Consideration about UAV command and control. Ground Control Station

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Abstract. In the field of UAV, information processing centers most often materialize through ground control stations (GCS) that are used in various variants from simple commercial products in the form of tablets or radio control stations for controlling the vector within the visual range at low altitudes and autonomies, or portable, fixed or self-propelled technologies for missions beyond the visual range at high altitudes and autonomies. The article wants an overview of the theoretical bases on the construction and operation of GCS and aspects of flight mission debriefing using freeware tools.

Simbols and acronyms

| Symbol | Description |
|--------|-------------|
| Tx/Rx  | Transmitter / Receiver |
| C2     | Command and control |
| NTSC   | National Television System Committee |
| BNC    | Bayonet Neill–Concelman |
| UART   | Universal Asynchronous Receiver/Transmitter |
| ISR    | Intelligence, surveillance, and reconnaissance |
| D      | Distance |
| ρ      | Density |
| GCS    | Ground Control Station |
| FPV    | First Person View |
| HDMI   | High-Definition Multimedia Interface |
| PPM    | Pulse Position Modulation |
| RC     | Radio Controller |
| V      | Speed |
| l, d   | Length |

1. Introduction on communication systems

Communication systems provide the means for sharing data between system elements and external entities. Most UASs today use radio frequencies (RF) to transmit data. These systems are configured either for direct or indirect communication beyond the visual range, such as satellite communications (SATCOM) or airborne radio relay.

Communication engineering is a difficult field that requires deep training and specialization to achieve performance. This chapter provides a simplified overview of communication methods for familiarizing the reader with the factors that determine the design of the communications system.

Communication systems are composed of several elements that can be integrated into several configurations. A simplex digital connection is shown in Figure 1 to highlight some common elements and their functions. Such a system consists of modems, transmitters, amplifiers and antennas.

Integration of antenna should find an adequate balance between aerodynamic effects, antenna coverage and proximity data of interconnected components of the communication systems. The type of antenna and the field of view necessary influence the integration approach. Integration of the communication system should play a major role in designing from the initial design phases, as subsequent attempts to adapt this critical system may be difficult to design for unmanned aircraft.
Antennas may require protection against weather phenomena such as rain, ice, humidity, wind. A constructive protection measure is the radom that is not perfectly dielectric (loss -0.5 to -1dB), which also offers an aerodynamic shape to reduce the resistance to advancing, [1]. Losses from atmospheric absorption are determined by water vapor and biatomic oxygen. Losses depend on RF frequency, $T_X$ and $R_X$ altitude and frequency range, see Figures 2 and 3.

In most cases, the GCS is ground or low altitude and the UAV operates at high altitudes where atmospheric absorption is lower. For example, for systems operating at frequencies below 10 Ghz at a required radius of less than 100 km, the absorption is less than 0.5 dB.

Rain precipitation can cause significant attenuation at frequencies above 5Ghz (see Figure 3), so analysis of communications resources requires approaches to worst-case scenarios.

RF antennas emit or receive RF energy and provide directionality, antenna size and configuration are often limited by geometric or operational constants with effects on the quality and characteristics of the beam. Figure 4 shows the gain pattern of a typical two-dimensional antenna.
UASs use antennas with a model that is omnidirectional in azimuth (for any angle of altitude, it gives the same gain in any direction to the horizon). These antennas often have a beam width of 25°, which maximizes gain to the horizon where the largest range is needed. Non-orientated antennas can be attached to the ground or to a moving vehicle in a position and constant orientation to the platform. These antennas must have a field with enough gain to communicate in visual line with the other communication elements.

Unmanned aircraft are generally equipped with externally mounted antennas, which significantly contribute to the strength of unmanned aircraft. To illustrate the problem, consider an antenna consisting of a long circular cylinder with diameter \( d \) and length \( l \). The resistance coefficient of a circular cylinder is about 1.2 when the Reynolds number is less than \( 3 \times 10^5 \).

Some antennas are aerodynamic blades, where the external conductive surface is also the aerodynamic surface. These may take the form of thin aerodynamic profiles that approach aerodynamic profiles or flattened diamonds. Most omnidirectional antennas used in UAS applications have vertical polarization, which requires the vertical orientation of the antenna. Vertical tail surfaces are often suitable locations for the antenna, provided the cell lock is sufficiently low, see Figures 5a, [10] and 5b [7].

![Fig. 5 Location of antenna (a.Insitu ScanEagle, b. Northrop Grumman FireScout)](image)

Low frequency communications systems (HF, VHF, UHF) may have large antenna lengths, such as a 100 Mhz antenna with a length of \( \frac{1}{2} l = 57.6 \) inches. Antenna placement on UAVs depends on a number of factors that affect the performance of integrated antennas, the ultimate goal is to provide an adequate gain for all UAV’s trailing angular directions.

2. **UAV command and control**

Command and control (C2) of UAVs allow the operator to operate 3D on the trajectory and understand the state of the unmanned airplane. The connection is used to control the aircraft unmanned, and the link down to receive health and status information [5]. This link is essential for the flight where the unmanned aircraft can not land without control. Ensuring C2 connection against interference and unauthorized use is essential, encryption features are recommended. Unintentional RF interference is also a risk. A backup of the C2 link provides redundancy if the C2 main link becomes unusable for any reason. Ideally, backup and primary C2 links use very separate frequencies and perhaps different bands to provide a diversity of frequencies.

The data link provided by the payload link is mission critical but not essential to the flight. ISR missions are based on receiving payload data to ensure the success of the mission.

The payload connection can become critical to flight when combined with C2 or is used to provide critical flight information, such as a video source from a FPV camera. Digital or analogue links can be used, although digital links are needed for most types of useful data. Data rates tend to be much higher than those for C2 links.

Analogue links are used almost exclusively to send analog video data in real time, usually in NTSC format. Video quality degrades gracefully when the signal-to-noise ratio is reduced below the
maximum quality threshold. The VHF and UHF frequencies provide enough bandwidth for video transmission, and these low frequencies are robust to atmospheric and rain absorption. Many tactical micro UAS systems use return links for analog video, although there are miniaturized digital data links.

Data link for digital payload provide flexibility for different types of data. Many transmissions can multiplex multiple data streams on an unmanned aircraft and then demultiplex them to the ground data terminal. Some upload links have the ability to convert analog video streams into digital video before transmission, often with the ability to compress video.

3. Ground control station (GCS)
The UAV’s ground control stations (GCS) vary from commercial devices, see Figure 6a [2], at specially designed interfaces mounted in portable (mini-mobile), mobile (trailers) structures, see Figure 6b [3] or fixed control facilities, see Figure 7, [4].

Some GCS have non-intuitive design elements that contain complicated selection sequences, unoptimized automation interfaces for performing minor or routine tasks. These design errors on GCS can be prevented by applying design and ergonomics principles to cockpit positions. GCS design issues may reflect a non-optimization of the UAS under development, which is not covered by existing regulations.

According to [11] we can highlight a comparative analysis of the types of commercial GCS software, as shown in Table 1.
4. The selected GCS concept
The selected GCS concept (see Figure 8) is based on the following main directions: the air vectors are able to evolve beyond the visual radius in air and surface space; the operation of GCS under simultaneous and separate operating conditions for both air and surface vectors; operation and maintenance of GCS through intuitive and minimal use of resources; GCS operation covers all phases of the mission from flight planning to debriefing. The GCS concept is based on an existing product [9], due to its size, weight and versatility.

GCS internal connections are: power supply (internal / external source); video signal transmission; transmission of the telemetry signal; transmission of control and command signal; external users' connections, [14]. GCS development takes into account a number of factors from the design phase, such as: structure and geometry, hardware and connection hardware, software component, and user interface. These are detailed as follows:

a. Geometry and structure design features are dimensionally and totally optimized in view of the mobility of GCS (rigid container, handles, transport rollers).

b. The hardware component is based on the opensource concept and uses a portable PC with CPU I3 level 8Gb RAM and HDD 1Tb, the display component is supported by 2x14-inch monitors with a dedicated 1Gb graphics card. Connections include USB, HDMI and BNC standards. The monitors can display tactical (control area) and equipment via telemetry, image and C2 for the two vectors. It is preferable to minimize operator response times by implementing touchscreen and multi-screen monitors.

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Table 1. GCS comparative analysis

| Mission /APM (Planner) | QGround Control | UGCS | DJI Go | DJI Ground Station |
|------------------------|----------------|------|--------|-------------------|
| OS                     | Win, (Win, Apple, Linux) | Win, Apple, Android, Linux | Win, Apple, Linux | Win, Apple, Linux |
| Open source            | ok              | no   | no     | no                |
| MAVLink                | ok              | ok   | ok     | no                |
| APM                    | ok              | ok   | ok     | no                |
| PX4                    | ok              | ok   | ok     | no                |

Fig. 8 GCS diagram, [9].
c. The software component is based on the APM 2 Planner / Mision Planner or Qplanner opensource codes that provide operator-friendly interface and vector navigation information and sensor operation both online and GCS stored data, see Figure 9, [6].

Fig. 9 The software, a. APM 2 Planner/Mision Planner, b.Qplanner

GCS design is about simplifying and optimizing the workload for a single operator who can command two vectors (UAV-UAV or UAV-USV) within a coordinated or separate mission. The use of open source autopilots will allow modification of the source code according to the applications that constitute the objectives of the project. GCS automatically detects system settings (plug-and-play), provides visual and audio alerts (battery low, video / control-loop loss).

GCS has a full set of connections: 2 serial (RS-232), USB, 2 Ethernet, 1 video IN, 1 VGA IN (optional), 1 microphone, 1 audio output. These are complemented by fast connections to antennas (fixed and mobile), internal accumulators, and external power supply (12V / 220V). The power supply system contains surge protection, overcurrent, reverse polarity, battery discharge protection, see figure 10. The GCS may have a radio module monitoring module for battery status, internal temperature and power consumption. For the proper functioning of the system it is necessary to use a generator group in the case of exceeding the autonomy of the internal batteries.

Fig. 10 Antenna tracker links, [8].

5. Mission Planner

5.1. Introduction

Mission Planner is a Windows-only software tool used to configure missions for UAV or UGV, see Figure 11, [12]. After loading the firmware into the automatic pilot board (APM 2.x, Pixhawk), proceed to: configuring and calibrating the selected mission vector for optimal performance and safe operation; planning to save and load missions; downloading flight logs; interfacing with a UAV hardware-in-the-loop flight simulator; monitoring, recording and analyzing telemetry data on ground and flight operations of the air vector; operation of the air vector in FPV mode.
5.2. Mission Planner upload (MP)

For correct use, a series of installation procedures are required after the user manual, as follows: download and install MP; starting and MP update (if applicable); loading the firmware version [12] for the type of air vector used with the autopilot connection (see Figures 11 and 12) and correctly selecting the data port; connect the autopilot to the computer; mission loading.

Mission Planning includes: setting the flight path with waypoints (manually or generated) and assigned GPS events (e.g., mission-specific commands: gimbal orientation / focus / trigger), photo labeling (required for photogrammetry, orthofotoplan, 3D terrestrial modeling), mission command list, see Figure 13.

5.3. GCS flight data screen

Shows telemetry transmitted by Ardupilot, see Figure 14.
5.4. Sensors calibration

*Calibration of the magnetic compass.* The calibration routine runs on the on-board controller is more precise than the previous off-board method that runs on the GCS, after initiating the calibration it is necessary to rotate the multicopter (front / back, left / right, up / down), see figure 15. After completion of the procedure you will have to restart the pilot automatically.

*Calibration of accelerometers.* The calibration procedure requires positioning of the multicopter as in Figure 15, the neutral position is essential for the horizontal flight.

*Calibration of the RC system.* The calibration procedure requires the movement of the RC-Tx sticks / switches and the storage of their maximum and minimum positions. The calibration interface is shown in Figure 16.

**Conclusions**

The development of unmanned aerial vectors over the last decade requires IT-based and smart-structure-based approaches that multiply the already recognized advantages of UASs. The combination of innovative technologies and new approaches to missions overcomes the classic frontiers of conventional robotics.
Operation of UASs is dependent on both costs and regulations and safety rules. A mission function, each air vector uses an operating mode based on a ground system with optimized development level. The use of GCS for certain categories of UAVs offers portability and versatility in operating with expanding mission management depending on the type of UAV chosen. UAV users can orient themselves in choosing commercial or manufactured UASs to be optimized on certain types of missions, the latter requiring solid IT knowledge and knowledge of system calibration algorithms. The introduction of GCS into operation involves increasing the logistics level from transport to energy management and maintenance of GCS.

The GCS commercial software offer covers the requirements of single-user drones with extensions of autonomous operation under redundant power conditions. Optimized GCS offerings for certain missions provide a degree of mission-independent operation and the complexity of sensor tasks. The introduction of GCS into the UAS C2 architecture brings obvious advantages to the integrated management concept by managing raw or processed data flow with implications for mission effectiveness and aeronautical safety.

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