UDC 681.5

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Corporative control of unmanned aerial vehicles based on synchronized motion

The paper considers the group control of UAVs that move along the route determined by the virtual leader. To solve the control problem, an approach based on synchronized movement along the route was applied. The control system uses PID controllers to generate signals that control the movement of an individual UAV.

Introduction

Unmanned aerial vehicles (UAV) are used to solve various commercial, civil and military tasks. An important application is the delivery of cargo to its destination. The UAV payload can be a package from an online store, a medical item to a hospital or a disaster area, or spare parts for maintenance in remote locations in commercial and civil fields. Payload delivery is also possible for military missions and is a safer alternative for delivery to hard-to-reach areas.

Various implementations of group control are possible. Traditionally, a group is presented as a leader-follower structure; the group can also act in a potential field or have a different nature of behavioral actions. However, recently the structure with a virtual leader has attracted interest when the leader represents a certain center of the group. The main advantage of this scheme is that each UAV has its trajectory along which the flight is carried out relative to the virtual leader. Therefore, the VL approach does not require interaction between team agents. It is believed that the structure is stable due to the absence of perturbations acting on the leader and, therefore, has a low probability of destruction of the structure.

The article considers the problem of the movement of a group of UAVs, the structure of which contains a virtual leader, along a given route.

Related work

The main result of [1] is the implementation of the optimal strategy for managing the “winner takes all” (WTA) model when moving towards the goal and joint competition of several UAVs (unmanned aerial vehicles). The proposed approach allows, under conditions of joint competition of several UAVs, to find the minimum control energy of several UAVs to implement the optimal route to the target.

An algorithm for the cooperative control of UAVs in the joint transportation of goods based on the decentralization of object management was proposed in [2]. The algorithm is implemented by a non-linear robust feedback controller, which constructs a total control vector based on the individual ones for each quadcopter.

An overview of some key deep learning and reinforcement learning methods for UAV control is presented in [3]. In particular, the issues of using information obtained by computer vision sensors for autonomous control and navigation, suitable kits for modeling and prototyping hardware platforms, security issues, and rules for using UAVs are discussed.

Stabilization, path tracking, and control of a UAV team consisting of a leader and a follower using a pair of controllers are studied in [4]. The PD2 controller is responsible for attitude stabilization, and the Integral Backstepping controller monitors the flight path and controls the movement of the leader-follower quadcopter. This non-linear control method divides the control into two loops: the inner loop is for position stabilization and the outer loop is for position control.

A robust servo control system based on a command initiated by an event H_∞ for several VTOL UAVs in a network system is studied in [5]. A tracking system with several UAVs triggered by the event H_∞ is transformed into an optimization problem with constraints by Hamilton-Jacobi inequalities. To solve this problem, Takagi-Sugeno fuzzy methods are used, which give an efficient approximation of a nonlinear system with several UAVs by a set of local linearized network systems.

Main results

The problem of motion by the route by several UAVs is considered. To solve this problem, a circuit with a virtual leader (VL) is used. An element of the UAV group is a four-engine device, implemented according to the scheme of a quadrotor.

Let us imagine that the dynamics of the virtual leader, as in [6], is described by a system of second-order differential equations to (x, y, z) the Cartesian spatial coordinate system, and (θ, φ, ψ) the Euler angular coordinate system. The Cartesian coordinates of the group elements differ from the same coordinates of the leader by horizontal shifts relative to the leader, the angular coordinates are the same, i.e.

$$x_i = x^* + \Delta x_i\,,\ y_i = y^* + \Delta y_i\,,\ z_i = z^* + \Delta z_i \tag{1}$$

$$\theta_i = \theta^* + \Delta\theta\,,\ \varphi_i = \varphi^* + \Delta\varphi\,,\ \psi_i = \psi^* \tag{2}$$

where Δx_i, Δy_i, and Δz_i are deviations relative to the spatial coordinates of the leader x^*, y^*, z^*; θ^*, φ^*, ψ^* – angular coordinates of the leader; i is the group member, $i \in [2, N]$. Equations (2) say stabilization of the position of the ith UAV along the trajectory in the Euler coordinate system. The geometric center of the structure coincides with the center of the location of the virtual leader, the angles $\Delta\theta$, and $\Delta\varphi$ determine the position of the ith UAV relative to the z-axis. Thus, we have a system with $N \geq 2$ UAVs and nonholonomic constraints.

It is assumed that the UAV structurally has sensors for measuring flight coordinates, elements of the flight control system. In addition, information about the route of the virtual leader is available to him. It is also assumed that there is no noise in the coordinate measurement channels. The cargo has a perturbing effect on the movement of each UAV.

The trajectory will be considered a straight or curved section of the route when moving toward the goal. The task of control is to stabilize the trajectory control of the group, the structure of which corresponds to the virtual leader.

In the interests of achieving control goals, it makes sense to present the control system in two parts, the first one solves the problem of controlling a separate quadrotor, and the second solves the problem of trajectory control. This approach makes it possible to implement the quadrotor control system as a system of angular stabilization at a given height, and the movement along the route of the quadrotor is represented by a change in the spatial coordinates *x* and *y* by the chosen law. In this case, the coordinates z and ψ are fixed, and angles θ and φ are stabilized. To control the flight of the quadrotor, we will use PID controllers. The architecture of the control system is shown in Fig. 1.

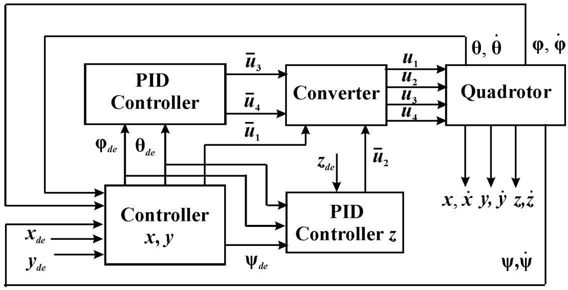

Fig. 1. The scheme of the quadrotor

The control of the quadrotor along the z coordinate is set by the PID controller, which generates signals in the form

$$u_{z_{de}} = k_{pz}(z_{de} - z) + k_{iz}\int_{t_0}^{t_k}(z_{de} - z)dt + k_{dz}(\dot{z}_{de} - \dot{z}) \tag{3}$$

$$u_{\psi_{de}} = k_{pz}(\psi_{de} - \psi) + k_{iz}\int_{t_0}^{t_k}(\psi_{de} - \psi)dt + k_{dz}(\dot{\psi}_{de} - \dot{\psi}) \tag{4}$$

where k_{pz}, k_{iz}, k_{dz} are the corresponding coefficients of the proportional, integral, and differential block of the PID controller that controls the *z* coordinate; $k_{p\psi}$, $k_{i\psi}$, $k_{d\psi}$ are the corresponding coefficients of the proportional, integral, and differential block of the PID controller that controls the coordinate ψ.

Rotational dynamics is determined by the equations [6]

$$\dot{\Phi} = \omega\Theta - \frac{J_r}{J}\Theta\Omega + l\bar{u}_3 = \omega'\Theta + l\bar{u}_3 \tag{5}$$

$$\dot{\Theta} = -\omega\Phi + \frac{J_r}{J}\Phi\Omega + l\bar{u}_4 = -\omega'\Phi + l\bar{u}_4 \tag{6}$$

The control signals $\bar{u}_3$, $\bar{u}_4$ by the quadrotor along the coordinates *x* and *y* are also set by the PID controller, which generates a control signal of the form

$$\bar{u}_3 = k_{px}(x_{de} - x) + k_{iz}\int_{t_0}^{t_k}(x_{de} - x)dt + k_{dz}(\dot{x}_{de} - \dot{x}) \tag{7}$$

$$\bar{u}_4 = k_{pz}(y_{de} - y) + k_{iz}\int_{t_0}^{t_k}(y_{de} - y)dt + k_{dz}(\dot{y}_{de} - \dot{y}) \tag{8}$$

The route of the group's movement is specified by the coordinates x_{de}, y_{de} in the horizontal plane and the angular coordinate of the direction ψde by the desired trajectory of the virtual leader.

To illustrate the effectiveness of the proposed solution for the synchronous movement of the UAV group, some model experiments were carried out. The experiments covered the movement of a group of 2, 3, 4, and 5 UAVs, which moved along rectilinear and curvilinear trajectories. Measurements were made of the master and output signals, deviations relative to the route of the virtual leader, as well as control actions for each aircraft. The conducted experiments showed good results and give hope for the practical implementation of the proposed approach.

Conclusions

The article proposes a new approach to group control, which assumes the synchronous movement of the UAV along the route determined by the virtual leader. The results of experimental modeling of the synchronized motion of a group give hope for further practical use of the proposed approach. The proposed approach can be further compared with approaches using backward step control to evaluate its effectiveness, for example [7]. Further research can be applied to group management in solving practical problems, such as delivering goods.

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