CONSIDERATIONS ABOUT CONSTRUCTION OF UAV GROUND CONTROL STATIONS

Vasile PRISACARIU[*], Mircea BOȘCOIANU[**], Dănuț BĂLOS[*], Cătălin CIOACĂ[*], Sebastian POP[***], Luige VLĂDĂREANU[****], Victor VLĂDĂREANU[****], Ana-Maria TRAVEDIU[****]

[*]"Henri Coandă" Air Force Academy, Brașov, Romania (prisacariu.vasile@afahc.ro, danut.balos@gmail.com, catalin_cioaca@yahoo.com),
[**]"Transilvania" University of Brașov, Romania (boscoianu.mircea@yahoo.com),
[***]Aerodrone Ltd. Brașov, Romania (aerodrone.uav@gmail.com)
[****]IMSAR București, Romania (luigiv2007@yahoo.com.sg, vladareanuv@gmail.com ana.travediu@yahoo.com)

DOI: 10.19062/2247-3173.2021.22.18

Abstract: *The safety levels of the flight have determined the operating standards of the UAS which are transposed into the operating capabilities and the high levels of reliability of the ground command and control systems / ground equipment. The ground control station (GCS) or C3 is a subsystem of the UAS that has its own command and control technologies in flight and communications with high speeds of data transfer over long distances. The ground control stations (GCS) of unmanned aerial vehicles allow a single operator to handle all flight-related tasks simultaneously with the acquisition of data from areas of interest.*

The article contains an overview of the construction stages of an experimental model of the portable ground station for the command and control of unmanned aerial vehicles on board.

Keywords: *ground control station, unmanned aerial vehicles UAS, experimental model.*

Acronyms

BNC	*Bayonet Neill-Concelman (connector)*	*C5I*	*Command, Control, Communications, Computers, Collaboration and Intelligence*
GCS	*Ground control station*	*EASA*	*European Union Aviation Safety Agency*
FAA	*Federal Aviation Administration*	*HALE*	*High Altitude Long Endurance*
ITAR	*International Traffic Arms Regulations*	*ISTAR*	*Intelligence surveillance target acquisition*
MALE	*Medium Altitude Long Endurance*	*OS*	*Operating system*
RCA	*Radio Corporation of America (connector)*	*RC*	*Radio Control*
		MCS	*Mission control System*
RJ	*Registered Jack (connector)*	*NCW*	*Network Centric Warfare*
NDAA	*National Defence Authorization Act*	*NVG*	*Night Vision Google*
UCAV	*Unmanned combat aerial vehicles*	*WLAN*	*Wireless local area network*

1. INTRODUCTION

1.1.Overview

The intensive use of UAS technologies in various military and civilian fields has raised the level of complexity of (ground) command and control equipment on hardware and software components.

Flight safety levels have determined UAS operating standards that translate into operational capabilities and high levels of reliability of GCS/ equipment, depending on the complexity of the air system from a simple phone or smart tablet PC, for the operation of commercial UAVs up to the control systems (mobile or fixed) of the HALE/MALE/ UCAV UAS.

The ground control station (GCS) or C3 is a subsystem of the UAS that has its own command and control technologies in flight and communications with high speeds of data transfer over long distances [1, 2]. The C3 infrastructure involves complex capabilities, such as: human-machine interface, C3 multivector, voice control, operation of mission sensors (eg in ISTAR concept). These capabilities allow operators to control air carriers for the safe and efficient conduct of flight operations through: planning, logistics functions, personnel and technical procedures [2, 3].

According to the references [4, 5] we have a series of categories and constructive examples regarding the ground control stations (see Fig. 1.1) that serve the unmanned aerial systems on board, such as: tablet PC, laptop, and fixed GCS.

(a) (b) (c)

FIG. 1.1 Ground control system (at the ground). (a.laptop, b. GCS portable, c.GCS virtual cockpit), [4, 5]

1.2. GCS risk analysis

The design and development of a ground control station must follow all the specific stages of the systems engineering process. The initiation of a risk analysis is based primarily on the identification of operational, functional and performance requirements (table 1.1).

Table. 1.1 Requirements list

Operational	Hardware and software	Performance
• operating environment conditions (eg. day/ night; radio interferences; electromagnetic restrictions) • use conditions (eg. ergonomics; vibration/ shocks; mobile/ stationary/ shipboard; transportability) • technical operating requirements (eg. operating system; joysticks; switches and buttons; display) • security requirements (eg. cyber-attacks protection)	• integrating COTS equipment and/ or custom technologies (eg. open system architecture) • Modularity and interoperability (eg. computing solution) • redundancy items (eg. power supply)	• Time operation • Size and dimensions • Easy to operate • Setup time • Reliability • Serviceability

In order to finalize the technical solution, the identification of the requirements categories is completed with system analysis and control. This stage balances requirements, costs and risks in a top-down, iterative and recursive manner. Adopting the technical solution also involves the analysis of risks that are associated with software, hardware and communications elements.

The operating system and the software applications are susceptible to cyber-attacks. Once it takes control of the operating system, it also translates into control over hardware resources [8]. As a central node, the intentional or natural risks associated with the communications field should not be ignored. The main risks and solutions identified for their mitigation are represented in table 1.2.

Table. 1.2 GCS risks register

Domain	Risks	Mitigation solutions
Software	– disrupt the service – loss control – loss data	– updated software – antivirus software – network firewall
Hardware	– disrupt the service – malfunction – reduce performance	– testing in-house – redundant architecture – standard protocols
Communication	– disrupt the service – loss control – loss data	– control access – resource management – encryption common

1.3.Criteria for the construction of command and control stations (GCS)

The design, construction and use of GCS are based on critical criteria, such as regulations and standards for design, construction (technology, materials) and operating (performance, C2, human resources), [16]. The construction of the GCS starts from the compliance of the civil and/or military aeronautical regulations (updated and consolidated variants), regulations valid for the international area where the GCS equipment will be used, [17, 18, 19].

The design concept of the GCS can determine both the functional performance of the final model and the capabilities of the controlled units (UAVs), therefore the following aspects must be considered from the design phase [20]:

a. the environment and operating conditions that may affect the reliability of GCS, day / night / NVG operation or radio interference;

b. the duration of the flight operations/missions involves the performance of the accumulators / energy sources and the GCS ergonomics (shape/ dimensions, weight);

c. on screen display requirements (monitor size) involving values of image data processing performance or operation under natural solar lighting conditions;

d. the number and type of switches and IT peripherals, they influence the performance of the operator and the security of the flight operations;

e. setting time, it has an impact on the results of flight missions, integrated software solutions are recommended;

f. operating systems, it is recommended to use fully functional OS that reduces operator stress and advanced and efficient control of the GCS unit;

g. maintenance level, refers to the options regarding spare parts/ IT products for maintenance;

h. compliance aspects, designs, manufacturers/ integrators and GCS users are required to meet compliance requirements by areas of competence (NDAA standard, ITAR [21], UAV-GCS operator licensing regulations / standards), [17, 18, 19];

i. the security level of the GCS platform, involves the issue of hijacking, blocking, GCS availability, encryption / data loss, cyber security policies;

j. software integration, involves the level of assignment of the firmware interface with the GCS equipment (GCS specific integration, input device integration protocols, input hardware modules, communications modules / USB/ COM).

1.4. Research and development directions

The research-development and operation directions of the GCS are focused on both manufacturing technologies and operationalization in civilian and military activities.

According to the references [11, 12, and 13], GCS technologies already incorporate some robotic functions based on artificial intelligence (AI) and machine learning (neural network).

FIG. 1.2 Pipistrel eVTOL cargo, [14]

FIG. 1.3 VTOL cargo drone, [15]

The preoccupation of researchers and specialists in the field of civil uses have been oriented for several years towards the field of transport (UAS cargo), see Fig. 1.2 /1.3 and integrated uses for the acquisition of data on atmospheric and environmental monitoring, [14, 15].

Military uses are primarily focused on Network Centric Warfare (NCW) approaches, which involve swarm coordination of UASs through the possible use of wireless local area networks (WLANs) based on WLAN hubs and two-way broadband. of satellite communications [9]. The command and control functions available on GCSs can be developed up to C3I or C6ISR [10].

International research focuses on GCSs that can use three-dimensional maps for 3D transposition of operational situations and smart peripherals for real-time data and command input (from flight stick / switch to verbal and gesture commands), [26 , 27].

2. EXPERIMENTAL MODEL OF GROUND CONTROL STATION

2.1. GCS operation

The ground control station (GCS) of unmanned aerial vehicles allows a single operator to handle all flight-related tasks simultaneously with the acquisition of data. The developed GCS is based on 3 interconnected hardware platforms (two tablets and a laptop PC) being integrated in a shock and water resistant transport box [25], see Fig. 2.1. The control station offers a standard autonomy of 3 hours in terms of portability and modularity depending on the type of mission.

FIG. 2.1 GCS, computer layout and startup panel and connections.

2.2. Technical data and performances

The most significant data on construction and operating performance are shown in Table 2.1. The ground control station consists of structural and transport elements, hardware, software tools and data connections, as follows:

Tabel 2.1. GCS technical data and performances

Parameter	Value	Parameter	Value
Dimensions	820x540x510 mm	Autonomy	3 h
Mass	10 kg	Software system	Android / Windows
Connectivity	USB, RJ, Ethernet, RCA, BNC	Software management	Mission planner / Qground control

a. structural and transport elements: sealed box and panels for the arrangement and fixing of control elements and connections, see Fig. 2.2, [25];

FIG. 2.2 Sealed box, [25]

Table 2.2 Technical data and performances - Tablet Samsung Tab S5e, [22]

DISPLAY		MEMORY / STORAGE	
Parameter	**Value**	**Parameter**	**Value**
Display	10.5 inch	RAM	4 Gb
Resolution	2560x1600	Internal / external memory	64 / 512 Gb microSD
CONECTIVITY		**SENZORS**	
Wired	microUSB	Video	13/8 MPx
Wireless / Bluetooth	802.11/ 5.0	GPS/gyroscope/accelerometer	yes/ yes/ yes
BATTERY		**DIMENSIONS / MASS**	
Capacity	7040 mAh	Dimensions	245x160x5,5 mm
Type	LiIon	Mass	400 g

b. connected hardware: two Samsung Tab S5e tablets (Table 2.2) with Android operating system [22, 23], Fig. 2.3; an HP Probook 450 G6 laptop companion computer with Windows 10 operating system (Fig. 2.4. and Table 2.3); control panel and in / out panel;

FIG. 2.3 Samsung Tab S5e, [22]

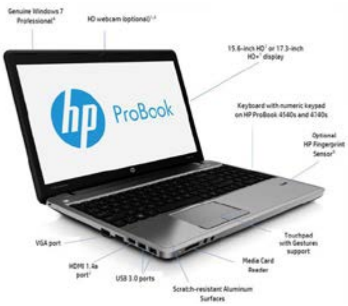

FIG. 2.4 Laptop HP Probook 450 G6 [24]

c. data connections: radio control system on the 3D trajectory (2.4 GHz), telemetry data transmission system (data link telemetry, 433 MHz), graphic data transmission system (image / video), storage system and data transmission from environmental sensors, see Fig. 2.5.

Data transmission can import / export specific signal both physically via USB, RCA, Ethernet, video and radio signal via Wi-Fi / Bluetooth standard via the two tablets and the laptop.

Table 2.3. Technical data and performances - laptop HP Probook 450 G6 [24]

DISPLAY		**CPU**	
Parameter	**Value**	**Parameter**	**Value**
Display	15.6 inch	Tipe / model / cores	Intel i5 / 8265U / 4
Resolution	1920x1080	Nominal /turbo frequency	1,6 / 3,9 GHz
MEMORY / STORAGE		**VIDEO**	
RAM / Frequency	8 Gb / 2400 MHz	Tipe	nVidia Gforce MX 130
HDD type / storage	SSD 256 Gb	Memory	2048 Gb
CONECTIVITY		**GEOMETRIE / MASA**	
USB / HDMI / RJ / Audio	Yes/ yes / yes / yes	Geometry	364.9 x 19 x 256.9 mm
Wireless / bluethooth	802.11 / 5.0	Mass	2 kg

Starting from the GCS concept from Fig. 2.5 we have the functional UAS architecture from Fig. 2.6.

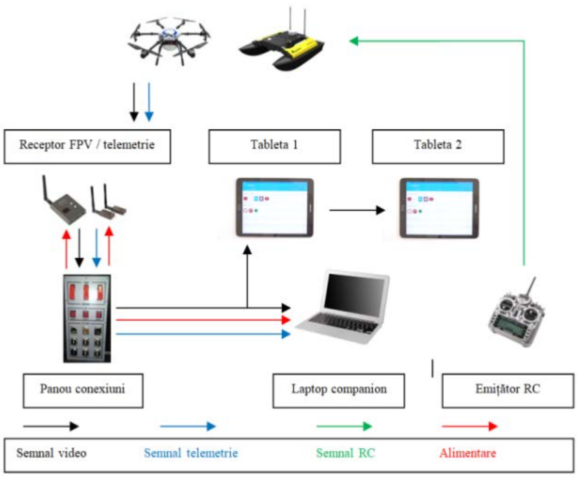

FIG. 2.5 Data and power diagram

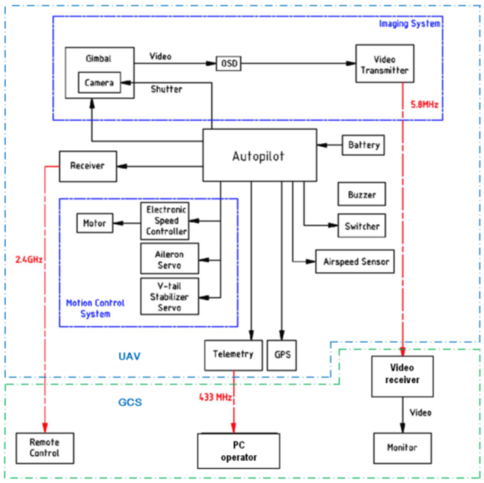

FIG. 2.6 UAS architecture, V-tail plane

Modules and connection diagram. The UAS architecture contains the two functional entities: the air vector (UAV) and the ground control station (GCS).

Air vectors (drone 1 and drone 2). It transmits telemetry (ex 433/915 MHz) and video (ex 5.8 GHz) data on flight and navigation performance. Receives RC routing signal for trajectory maneuvering from the RC transmitter (which can be integrated into GCS or standalone), frequencies used 2.4 GHz.

RC transmitter. Transmits the signal on the trajectory (optional depending on the degree of level equipment, receives telemetry data on the operation of air vectors).

FPV-GCS module. It receives telemetry and imaging data from aerial vectors (RCA port) and transmits it to display devices (companion laptop / tablet monitor) using the graphical interface of the Qground control software tool (USB port).

Laptop companion (PC operator). It offers the operator GCS (Qground Control), a series of facilities regarding the calibration, operation and simulation of the UAV flight. It receives image and telemetry data (USB port) on the mission management user interface.

Tablet PC. These provide the operator with visual data by navigation sensors (eg. navigation camera) and / or mission-specific sensors (FLIR / NIR camera, atmospheric sensors) via the microUSB port.

GCS management module. It consists of the connection and control panel that offers connection and management functions of the component electronic devices (receiver modules, laptop companion, tablets PC). This module also provides energy management with overvoltage protection to all GCS consumers.

3. ASPECTS REGARDING THE CONSTRUCTION OF THE GCS EXPERIMENTAL MODEL

The constructive stages of the experimental model are: establishing the GCS operating requirements (pre-design), design (in detail), manufacturing the structure and spare parts, bench running tests of the component systems, assembling and equipping the GCS, operating tests in real conditions of use, see Fig. 3.1.

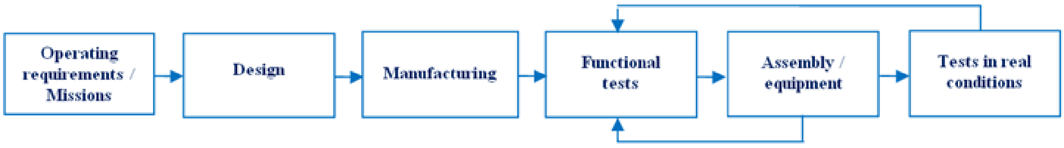

FIG. 3.1 Stage of GCS

a. starting from the selected concept [6], the requirements / missions of GCS determine the management of data connections from the air vector and the surface vector. Requirements for the implementation of the GCS are determined by design, operational and technological limitations see Fig. 3.2, [7].

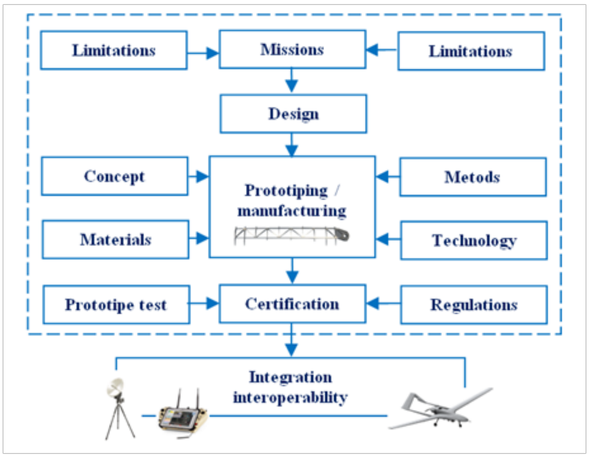

FIG. 3.2 GCS implementation management stage, [7]

b.GCS design is limited by the concept of low cost and portability, see Fig. 3.3. CAD tools (Solidworks, Autocad) were used for the design stage for geometric and functional aspects.

c. GCS manufacturing/realization is performed with the help of CAD / CAM technologies (3D and CNC printing), see Fig. 3.4;

d. the functional tests considered the verification of the functionality for connections and of the equipment.

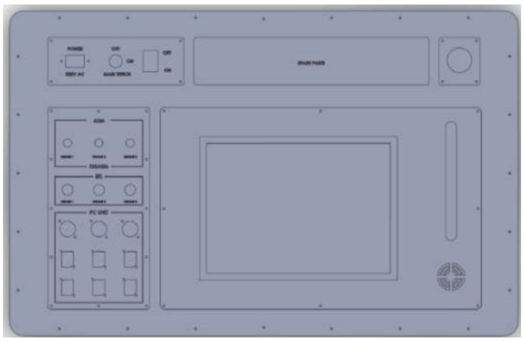

FIG. 3.3 Aspects regarding of the GCS main panel (design image)

FIG. 3.4 Realization of the upper signaling panel through CNC technology

e. assembly and equipment of the GCS, considered the portability conditions without affecting the operating performance (anti-vibration/anti-shock mounts), see Fig. 3.5;

f. the tests in real operating conditions were performed in normal weather conditions (without precipitation) during the day with temperature values in the range of 10^oC-22^oC, and included a series of aspects, the most relevant being: the preparation operations/ completion of missions; operation / acquisition of data within the mission;

(a) (b)

(c)

FIG. 3.5 GCS equipment, a. lower panels, b. upper panels, c. Power management panel.

CONCLUSIONS

The design, construction, testing and operation of unmanned aerial systems (GCS-UAS) involve a number of limitations that govern the life cycle of specialized technical systems. The GCS design provides an optimized approach to information on both the operating environment and data on the behavior of aerial vectors connected to the GCS, an optimized approach that determines the speed and accuracy of the operator by reducing cognitive load per unit time.

The paper exposed in the first part aspects regarding the theoretical considerations for the low cost design of a GCS-UAS and in the second part the concrete constructive stages are revealed, starting from the structure to the radio electronic equipment.

Future activities include the development of the Mission Control System (MCS) together with the Payload Control System (PCS) and the Communication System (CS).

ACKNOWLEDGMENT

This article was produced with the support of the documentation of the complex project, acronym MultiMonD2, code PNIII-P1-1.2-PCDDI-2017-0637, contract 33PCCDI/2018 funded by UEFISCDI.

REFERENCES

[1] Department of Defense (DoD) (2010). U.S. Army ―Unmanned Aircraft Systems Roadmap 2010-2035‖. Office of the Secretary of Defense. US Fort Rucker, Alabama;

[2] CAP 722, - Unmanned Aircraft System Operations in UK Airspace – Guidance‖ (www.caa.co.uk), ISBN 978 0 11792 372 0, Civil Aviation Authority 2010;

[3] K. Nonami, F. Kendoul, S. Suzuki Wei Wang, D. Nakazawa, ―Autonomous Flying Robots, Unmanned Aerial Vehicles and Micro Aerial Vehicles‖, ISBN 978-4-431-53855-4, Springer 2010;

[4] UXV Technologies, https://uxvtechnologies.com/, accesed at 11.12.2021;

[5] https://www.nbcnews.com/technolog/virtual-cockpit-what-it-takes-fly-drone-1c9319684, accessed at 11.12.2021;

[6] V. Prisacariu, C. Cioacă, D. Luculescu, A. Luchian, S. Pop, *Consideration about UAV command and control. Ground Control Station*, Journal of Physics: Conference Series, 5th International Scientific Conference SEA-CONF 2019, 1297(2019)/ 012007, doi:10.1088/1742-6596/1297/1/012007, IOP Publishing;

[7] V. Prisacariu, M. Boşcoianu, I. Cîrciu, *Management of robotic aerial systems accomplishment,* RECENT Journal 2/2012, Transilvania University of Brasov, Romania, ISSN 1582-0246, p. 203-217;

[8] K. Mansfield, T. Eveleigh, T. H. Holzer and S. Sarkani, *"Unmanned aerial vehicle smart device ground control station cyber security threat model*", *2013* IEEE International Conference on Technologies for Homeland Security (HST*)*, 2013, pp. 722-728, doi: 10.1109/THS.2013.6699093;

[9] Barnard Microsystems, *Grounf control system*, https://barnardmicrosystems.com/UAV/features /ground_control.html, accessed at16.12.2021;

[10] Command and control, https://en.wikipedia.org/wiki/Command_and_control, accesed at 16.12.2021;

[11] C. Oren, A. Verity, *Artificial intelligence (AI) applied to unmanned aerial vehicles and impact on humanitarian action*, Digital Humanitarian Network, 2020, https://www.updwg.org/wp-content/uploads/2021/02/Artificial-Intelligence-Applied-to-Unmanned-Aerial-Vehicles-And-its-Impact-on-Humanitarian-Action-May-2020-2.pdf;

[12] A.I. Khan, Yaseen A. Al-Mulla, *Unmanned Aerial Vehicle in the Machine Learning Environment. EUSPN/ICTH* conference (2019), doi https://doi.org/10.1016/j.procs.2019.09.442;

[13] Y. Liu, H..N. Dai, *Unmanned Aerial Vehicle for Internet of Everything: Opportunities and Challenges, Computer Communications*, Volume 155, 1 April 2020, Pages 66-83, doi: https://doi.org/ 10.1016/j.comcom.2020.03.017;

[14] UAS vision, https://www.uasvision.com/2020/09/10/pipistrel-accepting-orders-for-nuuva-evtol-cargo-drones , accessed at 19.12.2021;

[15] L. Kinthaert, *Cargo drones and data swarms: experts weight in on difgital transformation in shipping and maritime*, Seatrade maritime News-Technology, 2017, https://www.seatrade-maritime.com/technology/cargo-drones-and-data-swarms-experts-weigh-digital-transformation-shipping-maritime, accessed at 20.12.2021;

[16] A. Sabri Abdalla, V. Marojevic, *Communications Standards for Unmanned Aircraft Systems: The 3GPP Perspective and Research Drivers*, 2021, IEEE Communications Standards Magazine 5(1):70-77, DOI: 10.1109/MCOMSTD.001.2000032;

[17] Federal Aviation Administration - FAA, PART 107 - SMALL UNMANNED AIRCRAFT SYSTEMS, 2020, https://www.faa.gov/newsroom/small-unmanned-aircraft-systems-uas-regulations-part-107, accessed 10.11.2021;

[18] European Union Aviation Safety Agency - EASA, Unmanned Aerial Systems regulation https://www.easa.europa.eu/regulations/uas-unmanned-aircraft-systems, accessed at 12.12.2021;

[19] Autoritatea Aeronautică Civilă Română – AACR, Legislatie drone, Aeronave civile fără pilot la bord – operațiuni UAS, https://www.caa.ro/ro/pages/legislatie-drone , accessed at 10.11.2021;
[20] Ball M., Guide to choosing a Ground Control Station, UXV Technologies – UAV components, 2021, https://www.unmannedsystemstechnology.com/2021/10/guide-to-choosing-a-ground-control-station/, accessed at 01.12.2021;
[21] National District Attorneys Association, National Prosecution Standards (third editions), https://ndaa.org/wp-content/uploads/NDAA-NPS-3rd-Ed.-w-Revised-Commentary.pdf, accessed at 05.12.2021;
[22] Samsung Galaxy S5e, https://www.samsung.com/us/mobile/tablets/galaxy-tab-s/galaxy-tab-s5e-10-5-2019-wi-fi-sm-t720nzkaxar/, accessed at 05.12.2021;
[23] *Samsung Galaxy S5e, User manual*, SAM_T727_EN_UM_TN_UE2_070721_FINAL, 140p, https://downloadcenter.samsung.com/content/UM/202107/20210723053331076/SAM_T727_EN_UM_R_11.0_070721_FINAL_AC.pdf;
[24] https://store.hp.com/us/en/pdp/hp-probook-450-g6-notebook-pc-customizable-4sz43av-mb, accessed at 09.12.2021;
[25] https://www.echip.ro/genti-cutii-pentru-scule/972-cutie-pentru-scule-max-430.html, accessed at 05.12.2021;
[26] ONUR, Communication for UAVs and GCS: voice communication and recording system, airborne radio gateways, Ankara-Turkey, https://www.onur.net/, accessed at 19.12.2021;
[27] UAS voice, https://www.uasvoice.com/unmanned-traffic/voice-communication-recording-system-for-uas-applications/, accessed at 19.12.2021.