responsive control

1. INTRODUCTION

Modern dynamic objects are equipped with increasingly diverse control systems, among which the intelligent systems take a special place. Their main task is a search optimal decisions under uncertainty, characteristic for the object motion in a real environment. Supplying the dynamical systems with sensors of different nature, including video, which takes one of the first places.

Processing the video stream which is obtained from a video system installed at the facility, involves solving a number of tasks traditionally belonging to the category of artificial intelligence: pattern recognition, definition of the parameters of trajectory of motion by signal objects and others. In addition, tasks of definition in the video stream of useful information: target objects, the recommended trajectory. Some problems and their solutions were published by the authors in [1,2].

The purpose of this work is the development of intellectual abilities of control system in the direction of interaction with the external environment on the basis of multiagent approach.

The formulation and methods of solving these problems for a quite promising aircraft – quad-rotor are proposed below.

Quad-rotor is an aircraft in the form of rigidly connected four propeller rotors in a cross design diagram (Fig. 1). Rotors in pairs rotate in different directions to reduce the gyroscopic moment of aircraft.

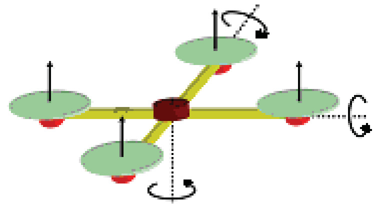

Figure 1 Diagram of quad-rotor

2. POSITION CONTROL CIRCUIT

Aircraft position control and the rotation around the axes are carried out by the changes of axial forces of rotors f_1, f_2, f_3, f_4. The inner circuit provides quad-rotor position [3].

Using the fuzzy controller is proposed for implement the internal circuit $FC : \varepsilon, \dot{\varepsilon} \to f_i, i = \overline{1,4}$.

Control system is a set of rules for solving problems of quad-rotor navigation. With introducing linguistic variables – Low, Middle, High for denoting the axial forces of the rotors the following control rules can be formulated:

If mode is «Climb» then

f_1 *is High*, f_2 *is High*, f_3 *is High*, f_4 *is High.*

If mode is «Hovering» then

f_1 *is Middle*, f_2 *is Middle*, f_3 *is Middle*, f_4*isMiddle.*

If mode is «Descent» then

f_1 *is Low*, f_2 *is Low*, f_3 *is Low*, f_4 *is Low.*

If mode is «Motion to the left» then

f_1 *is Middle*, f_2 *is Middle*, f_3 *is High*, f_4 *is Low.*

If mode is «Motion to the right» then

f_1 *is Middle*, f_2 *is Middle*, f_3 *is Low*, f_4 *is High.*

If mode is «Forward motion» then

f_1 *is Low*, f_2 *is High*, f_3 *is Middle*, f_4 *is Middle.*

If mode is «Backward motion» then

f_1 *is High*, f_2 *is Low*, f_3 *is Middle*, f_4 *is Middle.*

If mode is «Turn by clockwise» then

f_1 *is High*, f_2 *is High*, f_3 *is Low*, f_4 *is Low.*

If mode is «Turn by counterclockwise» then

f_1 *is Low*, f_2 *is Low*, f_3 *is High*, f_4 *is High.*

Introducing a similar set of rules one can solve problems of quad-rotor motion control for a given program (an example in Fig. 2) in nondeterministic environments with a special set of commands with such structure <mode, duration>, for example: <Climb, 10 sec>, <Forward, 20 sec>, <Hovering, 15 sec>,….

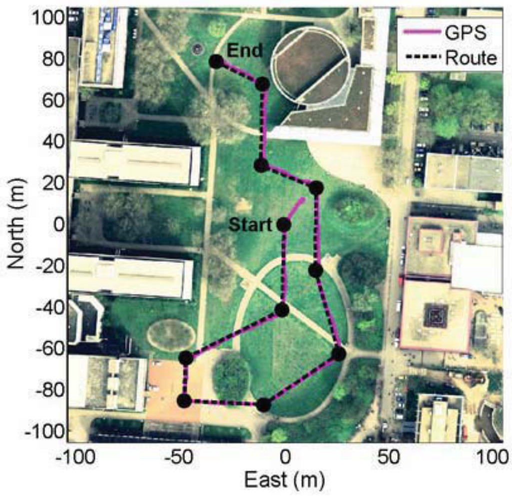

Figure 2 Example of flight program

3. LOGIC CONTROL CIRCUIT IN MULTIAGENT ENVIRONMENT

The external circuit is designed for logic control in a nondeterministic environment, i.e. when the environment is partially known.

Control feature is that quad-rotor capable of moving in three-dimensional environment in an arbitrary manner that allows to formulate a set of movement alternatives, as opposed to the two-dimensional environment, in which the problems of decision-making are usually considered.

Solving the main control problems associated with the execution of the flight mission in offline mode, is connected with decision making in conditions of active and nondeterministic environment. One of the modern approaches in the control is an agent-based performance control tasks. Quad-rotor may be represented as an agent, which makes a decision in a changing external environment. We'll divide the space in which there is quad-rotor into a three-dimensional grid with edge length corresponding to the average distance that quad-rotor travels during the processing of two adjacent frames. If the speed of video – 1 / 10 sec., the average flight speed – 10 m / s, time for work of the algorithm for determining the position – 1 / 20 sec., then the edge length – 1.5 m.

Quad-rotor in agent interpretation can be represented as a pair $Ag = \langle shmP, M \rangle$, where P – diagram of agent (database and knowledge), $M = \{Per, Dec, Trans\}$ – methods, which an agent has: perception $Per : E \to A_{in}$, decision-making $Dec : A_{in} \to A_{out}$, changing of environment $Tran : A_{out} \to E'$. Intellectual property of agents depend on dependence of ways of realization of these operations. Let us suppose the existence of the world.

Let us the existence of the world in which there is one or more agents (quad-rotors), and in which they can perceive information, make decisions and act. Collect information that the world contains at some time step t, and which corresponds to the task, is called a state of the world and is denoted as s_t. The set of all possible states of the world is denoted by s.

Let's consider a discrete set of time steps t = 0,1,2, ..., on each of which the agent must choose an action a_t from a finite set of available actions A. Intuitively, we assume that in order to act rationally at time t, while choosing the action agent must take into account past and future. The past includes the previously perceived information and the actions performed to t, the future – what kind of information the agent expects to receive and what actions to perform after the time t.

Suppose the following set of actions and the environment, respectively:

$$A = \{A_1, \ldots, A_n\}, E = \{E_1, \ldots, E_m\}.$$

Current actions is an element of set

$$a_i = A_j, i = 0,1,2,3, \ldots, j = 1, \ldots, n,$$

and current observations is an element of set

$$\theta_i = E_j, i = 0,1,2,3, \ldots, j = 1, \ldots, m.$$

Let θ_τ be observation of agent at time τ, while that for the optimal choice of action at time t the agent must take into account the complete history of observations θ_τ and actions a_t for $\tau \le t$. Conduct policy of agent is a function type

$$\pi(\theta_0, a_0, \theta_1, a_1, \ldots, \theta_t) = a_t \qquad (2)$$

which is based on all the perceived information for the time t and all actions to the last perception defines the behavior of the agent at time t (Fig. 3).

Figure 3 Determination of agent policy

During each call of function the memory of agent is updated and reflects new perception, and then the best solution is chosen, and this fact is stored in memory. The contents of memory is saved from one call to another. At each time t the agent chooses an action from a finite set of actions A.

The model of transition (world model) defines how the external environment changes under the action performed by the agent.

If the current state is s_t and the agent chooses the action a_t, one can consider two cases: in a deterministic world it is a model of transition – a mapping operation (s_t, a_t) into the new state s_{t+1} and in a stochastic world it is a probability distribution $p(s_{t+1}|s_t, a_t)$.

In the case of partial visibility of the environment, typical for dynamic system control, such an approach to modeling is more acceptable. In addition to the environmental conditions and actions of the agent it is useful to introduce also the function of preference $U(s)$, which gives the real number in correspondence to each of environment state.

Formally, for two states s and s', $U(s) > U(s')$ are fulfilled, then and only then the agent prefers state s of s', and $U(s) = U(s')$ then and only then the when for the agent states s and s' are indistinguishable.

To generate actions of agent - quad-rotor first of all must one define the set of possible states of the agent, taking into account the external environment, and a lot of actions.

We define the state of the agent in the form of vector <position,bar,goal> with elements: position – the position of quad-rotor as a vector of linear and angular displacements $(x, y, z, \alpha, \beta, \gamma)$, bar – presence of obstacles in different directions (front, left, right), goal – a sign of being in the target state («Hovering» over the given object, the detection of a certain goal, etc.).

The results of video with the definition of motion parameters on the basis of projective transformations are suggested to be used for determining of the position The algorithm is proposed in [1]. The presence of bar for motion of quad-rotor is defined based on video surveillance.

Then the base of rules for determining the behavior can be presented in form of Table 1:

Table 1: Agent knowledge base «Quad-rotor»

State	Action
Bar-front is true and Bar-rirgt is true and Bar-left is true	The mode «Climb»
Goal is true	The mode «Hovering»
Bar-front is true and Bar-rirgt is true	The mode «Motion to the left»
x is high and y is low and z is middle	The mode «Forward motion»
…	…

Formed knowledge base allows to perform various tasks of en-route flying. However, choice of agent policy is important under uncertainty, when the obstacles can not be recognized right now, but at some approximation to them. For this purpose, hypothesis about possible obstacles to the current images and the formation of the utility function are formed.

Let's consider the function that determines the best strategy in the form

$$a_t^* = \underset{a_t \in A}{arg\,max} \sum_{s_{t+1}} p(s_{t+1}|s_t, a_t) U(s_{t+1}),$$

where $U(s)$ – utility function of state $s(x, y, z)$, $p(s_{t+1}|s_t, a_t)$ – transition probability from state s_t in state s_{t+1}.

4. ILLUSTRATIVE EXAMPLE

Let us consider this problem in more detail on the following example. For simplicity of description the two-dimensional model of the world is considered.

Let the world in which the agent quad-rotor operates enable the agent to do the following steps: {Up, Down, Left, Right}.

Let us consider the case of full visibility of the agent, i.e. the agent knows its location.

Let also specified terminal states be desired (goal) with the function of preference 1, and two undesirable states with values of -1. Fig. 4 shows an example of the world fragment with the values of the function of the agent preferences at the nodes of permissible location. Each position is estimated a priori and the values of preferences are shown in Fig. 4. Let the initial state be the state of A1. Let us consider the transient stochastic model of the world with given transition probabilities to the desired state – 0.8, and perpendicular states – 0.2.

Suppose that each position is estimated a priori and the values of the utility function are shown in Fig. 4. Suppose also that the probabilities of states transition are given. Let us consider choice of the best transition from point B3. Let us define the best strategy in accordance with the formula:

$$\pi^*(s) = \underset{a}{arg\,max} \sum_{s'} p(s'|s, a) U^*(s').$$

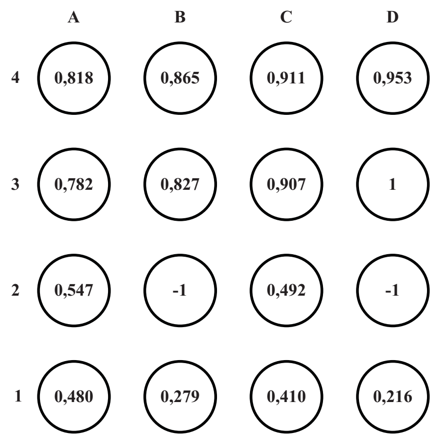

Figure 4 Fragment of world

The following motions of quad-rotor:

1. The mode «*Climb*»

$$p(B4|B3,Up)\cdot U(B4)+p(A3|B3,Up)\cdot U(A3)+$$
$$+p(C3|B3,Up)\cdot U(C3)=$$
$$=0.8\cdot 0.865+0.1\cdot 0.782+0.1\cdot 0.907=0.8609.$$

2. The mode «*Motion to the right*»

$$p(C3|B3,Right)\cdot U(C3)+p(B4|B3,Right)\cdot U(B4)+$$
$$+p(B2|B3,Right)\cdot U(B2)=$$
$$=0.8\cdot 0.907+0.1\cdot 0.865+0.1\cdot(-1)=0.7121.$$

3. The mode «*Motion to the left*»

$$p(A3|B3,Left)\cdot U(A3)+p(B2|B3,Left)\cdot U(B2)+$$
$$+p(B4|B3,Left)\cdot U(B4)=$$
$$=0.8\cdot 0.782+0.1\cdot(-1)+0.1\cdot 0.865=0.6121.$$

4. The mode «*Descent*»

$$p(B2|B3,Down)\cdot U(B2)+p(C3|B3,Down)\cdot U(C3)+$$
$$+p(A3|B3,Down)\cdot U(A3)=$$
$$=0.8\cdot(-1)+0.1\cdot 0.907+0.1\cdot 0.782=-0.6311.$$

Obviously, the best solution gives mode «*Climb*», despite the fact that $U(B4)<U(C3)$.

5. CONCLUSION

In this work the problems of UAV (type quad-rotor) control have been considered. Features of this aircraft allow to consider various pithy control tasks, among which: to stabilize the motion in various modes, to choose mode for solving problems performing flight mission, to define navigation parameters based on video stream processing, to interact with the environment and other aircraft. The use of the theory of fuzzy logic, multi-representation, as well as methods of computational geometry are suggested as a body of mathematics for solving these problems. Perspective integration into the control circuit of intellectual functions, allowing to assess the current situation (the detection of unforeseen obstacles, the reaching of the target, etc.) and to adjust automatically the program based on the motion of quad-rotor embodied logic of behavior.

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