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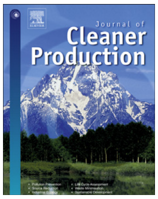

Multicopter platform prototype for environmental monitoring

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A B S T R A C T

Due to the ecological devastation of the natural environment, there is a constant need for monitoring the environmental features changes. Airborne engineering is now rapidly developing, enabling the construction of small automatic flying vehicles, so called multicopters or flying drones. The main objective of this study is to design and manufacture the low cost and low weight quadcopter platform prototype for the purpose of the environmental monitoring and research. A multirotor concept was created, which assumed some executive functions i.e. hovering, environmental data acquisition or Global Positioning System movement. On the basis of these assumptions, platform components were chosen. They include: the frame, drives, electronics and software. Also the presentation of the environmental measurement capabilities, with the use of multicopters was done along with the discussion on application capabilities, advantages and disadvantages of Unmanned Aerial Vechicles for analytical agriculture. On the basis of the project, a prototype quadcopter platform was built. During the tests some corrections to specific components were made. As a result of the whole process, a platform that is able to accomplish the tasks was created. All components of the multicopter have been described, materials used, mounting and connecting them, as well as the presentation of the specific device problems. The manufacturing cost of the drone prototype was lower than EUR 500, weight of less than 750 g and the drone performed all assumed tasks, which was considered a success of the project. Scientific value of the paper includes the guidance of cheap and efficient setup along with the applications.

1. Introduction

The quest for environmental sustainability is inextricably linked to the monitoring service. Monitoring is critical for environmental management. Environmental management decisions are dependent on monitoring; the same holds for reporting for legal purposes and reporting the environmental performance (Verschoor and Reijnders, 2001). Companies, life cycles, footprints, indicators, systems even whole cities and countries are subject of various monitoring activities according to achieve and maintain sustainable development (Kostevšek et al., 2015). Increasing efforts and resources have been devoted to research during environmental studies, including the assessment of various harmful impacts (Čuček et al., 2012). But environmental monitoring is not only limited to those impacts. Sustainability must be addressed from interdisciplinary and multi-cultural perspectives (Duić et al., 2015). It is capable to reach much more innovative achievements like for example automated registration of potential locations for solar energy production (Szabó et al., 2016), integrate various indicators into “families” (Galli et al., 2012) or recently developed interesting and promising cities' sustainability benchmarking index (Kılkıs, 2015).

All of this requires gathering great amount of various data. Availability of the updated data is becoming increasingly important in order to allow a rigorous analysis (Allouhi et al., 2015).

The issue of multirotor flying devices was taken up at the beginning of the twentieth century. As reported by Leishman (2006), one of the first documented prototypes, able to take off was Jeromede Bothezat's *Flying Octopus*. Multicopters are similar to helicopters but should be treated as a separate group of flying objects. They have higher maneuverability due to engines with fixed pitch propeller. Each motor is controlled independently by the flight controller. What allowed to resign from the precise helicopter rotor standard mechanics.

The impulse for the dynamic development in the multirotor area at the present time was the concept of Alexandre Dubus. It

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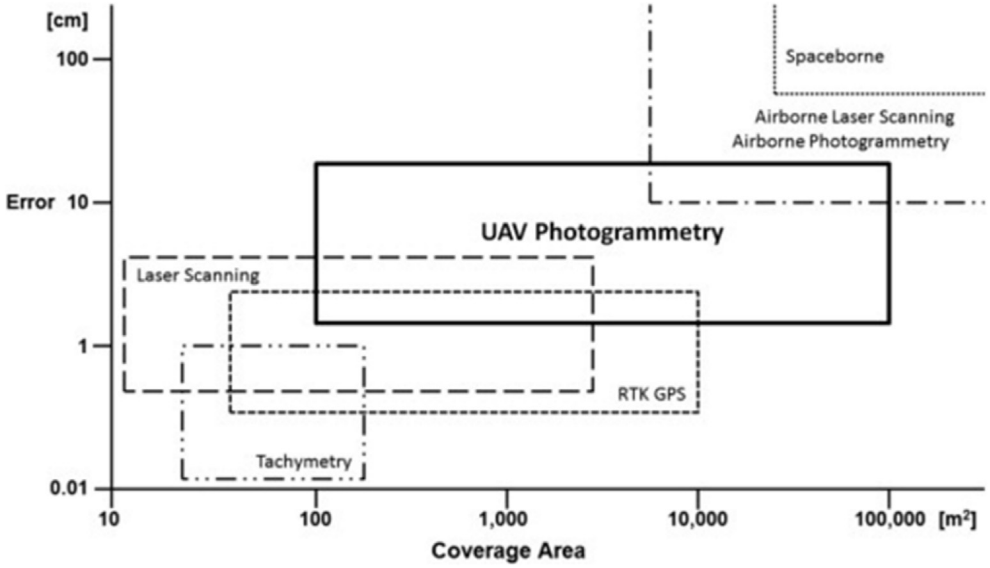

Fig. 1. Potential UAV system application areas in surveying tasks (Siebert and Teizer, 2014).

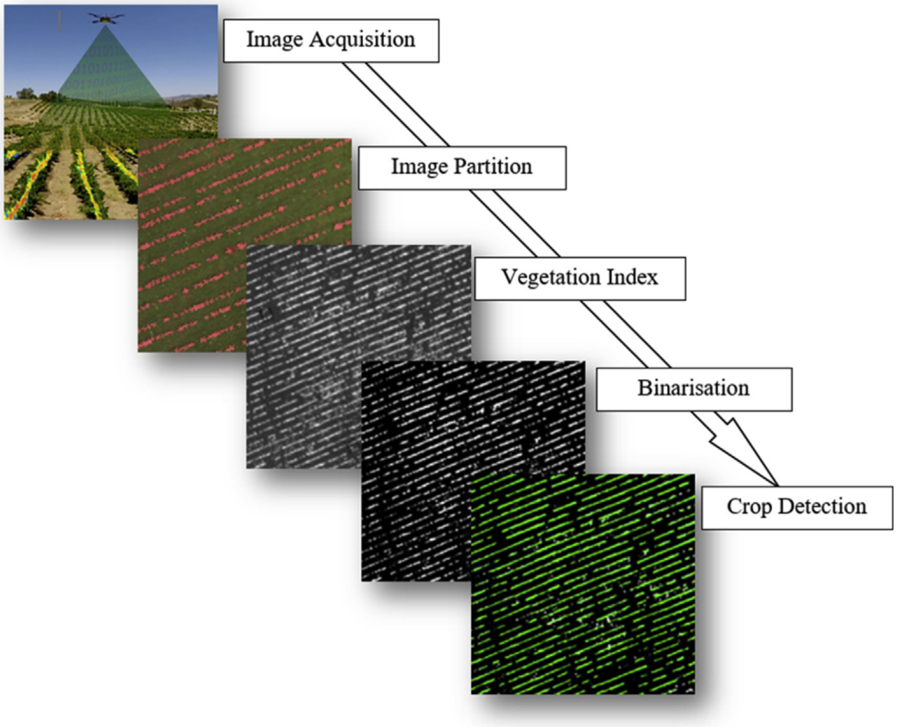

Fig. 2. Steps of the weed mapping system case study proposed by Pérez-Ortiz et al. (2015).

consisted of gyroscopes and accelerometers included in the keypad to the popular game console and the Arduino microcontroller. He is also the author of the program, the code for the microcontroller and the graphical interface. The entire project was called *MultiWii* (Banzi, 2008).

Typical multirotor aerial robots encounter several obstacles in the design and control. They have to be overcome to cater for expected industry demands that push the boundaries of existing multicopter performance. Research and experimentation in this field is now vastly developing. Many UAV prototypes are being constructed now and the performance of these systems is demonstrated in indoor and outdoor flight (Banzi, 2008; Buchi, 2011; Pounds et al., 2010).

Although environmental research with airborne equipment is becoming very popular, professional literature on small multirotor devices subject is still extremely scarce, and is still on a hobbyist grade (Dandois and Ellis, 2013; Nicol et al., 2011).

In this research authors give guidance on Small Unmanned Aerial Vechicles design and assembly. The novelty is pointed by extremely low cost while delivering fully operational features. System shows many innovative application possibilities, including newly spotted opportunity for analytical agriculture. All these

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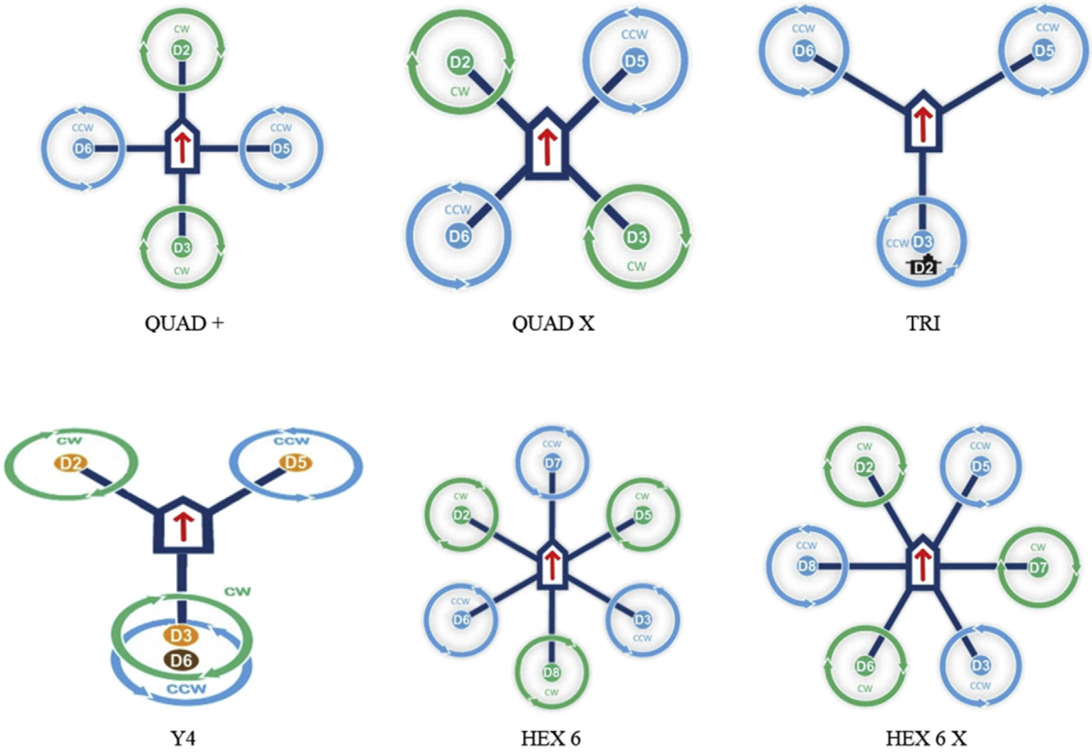

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Fig. 3. Basic multirotor platform configurations theuavguide,.

Fig. 4. Support frame of the designed SUAS.

features are connected to eco-design (Brones et al., 2014), life-cycle (Huber, 2008) and green analytical principles and approaches, which are very important part of modern sustainable development. The “green” approach to industry was started by Anastas and Breen (1997), basically in chemical industry as it was considered as the main environmental pollutant. After 20 years the “green” became in the spotlight for all the types of human activities.

2. The problem

Multicopter is a multirotor unmanned aircraft system (UAS). UAS are known under various different names and acronyms, such as “Unmanned Aerial Vehicle” (UAV), “aerial robot” or simply “drone” (Colomina and Molina, 2014). UAS recently evolved to small unmanned aircraft systems (SUAS) sometimes called mini or

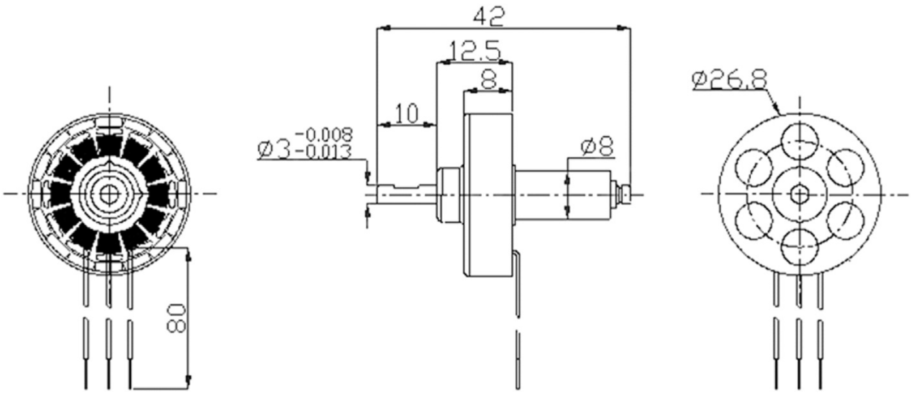

Fig. 5. Schematic view of the power unit with the basic dimensions.

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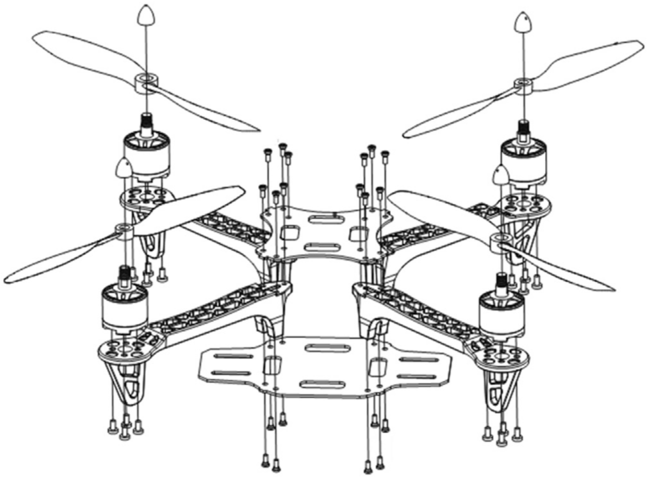

Fig. 6. Assembly view of the main frame, power units and propellers.

micro drones and included to low altitude multirotor platforms (LAMP) family. Since 2010 multicopters are increasingly being used as a tool for environmental research. To highlight the pace of multicopters' development it is enough to say that such a great book like (Aber et al., 2010) did not mention them at all. The development of new technologies is mainly due to the miniaturization of electronics and weight reduction. The ability to take very high resolution images with drones increases their importance for small-scale investigations. Quadcopters or hexacopters for example are used to gather high resolution images and subsequently to calculate a visible vegetation index (Rasmussen et al., 2013; Pérez-Ortiz et al., 2015; Vega et al., 2015). Often commercially available remotely controlled multicopters are used without any technical adaptations for monitoring crop biomass (Jannoura et al., 2015). Recently Yahyanejad and Rinner (2015)described multi-drone surveillance system and Gago et al. (2015) applied multicopters to water stress management in agriculture. Attempts to study small scale coast evolution was made by Casella et al. (2014). The problem

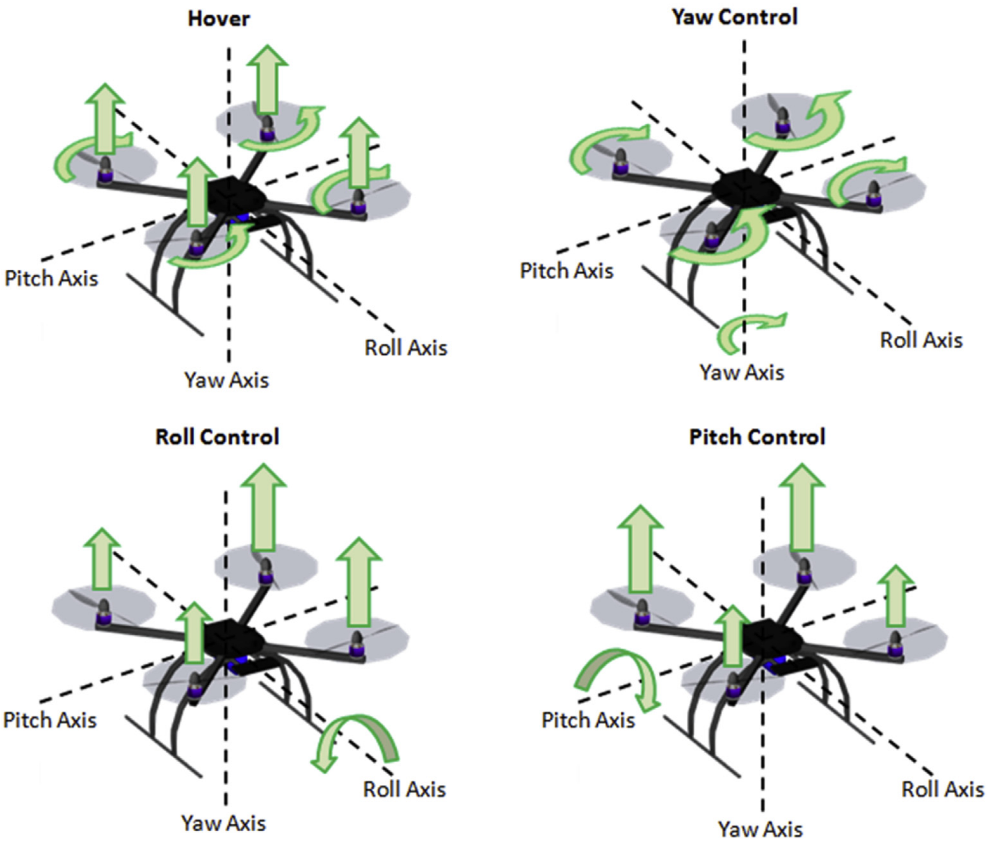

Fig. 7. The four fixed-pitch propeller quadcopter SUAS ways to achieve controllable and stable flight Vega et al., 2015.

Table 1
Available flight modes for applied FC.

Manual mode	Atti mode	GPS atti mode
Manually controlled by the operator piloting the SUAS in all axes. This mode is used primarily for sport flying or acrobatic.	The platform automatically stabilizes the position in all axes. A set of commands are used to set the SUAS in motion in desired direction while all other directions are stabilized.	The SUAS platform stabilizes itself using the additional external GPS module with a compass. In this mode, the device is capable of hovering at one point, without sideways drift, rotation, falling or ascent.

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of wind vector estimation and gas distribution mapping with the use of micro-drone was undertaken by Neumann and Bartholmai (2015). One of the common problems are heat loses in district heating systems and buildings. In authors' opinion this problem could be solved with the use of IR detection mounted on multicopters.

A major challenge is to develop an effective system of data acquisition, storage and online data analysis. For this purpose more complex devices and systems are introduced each year. UAV platforms are gaining more and more popularity and overlook those demands offering easier and much cheaper way of obtaining information. UAV systems cover the area which is not covered by other systems, as shown in Fig. 1. These are fully programmable devices allowing the autonomous flight and regular collection of information such as: airborne footage, thermal imaging, heat losses measurement in district heating, monitoring and analysis of energy grids, searching of hot spots in photovoltaic farms etc. This is only a small portion of the possibilities UAV systems can offer to reach cleaner production.

In this research authors aimed at building a medium-sized, easy to transport, multirotor platform from scratch. With total weight of less than 750 g and packing as much equipment as it is possible on a single platform. Next goal is to make system available for the cost of less than 500 EUR. In comparison to commercially available systems it is minimum 50% cheaper. Such system can be successfully used for the purposes of the environmental and industrial monitoring. The take-off mass of the device was set to be in the range of 600–800 g, with the basic components such as the support frame, a drive assembly, flight controller, FPV system, OSD and transceiver.

One of the issues covered by such system is the monitoring and quantitative assessment of crop in agriculture with the use of low altitude true color aerial photographs (Jannoura et al., 2015; Vega et al., 2015; Pérez-Ortiz et al., 2015). Authors propose to name that approach as *Analytical Agriculture*. One of the major problems in the analytical agriculture is the information hidden inside the images. There is need of image analysis to collect the appropriate information. One of the good case study of aerial crop surveying is presented by (Pérez-Ortiz et al., 2015). Schematic view of the crop detection algorithm according to Pérez-Ortiz et al. is shown in Fig. 2.

3. The project

Multicopter possible configurations at the moment are very diverse. The origins of this field of engineering makes it possible to provide a very large number of different types of platforms. The number of engines and how they are mounted is the basic distinction. The system of the arms both in the horizontal plane and the vertical plane is also an important feature. The most common configurations are those shown in Fig. 3.

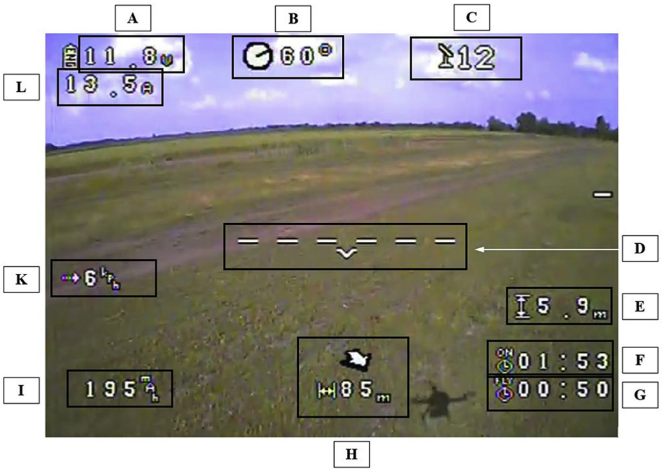

Fig. 8. Sample view of the OSD system.

3.1. Support frame – SF

Support frame used for the project is the product of *DJI* company with size of 330 mm. Product name is*DJI330*, shown in Fig. 4. The material used in its production is plastic –product name: *PA66 GF 30* and glass – epoxy laminated. This combination of materials has helped to achieve a durable and rigid structure.

One of the great advantages of this framework is the high strength of the materials used, stiffness, and the wide availability of spare parts. The arm cannot easily break or bend as it often happens with aluminum profiles.

3.2. Power unit system– PU

Choosing the drives for the specific multirotor platform one should be aware of one yet informal principle – half of the sum over all engines thrust must not be less than the total weight of the whole unit. This allows to build a platform that will be able to fly up into the air and maintain stable flight. Also some extra capacity will be left for additional equipment. This is the golden rule especially for the construction of quadcopters. This principle has been established recently, during the beginning of the design. The authors' particular design uses four *HexTronic 24g 1300 KV* motors, speed controllers *BlueSeries HobbyKing 12A* and three-bladed 8 × 4 × 3 propellers. The dimensions of a single power unit are shown in Fig. 5. The basic assembly view is shown in Fig. 6.

There is working principle which says that the half thrust of the system should be not less than the total mass of the platform, which is described by equation (1).

$$\frac{1}{2}T \geq m \tag{1}$$

where: T – thrust force of the system and m – total mass of the system.

The conducted tests led to the conclusion that one engine has approx. 400 g thrust. And four engines give 1.6 kg thrust, which covers the principle (1), as the platform total weight is less than 800 g. Applied regulators operate at a frequency of 50 Hz which results in a slight delay in response rods of platform control apparatus. The delay is small, but noticeable when driving platform manually. In the case of autopilot programming of the flight controller, these delays should not play a significant role.

3.3. Flight controller system– FC

This is an electronic system with at least a three-axis gyroscope and a processor responsible for motor control. More complex systems have an additional accelerometer, which is used for self-leveling platform, barometer which allows keeping height and magnetometer for anti-rotation around its own axis. FC is responsible for basic behavior of the SUAS, like hovering and flying along the desired direction. FC's basic tasks are shown in Fig. 7.

For this project *Naza M Lite* controller has been applied, equipped with a three axis gyroscope, three axis accelerometer and barometer. This FC is also supported by a highly accurate GPS receiver with a magnetometer. FC is fed through a special module, which also is a state indicating unit of the platform. Communication

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Table 2
Description of the information available through the OSD system.

	Basic OSD features description	Additional available OSD information
A	Power unit battery voltage	
B	Angle of rotation towards the north	Power of the radio link
C	Number of visible satellites	
D	Artificial horizon	Power unit temperature
E	Height above the starting level	
F	Total power-up time	SD card upload
G	Flight time	
H	Course and distance from the starting site	Acoustic altimeter level
I	Total power consumed	
K	SUAS speed	GPS coordinates
L	Current power	

Fig. 9. General view of the designed aerial multicopter platform prototype as a part of the small unmanned aircraft system (SUAS) with the manual controller console.

takes place through a tri-color LED. Such information as the number of GPS satellites connection, flight mode and the remaining battery power is available through it. The used flight controller allows the conduction of the flight in three modes shown in Table 1.

The accuracy of the used GPS module, as provided by the manufacturer, is 2.5 m in the horizontal plane and 0.8 m in the vertical plane. These figures were confirmed by performing a series of tests.

3.4. First person view system – FPV

FPV system allows transferring the image from the platform in real time and works like the eyes of the pilot. The image is most commonly transmitted at frequency of 900 MHz and 1.2; 2.4 or 5.8 GHz. The audio and telemetric data can also be connected to the image transmission. FPV system is an additional load to be carried by the platform. A typical FPV system setup consists of a video

Table 3
Basic features of the designed multicopter platform prototype.

Feature	Value	Comments
Weight	750 g	Despite the weight near the top limit, the platform is stable in flight, agile, predictable and has a reserve capacity of 50 g for extra equipment.
Flying time	12 min	The used battery is *3S* 2200 mAh allows overcoming distance of approx. 4 km.
Hovering time	15 min	Hover allows to take up to 10 min videos or up to 400 photos.
Max. speed	40 km/h	For safety tests were conducted in auto-stabilization mode, which is a speed limiting factor.
Max. RC range	1000 m	Max. video transmitting range is 800 m.
Cost	€ 499	System is relatively cheap in comparison to other robust and heavy duty platforms which cost above 1000 EUR.

Table 4
Some examples of multicopter platforms application for environmental monitoring and research.

Monitoring of	Research
Animal populations	Animal population development
Animal poaching	Plantations development
Natural resources	Air sampling at different heights and areas
Forest condition	Gases distribution
Agriculture condition	Exploration of shafts and caves
Landfill condition	Disaster management such as floods, fires, droughts, etc.
Pollutants emitters i.e. industrial plants, coal fired power plants, waste incineration plants, etc.	Surveillance and law enforcement
	Smog over cities
Rivers	Routes, waterways, coasts
Cooling towers/chimneys condition	Searching for persons and objects in difficult terrain
Hydro architecture condition	Damage and leaks of industrial plants
Mountain routes condition	Wind speed at different heights and areas
Nuclear power plant	Postal services
Hazardous gas concentrations in the mines	Infrared vision
District heat loses	Construction site assessment
Impact of sea storms on coastal areas	Low-lying coasts erosion and evolution

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camera or a still camera, video transmitter and receiver. More complex systems are equipped with separate power supply or systems to adjust the camera regardless of the position of the platform.

For this project authors used*TS5823*video transmitter. It is one of the smallest 200 mW AV transmitters with 5.8 GHz transmitting frequency. The weight of the transmitter is only 7.4 g. The transmitter is equipped with the omnidirectional polarized clover antenna type –improving range of device even 3 times in relation to the pole antenna. The video camera used in this project is *Sony 700TVL* industrial platelet camera with 3.6 mm lens. It provides a stable picture, quick response to the changing lighting and good video quality as for a surveillance camera. The chosen setup allows stable signal transmission in the open 800 m range.

3.5. On screen display system– OSD

OSD system is responsible for the application of the flight parameters on the video image transmitted to the controller. This helps with navigation and operating the platform by providing information such as: flight time, speed, distance traveled, battery voltage, artificial horizon etc. The complexity of the OSD system increases with the number of parameters given by the system. The information that the OSD system and the software allows to view on the camera image is presented in Fig. 8 and Table 2.

3.6. Radio control system– RC

RC system consists basically of the transmitter and the receiver. The transmitter is an electronic device that communicates via radio signal to the receiver. By moving the sticks of the controlling apparatus, proportional information is passed to the receiver. The main elements of the apparatus are two keypad console– shifters, allowing to control the SUAS flight. Additionally, the apparatus may be equipped with a programmable computer or microcontroller for automatic task performance.

*Turnigy 9X*console was used to control the flying platform. This is a digital, fully programmable, 9-channel apparatus. Standard equipment software allows adapting it to the specific application. *AFHDS* signal transmission system used in the apparatus searches 2.4 GHz band for 160 channels. This allows simultaneous operation of many of these transmitters without affecting each other's performance. However, the system working in the *AFHDS* technology tends to lose the transmitter – receiver communication occasionally, and the maximum RC range of the equipment is 800 m. These factors and some performed tests led to the replacement of the standard transmitter module to another. This new module was *FrSky* used to work in *ACCST* signal transmission technology. It provides a stable transmitter – receiver connection and a safe range in open area in excess of 1500 m. Rework equipment has been manufactured in a way that allows the selection of the *AFHDS* or *ACCST* operating systems.

4. Results

As a result of the performed research and tests, authors designed the prototype of small unmanned aircraft system (SUAS) in the form of quad X configuration multicopter platform. The system is designed as a base unit capable of automatic GPS flight with programmed trajectory and taking surface photos or video. Images are transmitted online and stored to the remote computer. The platform has a reserve capacity of 50 g for extra equipment such as thermal camera, thermometer, pressure sensor, various gas or dust probes etc. System is robust, heavy duty and the manufacturing cost of the custom made platform is 500 EUR. Fig. 9 shows the aerial mutlicopter platform prototype. Statistics and performance description of the platform are shown in Table 3.

5. Conclusions

Designed multicopter platform prototype for environmental research and monitoring is capable of stable hovering and flight for up to 15 min. This model is a generic setup with image transmitter and is prepared to become specified tool according to desired function. It has reserved slots for additional equipment such as thermometers, gas probes, infrared vision, wind speed probes, radars, sonars etc. One of the authors' research findings is that drones technology allows the small scale analytical agriculture. Table 4 presents application possibilities for environmental monitoring, research and control with multirotor aerial platforms. Authors indicate the newly spotted opportunity for Small Unmanned Aerial Vechicles to be an innovative tool for analytical agriculture.

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