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ORIGINAL ARTICLE

Challenges of Ground Control System in Ensuring Safe Flights for Unmanned Aerial Vehicles

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ABSTRACT – Unmanned Aerial Systems (UAS) are considered as evolving technology due to the diversity and feasibility of their applications. Generally, UAS are controlled by a ground operator in a ground control station (GCS). GCS can be used for several remote applications for unmanned vehicles; however, for the purpose of this review, GCS applications would be limited to its application on Unmanned Aerial Vehicles (UAV). Such stations are made up of basic components consisting of commercial-off-the-shelf components and low-cost equipment depending on the sophistication of the UAV. This requires that as UAVs evolve, GCS are equally upgraded to meet with the technological feet. This paper discusses the challenges associated with GCS in ensuring safe operations of the UAV. Hence, a brief background of GCS, its architecture, applications, inherent challenges and the proposed solutions are presented.

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INTRODUCTION

The dynamics of global threats as well as the quest for sustained and real-time surveillance has spurred nations to develop and employ credible security strategies for national defense and security. Threats such as terrorism, banditry, cybercrime, illicit drugs and weapons proliferation are the contemporary issues which threaten peace, security and economic prosperity of many nations, [1]. In Nigeria, the Armed Forces comprising the Army, Navy and Air Force have been challenged by a combination of most of the aforementioned security issues. In an attempt to curb the rising spate of insecurity, the Armed Forces of Nigeria (AFN) have employed more traditional methods to checkmate these issues, [1]. However, these approaches do not guarantee any success; hence, new methods with more robust advanced military technology need to be adopted.

The Nigeria Army (NA) have acquired armored personnel carriers (APC) and Tanks while the Nigerian Navy (NN) have acquired new ships and helicopters. The Nigerian Air Force on the other hand have acquired 4th Generation JF17 Thunder Fighter Jets, A29 Super Tucanos and Unmanned Aerial Vehicles (UAVs) [2-3]. This military hardware requires physical manning and operation with the exception of the UAVs, which are operated remotely through ground control stations (GCS), [4-5]. The use of the GCS is essential for effective operation of the UAV. It enables operators to employ the UAVs for surveillance, weapon deployment or other applications. It also allows the operators to remotely monitor and control the characteristics and operations of the vehicles GCS for UAVs. These applications expose the GCS to several factors which collectively affect the management and operations of UAVs.

As such, this review presents the emerging challenges resulting from the evolution of GCS with a view to proffering design solutions. To accomplish this objective, the paper discusses the classes of GCS in Section II. Section III identifies the appropriate criteria for the selection of a GCS for different classes based on UAV sophistication. It also describes the hardware and software architecture of a GCS in Section V, while section VI outlines the challenges associated with the operation and management of a GCS for UAVs as well as proposing design solutions that will ensure the safe and efficient operations of a GCS.

CATEGORIES OF GCS

The GCS for UAVs can be categorized into three types based on their size: small GCS, portable GCS and large GCS. The categories and characteristics of GCS are described in the Table 1 while Figure (1-3) depicts the types of GCS.

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Table I. Categories of CGS

Type of GCS	Characteristics
Small GCS	These are light weight devices that are usually hand-held. This type of GCS uses radio antennas as data communication links. Figure 1 depicts a hand-held small GCS for UAV.
PortableGCS	Portable GCS can either have single or double display units which can be set up to enable the pilot and a payload operator to work concurrently as shown in Figure 2. Typical control input devices of a portable GCS include joystick and keyboards like common radio-controlled UAV controllers. These devices are set up like manned aircraft cockpit to ensure optimal control in-flight. Furthermore, portable UAV GCS are designed to allow modular configurations which facilitates the flexible replacement of components; hence, maintainability is enhanced.
Large GCS	Large/Fixed GCS are designed for high-end military and commercial UAVs. These GCS can be fixed at a secured site, built within a container or set up as a virtual cockpit within a center of operations. Usually, this type of GCS has multiple monitors and operators as they receive video and sensor feeds from multiple channels thereby enabling maximum situational awareness. Figure 3 shows an example of a Large GCS.

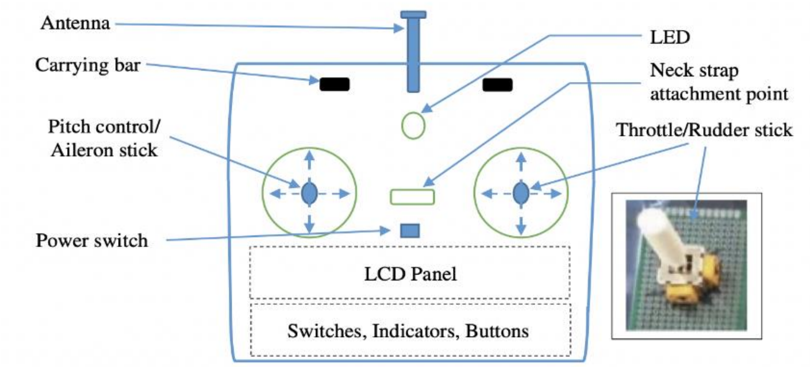

Figure 1. A hand-held Ground control station [6]

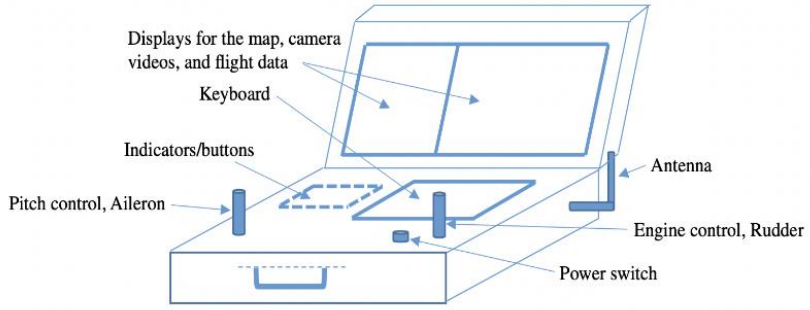

Figure 2. A Portable Ground Control Station [6]

Figure 3. A fixed Ground Control Station [7]

GCS COMPONENTS AND SELECTION PARAMETERS

An overview of the components which comprise a GCS are shown in Figure 4. The Figure depicts how data communication is achieved between the GCS and the UAV. This arrangement is made up of the GCS sector, application, input device and the telemetry. The GCS sector represents where the operator resides. It entails the human-machine interface used by the UAV Operator/Pilot for mission planning, software uploads, payload monitoring and control. The application is the autopilot software with which waypoint and loiter-points are created and telemetry data is viewed. The keyboard, joystick and mouse are the control input devices which are used to throttle the engine, control camera angles and enable manual flight mode. The communication between the GCS and the UAV can be cellular, digital or analogue. These data are transmitted between the operator (uplink-telecommand) and the UAV (downlink-telemetry) through various communication arrangements. A GCS serves as a bridge between the ground operator and the distant UAV [8].

The selection of a suitable GCS depends on the sophistication of the UAV and the specific task the UAV is designed to carry out. Hence, the factors that are considered in the selection of GCS include area of deployment, UAV performance, endurance, desired level of control, mode of information display, space, weight, weather, number of operators required and sophistication of tasks carried out by the UAV [8].

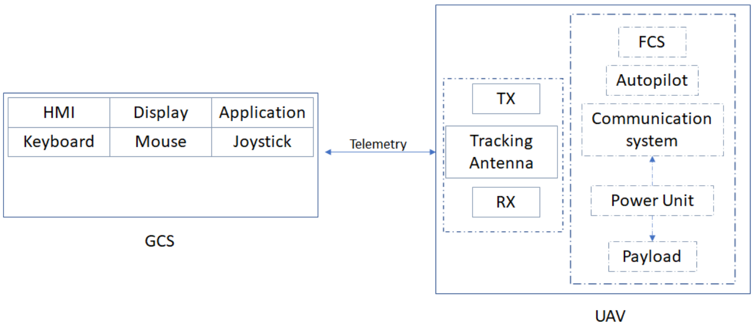

Figure 4. Basic components of a GCS

ROLES OF GCS

GCS are used in a variety of roles and applications depending on the use of the associated remotely piloted aerial vehicle. Some of the roles of the GCS include mission planning, payload data analysis and mission control.

Mission Planning

In mission planning, the GCS is responsible for planning the UAV path (waypoints) and setting the geographical coordinates about which to move (as shown in Figure 5). The waypoint specifies the phase of flight which indicates whether it is take-off, landing, recovery, fly by or fly over some given points [6].

Payload Data Analysis

The GCS processes data from the ground operator (telecommand) into telemetry information. In this role, data is collected, processed, exploited and archived during flight or post-flight operations. Payload data analysis also involves sorting, deleting and updating data while the UAV is on flight [9].

Mission Control

Mission control involves controlling UAVs from launch position while controlling, navigating and performing mid-flight rerouting using the control input devices. Accordingly, mission control is responsible for control, monitoring of payload and recovery of UAV [10] (as shown in Figure 5).

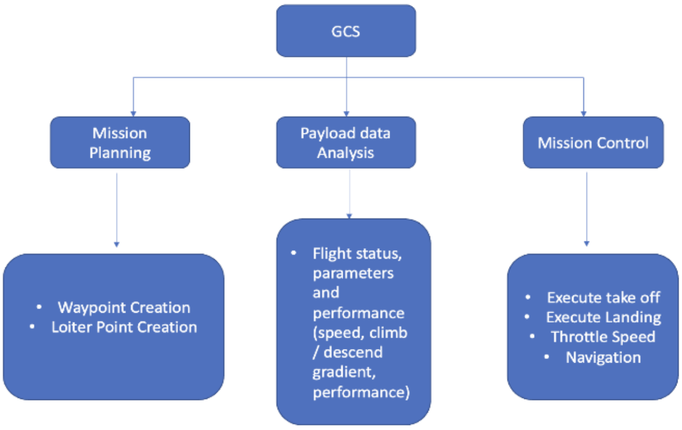

Figure 5. Roles of CGS

UAV GCS ARCHITECTURE

This section reviews the software and hardware architecture of the GCS for UAVs.

GCS Software Architecture

The GCS is a very important part of the UAV system [11]. The GCS has many interconnected hardware parts; nonetheless, the computer and its applications (GCS software) are the most critical elements of the GCS.

Getting information through the UAV involves exchanging and processing data between the human and the UAV. This interaction is made of a download process and an upload process. The download process refers to the retrieval and use of information obtained from the UAV. Upload, on the other hand, involves the sending of information, commands and control to the UAV [12]. GCS software provides the medium for the bi-directional communication between the GCS and the UAV [11-12]. Figure 6 shows a typical software architecture of a GCS. The structure primarily focuses on data flow. The UAV takes control and command from the GCS in a bid to perform different actions such as directing a camera towards a target or changing flight path or direction. These actions, which are facilitated by the GCS software, are collectively classified as primary mission, secondary mission and system monitoring tasks.

i. Primary mission task requires the GCS to track the waypoints of the UAV and provides a report of the coordinates of the target.
ii. Secondary mission task involves the navigation of the UAV using the GCS.
iii. Secondary mission task involves the navigation of the UAV using the GCS.

Additionally, the GCS software enables the monitoring of the video links in order to identify and record ground targets at each waypoint.

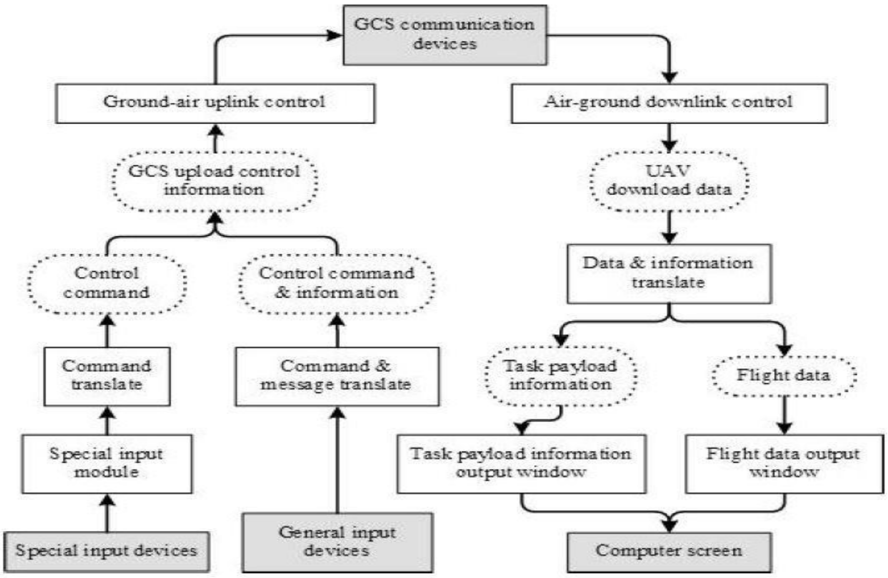

Figure 6: Typical structure of GCS software. [13]

Environment Data Receiver

The environment state data and flight data are obtained as messages that must conform to a defined set of format and then processed by the corresponding modules to make them visually presentable [14]. Real-time flight information and data are received on the GCS via the environment data receiver for proper communication, control and data monitoring. Figure 7 shows the relationship between the UAV and the environmental data receiver. [15].

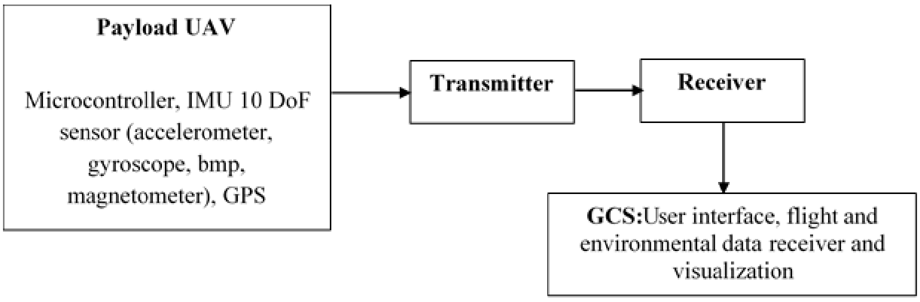

Figure 6: Relationship between the UAV and Environmental data receiver.

Terrain and Navigation module

Flight plans for a flight operation are created using the UAV Navigation's Flight Control System (FCS). It allows the creation of waypoints which automatically update their position in relation to a moving reference point. This moving external reference point on board the flying object may be any device capable of providing positional information such as GPS [15]. The visualization of the terrain environment and waypoints tracking are carried out by the terrain and navigation modules [16-18].

UAV Instrument module

The UAV instrument presentation module helps the user to perform monitoring tasks for the purpose of identifying the occurrence of failure. In flight, the UAV might be exposed to different weather conditions. The conditions as well as that of the UAV must be closely monitored as the current status of the system can help in the detection of fault and failure on the UAV before it get worse. [19].

Network Interface

Network interface module must be able to read incoming messages from flight data receiver and the UAV and propagate them to interested modules which can be deployed in a local or remote environment [12],[20]. The network interface system acts as a medium through which the GCS can receive data from the UAV; these sets of data are real-time video stream, flight platform data and environment state data [20].

Camera Module

Latest technology has deeply explored the different applications of camera on-board a UAV. The cameras can be used for different purposes such as UAV indoor navigation in a GPS denied terrain, surveillance, post disaster recovery mission, disaster monitoring mission, terrain visualization, etc. [20]. The camera vision subsystem on the GCS provides data which could be inform of imagery or videos gotten from the camera for planning and decision making [21]. Also, terrain view displayed by the camera module helps to visualize the UAV’s environment generated from the digital terrain model as well as the vehicle’s exact position and orientation.

GCS Hardware Architecture

Hardware components of a GCS may vary depending on the type of UAV being controlled. However, some generic components are implemented in a majority of GCS designs, this is shown in Figure 7 [22]. These components include gigabit ethernet, management computer, standard interface devices, terrestrial link, satellite link, general flight control console and so on.

GCS implemented in networked control systems showed that standard gigabit ethernet meets the time constraints which fast ethernet could not meet. The work of [7], described a new hardware architecture that allows up to 25 Gbps for automotive applications. The proposed multi-gigabit system has leveraged the existing technologies such as Vertical-Cavity Surface-Emitting Laser (VCSEL), multi-mode fibres and photodiodes. As shown in Figure 8, the FCC is the core component of the hardware architecture comprising the display interface, input device, computer and many more [23]. The content of the display interface can change to suit whatever needs to be displayed. The FCC also carries out the mission control and mission planning functions.

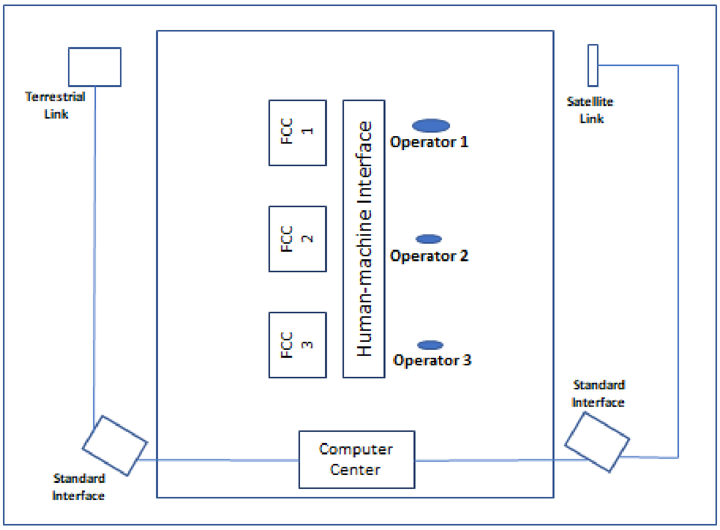

Figure 7: GCS hardware architecture.

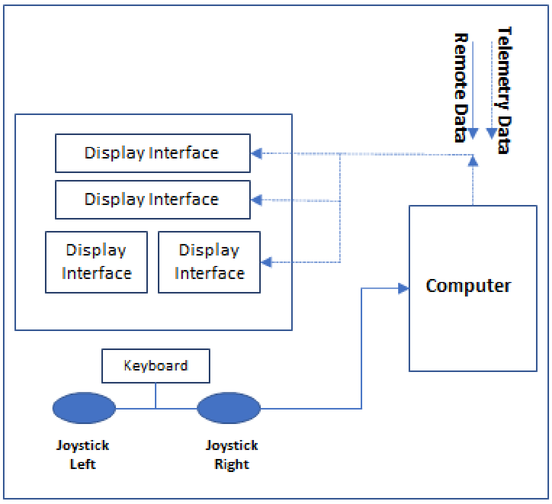

Figure 8. General Flight Control Console (GFCC)

CHALLENGES OF SAFE UAV FLIGHT

The UAV flights are directly affected by ground control stations as they serve as the means of piloting the UAV. Challenges associated with GCS are as categorized below:

Human Factors

According to an analysis carried out by [24] on the causes of accidents for the U.S. Hunter RQ-5, human factors were found to constitute 24% of these causes. Some of these factors are highlighted below.

i. Lack of basic technical training of operators.
ii. Time spent on monitoring flight leads to fatigue and reduction of attention span.
iii. Inability to properly read flight parameters.
iv. The physical environment of the GCS (Temperature, Lighting and Noise) [25].

Human Factors

Hardware reliability is a measure of a component's probability to fail. Low reliability of the hardware components means that such devices are prone to failure and pose a challenge to safe UAV flight.

Low Software Stability

The list below highlights issues affecting safe flight that are resultant form software malfunctions or issues.

i. Improper representation of data.
ii. Impact of weather on software functionality.
iii. Electromagnetic interference.
iv. Poor Vehicle Condition Assessment (does not effectively present critical information).

v. Loss of data link.
vi. Third-party Hack.

HUMAN FACTOR CONTRIBUTION TO UAV ACCIDENTS

To further analyze the human-oriented causes of UAV accidents, two unmanned UAV were considered: The U.S. Hunter RQ-5 and US Army Shadow (RQ-7). For the U.S. Hunter RQ-5, from the available data, 47% of the human factor accidents occurred during the landing phase while 20% of the accidents were caused by a pilot error during take-off (as shown in Table 2). A major cause of the accidents that occur when landing is the reversed motion of the UAV during the approach (left for the pilot is right for the UAV and vice versa) [24]. Besides piloting issues, other human factor issues such as handling alerts and alarms display design and crew procedural error can lead to accidents. Figure 9 shows the accident-cause distribution for the Hunter UAV [24]. The common challenge in display design is the improper display of necessary information for safe flight. The crew design issues occur when UAV crew fails to follow established procedure during operation [26].

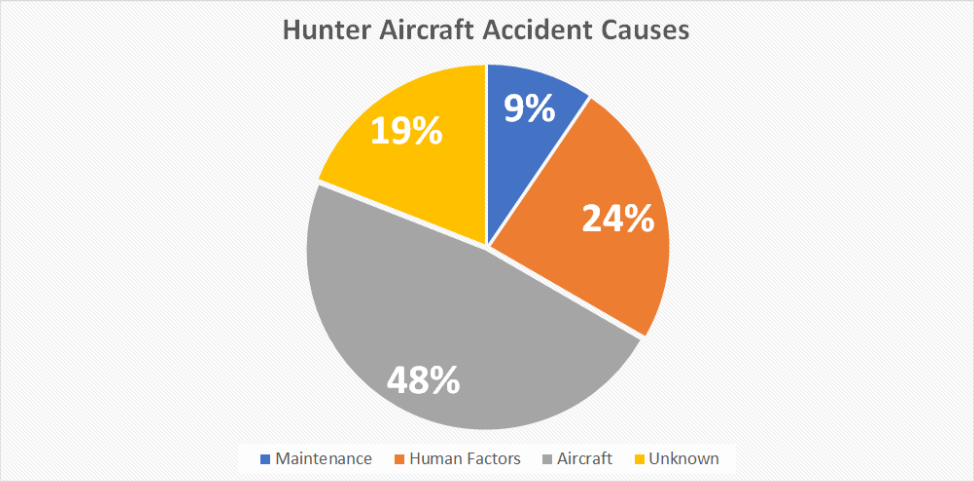

Figure 9. Accident-cause distribution of Hunter UAV [24]

Table 2: Breakdown of human factors issues for hunter accidents [24]

Issue	Number	Percent
Pilot-in-command	1	7%
Alerts and Alarms	2	13%
Display Design	1	7%
External Pilot Landing Error	7	47%
External Pilot Take-off Error	3	20%
Procedural Error	3	20%

Another UAV considered for the accident analysis is the US Army Shadow (RQ-7). Unlike the Hunter UAV, the Shadow makes use of a launcher for take-off and an automated system for landing [27]. This approach eliminated the human factor causes of accidents during take-off and landing by cutting off the influence of the GCS pilot during these critical phases of the UAV's flight. From the analysis (as shown in Table 3), a different trend was observed on the Shadow UAV when compared to the hunter UAV. Only 5 of the 24 accidents in the Shadow UAV were caused by human factors. Even though no occurrences are stemming from external pilot issues, the Take-off and Landing System (TALS) is not perfect and results in some accidents as seen in Figure 10 [24].

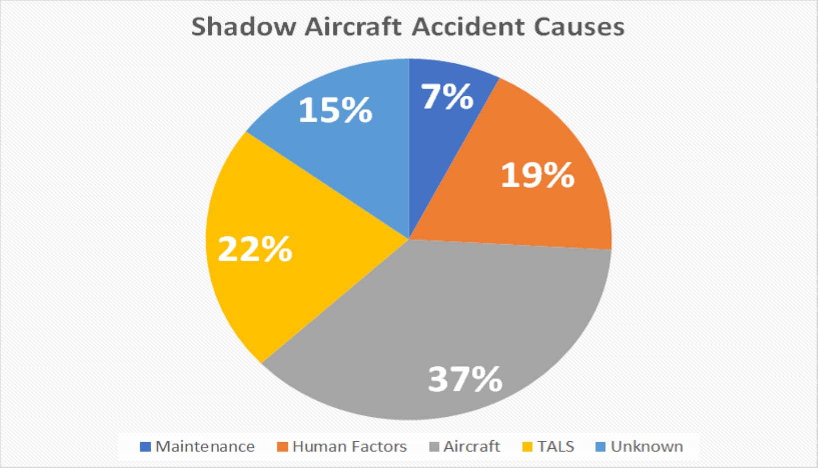

Figure 10. Accident-cause distribution for the Shadow UAV [24]

Table 3. Breakdown of human factors issues for the shadow UAV accidents [24].

Issue	Number	Percentage
Pilot-in-command	2	40%
Alerts and Alarms	2	40%
Display Design	2	40%
Procedural Error	2	40%

Further accident data for UAVs is obtained from U.S Army is analyzed by [28] in 2018. According to the findings of this study, there is a well-established, considerable percentage of manned aircraft accidents that may be traced to crew mistake. A similar pattern appears to be present in the data from UAVs. The current evidence also suggests that, as with manned aircraft, skill-based crew mistakes will continue to play a significant role in UAVs mishaps. More research is needed in this area because several of the studies included here revealed that judgment/decision mistakes were more prevalent than skill-based errors for some unmanned aircraft beyond those considered in this study (the MQ-1 and MQ-9). Furthermore, the continuing advancement toward more autonomous aircraft control, how the pilot/operator interfaces with the aircraft (HMI), and crew training are all interconnected and will all play a part in future unmanned aircraft mishaps.

In [29] an analysis was carried out 68 UAV accidents that occurred between 2011 and 2014 using information from Naval Safety Center in Norfolk, Virginia. The accidents were classified (Figure 11) according to severity, with Class A being the most severe in terms of material and human cost and Class E being the least severe. From the pool of accidents observed, the majority of accident were assigned a Class E tag.

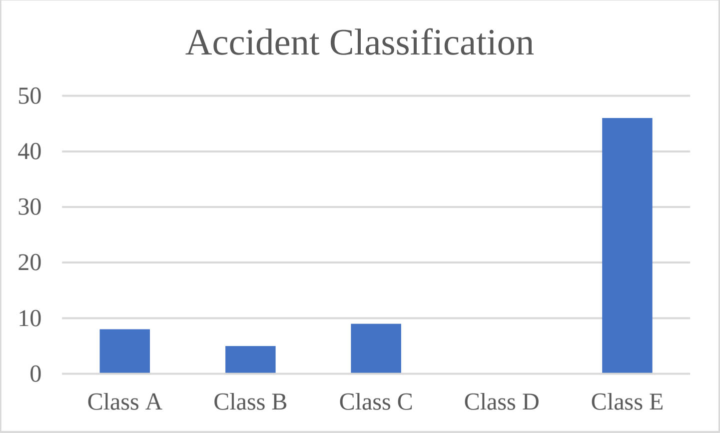

Figure 11. Accident Severity Classification

Table 4. U.S. NAVY Accident classification system [29].

Accident Class	Description
Class A	Class A mishap is an accident which results in $2 million or more in property damage, destruction of an aircraft, and/or injury or illness that results in a fatality or permanent total disability.
Class B	Class B mishap is an accident which results in property damage of $500,000 or more but less than $2 million, an injury or illness that results in permanent partial disability, and/or when three or more personnel are hospitalized for inpatient care as a result of a single mishap.
Class C	Class C mishap is an accident which results in property damage of $50,000 or more but less than $500,000 and/or an injury or illness that results in one or more days away from work.
Class D	Class D mishap is an accident which results in property damage of $20,000 or more but less than $50,000 and/or an injury or illness that is greater than a first aid injury that is not otherwise classified in another category of mishap.
Class E	Hazards are any real or potential condition that can cause injury, illness, or death to personnel; damage to or loss of a system, equipment, or property; or damage to the environment.

From the 68 accidents observed, 287 causes were identified and grouped into 3 broad groups, Human, Material and Special Factors [29] as shown in Figure 12.

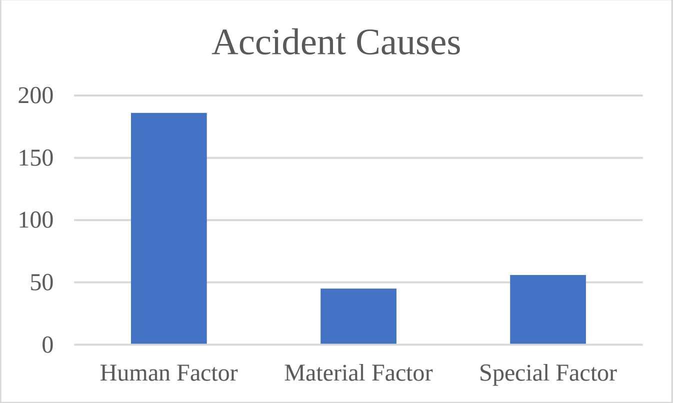

Figure 12. Breakdown of accident causes [29]

From Figure 12, it was is observed that human factor plays a major role in contributing to UAV accidents. However, most accidents occurred due to the combination of 2 or 3 of the identified factors. The human factors were further broken down (Table 5) to show the various activities leading to human caused accidents and how much each of these causes contribute.

Table 5: Breakdown of human factor errors [29]

Human Factor Group	Human Factor Issue	Percentage
Skill-Based Error	Inadvertent Operation Checklist Error Procedural Error Overcontrol/ Undercontrol Breakdown in Visual Scan	41%
Judgement and Decision-Making Errors	Risk Assessment During Operation	53%

	Task mis prioritization Necessaryaction rushed Necessary Action – Delayed Decision-Making During Operation	
Perception Errors	Misperception Error Incorrect response to a misperception	6%

In analyzing the human factors and other contributions to accidents for the UAVs, it can be concluded that deliberate action must be carried out when considering GCSs in order to minimize the effects of the identified accident causes. These actions are outlined in the next section.

PROPOSED SOLUTION TO FACTORS AFFECTING THE GCS

In this section, we present some solutions that can be adopted in a bid to overcome factors affecting GCS for UAV.

Standards and Guidelines Regulating Human Factors

To overcome human factors challenges that are inherent with ground control stations in design, standards and guidelines from [6] can be applied. Figure 13 shows the recommended dimensions for the GCS console and also the recommended human posture to minimize human error.

The Federal Aviation Administration (FAA) also compiled a design standard for human factors for commercial-off-the-shelf subsystems. Hence, when considering human factors in a design, this document can be considered as part of the requirements. The Military Handbook (MIL-HDBK 759C) is also used when considering the human engineering design of military equipment, Military Standards (MIL-STD-1472F) equally shows criteria for the design of military equipment [30]. This document helps the designer with criteria that can help to achieve the pilot and payload operator’s acceptable performance while reducing required skills and basic training time. The STANAG 4586 defines the data to be included in the architecture and format of messages while programming the mission control and map representation. Other guidelines can be considered while integrating human factors in GCS design.

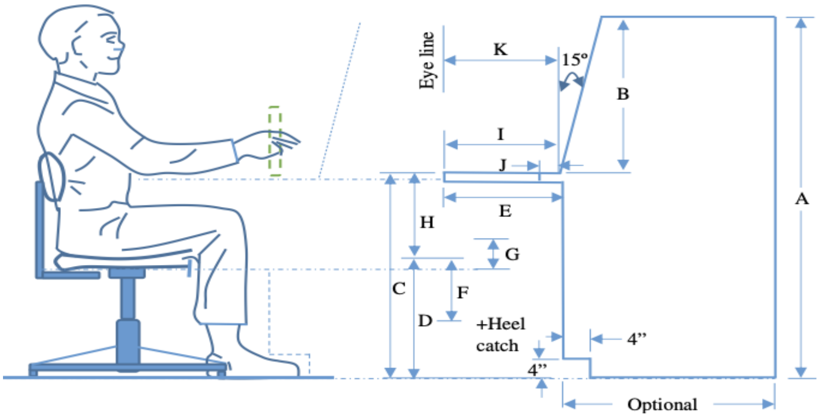

Figure 13. Standard GCS console dimensions [6]

Redundancy

Hardware and software reliability are some of the challenges considered in UAV design. Hence redundancy is applied as a method of duplicating critical components or functions. This becomes essential when considering some safety-critical systems whose failure could be catastrophic. The GCS which serves as the ‘stable’ component of the UAS is used to avoid accidents. It includes redundant components that are automatically activated when failure of the main components occurs. The work by [31] proposed a design where the GCS is a double workstation. Such a system would provide uninterrupted control because all necessary functions are easily accessible by both operators [16]. This provides redundancy for the pilot since the failure of one operator may not be catastrophic. Hence, the need to maintain a system of redundancy and synergy to enable effective operator decision making.

Training

Another key recommendation is the continuous update of training manuals for UAV crew training. Considering that UAV accidents involves skill-based errors. Continuous retraining of crew would effectively mitigate error caused by inadequate skills [28].

Data Analysis

The existing knowledge on UAV accident such as that presented in [24], [28] and [31] was derived by analyzing data available on UAV accidents when the research was carried out. This has helped to identify accident frequency by aircraft and to note the causes of some the accidents.

However, more deductions can be made by carrying out further research with a larger data pool. Variables such as total UAV flight hours, cost, accident rate regression and crew certification would go a long way to and possibly provide new insights [28].

CONCLUSION

GCS is one of the critical components of the overall architecture of an UAS. Several challenges are associated with the operations of a GCS, this include human factors, maintenance of hardware components and software interface design. In this paper, solutions which include implementation of established standards and guidelines, as well as provision of redundancies for the components in case of failure are also proffered to resolve these challenges. The evolution of GCS means more automation; nonetheless, inherent errors in the employment of human operators cannot be eliminated especially when there is no proper training. In order to overcome these challenges, this work proposes that a GCS can be designed with the human factor standards and guidelines, redundancy features for the hardware components and interface design considerations alongside better trained personnel to operate the components. This could minimize UAV accidents caused by GCS.

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REFERENCES

[1] Oshita, O. O., Alumona, I. M., & Onuoha, F. C. (2019). Internal Security Management in Nigeria. In O. O. Oshita, I. M. Alumona, & F. C. Onuoha (Eds.), Internal Security Management in Nigeria (1st ed.). Springer Singapore. https://doi.org/10.1007/978-981-13-8215-4

[2] Air & Cosmos. (2021, March 29). Delivery of JF-17N fighter aircraft. https://aircosmosinternational.com/article/nigeria-delivery-of-jf-17n-fighter-aircraft-3176

[3] Shinkafi, A.A., Oyenusi, F., Mohammed, A., Udeagulul, C., Ademuwagun, A. and Ubadike, O., 2021. Preliminary Engine Sizing for a Tactical Unmanned Aerial Vehicle. *ATBU Journal of Science, Technology and Education*, *9*(3), pp.268-277.

[4] Burns, C. M., Ho, G., & Arrabito, G. R. (2011). Mapping Ecologically to Modalities. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 55(1), 335–339. https://doi.org/10.1177/1071181311551069.

[5] Mohammed, A., Lawal, M. S., Hassan, A., Dandago, K. K., Ridwanullahi, I., Denan, F., Michael, M., Donatus, R., and Adamu, P. I., “A Survey of Flight Control Systems and Simulators of Aerial Robots,” FUW Trends in Science and Technology Journal, , vol. 6, no. 3, pp. 907 – 916, Dec. 2021.

[6] Sadraey, M.H., 2020. *Design of Unmanned Aerial Systems*. John Wiley & Sons.

[7] Mathiassen, K., Hyndøy, J.I., Østevold, E., Valaker, S., Danielsen, T., Baksaas, M., Olsen, L.E., Thoresen, M., Ruud, E.L., Selvåg, J. and Sandrib, J., 2019. Base defence demonstration at Trident Juncture 2018–Tact unmanned systems for base and force protection.

[8] Watts, A. C., Ambrosia, V. G., & Hinkley, E. A. (2012). Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use. Remote Sensing, 4(6), 1671–1692. https://doi.org/10.3390/rs4061671

[9] Ground Control Stations (GCS) for UAVs, Drones and Robotics. (2021). https://www.unmannedsystemstechnology.com/category/supplier-directory/ground-control-systems/ground-control-stations-gcs/

[10] Sándor, Z. (2019). Challenges caused by the unmanned aerial vehicle in the air traffic management. Periodica Polytechnica Transportation Engineering, 47(2), 96–105. https://doi.org/10.3311/PPtr.11204

[11] Kang, Y., & Yuan, M. (2009). Software design for mini-type ground control station of UAV. ICEMI 2009 - Proceedings of 9th International Conference on Electronic Measurement and Instruments, 4737–4740. https://doi.org/10.1109/ICEMI.2009.5274691

[12] Jovanović, M., Starčević, D., & Jovanović, Z. (2014). Reusable design of data visualization software architecture for unmanned aerial vehicles. Journal of Aerospace Information Systems, 11(6), 359–371. https://doi.org/10.2514/1.I010138

[13] Kang, Yiqi & Yuan, Mei. (2009). Software design for mini-type ground control station of UAV. 4-737 . 10.1109/ICEMI.2009.5274691.

[14] Perez, D., Maza, I., Caballero, F., Scarlatti, D., Casado, E., & Ollero, A. (2013). A Ground Control Station for a Multi-UAV Surveillance System. Journal of Intelligent & Robotic Systems, 69(1–4), 119–130. https://doi.org/10.1007/s10846-012-9759-5

[15] Nasution, T. H., Siregar, I., & Yasir, M. (2017, October). UAV telemetry communications using ZigBee protocol. In Journal of Physics: Conference Series (Vol. 914, No. 1, p. 012001). IOP Publishing.

[16] Amida, T., Chung, J., Roy, S., & Simon, E. (n.d.). Evaluating Uav Ground Control Station Design Using Available Human Factors Guidelines And Standards. Retrieved April 6, 2021, from http://www.ryerson.ca/~j3chung/

[17] Shinkafi, A.A., Oyenusi, F., Mohammed, A., Udeagulul, C., Ademuwagun, A. and Ubadike, O., 2021. Preliminary Engine Sizing for a Tactical Unmanned Aerial Vehicle. *ATBU Journal of Science, Technology and Education*, *9*(3), pp.268-277.

[18] Abdullahi, I.M., Isah, O.R., Aliu, D. and Muyideen, O.M., 2021. A Smart Real-Time Standalone Route Recognition System for Visually Impaired Persons.

[19] Hong, Y., Fang, J., & Tao, Y. (2008, October). Ground control station development for autonomous UAV. In International Conference on Intelligent Robotics and Applications (pp. 36-44). Springer, Berlin, Heidelberg.

[20] Oh, H., Won, D. Y., Huh, S. S., Shim, D. H., Tahk, M. J., & Tsourdos, A. (2011). Indoor UAV control using multi-camera visual feedback. Journal of Intelligent & Robotic Systems, 61(1), 57-84.

[21] Cooper, J., & Goodrich, M. A. (2008, March). Towards combining UAV and sensor operator roles in UAV-enabled visual search. In 2008 3rd ACM/IEEE International Conference on Human-Robot Interaction (HRI) (pp. 351-358). IEEE.

[22] Arrabito, G. R., Ho, G., Au, H., Keillor, J. M., Rutley, M., Lambert, A., & Hou, M. (2009). Proposed Techniques for Extending Ecological Interface Design to Tactile Displays: Using Tactile Cues to Enhance UAV Interface Design. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 53(1), 76–80. https://doi.org/10.1177/154193120905300117

[23] Liu, A. Z., Li, B. A., & Xi, A. M. (2013). Ergonomic and General Ground Control Station Design for Unmanned Aerial Vehicles. Applied Mechanics and Materials, 390, 388–392. https://doi.org/10.4028/www.scientific.net/AMM.390.388

[24] Williams, K. W. (2004). A summary of unmanned aircraft accident/incident data: Human factors implications.

[25] Prasannan, N., Xavier, G., Manikkoth, A., Gandhiraj, R., Peter, R., & Soman, K. P. (2013). OpenBTS based microtelecom model: A socio-economic boon to rural communities. Proceedings - 2013 IEEE International Multi Conference on Automation, Computing, Control, Communication and Compressed Sensing, IMac4s 2013, 856–861. https://doi.org/10.1109/iMac4s.2013.6526526

[26] Giese, S., Carr, D., & Chahl, J. (2013). Implications for unmanned systems research of military UAV mishap statistics. *IEEE Intelligent Vehicles Symposium, Proceedings*, 1191–1196. https://doi.org/10.1109/IVS.2013.6629628

[27] Giang, W., Santhakumaran, S., Masnavi, E., Glussich, D., Kline, J., Chui, F., Burns, C., Histon, J., & Zelek, J. (2010). Multimodal Interfaces Literature Review of Ecological Interface Design, Multimodal Perception and Attention, and Intelligent Adaptive Multimodal Interfaces.

[28] J. Jaussi and H. Hoffmann, "Manned Versus Unmanned Aircraft Accidents, Including Causation and Rates," International Journal of Aviation, Aeronautics, and Aerospace, 2018, doi: 10.15394/ijaaa.2018.1262.

[29] Oncu, M. (2014). An Analysis of Human Casual Factors in Unmanned Aerial Vehicle (UAV) Accidents. Calhoun: The NPS Institutional Archive. Monterey, California: Naval Postgraduate School.

[30] Stark, B., Coopmans, C., & Chen, Y. (2012). A framework for analyzing human factors in unmanned aerial systems. Proceedings 2012 5th International Symposium on Resilient Control Systems, ISRCS 2012, 13–18. https://doi.org/10.1109/ISRCS.2012.6309286

[31] Makkay, I. (2013). Redundancy for UAV's—ground control stations. Bulletins in Aeronautical Sciences, 25(4), 46-52.