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UNMANNED AERIAL VEHICLE – HUMAN PERFORMANCE EVALUTION UNDER CRITICAL OPERATIONAL SCENARIO

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1 Introduction

The design of Unmanned Aerial Vehicle - (UAV) applied in defense domain has its foundations on the anti-terrorism war that had its resurgence from 2008 and because of the attack on the twin towers in 2001. The environment was conducive to the development and use of UAV generating the basis for the concept of the so-called mosaic war. This concept is the main vector that directs the design and future use of UAVs. In this context the design of the user interfaces of new UAVs are not based on previously established aviation display concepts. The reason is that these aircraft are not "flown" in the traditional sense of the word, they are commanded by a pilot/operator in a Ground Control Station (GCS). This is a paradigm shift that must be understood to increase operational capability and safety. At the core of this paradigm there are questions related with the adequate Human Machine Interface to increase situational awareness. This manuscript discusses the matter and investigate issues related to the appropriate level of pilot autonomy; the influence of the human-machine interface on decision-making; the design of adaptive interfaces; the use of innovative technologies for human-machine interaction; investigation of interaction between UAV with ground troops and Command and Control. To shed some light in these questions the manuscript proposes and describe the construction of an HMI prototype that emulate the UAS operation in a simulate combat environment. The investigation is based on a process where scenarios and tasks are defined, HMI with different approaches are built, design and analysis of experiments where human performance is measure using physiological sensors allowing quantitative answers about the adequate design. Based on this process it is expected that human performance under critical operational conditions can be evaluate and generate the best HMI solutions aiming reducing workload and situational awareness increase.

2 Bibliographic Review and Problem Contextualization

As part of the extensive use of UAV in the war on terror, a statistical database was created (WILSON, 2018), (KREUZER, 2015) consolidating 3 key points that justifies research to improve the use of UAVs in the diffuse scenario of current conflicts, they are:

1 - Safety – statistical data show that the rate of accidents and incidents of UAV is 100 times higher than that of manned aircraft (WILSON, 2018). These numbers drastically increase the cost of the operation (KREUZER, 2015). Although they do not have crew members that can generate direct fatalities from safety events, these aircraft can interfere with normal air traffic exposing third parties and even causing eventual damage on the ground (DUBOI, 2013).

2 – Mission accomplishment or operational performance – the fact of being remotely piloted takes away from the pilot a series of extremely important sensory cues to maintain adequate situational awareness for optimal operational performance (PESTANA, 2013). Additionally, according to WILSON, 2018.

"The design of the user interfaces of these systems are, for the most part, not based on previously established aviation display concepts. Part of the cause for this is that the developers of these system interfaces are not primarily aircraft manufacturers. Another reason is that these aircraft are not "flown" in the traditional sense of the word. Only one of the reviewed aircraft (Predator) has a pilot/operator interface that could be considered like a manned aircraft. For the other UA, control of the aircraft by the GCS pilot/operator is indirectly accomplished with menu selections, dedicated knobs, or preprogrammed routes. These aircraft are not flown but “commanded.” This is a paradigm shift that must be understood if appropriate decisions are to be made regarding pilot/operator qualifications, display requirements, and critical human factors issues to be addressed.

3 – Mosaic warfare and distributed situational awareness – as opposed to the so-called monolithic warfare (use of high-performance equipment, high technology, and costs), the mosaic warfare assumes the use of small vectors with simpler and cheaper technology deployed in a such way that they complement each other to perform a very precise surgical task (HAYSTEAD, 2020). In this speculative scenario, UAVs support ground troops, creating a network designed to fulfill a specific mission. In this context, the concept of distributed situational awareness emerges where the achievement of a goal is only possible through the interaction of multiple vectors and multiple agents (DUBOI, 2013).

As a common theme and crossing these 3 concepts, there is situational awareness, which in turn is structured through the various HMI that all the actors involved need to interact with the operational environment to accomplish mission.

This manuscript is structured to address issue number two: human performance under critical operational scenario. The goals of the work presented here are the following:

1. Define a simulation representative of critical operational scenario.
2. Implement different approaches in terms of HMI solutions.
3. Define experiments that can be used to evaluate the human performance running the simulation.
4. Define physiological sensors to analyses the pilot workload and situational awareness optimization as a function of different HMIs.

3 Critical Operational Scenario Definition

Real UAV´s operation scenarios use two specialists: one to command (or piloting the UAV’s) and other to operate sensors and analyze information. The defined scenario aims to identify HMI’s that optimize the performance of a UAV operator in missions that support the Air Force Intelligence, Surveillance and Reconnaissance (IVR) Task. In this scenario, an operator's workload will be evaluated, if he accumulates the function of piloting the UAV and operating sensors. The simulation shall implement the reconnaissance functions using an electro-optical POD that operates in the visible and infrared spectra.

The mission considers the kidnapping of the Brazilian Minister of Defense carried out by guerrillas during an attack on the 2nd Special Border Platoon. The attack was carried out by a small group that approached Querari, Figure 1, in two small boats, sailing along the Vaupés River in Amazon basin

Figure 1 – Situational map extracted from the simulation environment.

After the attack, the group followed the river towards the municipality of Mitú, in the Department of Vaupés.

The UAV in Iauaretê were deployed for an aerial reconnaissance mission. The initial orders were to take off and head for the municipality of Querari (AM), while the Brazilian Army carried out intelligence actions on the spot. The UAV mission consists of providing reconnaissance information to ground troops (GT) to allow the rescue of the minister and avoid collateral damage since the Guerrillas are enmeshed with civilian population inside rain forest.

3.1 Mission Definition

Mission and tasks assign to UAV operator will be composed by the investigation of up to 4 Reconnaissance Areas (RA) that can be grouped and rearranged based on a total of 13 simulated possible RA's.

Pilot tasks can be summarized based on the following process (Figure 2):

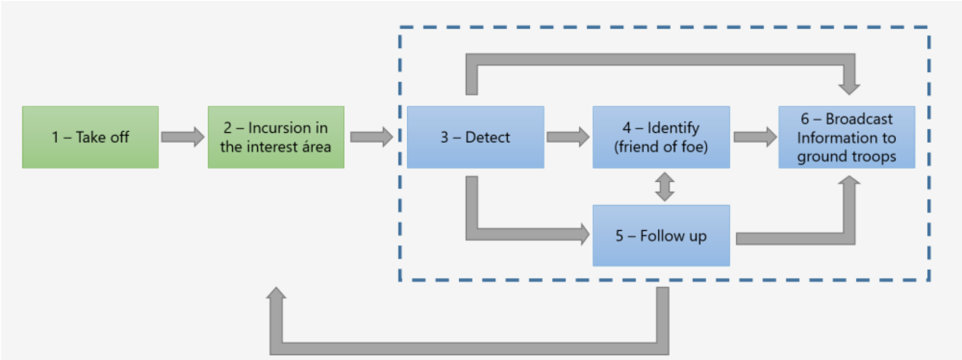

Figure 2 – Tasks assign to UAV operator.

The new proposal HMI's effectiveness in providing increase in situational awareness and performance as well, will be evaluated based on the following attributes associated with the accomplishment of tasks 3 to 6 on Figure 2: quickness, completeness, accuracy of information.

Figure 3 describes the entire simulation scope.

Figure 3 – Reconnaissance Areas – RA's.

Some RA have no enemy activities while others have. The pilot/operator performance will be evaluated based on its capacity to identify friend or foe elements and communicate with GT on time to avoid human losses.

Mission definition described on this paragraph are related to RA's 1 to 4. Every operator/pilot will carry out the mission twice and for each scenario it is foreseen variations in the elements that compose to avoid previous learning.

Examples for RA 2 (no enemy activities) and RA4 (with enemy activities) scenario definition and variations are presented below.

For RA 2 variation 1**,** the following scenario is defined:

- T0 mission start (T): UAV over Querari waypoint
- Reconnaissance Area: RA 2
- Variation 1:
  UAV expected arrival time: T + 01:00 min
- Ground troops #1 arrival: T + 04:00 min
- Civilian in open area (friend or foe?)
- 1 Civilian go outside house when GT arrives (friend of foe?)
- GT abandon RA in T+06:00

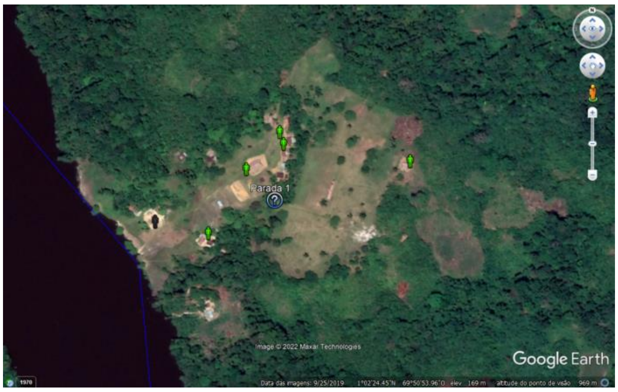

Figure 4 – RA 2 variation 1.

For RA 2 variation 2, similar scenario is defined, excepted for the elements disposition.

Figure 5 – RA 2 variation 2.

For RA 4 variation 1 the following scenario is defined:

- UAV expected arrival time: T + 20:00 min
- Ground troops #2 arrival: T + 20:00 min
- 8 Civilian in open area (friend or foe?)
- 1 Enemy settlement
- 1 enemy in open area
- 1 enemy go outside house 2 min after GT #2 arrives.
- Expected enemy activity 4 min after GT #2 arrives.
- GT #2 abandon RA in T + 25:00 min

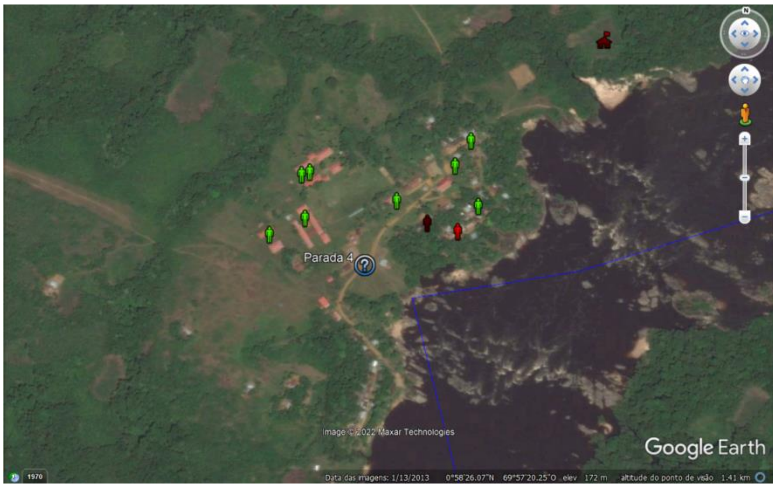

Figure 6 – RA 4 variation 1.

For RA 4 variation 2, a similar scenario is defined, excepted for the elements disposition.

Figure 7 – RA 4 variation 2.

4 Design of Experiments and Physiological Sensors for Human Performance Evaluation

In order to measure the pilot's performance during the mission execution, it is essential to evaluate the effects of information overwhelm, through his workload. For this, it is necessary to analyze their physiological responses, which can be done through some parameters such as: changes in cardiac activity, brain response, respiratory frequency, eye movements, galvanic skin response, skin temperature.

Thus, it is possible to monitor changes in these parameters and then identify different human behavioral responses (ALAIMO, 2018), creating a workload variable from the interaction between the previous parameters. In this work, an experiment project will be proposed to validate the best HMI approach to reduce the workload and increase situational awareness aiming the UAV operation by a single pilot.

The Design of Experiments strategy will be Balanced Incomplete Block Design (BIBD) with the following parameters combination:

- 2 operators with a basic HMI
- 2 operators with an advanced HMI
- 1 operator with a basic HMI
- 1 operator with an advanced HMI

Advanced HMI will incorporate functionalities that enable UAV autonomous flight. Basic HMI considers displays and inceptors that will force the UAV be piloted (pilot in the loop) and not commanded

5 Simulation Architecture

Communication and applications used to build the simulation environment is described in Figure 8.

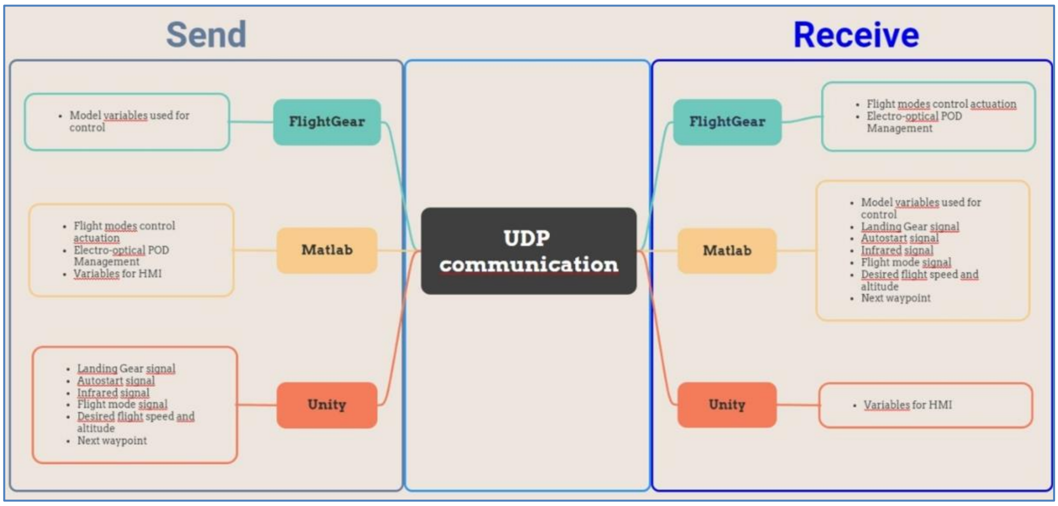

Figure 8 – Simulation architecture

Aiming real-time data flows, it was used User Datagram Protocol (UDP) protocols in communication between applications.

Three different software were used: FlightGear, Matlab and an application created with Unity.

FlightGear is responsible for generating all flight mechanics data and graphical representation of aircraft behavior with its sensors.

Matlab is responsible for managing the performance of the aircraft control meshes and managing the Electro-Optical POD.

Figure 9 illustrates the UAV model in Matlab/Simulink.

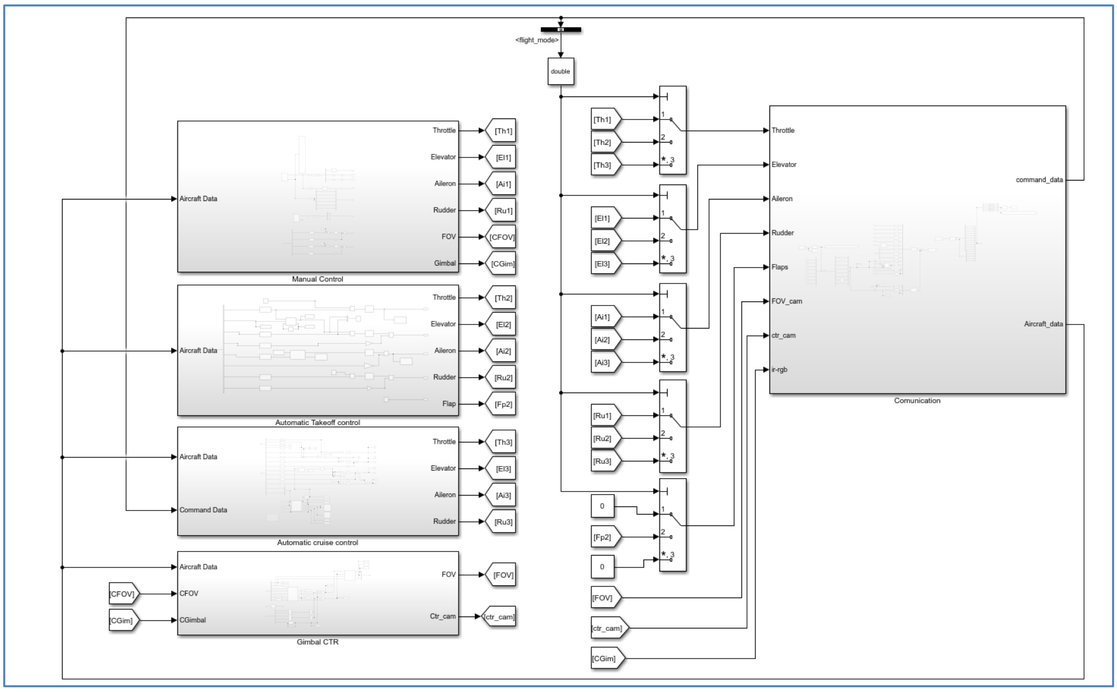

Figure 9 – UAV model.

The application developed in Unity generates the commands signals for landing gear, auto-start, brakes, electro-optical POD, and flight modes: manual (pilot in the loop), autonomous takeoff and cruise.

The Unity application also inserts the speeds and altitudes desired for flight and command the navigation between choose waypoints.

FlightGear sends flight mechanics data to Matlab. Matlab in its turn sends flight mode control and Electro-Optical POD management to FlightGear and flight status variables to the Unity application that runs the HMI.

FlightGear receives the control actuation of flight modes and POD data. Meanwhile, Matlab receives all data from FlightGear and the HMI interface. The application receives the flight state variables.

6 HMI Proposed Solutions

Three screens were developed for the HMI interface: Situational Display, Primary Flight Display and a Flight Management Display.

6.1 HMI - Situational display

Situational display showed on Figure 10 uses openstreetmap projection.

Figure 10 – Situational display.

The following functions were implemented in this HMI:

1. UAV Trajectory: UAV trajectory can be followed with a trace of flight history. Since the main mission is related with reconnaissance this function is especially useful to provide information about areas already explored by UAV and the electro-optical sensor.
2. Waypoint management: It is possible to manage Waypoints position, create Interest Areas (blue area on the map) and Avoidance areas (red areas). The UAV will automatically follow a flight plan based on this designation.
3. Option bar: the option bar enables change screens between the computer monitors, change the map layout, search for a specific location, turn the infrared on or off, center the map on a specific Waypoint and restart the interface.

6.2 HMI - Primary Flight Display (PFD)

The main goal of the PFD (Figure 11) is to provide UAV flight information and status and radio frequency management.

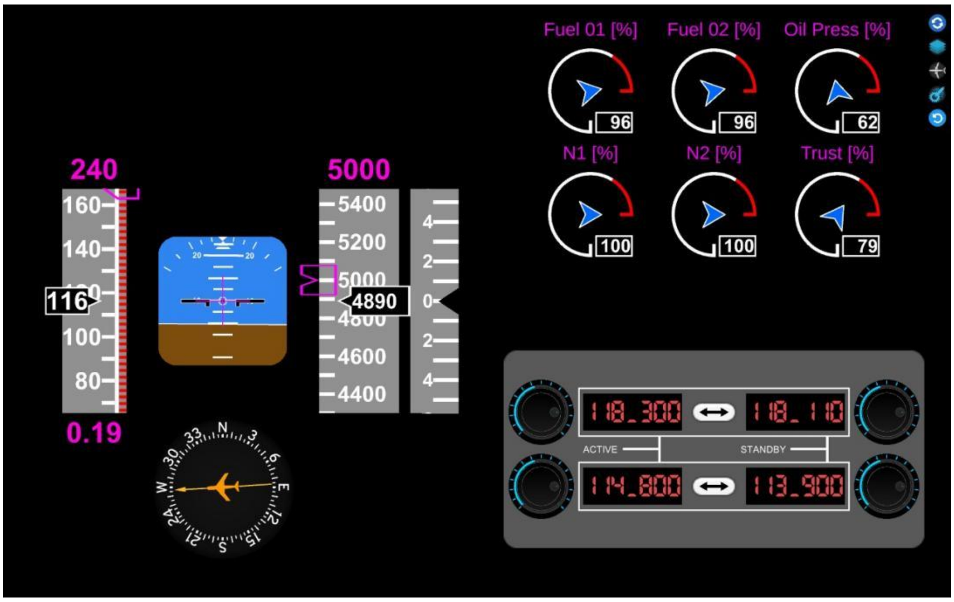

Figure 11 – Primary Flight Display.

It is divided into three sections: one for flight status second for engine indication and monitoring and a radio frequency management.

Additionally, there is an option bar that enable change the screens between the computer monitors, command landing gear up and down, command auto-start, brakes, define the flight mode and configure the desired speed and altitude.

6.3 HMI - Flight Management Display (FMD)

Flight plan can be managed by the FMD, as showed in Figure 12.

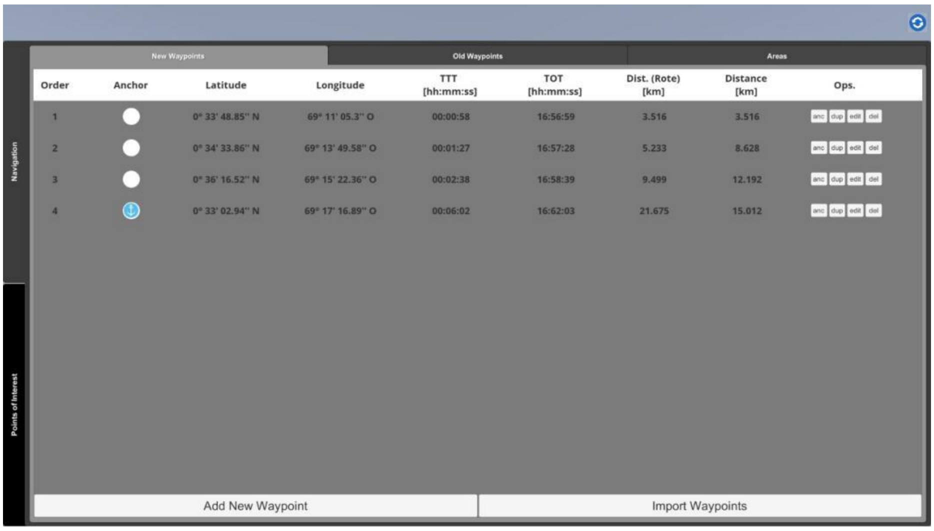

Figure 12 – Flight Management Display.

This HMI provides information about all Waypoints presented on the Situational Display. It is divided into three screens: New Waypoint, Old Waypoint and Areas.

The following information are presented on the New Waypoint screen:

- The order, whether the aircraft will anchor over the waypoint and starts a reconnaissance flight pattern.
- Position: latitude and longitude.
- The time-to-target (TTT) estimated time to arrive at the point from the present position.
- The estimated hour to arrive on the point, time-on-target (TOT).
- The distance following the route to reach the point (Dist. route).
- Direct distance of the aircraft the point (Distance).

Additionally for each waypoint it is possible to configure data for docking, edit the point location, duplicate, or delete the point. It is also possible to add new waypoints by typing the coordinates or import data from an external file. The waypoints can be ordered to generate a new route pattern.

The Old Waypoints screen register the parameters associated with the Waypoints where UAV already has passed. It is presented the same information as described previously in addition one old Waypoint can be duplicated and transformed in a New.

Area Screen is composed of the following information:

- Order
- Kind of area: avoid or Interest
- Waypoint at the center of the Area
- TTT, TOT, Dist. Route and Distance to the Waypoint at the Center of the Area.

6.4 The Electro-Optical Display

The electro optical sensor operation functions such as target acquisition and autotracking (gimbal control) were implemented following the approach of Hands on Throtlle and Stick (HOTAS). This baseline HMI philosophy keep adherence with combat aircraft interface.

Figure 13 – Electro-optical pod and autotracking function.

7 Conclusions and Future Plans

This manuscript described the design and setup of a new HMI prototype to simulate UAV´s operation in a critical operational scenario. The Air Domain Study project where this initiative is associated has as main objective the investigation of human factors and human-machine interface design for systems used in future military concepts. In a previous vision, future scenarios were conceived with the following characteristics:

- Extensive use of UAV's;
- Joint operation scenarios with Ground troops, UAV, Command and Control Stations;
- Increase in on-board intelligence, whether on the aircraft or on the ground station – therefore, the situational awareness, workload and performance of the pilots and operators involved can be unpredictably affected by the human-machine interface design;
- Concept of distributed or team situational awareness - situational awareness is no longer an individual attribute, but an attribute of a multi-agent system.

The scenarios produced in this step, simulations and HMI's developed so far comply with this high level future scenarios hypothesis and can be used to validate requirements definition for new HMI.

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10 Copywrite statement

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