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Organization of Interaction Between A Group of Unmanned Aerial Vehicles and A Ground Control Station

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Abstract

This paper examines the use of civilian UAV swarms in urban environments, focusing on improving communication through a specialized relay quadcopter with a narrow-beam antenna. Swarm operation offers cost efficiency and reliability but requires precise navigation and stable communication amid urban interference. By combining navigation data from all swarm elements, the system achieves accurate positioning to guide the relay's antenna, enhancing range, interference resistance, and security of the link to the ground control station. The study also reviews antenna control systems and communication standards like WiMax. Although relay use may cause data delays and risks from single-point failure, redundancy strategies help maintain reliable communication, making the approach promising for urban UAV applications

Keywords: Unmanned Aerial Vehicles (UAVs), UAV swarm, narrow-beam antenna, autonomous flight, navigation system, radio communication, urban environment, swarm coordination, WiMax technology, communication relay, interference resistance, payload, flight control, data transmission, redundancy.

Introduction

Unmanned aerial vehicles (UAVs) are currently being actively used in urban environments. Functionally, a civilian UAV is designed to carry various onboard equipment—referred to as the payload.

The payload of UAV systems includes [1]:
- observation equipment (sensors of various wavelength ranges);
- communication and data transmission equipment;
- cargo delivery means.

The payload can be placed both inside the UAV and on its external mounts.

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Automatic systems of civilian UAVs, equipped with a full autopilot, require minimal training of ground personnel, while performing tasks at a great distance from the base location, out of contact with the ground station, and in any weather conditions. They are easy to operate, mobile, quickly deployable, and do not require ground infrastructure. The high performance of UAV systems and complexes equipped with a full autopilot reduces operational costs and personnel requirements. The presence of a full autopilot is what distinguishes a UAV from a remotely controlled model [2].

UAV flight control — management of its movement parameters [1]:
- angular coordinates;
- angular velocities and accelerations;
- range;
- altitude;
- lateral displacement.

Modern onboard navigation and control systems of civilian UAVs include [1]:
- integrated inertial navigation system;
- satellite navigation system receiver;
- UAV autopilot module.

Main tasks of the UAV autopilot [2]:
- automatic control of the UAV during flight along a specified trajectory;
- stabilization of the UAV's angular orientation during flight;
- determination of navigation parameters (coordinates, angular orientation, UAV motion parameters);
- transmission of telemetry information about navigation parameters, angular orientation, and UAV control parameters;
- control of onboard equipment.

Let us describe the advantages of using a swarm group of UAVs for civilian applications [3]:
- reduction in UAV cost due to mass production of inexpensive single-function UAVs, compared to multifunctional individual UAVs;
- duplication of the payload ensures the quality of task execution;
- exchange of navigation data within the "swarm" ensures the quality of position and orientation determination of the swarm elements;
- ability to transport (deliver) a large volume of cargo.

Disadvantages:
- The need for precise determination of the position and orientation of each element of the "swarm";
- organization of communication between the elements of the "swarm";
- the need to organize the structure (formation) of the flight of the "swarm" elements;
- organization of interaction between the UAV group and the ground control station.

However, in the presence of interference in urban environments (2.4 GHz, 5.6 GHz), control of the "swarm" of quadcopters must be continuous, stable, and prompt. To improve radio communication characteristics, it is proposed to use narrow-beam antennas in the "swarm" (on the leading quadcopter). Since narrow-beam antennas need to be directed at the radio communication subscriber with high precision, combining navigation data from all elements of the "swarm" will allow determining the position and orientation of the quadcopter with the narrow-beam antenna with sufficient accuracy [4].

Thus, the navigation system of civilian quadcopters must solve the following tasks [4]:

- preparation for launch using commands and data from the launch system of each quadcopter, ensuring control of the onboard equipment status of the “drone” and providing the control results to the launch system;
- execution of automatic flight for each quadcopter along the established route, maintaining flight parameters (altitude, speed, and course) specified for each segment of the route, as well as maintaining the specified distance between elements of the “swarm”;
- targeting an object specified by the operator or by the reconnaissance and aiming system of the “single-function” quadcopter;
- guidance of the “swarm” or a group of swarm elements to an object with specified geographic coordinates;
- targeting an objective marked on a digital terrain map or on a video image of the terrain by a “functional” UAV;
- return to the landing site, execution of the pre-landing maneuver, and landing of the group of quadcopters;
- the ability for the operator to participate in the flight control process of each quadcopter, taking into account its position within the “swarm”;
- execution of various tasks in challenging weather conditions, under natural and artificial interference, including in urban environments and rocky-forested terrain;
- aiming the narrow-beam antenna of a specialized quadcopter with the required accuracy at the radio communication subscriber.

Therefore, improving the accuracy of determining the coordinates and orientation of each quadcopter in the “swarm” is relevant and enhances the radio communication characteristics between the specialized quadcopter and the radio communication subscriber (ground control station).

The authors of the article propose using comprehensive processing of navigation information from each element of the “swarm” to calculate a navigation correction coefficient [4].

The proposed typical operation of the narrow-beam antenna on the quadcopter is shown in the figure 1 [5].

A typical narrow-beam antenna control system includes:

1. An antenna system (AS), whose radio-technical parameters are selected based on requirements ensuring the necessary communication range;
2. AS servomechanism, providing spatial orientation of the AS radiation pattern (RP) towards the radio communication subscriber;
3. Automatic direction tracking system (ADT), ensuring stable automatic tracking of the radio communication subscriber within the confident capture zone of the ADT system’s bearing characteristic;
4. Radio receiving device, ensuring the generation of the “Communication” signal, which determines the reception of information with the specified quality;
5. AS control processor, providing:

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- analysis of the current state of the AS control system;
- generation of control signals for the servomechanism to ensure the spatial orientation of the AS in accordance with the flight mission and the spatial scanning algorithm;
- analysis of communication availability;
- analysis of the possibility of switching the AS servomechanism from “External Control” mode to “Auto-Tracking” mode;
- generation of the signal to switch the AS servomechanism to “External Control” mode.

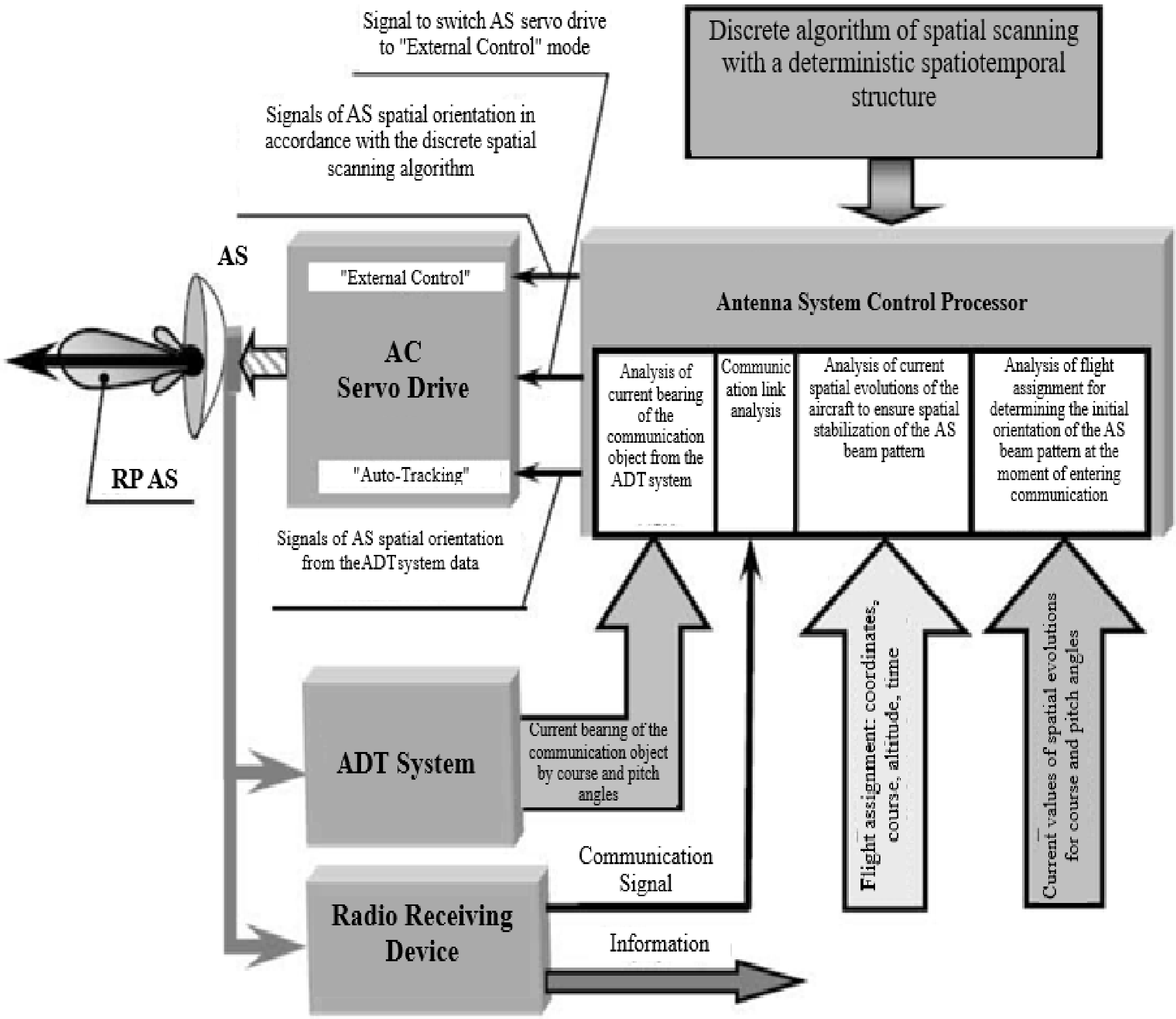

Diagram of the narrow-beam antenna on the quadcopter

Possible operating frequencies correspond to communication standards (Wi-Fi, WiMax).
WiMax 802.16d Technology Parameters [6]:
- throughput up to 75 Mbps;
- range 20–80 km;
- frequency range 1.5–11 GHz.

Parameters of the promising WiMax 2 802.16m technology [6]:
- throughput up to 0.1–1 Gbps;

- range 120–150 km;

The parameters of the WiMax 802.16d technology meet the radio communication requirements imposed on the quadcopter–ground control station radio link. The use of the advanced WiMax 2 802.16m technology will significantly expand the radio communication capabilities of UAVs.

However, the use of a narrow-beam antenna is justified only on one quadcopter, which will relay data between the ground control station (radio communication subscriber) and the “swarm”.

Communication within the swarm can be carried out using standard means or via an optical communication channel.

Advantages of using a narrow-beam antenna on a specialized quadcopter compared to a standard antenna:

1. Increased range of the quadcopter group in all directions, making it possible to deploy the group in hard-to-reach areas where there is no ground relay station.
2. The ability to transfer control of the quadcopter group to another ground control station, meaning that the UAV group control is part of an integrated navigation and data exchange system.

Disadvantages:

1. Data transmission delay to the ground control station, since data is not sent directly to the ground control station but through a specialized quadcopter with a narrow-beam antenna.
2. The likelihood of losing the communication channel with the ground control station increases, as data transmission depends on a single quadcopter relay. The solution to this problem lies in using a redundant quadcopter.
3. The operational time of the aerial relay is limited because the main energy load for data transmission is placed on it.

Thus, the use of a narrow-beam antenna on a specialized quadcopter relay is designed to achieve a significant improvement in radio communication characteristics between the relay and the ground control station, such as interference resistance, throughput, protection against interference, and security against radio direction-finding systems and unauthorized radio access systems.

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