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DRONE FOR ARTILLERY RECONNAISSANCE MISSIONS

Silviu-Mihai PETRIȘOR, Cristian TODOȘ

Abstract: *The authors of this scientific paper have created a drone intended for artillery reconnaissance missions at a 1:1 scale. In this study we present aspects regarding the objectives of the practical-applicative research, the organology of a practical example of the construction of the technological product, the technical problem that the constructive solution solves, its advantages and the possibilities of its implementation as well as some conclusions derived from the practical-applicative research.*
Key words: *artillery reconnaissance, drone, practical realization, vanguard element, human-artificial partnership*

1. INTRODUCTION

The military advanced remote-controlled technologies that do not require a human crew on board are used in all areas such as land, air, naval, space and are the basis of the new era of development of the next generation technologies because, they can carry out dangerous missions without endangering the life of the operator, or without exposing him/her to certain risks and threats to his/her health [6].

Scouting, surveillance and reconnaissance missions are the most effective and easy to accomplish by UAVs (Unmanned Aerial Vehicles) because they cover a large visualizing area of the tactical field from the air and have a low risk of being detected [13]. The contemporary military scientific space is permanently preoccupied with the robotization of the battlefield, even with ways to replace the human factor with the technological one in dangerous areas. In particular, the field of artificial intelligence has known a very wide development, even if it is very difficult and unethical to replace human reason with artificial intelligence implemented in a robot [3], [4], [5].

The current conflicts going on in the world demonstrate the usefulness and the necessity of using drones in military actions. The transmission of data and images in real time offers the operator an "*eye*" in the sky, by means of which he/she can avoid any change in the situation during a mission, and not only then [14]. Research and data collection structures can establish and determine the optimal course of action [1], [12].

To make UAVs more efficient in military actions, they have been built in different sizes, so that each drone, according to its characteristics, is efficient during the missions specific to the organological characteristics of the drone. For example, in urban combat it is preferable to use drones of mini, micro and nano sizes, because they sneak more easily through the premises of buildings and even inside them. For long-range, high-endurance long-range surveillance, Tier 2+ drones like the RQ-4 Global Hawk military drone are preferred [15], [16]. In general, military mini-, micro-, and nano-drones are used in military operations to scout enemy actions having a very close range in relation to the operators. Most of the utilized drones are medium-sized ones, operating at medium and high altitudes and

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having a very long flight time of about 50 h [11], [2].

The current stage of the emergence and development of UAVs, nationally and internationally, has experienced strong changes and spectacular development due to their importance and efficiency in military missions with a high degree of risk as well as in civilian ones [10]. The development of technology has had a significant impact on the research and development of the latest generation of UAVs, because it has been possible to implement on them small audio-video devices, sensors specific to the field in which they serve, sensors that have a very good quality and automatically the efficiency of their use increases, but, at the same time, their size and, implicitly, their weight are reduced [7]. At national level, a strong development of these UAVs is being attempted, especially in the military field, since the implementation of these technologies in special applications is necessary due to the absence of the human pilot, since they generally operate in areas with a high degree of risk for the health of the human operator and thus the loss of his/her life is avoided.

In the present scientific demarche, we wanted to develop a drone with vertical take-off, multi-rotor type, without a pilot on board, a drone that does not require a take-off runway, its launching being done by different methods (catapulting, assisted by a rocket, etc.). Due to its small size, it can be used especially in urban combat for scouting and intelligence gathering from small or confined spaces. It can be easily transported and operated by a single military, performing missions in different operational environments.

The technological product that we made can be operated even from points near the front line; in this way it can collect information about the enemy, its position as well as information about the mode of action in the field, data that are collected and provided especially to artillery subunits and to units used for the long range fire support of the maneuver companies.

The technological product made on a 1:1 scale is a technological product with a simple mechanical structure, made of minimal components necessary to fulfill its missions, in order to avoid high production and maintenance costs. It consists of two major components, namely: the frame and the electronic systems. The technological product is lifted off the ground and propelled by means of four motors, each of which being mounted on an arm of the quadcopter.

The technological product can demonstrate formidable effectiveness on the battlefield, especially due to its maneuverability, its small dimensions ensure that it can be easily carried by a single person. Moreover, it can also operate in an open field, as well as inside buildings, due to the long flight distance it can travel, but also due to the short flight time. In addition, due to the video camera, goggles and transmission unit, it provides the necessary information for the accomplishment of the military objectives. The production costs are relatively low and the operating cost is zero, and, in addition to these, it can operate under any weather conditions.

2. PRACTICAL REALIZATION OF THE UAV-Avangard Drone TECHNOLOGICAL PRODUCT

2.1 Objectives of the practical-applicative research

The UAV-AvangardDrone model that we have made and presented in this paper is small in size and has been designed to be used in information gathering, surveillance, scouting and battlefield reconnaissance missions, providing, in this sense, the protection of the military or civilian personnel involved in the mission. The UAV performs reconnaissance and intelligence gathering missions with a high degree of efficiency without the military being present in the middle of the action and without being subjected to a high degree of risk. Moreover, it did not require high financial resources for its research, design, manufacturing and maintenance.

UAV-AvangardDrone was conceived, designed, modeled and manufactured to meet the following operational objectives:

- to transmit information from the battlefield in real time through very high resolution images;
- to monitor and survey the tactical field under all weather conditions;
- to be operated at team/platoon level by a single military, right in the middle of the action;
- to be built with a budget as low as possible so that it can be purchased in large quantities and without causing great damage to the budget when it is destroyed;
- to be able to operate inside buildings, and in confined spaces;
- to be able to fly for at least 30 min.;
- to have a maximum range of 2 km;
- to be packed and transported by one military person;
- to be easily launched in a very short time.

2.2 Conception and practical realization of the technological product. Description of the components and the manner of assembling them

In order for a drone to be able to fulfill the operational requests and objectives, it has in its composition components specific to the entrusted missions.

Therefore, we present a constructive variant of the drone according to the designed innovation (Fig. 1, a, b).

It consists of two major components, namely:

- The frame (hull of the aircraft) – the part that supports the electronic systems;
- The electronic systems: flight controller, motors, accumulator, transmitter/receiver, video camera.

a)

b)

Fig. 1 a), b) UAV-AvangardDrone-type technological product

The frame or hull of the aircraft serves as a support for mounting the other component elements. It can also be called the "*skeleton*" of the aircraft, and the important characteristics are the size, shape and material from which it is made. It must be very resistant, but, at the same time, it must be low weight. Carbon fiber was chosen for the construction of this part because it is light, robust and rigid. The main body is rectangular in shape, with a length of 5 cm, a width of 3 cm and a height of 4 cm. It consists of two main parts, namely: the lower part and the upper part of the frame which are joined by means of carbon fiber tubes, with a height of 3 cm, in order to facilitate the mounting of electronic systems on the upper part of the frame. This frame was built to be as resistant as possible in case of a hard impact of the quadcopter with the ground. In addition, four carbon fiber arms were added, which are individually removable, with a width of 4.5 mm and a length of 12 cm. These arms form a locking arrangement in the lower part of the frame which has the role of strengthening and supporting it. An X-shaped part, also constructed from carbon fiber, as shown in Figure 2, was added over this structure to further strengthen the arms and body of the frame, thus providing a 9.5 mm strength structure. This frame was designed with a height of 4 cm having in view the assembling, on the mechanical structure, of the electronic systems consisting of the LiPo battery, the video camera, the transmission unit, etc. Due to its carbon fiber composition, the structure is strong and durable, weighing 165 g.

Some of the essential elements of the drones are represented by the actuating motors of the mobile crew. If they stop working, the drone can no longer take off, consequently, it can no longer fulfill its mission. The drive motors are exposed to environmental factors during the flight, even to contact with the ground, if the operator is not skilled and experienced in operating the drone, this being likely to lead to the damage or even to the destruction of the motors. In this sense, the technical problem previously presented was solved by the authors by the designing, manufacturing and practicing on the technological product of some protection circular bar systems for the motors. These are made of carbon fiber, designed by means of the CATIA software and produced with a 3D printer. They are very light, but, at the same time, they are very resistant, and due to their very low weight, they do not influence the flight time of the drone. The protective circular bars protect the motors against dust and particles, against adverse weather conditions, but also confer it resistance against shock in case of contact with the ground or with any other hard object (Fig. 3). They give the technological product a pleasant design, have a special look and do not influence the aerodynamic shape of the drone.

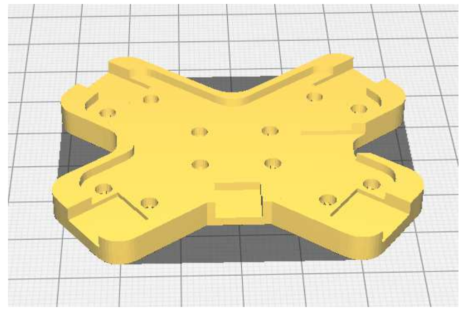


Fig. 2 The X-shaped part

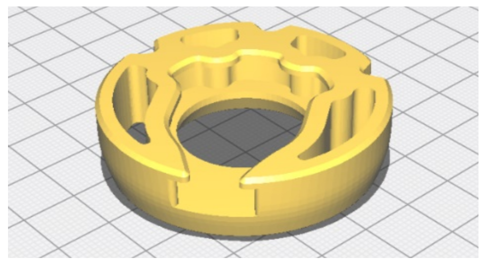


Fig. 3 Protective circular bars

In order to increase the safety of the drone and to also add to the strength of the frame and its protection, four fixed supports (Fig. 4) were designed and made. They have the role of protecting the technological product and the drive motors in case of contact with the ground or with hard surfaces. These are made of carbon fiber, a light and very resistant material, and the weight of the parts does not influence the flight duration of the drone. The parts were made with a 3D printer. Grooves were made inside the supports to reduce the weight of the assembly, so as not to affect the resistance of the organological elements and the thickness of the walls was set at 2 mm.

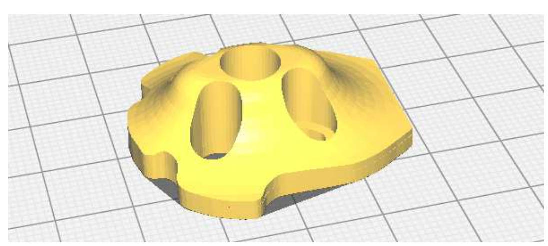
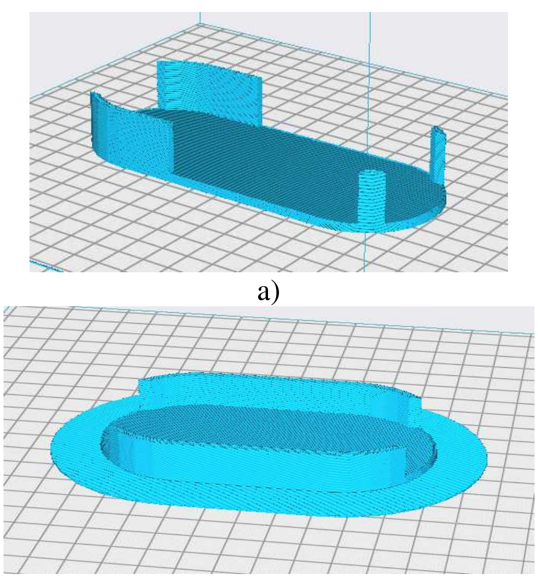


Fig. 4 Fixed supports

They were mounted on the lower part of the arms, at a distance of 3 cm from the motors.

In order to give more safety to the optimal operation of the quadcopter, two parts were made in order to protect the electronic systems as well as the frame (Fig. 5 a, b). The two support parts of the technological product were first designed by means of the CATIA software and then they were manufactured by means of the 3D printer. They are made of PLA type filament. The chosen material is very easy to process, and, due to its composition with polylactic acid, it is considered to be a material based on a thermoplastic polyester obtained from sugar cane or corn starch. This represents a renewable resource used in the mechanical structure of the practically realized technological product. A great advantage of this type of material is the fact that it can be recycled, and as a result of this process, it does not lose its mechanical properties. On the other hand, it does not harm the environment and it is biodegradable. The time required for degradation is significantly lower than in the case of other plastics that take centuries to degrade. The two protective pieces are joined together by means of white tape that is wrapped around them and, in addition to this, it gives the drone an appearance that can be harder to notice while in the air (camouflage).



a)

b)

Fig. 5 Protective part: a) lower part, b) upper part

The First-Person View (FPV), also known as remote-person view (RPV), is a new method used to control a vehicle from a distance by radio waves, from the perspective of a pilot in the aircraft cockpit. This method is used to fly an aircraft without a pilot on board. The aerial vehicle proposed by this scientific demarche, helps the operator by means of the video camera provided to coordinate it and give it the desired direction, because it is connected to a transmitter that sends the video signal to a monitor in the possession of the military operator. In order to make a video transmission, in real time, two components were deemed necessary and were taken into account by the authors: an aerial component, which is a video transmitter, and a terrestrial component and a video receiver. A basic FPV system consists of a video camera, an analog video transmitter on the aircraft, with a video receiver and a display screen carried by the military operator.

The state-of-the-art technology and the specialized hardware equipment practically give the drone the ability of self-stabilizing or of autopiloting (the aircraft returns by itself to the point where it left from) if the connection between the operator and the drone is interrupted. The system of on-screen display of flight data and GPS navigation facilitates thus a much closer connection between the operator and the drone [9].

An important feature of the video camera is the fact that it can be actuated by two servomechanisms in order to look both down for terrain surveillance and also up to prevent an attack from another drone, as well as to look for other aerial vehicles flying above it. This DJI FPV Air Unit system is a digital video and wireless control component that transmits data wirelessly. The digital transmission system transmits video signals with low latency and has a signal transmission range of up to 7 km. The system also offers the possibility to communicate with the controller on the ground and to transmit video images through the same digital link, with the specification that it must be connected to the goggles as well as to the controller at the transmission unit via PPM or SBUS. By using this system, one avoids any interference that may be caused by any system on the same frequency, providing stable control and a video link over long distances. The system also offers the possibility of recording the video directly on the Air End module and/or on the DJI goggles; thus it can be played as many times as the user wants.

The transmitter used by the drone is an OcuSync Video Transmission Module and is made by DJI. It operates on two digital video transmission frequencies, namely 2.4 and 5.8 Ghz, respectively. It features two live view modes, namely: if the images are transmitted in high quality mode, they will have a 40 ms-delay, and if they are in low quality transmission mode, they have a delay of up to 28 ms, and the maximum distance up to which the drone can be controlled is up to 7 km.

In order for the drone to be as effective as possible in surveillance and reconnaissance missions, it necessitates a transmission of the images that is as clear as possible, the unit transmitting images of a quality of up to 1280x960 HD. In order to avoid interference with other devices transmitting images on the same frequency, the possibility of choosing from 12 digital video channels to transmit the signals was taken into consideration.

In order for the operator on the ground to be able to see what an airplane pilot normally sees while in flight, in addition to the other related electronic systems, he/she needs goggles that simulate virtual reality and give the operator a clear image obtained by the "*eyes*" of the drone (Fig. 6). He/she can see by means of these goggles everything recorded by the camera mounted on the front of the frame of the drone. The operator sees more precisely the things and people from the area where the drone is located and whatever else is needed to perform reconnaissance, intelligence or surveillance missions. Furthermore, by means of these goggles, he/she can see where to direct the drone, towards which objectives, places that are of interest for the fulfillment of the missions. These DJI FPV Goggles V2 virtual reality goggles are the receiver used by the military controlling the drone. They offer a very wide field of view of 150º, which gives the operator the feeling that he/she is right there [18]. In order to avoid interference with other systems in use, the receiver must work on the same operating frequency as the transmitter, which can be between 2.400-2.4835 GHz or 5.725-5.850 GHz and must be capable of receiving at least 40 channels. These goggles also enable the user to magnify the image by 2 inches (x2), a very important thing used in surveillance, intelligence and reconnaissance missions. This gives the operator the possibility to gather information more easily when the drone is on missions that require a higher flight altitude. In order to make the goggles more comfortable to wear, these are very light weight and quite ergonomic and the operator will enjoy using them. The goggles use a rechargeable battery with a capacity of 1800 mAh, which gives the operator about 110 min during which he/she can feel the thrill of the flight and see everything through the "*eyes*" of the drone.

Just as the pilot of an airplane controls the airplane with the help of the yoke, the operator of an unmanned aerial vehicle needs a remote control by which he/she transmits the manual command to the UAV by means of radio waves, and gives it the desired direction with the help of the receiver mounted on the drone.

In order to control and fly the drone with the help of radio control, the operator needs training in the field, especially to avoid the destruction that can be caused due to the lack of experience in controlling the drone.

Fig. 6 Dji FPV Goggles V2 [18]

Due to the destination and the operational objectives for which the drone was designed and manufactured, it can only be controlled with the help of radio waves, because it can move away from the operator at a distance of 2-3 km and with a maximum autonomy of 1 h.

The selected TX16S-type station (Fig. 7) consists of two main components: the radio control and the transmitter with the receiver (the transmitter is embedded into the radio control, and the receiver is mounted on the drone), respectively [19].

Fig. 7 Radiomaster TX16S-type radio control [19]

The Flight Controller is one of the most important components of this quadcopter, representing the brain of the drone and performing very important roles and functions. In order for this flight controller to be able to control the aircraft, it needs additional software compatible with it, which enables those who produced the technological product to program the aircraft in order to control it according to the assigned missions. It can be programmed to command the quadcopter to operate autonomously by automatically receiving data from GPS systems, but it can also operate in manual mode, obtaining data and commands from the human operator via radio control. The working principle of the controller is that it receives the data and information either automatically or manually from the human operator through the station receiver, by means of telemetetry and GPS, and, at the same time, it actuates the four motors of the quadcopter. For the control of the quadcopter, a dynamic flight controller with the best processor was chosen so that the received data are processed in the shortest time possible so as to avoid delays in the communication, coordination and control of the human operator with the technological product. At the same time, we had in mind the possibility of communicating with the other components and electronic systems that are mounted on the quadcopter. Thus, we offered a varied range of ports. This flight controller is called T-Motor F7+F55A PROII HD STACK (Fig. 8) and is most commonly used on multi-rotor unmanned aerial vehicles [17].

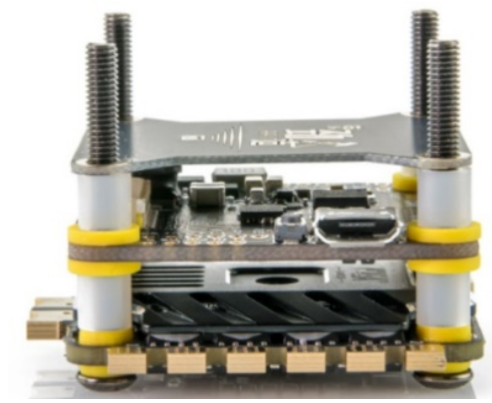


Fig. 8 T-Motor F7+F55A PROII HD STACK [17]

As one can see in the figure above, on the side of the controller, there is a USB port that enables its connection to a laptop, phone or tablet. As a result of the connection of the flight controller with a laptop, phone or tablet, the operator has the possibility to access a program that facilitates the creation of settings, the planning of a flight path or even of flight modes. At the same time, this program enables the operator to gradually check the flight controller, especially the engines to avoid any unpleasant incidents. Thus, one can check if the values received from the radio control fall within the optimal operating parameters and if the accelerometers respond appropriately to the commands for movement on each axis.

Depending on the operator's needs, he/she can set the flight controller to make the drone fly in several modes (Fig. 9). These needs are determined by the type and objectives of the mission that is to be carried out [20].

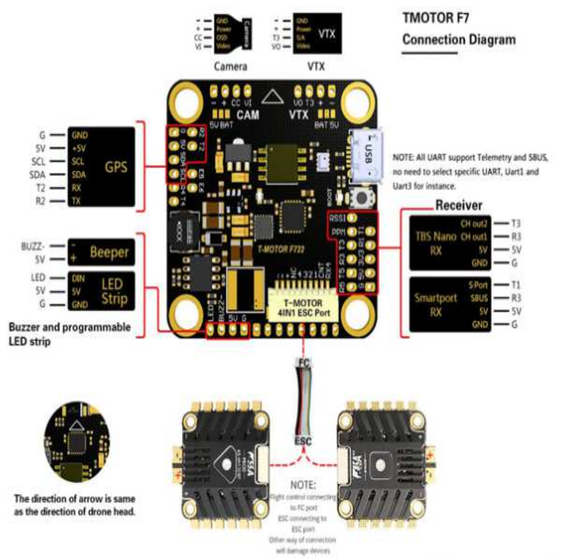
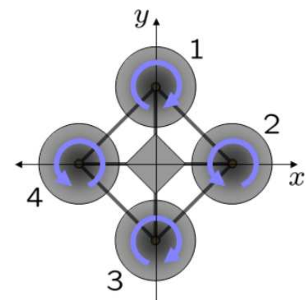


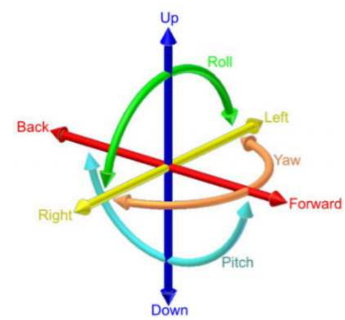
Fig. 9 Diagram showing the connection of the T-Motor F7+F55A PROII HD STACK flight controller: GPS, Receiver, Camera, Bell and programmable led tape [20]

The configuration designed and implemented in this technological product enables the drone to take off and land anywhere, regardless of surfaces or weather conditions. It does not need a runway because it takes off vertically, with the 4 motors providing the necessary power to lift the quadcopter into the air in a very short time. This gives it an advantage in missions that need to be accomplished in very short time. Each rotor provides both lift and torque. The flight control of the quadcopter-type unmanned aerial vehicle is ensured by the independent variation of the speed, but also of the torque and lift of each rotor. In general, the direction of rotation of the 4 rotors is not the same, because in order to be easily and efficiently controlled and to compensate for the torsion effect of the motors, two of these motors rotate clockwise and the other two rotate counterclockwise, thus annulling the angular momentum of each propeller due to the other that rotates in the opposite direction. This direction of movement is shown in figure 10 a, b [8].

The electric motors that are used on the quadcopter we built are of the brushless type (without brushes), which develop a high power in relation to their weight.



a)



b)

Fig. 10 a) Direction of rotation of the motors, b) Direction of movement of the drone

These motors were manufactured by Lumenier and are called *Lumenier 2306 JohnnyFPV Cinematic Motor* [17]. The motor is fitted with a 4mm titanium tubular shaft with a screw-type end and is available in a 3kV version to best suit the operator's configuration. The shaft was chosen to be made of a titanium-type material as it offers light weight and a significant strength and durability together with the high quality threads. A speed controller was used to control and regulate the speed of an electric motor. It not only controls and regulates speed, but it can also provide motor rotation reversal and dynamic braking. These speed controllers are especially used in models of unmanned aerial vehicles that are controlled by radio command.

The component part of the quadcopter that sets it in motion is the propeller. To set the entire quadcopter assembly in motion, 4 propellers were produced. These propellers were made based on the criteria set by the engine manufacturer, which provides certain standards so that their utility is as efficient as possible and the engines can reach their maximum operating capacity without problems. The size of the propellers is especially important as this must be in accordance with the size and the driving power of the engines. For the technological product, DAL Cyclone T5043C Pro Propellers were chosen as they offer faster turns, an excellent aerodynamic design and are much quieter.

2.3 Possibilities of implementing the drone in tactical field reconnaissance missions. Conclusions of the practical-applicative research

The role of artillery reconnaissance is to acquire timely data about the enemy and the terrain, data that are necessary for deploying artillery in battle formation, for opening and continue firing.

Using the technological product equipped with modern optoelectronic systems and manufactured at a 1:1 scale, it can provide accurate data in real time, and, due to its increased observation range, it can track the fragmentation of multiple projectiles, so that the firing has a percentage of 100% of hitting the target. Due to its small dimensions, the technological product can infiltrate into forests, confined spaces, areas where the observation by means of binoculars is impossible even when using aerial images, areas where the presence of a military is required to provide data about the target, or even data about the effect of the shootings. Therefore, both tanks and other important objectives, especially when in arranged firing positions, can be easily discovered with the help of this drone. Observing targets and objectives at night and under low visibility conditions (fog, snow, etc.) is no longer an impediment. This can be done with the help of the drone, obtaining the desired information through the use of cameras with thermal imaging and telemeter. The production costs of the UAV-AvangardDrone technology product are relatively low and the operating cost is zero. In addition, it can operate under any weather conditions.

3. ACKNOWLEDGEMENT

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DRONĂ PENTRU MISIUNI DE RECUNOAȘTERE ARTILERISTICĂ

Rezumat: *Autorii prezentei lucrări științifice au realizat la scară 1:1 o dronă destinată misiunilor de recunoaștere artileristică. În acest studiu sunt reliefate aspecte privind obiectivele cercetării practic-aplicative, organologia unui exemplu practic de construcție a produsului tehnologic, problema tehnică pe care o rezolvă soluția constructivă, avantaje și posibilitățile de implementare al acestuia cât și câteva concluzii desprinse în urma cercetării practic-aplicative.*

Silviu-Mihai PETRIȘOR, Ph.D, Eng, Associate Professor, "Nicolae Bălcescu" Land Forces Academy, Technical Sciences Department, E-mail: robmilcap@gmail.com, No. 3-5, Revoluției Street, 550170, Sibiu

Cristian TODOȘ, 2LT, Artillery Officer, Master student, "Nicolae Bălcescu" Land Forces Academy, Faculty of Military Management, E-mail: todoscristian@gmail.com, No. 3-5, Revoluției Street, 550170, Sibiu