Visualization of the Flight of Unmanned Aerial Vehicles according to the "Master - Slave" Model

M. Pyvovar, O. Pogudina, D. Kritskiy

Abstract— This paper examines unmanned aerial vehicles, namely the possibility of using UAV swarms and the types of swarms according to control methods. A scenario of interaction of two UAVs was formed according to the "master - slave" model in the "teacher" or "mentor" modes, on the basis of which a simulation model of the behavior of an unmanned aerial vehicle in a group was obtained, using the development of a software product for visualizing the flight of a UAV with using the CoppeliaSimEDU information system. The method for visualizing the dynamics of the movement of complex objects in a three-dimensional scene has been further developed, which also includes objects of different geometric structures (trees, buildings, etc.). This allows to get a rational scenario of flight on a known terrain in advance, taking into account natural and artificial obstacles on the way.

Keywords— unmanned aerial vehicle, swarm, "master – slave" model, simulating the flight.

I. Introduction

The development of unmanned aerial vehicles (UAVs) began in the 19th century. Unmanned balloons, which were filled with explosives and were used during the fighting by the Austrian armed forces in 1849, became the forerunners of modern UAVs. Later, the first prototypes of UAVs were created and used during the First World War. Radio-controlled aircraft that flew out of sight, aerial torpedoes and jet targets were invented during World War II.

At the end of the 20th century – the beginning of the 21st century, the topic of studying and using UAVs became even more relevant. According to many experts, unmanned aerial vehicles are the most promising direction in the development of aviation. This is explained not only by the fact that their mass production and use is cheaper and easier than using manned aircraft, but also by the fact that some types of UAVs, due to their small size, are able to solve problems that are inaccessible to manned aircraft. Today, various unmanned vehicles are used both in the military and in public spheres of life, and every year their functionality is improved and supplemented (Fig. 1). Sometimes it is necessary to use several groups of UAVs in order to cover a larger area or to obtain several points of view. A collection of UAVs that are used simultaneously to perform a specific task is called a swarm. Such unmanned aircraft work together and report their position and other useful information, taking into account predetermined time intervals. The spatial location of UAVs, one relative to the other in space, is a key element for their interaction [1]. The using of groups and complexes of small-sized unmanned aircraft can significantly increase the scope of their application. A number of problems that complicate the use of small-sized UAVs disappear with group use. In particular, the collective use of unmanned aircraft is relevant in geodesy, geography, dosimetry, security, reconnaissance, while searching for missing people, etc.

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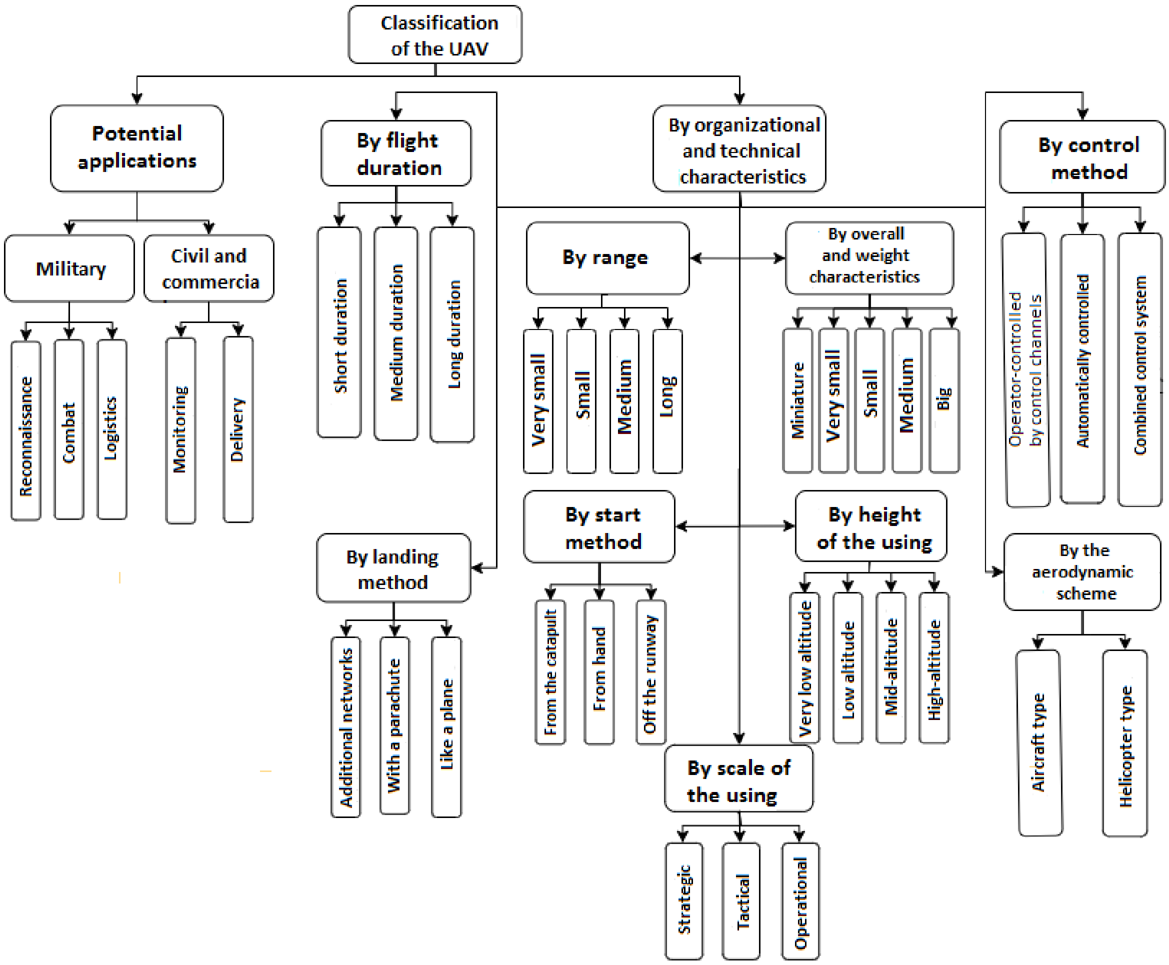

Fig. 1. Classification of the UAV

II. Literature Analysis

There are two types of swarms in terms of management methods. The first type of swarm consists of devices of the same type, which are designed to perform one common task and act as a distributed object. Such a swarm can be attributed to independently organized systems characteristic of natural formations (similar to the behavior of insects, birds, fish, united in swarms, schools that exchange information and perform a common task using collective intelligence). For such a swarm, there is no centralized system for controlling the behavior of each individual. Local and sufficiently random interactions lead to such global swarm behavior that cannot be controlled by individual agents. In this case, a multi-agent system is obtained that has self-organized behavior and which, in total, must exhibit some “smart” behavior. In the second type, the swarm consists of vehicles that have different payloads and perform different functions within the framework of a common task. The multi-agent method of swarm control provides for the presence of control, and control commands can come both from the control system external to the swarm, and from the "designated" ("local") leader who is inside the swarm. This leader transmits and executes commands that come from the manager of the center's property (as a rule, the control is carried out by one operator, while such tasks as maintaining the distance between vehicles, avoiding obstacles, choosing a flight route, etc. are performed without his participation), and others agents perform actions following simple rules [2].

Three possible management strategies can be considered:

1) centralized – remote control with a dedicated base station, the swarm leader is appointed from the central node;
2) decentralized – the swarm leader is determined on the basis of any algorithm and does

not depend on the central control station;

3) mixed – combines the advantages of centralized and decentralized strategies by allocating the swarm leader if it is necessary based on one of the algorithms with the transfer of control rights to the operator [3].

Modern research on the use of UAV swarm intelligence is mostly aimed at solving military problems. Research directions for future intelligent swarm systems are aimed at the adaptive capabilities of UAV autonomy and work in large heterogeneous teams of intelligent agents.

Among the projects related to the UAV swarm, the following can be distinguished:

– CODE is a program aimed at overcoming the limitations on the scale and profitability of UAV operations by building cooperation and joint autonomy. Developers are trying to create an open, modular architecture that is resilient to bandwidth constraints and connectivity problems [4];

– Perdix is a UAV swarm system developed by the US Department of Defense's Office of Strategic Opportunities. UAV Perdix is not pre-programmed – it is a collective organism that has a distributed brain to make decisions and adapt to each other. The entire swarm does not have a leader – each Perdix UAV "communicates" and "cooperates" with all devices, therefore it can adapt to any changes in flight [5];

– LOCUST is a technology of cheap-to-manufacture autonomous swarm UAVs, which allows you to quickly launch up to 30 unmanned aerial vehicles into the air, which are combined into intelligent networks. Control of UAVs connected to each other using an adaptive wireless network is carried out by a ground operator [6];

– Gremlins is a technology designed to conduct electronic reconnaissance and suppress air defense (air defense) assets. After completing their mission, the aircraft must return to the carrier, where they are installed on board the aircraft with the help of special equipment. Among the technologies, one can single out high-speed digital flight control [7];

– OFFSET provides swarm creation capabilities for small urban ground units. Among the features are the autonomy of the swarm, an improved interface that allows users to track and control many unmanned platforms [8].

Domestic research is aimed at planning the trajectory of UAVs in a group without the possibility of adapting the formation and providing autonomy to a separate UAV [9-10].

Most of the models used in the developed projects consist of devices of the same type that perform one common task and do not have any centralized behavior control system. Therefore, it was decided to pay attention to the UAV according to the second type of control, when the control commands come from the "appointed" leader.

Using the CoppeliaSimEDU information system, a program was built that displays the scene and behavior model of two UAVs, where one aircraft obeys the other – the leader of the swarm.

III. Object, Subject, And Methods Of Research

The **object** is "master – slave" UAV model.

The **subject** is the process of simulating the flight of unmanned aerial vehicles (UAVs) according to the "master – slave" scheme, with the possibility of choosing the UAV control modes "teacher" or "mentor".

The **goal** is to improve the quality of interaction between unmanned aerial vehicles according to the "master – slave" model during the flight mission through constant control between objects.

The **tasks to be solved** are: to analyze the classification of existing UAVs; to analyze the parameters and model of interaction of unmanned aerial vehicles in existing groups, flocks, associations, swarms; create a scenario of interaction between two UAVs according to the "master – slave" model; to develop a program for visualization of the flight of unmanned aerial vehicles according to the "master – slave" model; to conduct flight testing according to the proposed model on the stages where there are different geospatial objects.

The **methods** used are: a simulation method for the development of a UAV flight visualization subsystem, a graphical modeling method for creating a model of an unmanned aerial vehicle of an aircraft type, methods of the theory of an algorithm for developing a scenario of interaction between two UAVs.

The **following results** were obtained: Classification of unmanned aerial vehicles; graphic model of the Mini-Flight-M aircraft; schema of interaction of two UAVs in the "teacher" or "mentor" modes; developed software product for visualization of UAV flight according to the "master – slave" model using the CoppeliaSimEDU information system.

IV. Results

The user is the initiator of the visualization of the flight of unmanned aerial vehicles. The program is written in the Lua scripting language, which is an extended programming language designed to support general procedural programming. Figure 2 shows the structure of the flight visualization model.

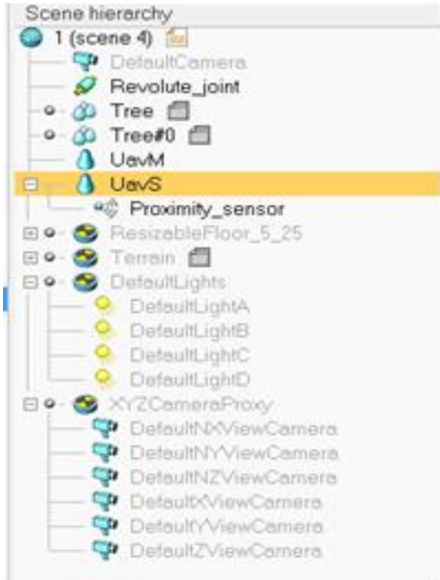

Fig. 2. The structure of the flight visualization model

The main stage 1 contains the following elements:

– several camera objects that allow you to see the scene if they are associated with a view;
– several light objects that provide illumination of the scene;
– representation reflecting what the camera sees. Views are contained on pages;
– several pages that contain one or more views;
– environment with properties such as the surrounding world, fog, background color, etc.;
– soil, consisting of objects grouped into a model, including several tree objects;
– UAV-M and UAV-S unmanned aerial vehicles, developed in SolidWorks and imported into an existing scene.

One of the graphic models developed by the UAV for the program is "Mini-Flight - M" with the following tactical and technical characteristics (Fig. 3):

– takeoff weight up to 90 kg;
– target and additional load weight up to 20 kg;
– flight duration more than 30 minutes;
– engine thrust 400-410 N.

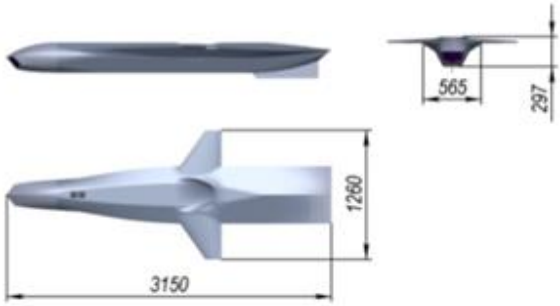

Fig. 3. General view of the aircraft "Mini-Flight - M"

There are several modes of operation in the program: RP and RPYT. Teacher Mode (RP) requires two input devices, one of which will be configured for roll and pitch and the other will be configured for other functions. Using the functionality of the switch (reflected in the configuration), the second controller also can change roll and feed.

The Mentor Mode (RPYT) requires two input devices, one of which will be configured for roll, pitch and thrust, and the other will be configured for other functions. Using the functionality of the switch (reflected in the configuration), the second controller can also change roll, tilt, yaw and thrust.

If you connect more than one input device, you can switch to one of the modes. You must first select the device to be used for the teacher and then map it. Next – the device that needs to be used for the student, and then – its matching. Once this is done, it is possible to see open devices and configurations at the bottom of the interface.

The stage preparation process can be divided into several stages:

– creating or modifying a polygon model in CoppeliaSimEDU;

– export of a model of an unmanned aerial vehicle to the URDF format;

– specifying the properties and parameters of all objects in the simulator.

Proceed to the space settings. At first, everything is disabled for calculations – objects will not fall under the action of gravity and bounce off each other, but will fly through other objects.

The ground itself and the supports (in the junior category) should be displaced, as if rigidly glued to the floor of the stage, but when game objects hit them, they should be taken into account and spring. Therefore, it is necessary specify "Body is respondable", indicating that the object is counted for collisions. Collisions with all objects must be considered in the simulation.

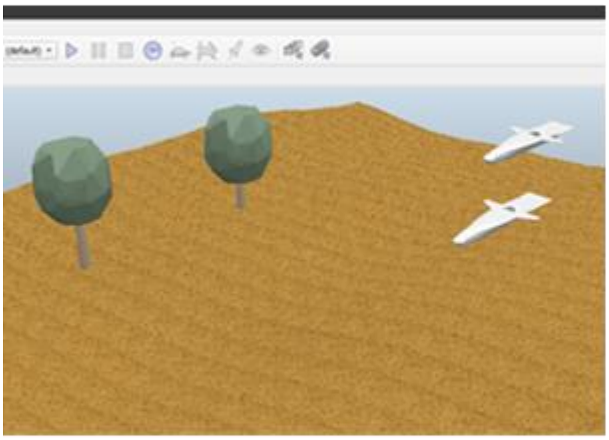

Fig. 4. Model of flight visualization of unmanned aerial vehicles according to the "master - slave" model

To simulate the movement of a swarm of UAVs, several models of unmanned aircraft were placed on the stage and their initial positions were corrected

After adding a script for interaction with Ros and subscripts for modeling control programs, the simulation of the UAV command's behavior was launched (Fig. 4).

A patent “Visualization of the flight of unmanned aerial vehicles according to the "master - slave" model” (№ 100840, registration date – 21.12.2020) was obtained for the developed program [11].

V. Conclusions

In this study, unmanned aerial vehicles were analyzed and a classification of existing UAVs was obtained: according to the purpose and according to organizational and technical characteristics. Possibilities of using UAV swarms and types of swarms by control methods are considered.

A scenario of interaction between two UAVs was formed according to the "master - slave" model in the "teacher" or "mentor" modes, on the basis of which a simulation model of the behavior of an unmanned aerial vehicle in a group was obtained for the first time, by developing a software product for visualizing the UAV flight using the CoppeliaSimEDU information system.

In general, the main result of this work is the further development of the method for visualizing the dynamics of the movement of complex objects in a three-dimensional scene, which also includes objects of various geometric structures (trees, buildings, etc.). This makes it possible to obtain the optimal flight scenario on a previously known terrain, taking into account natural and man-made obstacles on the way.

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