IJISEA Original Papers

International Journal for Interdisciplinary Sciences and Engineering Applications

Orange Publications

IJISEA

International Peer-Reviewed Journal

www.ijisea.org

ISSN:2582 - 6379

Contact : editor@ijisea.org

ISSN: 2582 - 6379
Orange Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2024, Volume 5 Issue 3
www.ijisea.org

A Review on Drone Ground Control Station, Configurations, Types and the Communication Systems

Lijalem Gebrehiwet[1], Yared Negussie[2] Eshet Tesfaye[3]
[1,3]Aerospace and Satellite Communication Researcher, Ethiopian Space Science and Geospatial Institute, Addis Ababa, Ethiopia
[2]Machine and Equipment Production Researcher, Manufacturing Technology and Engineering Industry R& D Center, Addis Ababa, Ethiopia

lijalemgg2013@outlook.com, yared222@yahoo.com, eshettesfaye377@gmail.com

ABSTRACT

There are different designs and applications of ground control stations nowadays. The main purpose of this review article is to identify the gaps of drone ground control stations related to their functional and operational requirements. Furthermore, it examines alternative GCS design configurations for diverse applications. The several GCS types and drone communication protocols that are currently in use are covered in precise detail in the technology section. UAV smart device and MAVLink protocol for bidirectional wireless communication between drone system and GCS are key technologies that enable complete drone dominance for a given mission. Other technologies, such as the Paparazzi UAV, enable extremely complicated and completely autonomous missions without the operator's involvement. They're all products of the GCS software development process. The various GCS configurations, purposes, types, and designs highlight any gaps or limitations on their applicability for certain missions. The best technology gaps in UAV/GCS development are those related to fully autonomous flight and the ability to control several aircraft within a single system.

Key words: Drones; Ground control station; GCS systems; Drone Communication; GCS software

Abbreviations: GCS, Ground Control Station; MAVLink, Micro Aerial Vehicle Link; UAV, Unmanned Aerial Vehicle

I.INTRODUCTION

Unmanned aerial vehicles (UAVs), frequently referred to as drones or RPAS (Remotely Piloted Aerial Systems), are widely used and have attracted a lot of attention in the past ten years, which carry out a number of tasks without the need for human assistance. The design of ground control stations, communication technologies, and flight endurance are the primary key limitations for unmanned aerial vehicles' design [1]. A systems software called control stations, which are in charge of creating the flight plan, monitoring the complete mission plan, and displaying telemetry data pertaining to UAVs, to track and define the flight path can be employed [2]. A number of essential elements must be met, including decision-making, environmental conditions, crew training, mission planning, setup time, platform security, durability, redundancy, and reliability, as well as human interaction and service [3]. A drone is remotely commanded by an operator from a powerful intelligent computer system. A ground control station is made up of radios, computers, and other electronic components to receive and send signals.

II. GROUND CONTROL STATIONS

The purpose of the ground control station (GCS) is to operate the UAV from a distance and it displays some data to operators to give an adequate degree of situational awareness [4]. The GCS comes in several configurations. Many factors such as layout, information component, representation scheme, and human operation methods, must be taken into account for the design phases in order to construct the ground control station for unmanned systems [5]. It can range in size from a little handheld gadget to a large console station. In military applications the GCS serves as a central hub for the intelligence, surveillance, and reconnaissance (ISR) data even though the unmanned aircraft and GCS may be thousands of miles apart [6]. Facilities including digital maps, satellite communication links, displays, mission planning, data exploitation, and image processing capabilities are all incorporated in the GCS [7].

1. GCS Requirements

There are some descriptions of several important elements involved in the design, control, and operation of GCS, such as the communication interface, multi-UAV coordination, functional requirements, software development, and implementation [5] [8]. The GCS is required to meet the basic functional and operational requirements to maximize their utility.

2. Types and Classifications of GCS

The nerve centre for UAV operations is the ground control station. A typical UAV ground control station has two consoles for the aircraft operator and payload operator [9]. The GCS uses for ISR by the data generated from the payload [10]. The following are some of the components or key aspects of GCS namely, user interface; Communication system; mission planning & execution; telemetry & status monitoring; payload control; safety features; data logging and analysis; multi-UAV coordination; software development and testing [11] [12]. Different terms are being used like “Ground Control Station (GCS)”, “Command and Control Station (CCS)”, “Mission Control Station (MCS)”, and “Mission Planning and Ground Control Station (MPGCS)”. Smaller UAVs are controlled via visual contact, while the larger ones are equipped with communication systems. If data link is installed, ground station may support flight control without visual contact with UAV through software application [13]. The general GCSs are classified as Basic GCS, Portable GCS and Permanent **(Fixed Installation) GCS.** Depending on the specific purpose of GCS (Military GCS and Non-military GCS). Depending on the cyber security protection of GCS, they are classified as Smart GCS and Basic GCS. The other main type of classification is on the flexibility of design and operation of GCSs as General purpose GCS and Universal GCS.

3. GCS Main Categories

There are several sizes and levels of complexity for ground control stations that might be as little as a backpack sized or as large as permanent structures. The most common type of ground control station is called a basic GCS. Smaller, simpler hobby or commercial drones frequently use it. It could be a laptop, tablet, or mobile phone with specific software installed on it. Even with the basic GCS, users may still interact with the drone, configure it for autonomous operation, and even take direct control of it [7] [8] [9]. On the other hand, portable GCSs are more reliable and adaptable. In comparison to basic GCSs, portable GCSs units offer a larger interface and more functions. A 3-Axis joystick is used in the HOTAS (Hands on Throttle and Stick) configuration, which is used by some portable GCS units to control the UAV's roll, pitch, and yaw [9] [14].

Figure 1: Basic, portable and permanent GCS

A more advanced and specialized ground control station is a permanent (fixed installation and vehicle mounted) GCS. It is usually put in a fixed location and is made for long-term use. Additionally, the GCS can be configured to monitor and control sensors and measurement apparatus [14]. These may have multiple monitors and operator stations with layered video and sensor feeds for maximum situational awareness [9]. The Ground Control Station works with several UAV models made by the same manufacturer. This firmware is used to set all of the flying modes, including Auto, Loiter, RTL, Alt hold, and stabilize [7] [10].

4. Mobile Ground Control Station (MGCS)

MGCS is preferred for extended missions requiring optimal operational capability, seamless integration, and user comfort. Control stations of the MGCS type can be erected inside a variety of shelters and containers [15]. The MGCS has cutting-edge electronics and is an essential component of actual flight operations. These days, mobile control stations serve a multitude of additional functions. For example, it obtains real-time data from peripherals, and operates a UAV for surveillance [16].

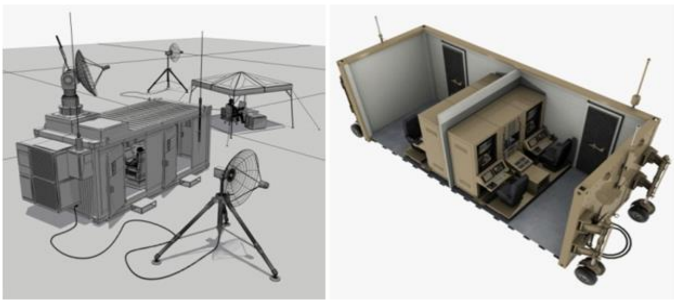

Figure 2: Mobile Ground Control Station

5. Mini-Portable (Low-cost) GCS

All pre- and post-flight aircraft operations, as well as engine functions, can be carried out using the robust, compact Portable Aircraft Control Station (PACS). A portable ground control station including a hand controller, a ruggedized laptop, an RF transceiver unit, and a controller box is usually used to operate and monitor small unmanned aerial vehicles (SUAVs) [17]. The portable GCS platform is an easy to transport and mount with all the control features that can be expected from a professional ground control platform [18]. The system values portability since its components are generally lighter and easier to transport rather than those traditionally used in a ground control station [19].

Figure 3: Portable Ground Control Station

6. FPV Ground Control Stations

An FPV ground station is a dedicated setup for receiving greatly enhanced FPV video signals [20]. The advancement of security surveillance camera technology has led to the creation of FPV cameras, which are compact, lightweight, and fairly priced video collecting equipment [21].

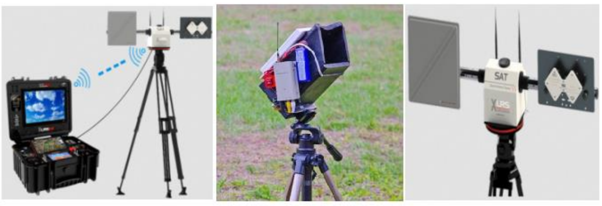

Figure 4: FPV GCS

Professional ground control stations can be used over longer distances for FPV and UAV applications that are installed with an integrated radio.

7. Non-military Drone Ground Control Stations

The GCSs are available in different designs and applications to suit for wide ranges across various fields for civilian applications in **Environmental Monitoring, Infrastructure Inspection, Search and Rescue, Media and Entertainment, Scientific Research, Security and Surveillance.** UAVs have so far had little presence in the field of civil applications but most air-based reconnaissance systems are currently used for military purposes [22] [23] [24][25].

Figure 5: Mobile Operations Centre (MOC) for research

UAS use for commercial and civilian purposes has grown the fastest. They are currently used in the civilian sector for their scientific missions or research projects, which encouraged the development of GCS specifically for this purpose [26].

8. UAV Smart Device GCS

UAVs are predominantly employed to assist military operations in the areas of intelligence gathering, reconnaissance, and surveillance. Research on cyber security risks to UAVs and conventional GCS has been conducted recently. The usage of UAV smart devices GCS aims for safe operation [27]. Secure

ISSN: 2582 - 6379
Orange Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2024, Volume 5 Issue 3
www.ijisea.org

communication links between the GCS and the end users in the battlefield network, as well as between the GCS and the UAV, must exist at the GCS [28].

Figure 6: Smart Devices GCS Network

9. The Immersive GCS – IGCS

The best design option to collect photos and videos provided by UAVs is to integrate graphic clusters and UAVs to create an immersive virtual control station. Real-time rendering of the films produces 3D renderings that are shown as a virtual scene on miniCAVE [29].

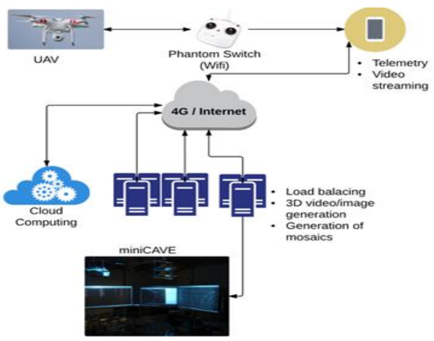

Figure 7: Immersive ground control station

Researchers claim that virtual reality (VR) is the most sophisticated method of user engagement with computer programs [30].

10. Desktop and Mobile GCS Worldwide

GS is usually operating on a ground-based computer, phone, or transmitter with a typical software application that connects to a UAV using USB cable or wireless telemetry. It provides real-time information about the position and performance of the UAV and can act as a "virtual cockpit," displaying many of the same instruments as a real aircraft [31]. It's also frequently used to see live video feeds from UAV cameras. Prior to operation, the autopilot's configuration must be set up, and the firmware must be updated. The vehicle and selected computing platform will frequently determine the GCS to be chosen [32]. The GCS selection platforms are ready-to-fly, DIY/kit and Code developers. Many users prefer ready-to-fly because of its ease of use and portability when using GCSs on a phone or tablet. While code developers will benefit from some of MAVProxy's features, DIY/Kit users and developers will need some GCSs or another more full-featured GCS because they frequently have access to configuration and analysis tools. Some of the GCSs commonly in use are shown below [31] [32];

II. CONFIGURATIONS OF GCS

One or more operator stations for air vehicle control, radar operation, mission control, payload operation, payload data processing, and system maintenance are often included in a UAV GCS. The four

ISSN: 2582 - 6379
Orange Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2024, Volume 5 Issue 3
www.ijisea.org

components that make up UAV systems are UAV, GDT, GCS, and Payload. Furthermore included in the ground support equipment are tools, generators, and capture cable.

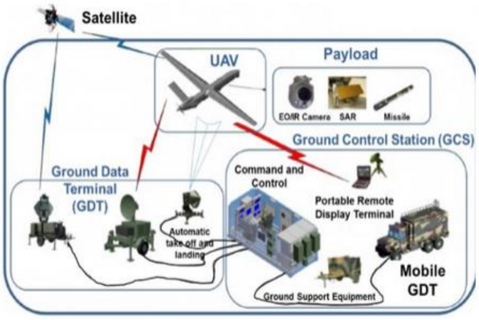

Figure 8: UAV interface with GDT/GCS

The communication between the UAV and GCS is provided by the ground data station via the Q, C, S, UHF, and other bands as shown below [33]. The UAVS has one downlink (C/L/S/Q/KU) and two uplinks (UHF and C/L/S/Q/KU). This is beneficial since it keeps the UAV under control in the event of a downlink issue, if it loses control in the event of an uplink. Therefore UAVS has two uplinks with different frequency range that are transmitted simultaneously. Figure 8 displays the block diagram of a typical UAV equipped with GDT/GCS [33] [34].

1. Air Vehicle Operator Station

This station provides man-machine interface for air vehicle controller to control and fly the UAV. It consists of an optional video data display, a UAV trajectory display, a UAV flight parameter display, and an air vehicle command console [7] [35].

Figure 9: The control room for NASA's Global Hawk Unmanned Aircraft

The external console and the GCS are connected appropriately via copper or fiber-optic cable. The pilot can view all pertinent flight data, including aircraft attitude, altitude, heading, speed, and engine parameters, on the UAV parameter display [7].

2. Payload Operator Station

The Payload Operator (PO) is in charge of running the POS. The payload can be a gimbal needed to operate it for directing in a certain direction, tracking targets, switching between IR and EO sensors, recording video, and so on. The PO may utilize different software, and it won't interfere with the GCO in any way [7] [34].

ISSN: 2582 - 6379
Orange Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2024, Volume 5 Issue 3
www.ijisea.org

Figure 10: Payload control station displays

The payload control logic and UAV can communicate in both directions. Through GDT, the UAV receives the command from GCS. The other option comes from UAV telemetry (flight data) and the video, where the payload's images are transmitted by GDT (wireless) to the GCS in the opposite direction as shown below [7] [34], there is a cabled interface between GDT and GCS.

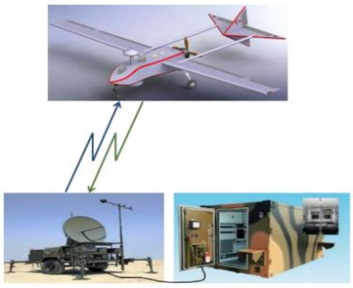

Figure 11: UAV-Payload commanding logic

3. Mission Commander's Station

The Ground Control Operator, or GCO, is in charge of operating the MCS. Pre-flight inspections, mission definition, mission, flight reports, and emergency procedures are all under the purview of the GCO. True and indicated airspeed, ground speed, plane location, virtual horizon, fuel and battery condition, direction, altitude, wind speed and direction, and many other flight-related parameters can all be monitored by the GCO using the instruments [7] [12]. During UAV missions, the mission commander's station offers facilities for editing and validating the mission plan as well as for monitoring system operation. This station has the capability to oversee and manage the radio frequency systems [36].

Figure 12: Mission Control station display

4. Radar Operator's Station

Controls for the tracking antenna systems and RF packages, including the transmitter and receiver, are integrated into this station. The drone radar, an essential part of counter-drone technology is the operator's

ISSN: 2582 - 6379
Orange Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2024, Volume 5 Issue 3
www.ijisea.org

station, which includes drone detection radar, types of drone monitoring equipment, and counter-drone technology itself. Monitoring, detection, categorization, locating, tracking, and alerting are all done with counter-drone technology [7] [37].

5. Data Interpreter's Station

The purpose of this station is to examine and decipher the pictures that the UAV has captured. This station is made up of image processing equipment that offer functions including photogrammetry, video snap shooting, hard copy printout of video frames, and picture enhancement, etc [7] [38].

6. Communication System (CS)

Drone communication is a new field of study with potential applications in both the military and the civilian worlds. Drone communication keeps drones connected to a ground station at a sufficient data rate to strengthen real-time transmissions. The link that receives the video signal from the aircraft and sends it to the ground can be one-way or two-way. The tracking of the UAV is one of the CS's duties. Antennas pointed at the UAV significantly improve signal quality and range [7] [39].

Figure 13: Drone Communication Systems

Satellite (SATCOM), cellular, radio frequency (RF), and drone-to-drone communication are some of the drone ways for communications [40]. GCS use a variety of communication techniques, including cellular communication (4G, 4G LTE, or 5G), unlicensed radio frequency (RF), and satellite communications (SATCOM) [41]. Systems components and outside entities can share data as a result of communication systems technology. Nowadays, the majority of UASs communicate data is via radio frequencies (RF).

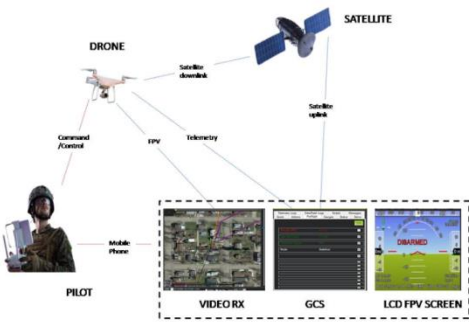

Figure 14: GCS-drone communication via satellite

The Figure below shows simplex digital connection with modems, transmitters, amplifiers, and antennas as some common components. Antenna coverage, aerodynamic impacts, and proximity data of linked communication system components should all be balanced appropriately during antenna integration [42]. A geometric or operational factor frequently limits the antenna size and configuration, which can affect the beam's quality and characteristics [43].

A. Drone communication protocols

The guidelines and conventions that control how devices communicate with one another are known as communication protocols. A variety of communication protocols are used in the drone industry to enable communication between a drone and its ground control station as well as between drones operating in the same airspace. Drones can communicate using a variety of widely used protocols, including FPV, Drone code Protocol, Mavros, MAVLink (Micro Air Vehicle Link), telemetry, and DJI SDK which are described below [44].

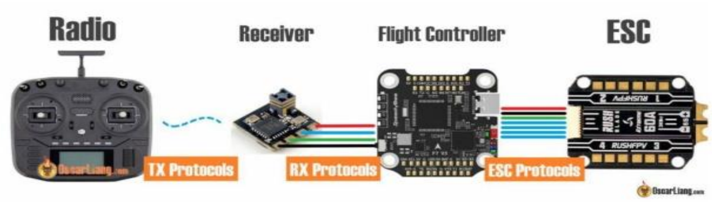

Figure 15: FPV protocols

B. Telemetry Module

A telemetry module is a transmitter that provides the drone with telemetry data by receiving and sending it. The two radio modules that make up the telemetry modules in some system are each assigned a distinct device ID. The MAVLink communication protocol is used by the telemetry module to communicate with the others [45]. To prevent interference, telemetry systems frequently employ frequency bands distinct from those used by RC protocols [56].

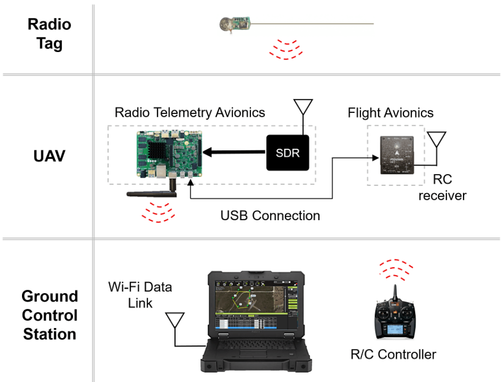

Figure 16: Communication via **data radio link and telemetry module**

C. MAVLINK Communication Protocol

As a result of its minimal overhead and capacity to handle a wide range of payloads, including video and telemetry data, it is a popular option as a communication protocol. A secure point-to-point communication system called the MAVLink protocol enables information sharing between two entities. The drone system transmits telemetry status data and the GCS sends commands to ensure proper flight [45].

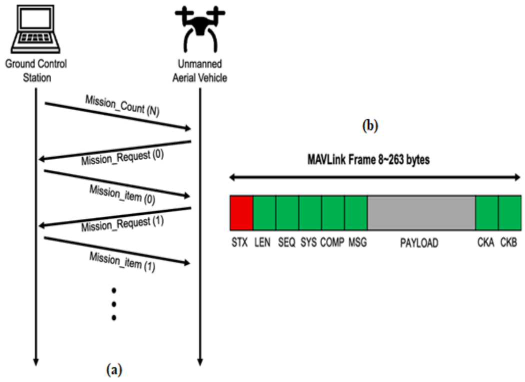

Figure 17: (a) MAVLink waypoint protocol procedure (b) MAVLink protocol data frame structure

This protocol is specifically designed to exchange data, including radio control channels, airspeed, altitude, drone climb rate, pitch, yaw, and roll Euler angles, IMU details and raw GPS data gathered. The main components of a MAVLink message, system ID, message ID, and payload [46].

D. Mavros

MAVLink is the foundation for the communication library Mavros. Simple message-sending and receiving interface that facilitates drone integration with ROS-based systems [45] [46].

E. Drone code Protocol

The Drone Code Protocol, an open-source platform for unmanned aerial vehicles, used by Drone Code Projects, is a communication protocol built on the MAVLink platform [45][46].

F. DJI SDK (Software Development Kit)

Varieties of communication protocols are included in the DJI SDK and are utilized to operate DJI drones as well as access their sensors and other data [47].

7. UAV communication techniques

The communication technique must provide a high enough data rate to handle the transfer of images for suitable UAV data link. Moreover, the data rate ought to be sufficient to enable GPS, altitude, and flight command data to be transmitted more often.

A. Cellular networks

Mobile communication services, including GSM, UMTS, WiMAX, and 4G LTE, can be 2G, 3G, or 4G based services. Due to possible coverage issues in remote locations and high operating expenses, using a commercial cellular network such as 2G and 3G networking services for UAV applications may not be feasible. The commercial expenses of a privately run network are substantial, even though 3G is more appropriate for these situations [48] [49].

ISSN: 2582 - 6379
Orange Publications
International Journal for Interdisciplinary Sciences and Engineering Applications
IJISEA - An International Peer- Reviewed Journal
2024, Volume 5 Issue 3
www.ijisea.org

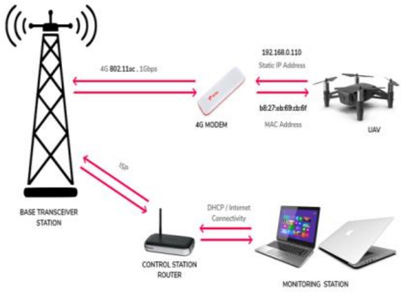

Figure 18: 4G network diagram

B. Satellite communication

Cellular networks use an external network to relay the signal rather to send data directly between the UAV and the ground station. Owing to its dependence on orbiting satellites, satellite communication finds a lot of applications in remote locations where other wireless communication methods' range is constrained [50].

C. Free-space optical communication

A modulated light beam can be used to track and communicate with the UAV instead of sending data via an indirect link between the UAV and the ground station. In order to point a modulated laser beam at a UAV, pointing-acquisition-tracking (PAT) devices have been developed. These systems use a wrist-like construction [51] [52].

D. Wireless LAN

The IEEE's wireless local area network standard is arguably one of the most widely used (WLAN). In order to develop wireless networks in households and corporate buildings, WLAN is frequently employed [53].

E. UAV communication software

Software was built for the ground station and the UAV to control the data transfer. Latitude, longitude, altitude, velocity, battery status, direction control, and image data are among the data that the UAV transmits. An interface between the GPS Data class and the UAV's sensors is provided by the GPS Handler class [53].

F. Data Link

The data link facilitates the essential communication between the several ground-based and aerial systems operators' stations.

8. The command and control (C2) link

It is essential link in drone operations where the aircraft is either programmed to fly autonomously or is being remotely commanded by a human. The communications components between the UAV and the GCS are transmitted over the C2 link. The design, security, and management of the C2 Link encompass a multitude of potential architectures and issues [54] [55]. The UAV operating range determines the chosen communication link. Line-of-sight (LOS) missions, where control signals can be sent and received via direct radio waves, and Beyond-Line-of-Sight (BLOS) missions, where the drone is controlled via satellite communications or a drone itself, are the two categories into which drone missions are classified based on their distance from the GCS [56]. It is possible to keep the C2 Link beyond BRLOS or within radio line-of-sight (RLOS). As long as the remote transmitter has RLOS to RPA and transmissions are completed in a comparable amount of time, the transmitter and receiver are within mutual radio link coverage and can communicate directly or through a terrestrial network [54] [55]. RLOS schematic is presented below to simplify the C2 link [57].

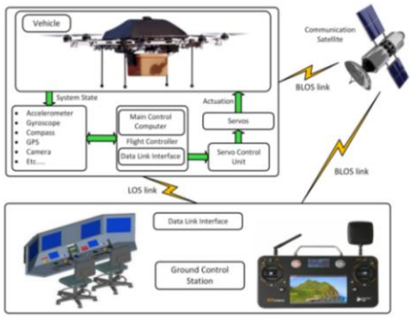

Figure 19: Simplified graphics of RLOS architectures

Any configuration in which the transmitters and receivers are not in RLOS is referred to as BRLOS. This includes all satellite systems in which an RPS uses a terrestrial network to interact with one or more ground stations. The technical and performance specifications of the RLOS and BRLOS C2 Links must be established and approved globally in order to support multinational operations [66] [67].

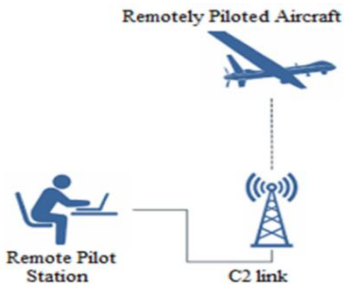

Figure 20: Simplified graphics of BRLOS architectures.

A. Paparazzi UAV

This is an open-source drone hardware and software project that includes ground station software and autopilot systems for fixed-wing, hybrid, multicopters, and multirotor aircrafts. The major goal of the design of paparazzi UAVs was autonomous flight, with manual flying is secondary. It was intended to be portable and capable of controlling several aircraft on the same network from the outset. This makes it easy to create very complex fully automated missions without the operator's intervention [58]. Using an Android device, a program allows users to operate a paparazzi aircraft. Since the Android application and server are linked via Wi-Fi, they need to be on the same network. To get a project up and running, a few steps must be taken once Paparazzi UAV and a program are connected to the same network [58]. The Paparazzi uses many controller and sensor boards or autopilot boards which are based on the STM32 micro-controller [59].

Figure 21: Paparazzi equipped UAV

III. CONCLUSIONS

The description, kinds, and designs of drone ground control stations (GCSs), together with their functional and operational requirements, are covered in this review paper. Furthermore, it reviews alternative GCS design configurations, types, and classifications for diverse applications. The several GCS types and drone communication protocols that are currently in use are covered in precise detail in the technology description. UAV smart device GCS as well as MAVLink which is the micro air vehicle link communication protocol used to allow bidirectional wireless communication between drone system and GCS are the decisive technologies to allow full dominance of drone for specific mission. There are also technologies which allow very complex fully automated missions without the operator's intervention like the Paparazzi UAV. The capacity to operate many aircraft within a single system with a full autonomous flying are the two greatest technology gaps in UAV/GCS development. The multi-drone mission and their algorithms by using a single GCS with autonomous flight mode and receive all live data of the flight path as well as the mission accomplishment set to the flying machines must be updated with the help of web-based tools, mobile applications, defining the way point with optimized efficiency, testing and debugging the errors with unexpected behaviour by improving drone firmware and softwares. The imaging algorithms are related to photogrammetry, image stitching and object detection. The improved algorithms can ensure the importance of a self-organized and cheap drone GCS design with ensured and secured data broadcasting which can be used for a complex operation.

REFERENCES

[1] **Singhal, G., Bansod, B & Mathew. L. (2018). Unmanned Aerial Vehicle classification, Applications and challenges: A Review.** *Preprints* [*Online*].

[2] **Mohsan, S. A. H., Othman, N. Q. H., Li, Y., Alsharif, M. H. & Khan, M. A. (2023). Unmanned aerial vehicles (UAVs): Practical aspects, applications, open challenges, security issues, and future trends.** *Intelligent Service Robotics* ***16****(*1*)*, 109 –137.

[3] **Leuchter, S., Partmann, T., Berger, L. Blum, E. J. & Schönbein, R. (2007). Karlsruhe Generic Agile Ground Station.** *Future Security, 2nd Security Research Conf.,* 159-162.

[4] **Jan, S. U., Abbasi, I. A. & Algarni, F. (2021). A Key Agreement Scheme for IoD Deployment Civilian Drone.** *IEEE Access*, **9,** 149311–149321.

[5] **Kwon, Y., Heo, J., Jeong, S, Yu, S. & S. Kim (2016). Analysis of Design Directions for Ground Control Station (GCS).** *Journal of Computer and Communications*, **4,** 1-7.

[6] **Segor, F., Bürkle, A., Partmann, T. & Schönbein, R. (2010). Mobile Ground Control Station for Local Surveillance.** ***Proc. IEEE*** *2010 Fifth International Conf. on Sys.,* 152-157.

[7] **Natarajan. G. (2001). Ground Control Stations for UAVs.** *Defence Sci.*, ***51****(3)*, 159-162.

[8] *Yan, L., Duan, H., & Deng, Y. (2022).* **Design and Implementation of a GCS for Multiple Fixed-Wing UAVs.** *Advances in Guidance, Navigation and Control, ICGNC, 845.*

[9] **John Mc Hale (2010).** GCS for UAVs are becoming networking-hub cockpits on the ground for U.S. unmanned forces. *M & A*, Tennessee, Special Rep.16723798.

[10] **Gebre-Egziabher D. & Xing, Z. Q. (2011). Analysis of unmanned aerial vehicles concept of operations in its applications.** *Intelligent Transportation Systems Institute Centre for Transportation Studies, University of Minnesota,* Final Rep. CTS 11-06.

[11] **Liang, X., Zhao, S., Chen, G. Meng, G. & Wang, Y. (2021). Design and development of ground station for UAV/UGV heterogeneous collaborative system.** *Ain Shams Eng. J.*, **12**(4), 3879-3889**.**

[12] **Hobbs A. & Lyall B. (2016). Human factors guidelines for unmanned aircraft systems.** *Ergonomics in Design*. ***24 (3)*****,** 23-28.

[13] **Sadraey M.H. (2017). Ground Control Station. In: Unmanned Aircraft Design.** ***Synthesis Lectures on Mechanical Engineering*****,** Springer, 141 - 156.

[14] **Portable Ground Control Station: A Universal Off-the-Shelf Solution (2012). Datasheet.**

[15] Guerra, M., Rhudy, M., Gu Y., et al. (2012). Mobile Ground Control Station Development for Fault Tolerant UAV Research. *AIAA Guidance, Nav., & Con. Conf*. 1-10.
[16] Sarigul-Klijn N. and Sarigul-Klijn, M.M. (2016). A Novel Sea Launch and Recovery Concept for Fixed Wing UAVs. *54th AIAA Aerospace Science Meeting.*
[17] Soares, D.A., Ramos, A. C. B. and Junior, R. A. C. (2017). Development of a Portable, Low-cost system for GCS for Drones. *Adv. in Intell. Sys. & Computing,* 2017, 767-771.
[18] Vasile P. et al. (2019). Consideration about UAV Command and Control. Ground Control Station. *5th International Scientific Conference SEA-CONF,* 1- 9.
[19] Homg, Y. Jiancheng J. and Tao, Y. (2008). Ground Control Station Development for Autonomous UAV. *Inter. Conf. on Intel. Rob. and App*, 36-44.
[20] Singh S. et al. (2021). FPV Video adaptation for UAV Collision. *IEEE Open Journal of the Comm. Society*. 2, 2095 – 2110.
[21] Tezza, D., and et al. (2020). Let’s Fly! An Analysis of Flying FPV Drones through an Online Survey. *Interdis. Workshop on Human-Drone Interaction (iHDI).*
[22] Jeler, E.G. (2019). Military and Civilian Applications of UAV Systems. Retrieved from The Balance Careers.
[23] Cox, T. H., Nagy, C.J., Skoog M.A. and Somers, I.A. (2004). Civil UAV Capability Assessment, December 2004.
[24] Al-Dosari, K., Hunaiti, Z. and Balachandran, W. (2023). A Review of Civilian Drones Systems, Applications, Benefits, Safety, and Security Challenges. *The Effect of Information Technology on Bussiness and Marketing Intelligence Systems,* 1056, 793 – 912.
[25] Buker, T.J., Luxion S.P. and Lyall, B. (2012). The Design of the UAS Ground Control Station: Challenges and Solutions for Ensuring Safe Flight in Civilian Skies. *Proc. of the Human Factors and Ergonomics Society 56th Annual Meeting*, 51 – 55.
[26] Austin, R. (2010). Unmanned Aircraft Systems: UAVS Design, Development and Deployment. 1st ed., a John Wiley & Sons, Ltd.
[27] Mansfield, K.M., Eveleigh, T.J., Helzen, T.H. and Sarkani, S. (2015). DoD Comprehensive Military Unmanned Aerial Vehicle Smart Device Ground Control Station Threat Model. *Defense Acquisition Research Journal (ARJ)*, 22(2), 240–273.
[28] Mansfield, K., Eveleigh, T., Holzer, T. H. & Sarkani, S. (2013). Unmanned Aerial Vehicle Smart Device Ground Control Station Cyber Security Threat Model. M.S. thesis. School of Eng. Manag. & Sys. Eng., George Washington University, Washington.
[29] Paiva, G.G.D., Dias, D. R. C, Guimarães, M. D. P. & Trevelin, L. C. (2017). Immersive Ground Control Station for Unmanned Aerial Vehicles. *17th International Conference of Computational Science and Its Applications (ICCSA),* 595-604.
[30] Agrawal, S.S. and Ritika, R. (2020). V R: An Overview. *CSI Com., 44* (4), 1 – 60.
[31] . Putera, A. S & Ramdani, F. (2018). Software Testing by Standard Software Metrics Method; Study Case & quot; Mission Planner & quot; as UAV Ground Station Software. *Journal of Teleco. Elec. and Comp. Eng. (JTEC)*. *10(1-8),* 123–128.
[32] Ball, M. (2021). Guide to Choosing a Ground Control Station.
[33] Arise, L. (2020). Satellite Frequency Bands: L, S, C, Ku, Ka-band-UPRC.
[34] Çuhadar, İ. & Dursun, M. (2016). Unmanned Air Vehicle System’s Data Links. *Journal of Automation and Control Engineering*, 4(3), 1-10.
[35] Hobbs, A. & Lyall B. (2016). Human Factors Guidelines for Unmanned Aircraft Systems. *Ergonomics in Design*, *24*, 23-28.
[36] Iordache M. (2020). Mission Commander: C & C. *Land For. Acad. Rev.*, 25(97), 1-10.
[37] Gong, J., Yan J., Komg D. and Li, D. (2023). Introduction to Drone Detection Radar with Emphasis on Automatic Target Recognition (ATR) technology. Eng. Comp. Scie. *Preprint Doi: 10.48550/arXiv.2307.10326.*

[38] *Zmejevskis, L. (2022). What is Drone Mapping?*
[39] Sharma, V. (2019). Advances in Drone Communications, State-of-the-Art and Architectures. *MDPI - Drones, 3*(1), 1 – 2.
[40] Park, S., Lee, J., Jumg S. and Kim J. (2023). Signal and Communication Technology (SCT) (UAV Communication and Networks). Available: https://link.springer.com/.
[41] Becker, S. (2023). Cellular Communication.
[42] Prisacariu, V., Cioacă C., Luculescu, D., Luchian, A. & Pop, S. (1966). Consideration about UAV command and control. *Journal of Physics: Conf. Series, 1297(1):*012007, 1- 9.
[43] *Blake, L. V. (1966). Antennas. New York: Wiley.*
[44] Shin, L., Marcano N. J. H. and Jacobsen R. H. H. (2021). A review on Comminication Protocols for Autonomous Unmanned Aerial Vehicles for Inspection Application. *ScienceDirect, Microprocessors and Microsystems*. *86*.
[45] Haque, S. R., Kormokar, R. & Zaman, A. U. (2017). Drone Ground Control Station with Enhanced Safety Features. *2nd Inter. Conf. for Convergence in Tech. (I2CT),* 1207-1210.
[46] Butcher, N. Stewart A. and Biaz, S. (2014). Securing the MAVLink Communication Protocol for UAS. *Computer Science, Engineering.* Tech. Rep. # CSSE14-02.
[47] Cai, K. (2021). Introduction to the Basic Functions of DJI SDK. DJI Developer Support.
[48] Gu, G. & Peng, G. (2010). The Survey of GSM Wireless Communication System. *International Conference on Computer and Information Application (ICCIA)*, 121-124.
[49] Wypych, T., Angelo, R. & Kuester, F. (2012). AirGSM: An Unmanned, Flying GSM Cellular Base Station for Flexible Field Com. *2012 IEEE Aerospace Conference*, 1-9.
[50] Aston, P. (2000). Satellite Telephony for Field and Mobile Applications. *Aerospace Conference Proceedings, 2000 IEEE*, 2000, 179-190.
[51] Sofka, J., Nikulin, V., Skormin V. & et al. (2009). Laser Communication between Mobile Platforms. *IEEE Transactions on Aerospace and Electronic Systems,* 336-346.
[52] Nikulin, V. & Khandekar, R. (2010). Demonstration of a Mobile Tracking System for Laser Communications. *IEEE 26th Conv. of Elect. & Electro. Eng. in Israel*, 2010, 781-785.
[53] Berkel, S. V. & Kooten, X. F. (2012). *Ground Station User Interface and Data Link: An Implementation for UAV.* M.S. thesis, Dept. Comp. Eng., Delft Univ. of Tech.
[54] *ICAO (2023). Remotely Piloted Aircraft System (RPAS) Concept of Operations (CONOPS) for International IFR Operations. ICAO RPAS Concept of Operations.*
[55] Kerczewski, R. J., Wilson, J. D & Bishop, W. D. (2016). *Satellite Communications for Unmanned Aircraft C2 Links: C-Band, Ku-Band and Ka-Band*. *NASA Glenn Research Center,* Tech. Rep.
[56] Marshall, D. M., Barnhart, R. K. and Shappee. E. (2015). *Introduction to Unmanned Aircraft Systems.* CRC Press. Available: https://www.taylorfrancis.com/.
[57] Altawy, R. & Youssef, A. M (2016). *Security, Privacy, and Safety Aspects of Civilian Drones: A Survey*. *ACM Transactions on Cyber-Physical Systems*, 1(2), 1–25.
[58] Soares, D. A. Ramos, A. C. B. & Costa Junior, R. A. (2018). *Development of a Portable, Low-Cost System for GCS for Drones. Advan. in Intel. Sys. & Comp.,* Springer.
[59] Hattenberger, G., Bronz, M. and Gorraz, M. (2014). Using the Paparazzi UAV System for Scientific Research. *ENAC, MAIAA*, Univ. of Toulouse, F-31400 Toulouse, France.

IJISEA
Original Papers

www.ijisea.org

IJISEA
www.ijisea.org

International Peer- Reviewed Journal