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DEVELOPMENT OF THE EXPERIMENTAL MULTIROTOR UNMANNED AERIAL VEHICLE HELICOPTER MODELS OF THE XZ-SERIES

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Abstract

In a large number of cases, depending on the aims and tasks of the remote Earth sensing experiment, the usage of airplane and helicopter flying laboratories is economically well-founded. On the other hand, surveys of dangerous areas are often needed (wildfires, radiation accidents, explosion hazard facilities, etc). In all those cases it is expedient to use unmanned aerial vehicles (UAVs). During the last few years, the radio controlled UAVs have gained large prominence, specifically the multirotor helicopters have established themselves as the standard surveying and research flying platforms. They are predominantly used for the purpose of remote sensing studies.

In the current article, authors have presented the benefits of the unmanned multirotor helicopters, designed for remote sensing applications of specific areas of the Earth surface. The idea and realization of three new models of multirotor helicopters from the XZ-series are disclosed. The major technical and operational capabilities are analyzed and diagrams of the avionics of the discussed models are shown. Special attention is devoted to the airframes. The implementation of the XZ-series helicopters in projects developed in Space Research and Technology Institute at the Bulgarian Academy of Sciences is discussed. Mainly, attention is drawn to the National Aerospace System for remote sensing of the Earth in the context of its usage for monitoring and protection from natural disasters.

Introduction

In some cases, for the purpose of remote sensing over test areas and firing grounds, it is necessary to obtain photographs from low altitude (10–

100 m) and scale in the order of 1:500 or 1:700. The area covered by such photographs may be in the order of several hundred to several tens of square meters. The utilization of aircraft and helicopter laboratories in such cases is economically feasible. In other cases, remote sensing surveys over dangerous in radiation or other sense areas, large fire zones, explosive hazardous depots and so on are required. In all those cases it is recommended that unmanned aerial vehicles (UAVs) are being used, also called remote controlled or radio controlled flying models. It is possible to engage specifically designed for the above purposes UAVs or general purpose models.

During the last few years, the radio controlled UAV multirotor helicopters become more and more topical as research and mainly as remote sensing platforms. These helicopters are distinguished with lowered complexity low price and small dimensions. Particularly appreciable benefits in comparison to the classic small helicopters are the absence of cyclic and collective pitch control of the rotor blades. This fact extremely simplifies the design and thus lowers the initial cost of the system and at the same time reduces the maintenance costs of such a multirotor helicopter, while the probability for a catastrophic crash is lowered. Another benefit is the lower rotors diameter of the multirotor helicopters in comparison to the classic small helicopters with only one rotor. Thus, the kinetic energy in any of the rotors of the multirotor helicopter is considerably lower than the energy in the single rotor of the classic small helicopter. The latter feature increases safety during operation of the multirotor helicopters. Furthermore, some small multirotor helicopters have frames around their propellers in order to increase even more the safety of operation.

Different designs and configurations have been developed: with two propellers, with three propellers and so on. Most common are the four-rotor helicopters, because this number of rotors is the minimal number that ensures full control without the need of additional control surfaces or rotor tilt mechanisms.

Table 1 discloses representative models of UAV helicopters with one or several rotors.

Table 1

Name	Country of manufacture	Rotor number	Propulsion	Optimum payload, kg	Total weight, kg	Service ceiling, km
Black Hornet Nano	Norway	1	Electrical	0.005	0.016	0.030
XZ-1	Bulgaria	4	Electrical	0.2	0.8	4.0
XZ-2	Bulgaria	8	Electrical	0.4	1.6	5,0
ARF MikroKopter	Germany	8	Electrical	1.4	5.0	4.0
Skeldar V-150	Sweden	1	I.C.E.	55	150	3.5
Parrot AR.Drone	France	4	Electrical	0.5	2.3	2.4
INFOTRON IT180 UAV	France	2	I.C.E.	5.0	19.0	3.0
БПЛА ZALA 421-22	Russia	8	Electrical	2.0	8.0	1.0
Honeywell RQ-16 T-Hawk	USA	1	I.C.E.	2.0	8.4	3.2

Unmanned helicopters of the XZ-series

The XZ-series occupies a competitive place among the modern UAV helicopters. The models in the series encompass a number of innovations in the avionics features and components as well as in the design of the airframe. The first member of the series is XZ-1. This is a four-rotor helicopter, meant as a test bed during the development of the MotorA motor controller series from version 1.0 to version 5.0 and the Z-Pilot v1.0 autopilot. XZ-1 is a proof of concept of certain innovations such as the patented technology battery unit BatA. The general appearance of XZ-1 is shown on Fig. 1.

Fig. 1. General view of XZ-1

Fig. 2 presents the airframe plan of XZ-1, which is in the well-known “H”-configuration. The benefits of this configuration exceed its drawbacks and for this reason the given design was used in the first model of the series. The benefits of the “H”-design toward the classic “X”-design follow:

1.The inevitable torsion and bending of the airframe is beneficiary, because it happens mainly during yaw orientation change. This torsion accelerates the yaw motion in the desired direction and increase the efficiency of the yaw orientation change process.

2.“H”-airframe offers a fuselage where on lots of modules may be easily installed.

3. First person view video camera (FPV) is attached to one end of the fuselage and is not “shadowed” by the propellers.

4. The moment of inertia along the pitch axis is increased thus making the helicopter more stable.

5. “H”-airframe guarantees counter rotation for each tandem of rotors, mounted at the ends of any of the two rotor beams. The opposite direction of rotation causes the gyroscopic effects of the two rotors on one beam to cancel out in contrast to “X”-airframe where both propellers on each beam are rotating in one and the same direction causing strong unwanted gyroscopic effects.

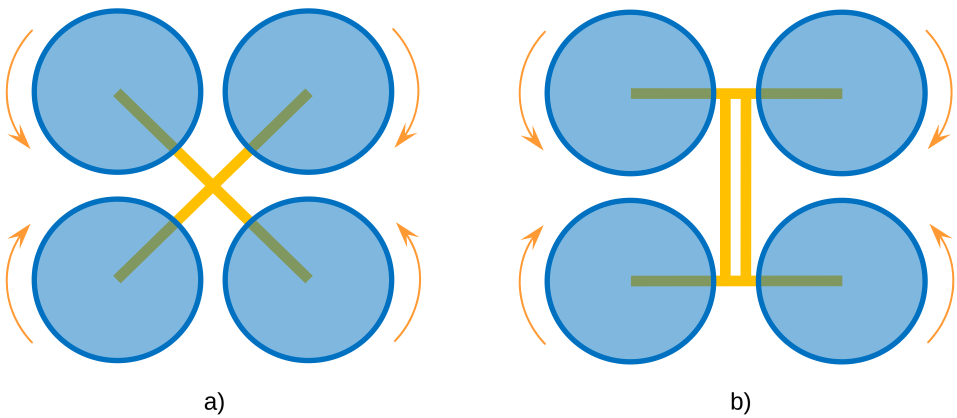

Fig. 2. a) Classic four-rotor helicopter in “X”-configuration also called “cross”or „star”; b) XZ-1 is based on the “H”-configuration also called “fuselage”

Drawbacks of the “H”-airframe toward the “X”-airframe:

1. “H”-airframe is heavier with about 10% compared to “X”-airframe with the same rigidity due to the presence of fuselage and the larger distance between the propellers.

2. “X”-airframe is simpler to manufacture.

Technical characteristics of XZ-1

The main characteristics of XZ-1 are demonstrated in table 2.

Table 2

Type	Experimental
Number of rotors	4
Propulsion	Electrical
Energy source	Electric battery
Total mass	0.8 kg
Payload	0.2 kg
Service ceiling	4 km
Autopilot system	**1.** Z-Pilot v1.0 **2.** Autopilot sensor unit SensorA v1.0 Includes: • Gyroscope • Accelerometer • Magnetometer • Barometer • Thermometer **3.** GPS unit
Payload	Additional sensor unit SensorB v1.0 Includes: • Thermometer • Moister meter • Ionizing radiation meter (beta and gamma) • Non-ionizing radiation meter • Gas sensors (CH_4, SO_2, CO_2, H_2S, O_2, NH_3, etc)
Motor controllers	MotorA v5.0
Patented innovations	Battery block BatA v1.0

Diagram of the helicopter avionics is presented in Fig. 3. Special attention is drawn to the motor controllers. One motor controller drives two motors, placed at the ends of a beam in the helicopter airframe. Two controllers are used. The latter are connected to the autopilot using digital interface. The communication protocol allows starting, stopping and power control based on a rich set of parameters. Autopilot receives information from the motor controllers about the rotations per minute, the used power, etc. The helicopter orientation is calculated through sensors, placed in the main autopilot sensor board SensorA. Unit DistanceA serves to calculate the distance to ground and near objects. To the autopilot are attached several other modules: light signal unit, GPS, radio transceiver and payload. The payload of XZ-1 is 200 gr and consists of additional sensor unit SensorB.

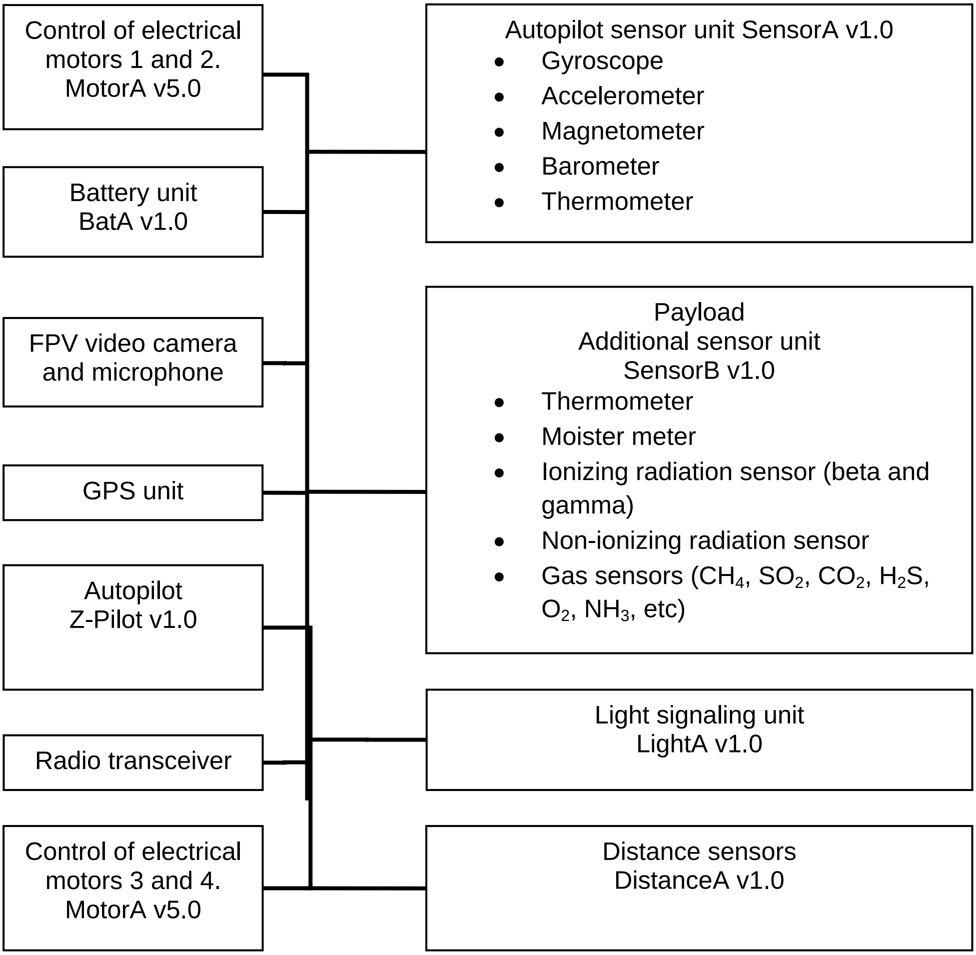

Fig. 3. Diagram of XZ-1 avionics

XZ-series helicopters with 8 rotors

In order to increase the reliability of the helicopters and their payload capabilities, without increasing the rotor diameter, helicopters with greater number of rotors are used. XZ-series helicopters XZ-2 and XZ-3 have eight rotors each and can carry two times more weight in respect to XZ-1. Fig. 4 shows a classic airframe of an 8-rotor helicopter. The airframe is a "star"-type one. This type of airframes is widespread, but has serious drawbacks seen with "naked" eye. The rotor distribution in space requires a large sized airframe with extreme distances between the propellers. Such an airframe becomes heavy and cannot easily go through narrow openings on buildings. The rigidity of this airframe against torsion is extremely insignificant due to beams mounting in a single point.

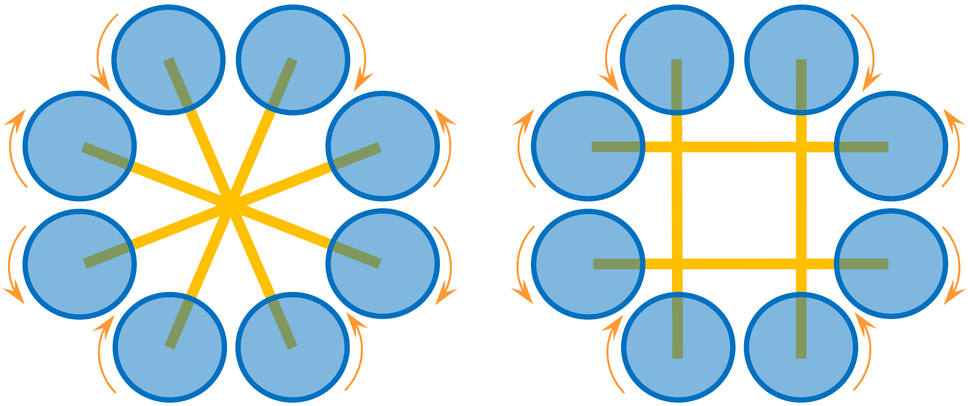

Fig. 4. Classic 8-rotor helicopter in "star"-configuration

A similar airframe is the "square"-construction airframe. It is shown on Fig. 5. The "square"-airframe has all the drawbacks of the "star"-airframe except that it is more resistant to torsion. This resistance is not significant.

To address these drawbacks the XZ-series offer models XZ-2 and XZ-3. XZ-2 is presented on fig. 6. It is based on the "H"-airframe of XZ-1. Thus XZ-2 offers a fuselage with all the accompanying benefits resulting from this construction. On the other hand, the propellers of XZ-2 are placed close to each other thus ensuring the helicopter can pass through narrower openings. The beams connecting the rotors are short and rigid, and hence the construction is lighter and more stable than the classic airframe constructions. Placement of units of the avionics and the payload is comfortable and the video camera is not jeopardized from visual interference from the propellers. The shorter overall length of the airframe beams of XZ-2 leads to lower aerodynamic drag in comparison to the “star”-airframe and the “square”-airframe.

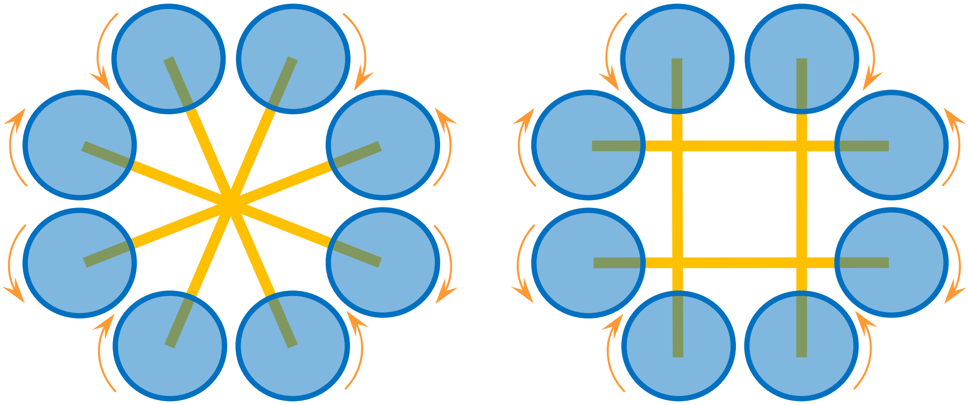

Fig. 5. Helicopter with 8 rotors in “square” configurations

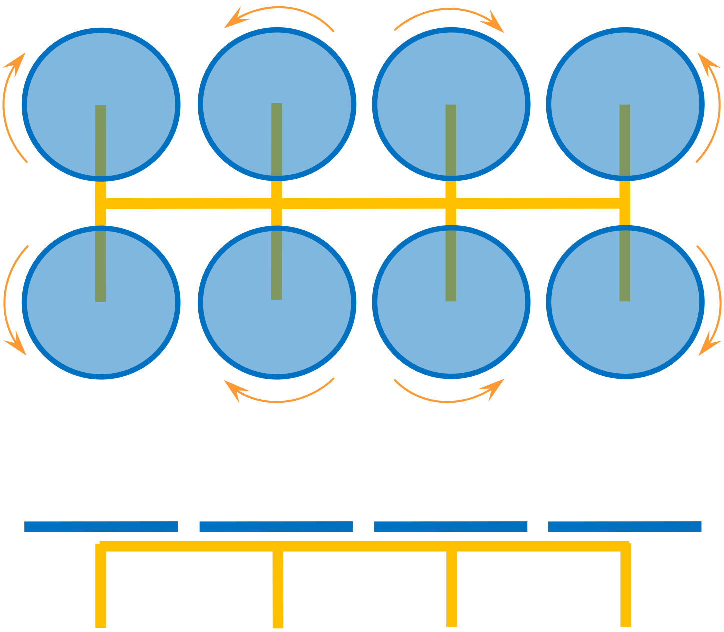

Fig. 6. XZ-2 uses „fuselage”-design,which is derived from the “H”-airframe of the XZ-1 four-rotor helicopter

Technical characteristics of XZ-2

The main characteristics of XZ-2 are presented in table 3.

Table 3

Type	Experimental
Number of rotors	8
Propulsion	Electrical
Energy source	Electric battery
Total weight	1.6 kg
Payload	4 kg
Service ceiling	5 kg
Autopilot system	1. Z-Pilot v2.0 2. Autopilot sensor unit SensorA v2.0 Includes: • Gyroscope • Accelerometer • Magnetometer • Barometer • Thermometer 3. GPS unit
Payload	Video camera with gyroscopically stabilized platform.

XZ-2 avionics diagram is shown on Fig. 7. The new motor controller MotorA v6.0 drives only one motor. This fact allows the motor controller to be placed closer to the motor in order to decrease the electromagnetic interference. Autopilot Z-Pilot v2.0 uses a larger number of sensors spread along the airframe in a unique configuration aiming at increasing the signal to noise ratio.

Another model of the XZ-series is XZ-3 helicopter. The difference between XZ-2 and XZ-3 is found in the airframe design. Similar to the first two models of the series, XZ-3 owns planar airframe, nevertheless its airframe has properties of a volumetric airframe, namely the XZ-3 airframe is superiorly resistant to torsion and bending in comparison to all so far mentioned 8-rotor helicopter airframes (fig. 8). This fact is due to the crossed structure of the airframe that exhibits features of a three-dimensional airframe structure, for example geodetic structure, monocoque structure, etc. At the same time the XZ-3 airframe is planar. Any axis of torsion meets resistance, cause by bending of one of the airframe beams.

This capability of XZ-3 is not present in the other 8-rotor helicopters. Also, XZ-3 has smaller dimensions compared to the classic models such as “star”-airframe and “square”-airframe thus becoming light and maneuverable.

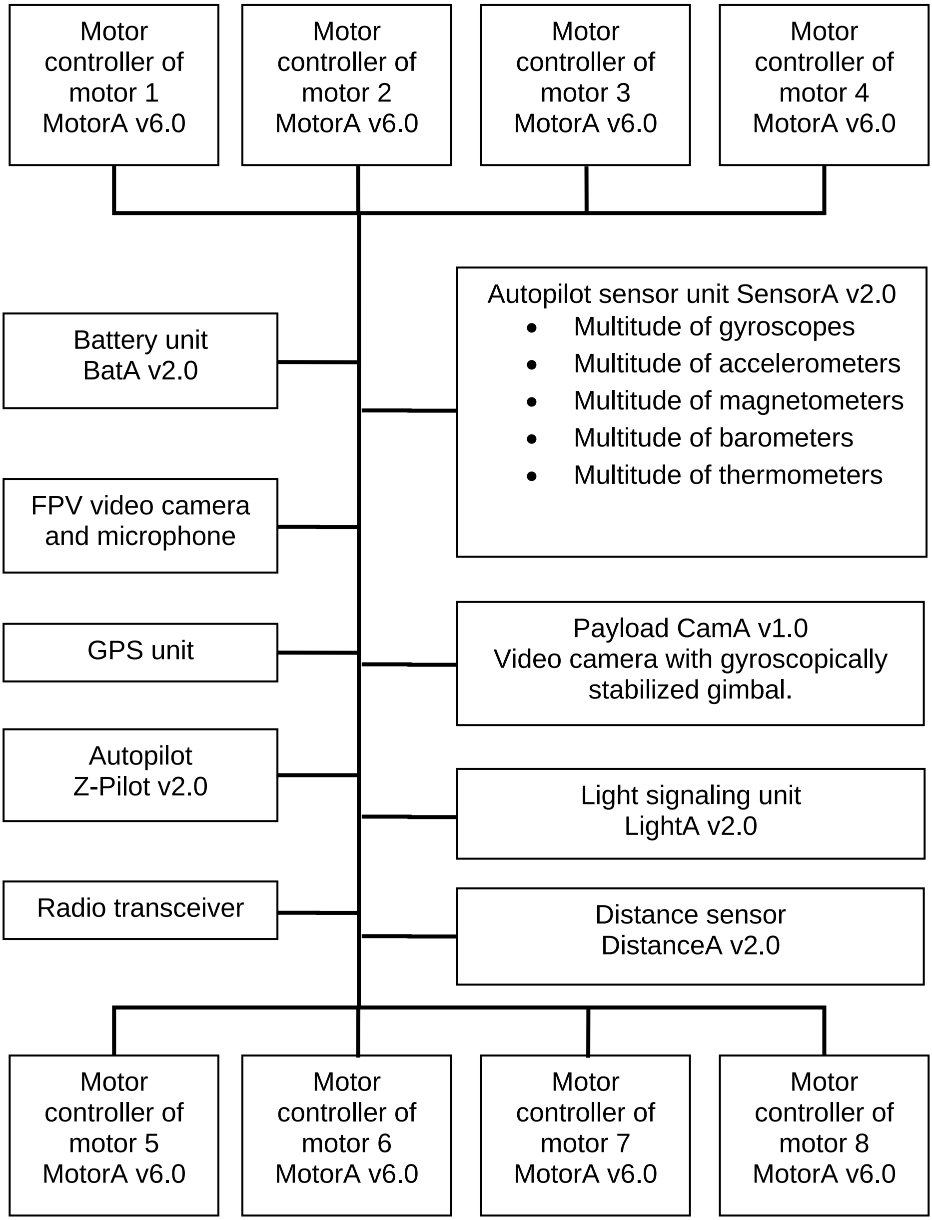

Fig. 7. Diagram of the XZ-2 avionics

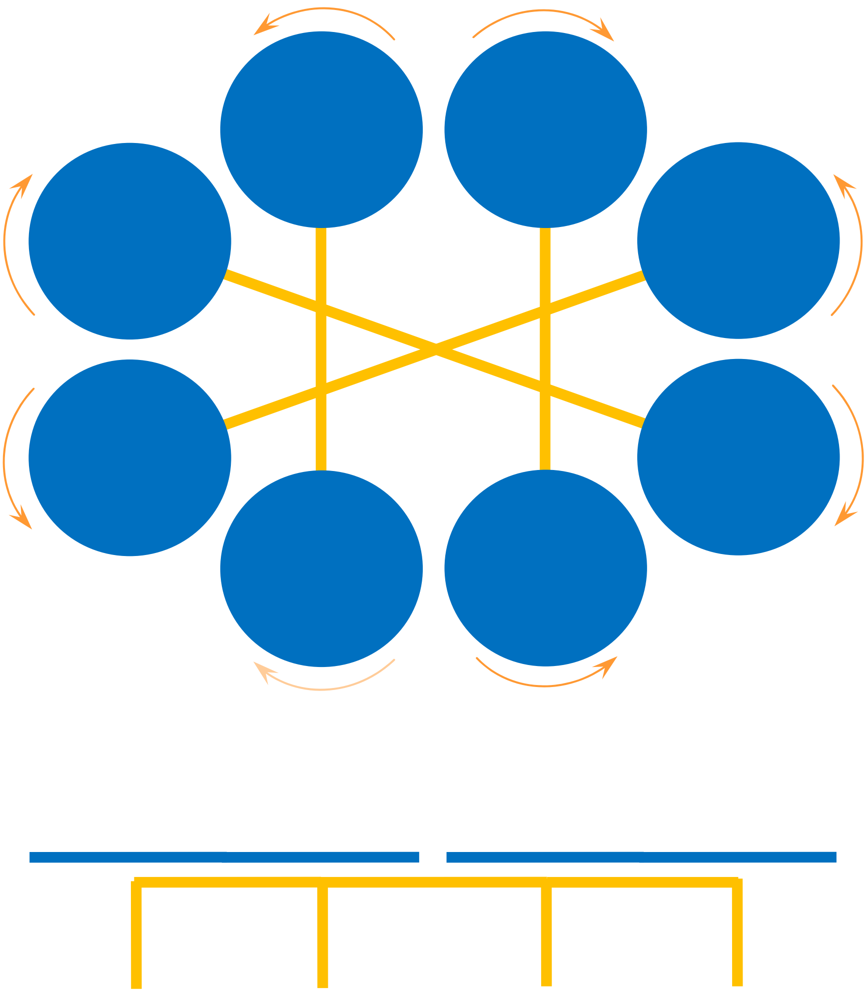

Fig. 8. XZ-3 with its unique configuration

Conclusion

The developed models of the XZ-series offer the opportunity to demonstrate innovations in the unmanned multirotor helicopter design and serves as a well suited test bed for experimentation and improvements. In the future the XZ-series helicopters will be implemented in different projects. Example candidates are pollution monitoring, disaster management, remote sensing, geophysical surveying, rescue missions, etc.

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ЕКСПЕРИМЕНТАЛНИ МОДЕЛИ МУЛТИРОТОРНИ БЕЗПИЛОТНИ ХЕЛИКОПТЕРИ ОТ СЕРИЯТА XZ

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Резюме

В редица случаи в зависимост от целите и задачите на експеримента за дистанционно изследване на Земята използването на самолетни и вертолетни лаборатории е икономически необосновано. От друга страна често се налагат изследвания в опасни райони (горски пожари, радиационни аварии, взривоопасни обекти и др.). Във всички тези случаи е целесъобразно използването на безпилотни летателни апарати (БЛА). През последните години все по-актуални стават радиоуправляемите безпилотни мултироторни хеликоптери като платформи за реализация на изследователска дейност, и преди всичко за дистанционни изследвания.

В статията са представени предимствата на безпилотни мултироторни хеликоптери предназначени за дистанционни изследвания на специфични райони от земната повърхност. Разкрита е идеята и реализацията на три нови модела мултироторни хеликоптери от серията XZ. Анализирани са основните технико-експлоатационни параметри и блоковата схема на авиониката. Особено внимание е отделено на планерите. Дискутирано е внедряването на хеликоптерите XZ в разработваната в Space Research and Technology Institute at the Bulgarian Academy of Sciences национална аерокосмическа система за дистанционно изследване на Земята, в контекста на използването й за мониторинг и защита от природни екокатастрофи.