DESIGN OF AN ADVANCED GROUND STATION FOR SIMULTANEOUS CONTROL OF MULTIPLE UAVS IN A COORDINATED MISSION

Alessandro Ceruti, Francesca De Crescenzio, Francesca Flamigni, Franco Persiani
DIEM - Mechanical Nuclear and Aerospace Engineering Department
University of Bologna
Via Fontanelle 40, Forlì (FC) 47100
ITALY

Keywords: *Civil UAV, UAV Ground Control Station, Man-Machine Interface, Virtual Reality*

Abstract

In this paper an interactive human-machine interface for UAVs (Unmanned Aerial Vehicles) mission control is described. It provides a functional scenario to manage coordinated formations of civil UAVs. The aim is to enhance the capabilities of unmanned vehicles in case of complex tasks.

Based on the implementation of an immersive environment - as a multiple screen stereo visual system equipped with interactive devices, such as virtual gloves - the system allows a formation to be controlled directly in the 3D graphic scene. By selecting and grabbing the trajectory waypoints in the scene the operator can intuitively modify UAVs mission paths. Moreover, communication between ground support and onboard logic is managed by means of high level orders. Simultaneous control of multiple aircrafts is obtained and one or two operators manage the whole mission in a single control station.

Both the telemetric data and the images coming from onboard cameras and sensors are simulated in the advanced ground station and visualized in the virtual 3D scenario. One of the most effective features of the immersive environment is based on real time mapping of the live images – consisting also in false color maps and contour maps – as textures on appropriate areas of the synthetic terrain model.

The background logic is "sensor driven" since some flight modes allow the operator to drive the sensor window on a (even moving) target, while the flight path of each UAV is automatically adjusted to perform the monitoring task.

In order to further increase the situational awareness UAVs flight information are presented to the operator intuitively as 3D paths visualized as channels in the air-space.

In some of the operation modes, the background logic automatically helps the operator in controlling multiple UAVs flying at the same time, showing a list of suggested actions and graphic aids on the scene.

According to the displayed information the operator can perform new decisions, for instance re-planning the mission or selecting new targets.

The mission is based on contemporary control of two UAVs, which should find an oil tanker that discharges oil in the sea. Once detected the slick, one UAV must track it while the other aircraft searches the oil tanker, driving for the civil protection intervention.

1 Introduction

Technological developments in the design of Unmanned Aerial Vehicles (UAVs) are opening the way towards their exploitation in a wide range of civil applications. In particular, these vehicles are becoming more and more autonomous and equipped to be able to fly at high endurance in order to perform their mission in wider areas [1].

That means significant advances are expected in the typical mission scenario of *Intelligence, Surveillance and Reconaissance*

(ISR). The main aspect of this kind of mission, as known, is that the UAV/UAVs is equipped with a set of sensors to surveill a specific location with the aim of delivering data to a ground support system and receive mission planning and control specifications. Furthermore, the UAV could operate in hazardous conditions, such as unstable air or obscuring smoke, due to natural or man-induced disasters [2].

When the UAV/UAVs are in the "*Out of Line of Sight*" case, the mission control can be achieved through the UAV Control Center, located at a fixed place. In this case the Control Center controls the AV navigation through a communication DL. The UAV Control Center should provide Mission Planning functions such as pre-flight mission planning and Update and Reprogramming during in-flight mode. The Data Manipulation function, in addition, should display the imagery and data coming from the vehicle or from a Mobile Control Station. Such a Control Station should allow to exploit the control of multiple UAVs without loss of information.

The role of operators in this complex scenario evolves into a supervisory function [3] and requires the use of innovative Man-Machine Interfaces (MMI) to communicate with the vehicle and its payload. Human factors issues regard the achievement of good levels of crew coordination and situational awarness [4]. In the case of a Control Center for civil applications several considerations must be done in order to accomplish these requirements. In particular they comprise the design of the control/display system, the system time delay and the levels of system fidelty. The images gathered in a safe mode can be delivered to a Incident Command Center where Disaster Managers are supported in their decision procedures.

In few recent years multi-screen technology has been widely applied in Virtual Prototyping, in Virtual Training, in VR-based (Virtual Reality-based) modelling applications, but also in Flight Simulation, Design Review and many other collaborative uses.

This paper describes an innovative Man-Machine Interface for a UAV Control Center based on VR (Virtual Reality) technologies. The aim is to investigate how the exploitation of advanced display devices and the extent of interaction and automation can enhance the mission awareness in VR collaborative environments.

2 System Architecture

2.1 General description and First Lay-out

The main objective of this system is the integration of the main functions required to a UAV GCS (Ground Control Station) in a VR-based environment. The hardware equipment and the software have to provide the three main functions of mission tracking/planning, observing and piloting.

In civil applications, such as the monitoring of an extending fire or of a natural disaster, the mission control would be performed from a fixed location Control Center while a Mobile Ground Control Station is limited to the initial and final phases of the mission. An efficient and advanced Virtual Reality visualization support, on the other hand, can be installed in a fixed location while the AV navigation is performed by radio or satellite communication DL (Data Link).

This system is composed by two main modules: an air vehicle sub-system and the VR Control Center (Fig.1). The vehicle sub-system is simulated and consists of the following components: a Flight Control System implemented in Matlab/Simulink and sized on the model of the Pioneer UAV and a MP (Mission Payload) control system.

The aim of the VR Control Center is to provide the interface between the operators and the AV. It provides the reconstruction of the airspace and displays the imagery and data coming from the Air Vehicle and from its MP.

The Data Link is simulated by a basic TCP/UDP communication.

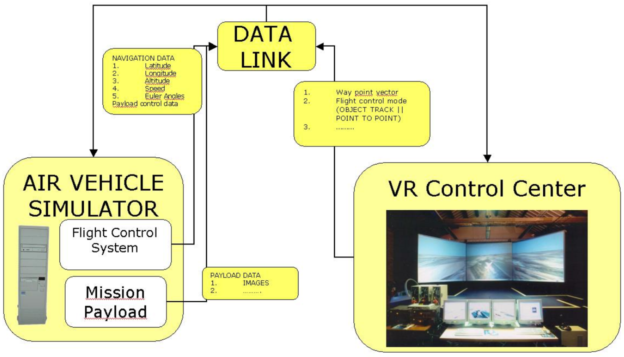


Fig. 1 System Architecture

2.2 Air Vehicle Simulator

2.2.1 Flight simulator features

The developed flight simulator is a non linear aircraft dynamic model based upon the solution of the rigid body motion equation using the quaternion form for the determination of attitude instead of the Euler angles. Forces and moments are calculated keeping into account aerodynamic, gravitational, propulsive, atmospheric and gyroscopic contributions. The non linearity is obtained deriving aerodynamic derivatives from look-up tables depending on aircraft attitude, speed, control surfaces deflection, fuel consumption. The aircraft model simulated is the Pioneer, a UAV suitable for civil missions [5] like territory observing and monitoring, chemical data collection and others. Pioneer dynamic model (aerodynamic derivatives, dimension, weight, inertia moments) has been implemented from experimental data [6].

2.2.2 Flight Control System

Aircraft Flight Control System (FCS) developed for this work is composed by three inner loops: *Stability & Control*, *Navigation* and *Supervision Logic*. The *Stability&Control* loop has been developed using the optimal control theory: a Linear Quadratic controller regulates the aircraft stability and control, according to the desired speed, altitude and rate of turn. *Navigation* is based upon a waypoint list in the form {Latitude, Longitude, Altitude, Speed}. Once two subsequent waypoints have been selected by the supervision logic level, the correct rate of turn is calculated using the navigation law [7]. The *Supervision Logic* has been modeled by means of a state machine that performs the mission management according to commands received by the Control Center (Fig.2). The ground operator, for instance, can switch the UAV flight control mode in the manual, in the semi-automatic and in the automatic one. The manual mode enables the UAV to be piloted from a dedicated ground control station (GCS), equipped with a joystick. The semi-automatic mode enables the UAV to follow a pre-defined flight path derived from a list of waypoints. Finally, in the automatic mode the vehicles autonomously stop the waypoint navigation to monitor the slick or to detect and track the ship, driven by an event detection feature. In the case study considered once one UAV localizes the slick, it communicates with the second to update navigation. If the second UAV detects the ship the tracking can start, otherwise a spiral centered on the slick position is performed until ship is detected and tracked. Once the Return To Base (RTB) command has been sent the UAVs stop loiter and steer to the first Waypoint: the control is taken from the GCS so that vehicles can safely land.

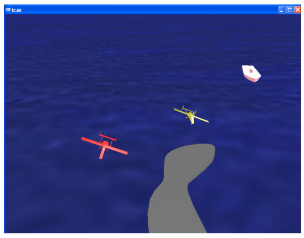
UAV1 / UAV2	in automatic mode localized slick	in semi automatic mode localized slick	in automatic mode not localized ship	in automatic mode localized ship	in semi automatic mode localized ship	in semi automatic mode not localized ship
in automatic mode localized slick	UAV1 tracks slick, UAV2 searches ship	UAV1 follows waypoints, UAV2 tracks slick	UAV1 searches ship, UAV2 tracks slick	UAV1tracks ship,UAV2 tracks slick,	UAV1 tracks ship, UAV2 tracks slick	UAV1 follows waypoints, UAV2 tracks slick
in semi automatic mode localized slick	UAV1 tracks slick, UAV2 follows waypoints	UAV1 follows waypoints UAV2 follows waypoints	UAV1 searches ship UAV2 follows waypoints	UAV2 follows waypoints UAV1 tracks ship	UAV2 follows waypoints UAV1 follows waypoints	UAV2 follows waypoints UAV1 follows waypoints
in automatic mode do not localized ship	UAV1 tracks slick, UAV2 searches ship	UAV1 follows waypoints UAV2 searches ship				
in automatic mode localized ship	UAV1 tracks slick, UAV2 tracks ship	UAV1 follows waypoints UAV2 tracks ship				
in semi automatic mode localized ship	UAV1 tracks slick, UAV2 tracks ship	UAV1 follows waypoints UAV2 follows waypoints				
in semi automatic mode not localized ship	UAV1 tracks slick, UAV2 follows waypoints	UAV1 follows waypoints UAV2 follows waypoints				

Fig. 2 Supervision Logic

2.3 The Virtual Reality Immersive Environment

The visual interface of the Ground Station is based on the CAVE-like (Cave Automatic Virtual Environment) system at the Virtual Reality Laboratory of the University of Bologna (Fig.3). The I.R.R. (Immersive Reconfigurable Room) is built on top of a client-server architecture where 3 PCs stand as graphic servers, each driving a video-projector [8]. Virtual devices, like Hand Tracking and Virtual Data Gloves, are managed by a master computer, giving also console control of other workstations. Each graphic workstation server is powered by a P IV 2 GHz connected to a Gigabit Ethernet connection (1000 MBit/sec). On the side of graphic accelerators, each PC is equipped with high-end workstation graphics enabled for stereo vision and Frame Lock capability. Data exchange between master and servers have been reduced to a simple MPI (Message Passing Interface).

The I.R.R. is composed by one central panel and two lateral screens that can be rotated from 0° up to 90° with respect to the central unit.

The retro-projection and the screen architecture features make this environment the ideal puropse for a wide range of concurrent applications. A multi-user virtual environment allows different operators to share their competecies with the aim of event time reduction and situational awareness increase. The cooperation is based on the real time analisys of informations and the interactive interface, which is based on the proper utilization of virtual devices.

3 The MMI (Man Machine Interface) in the Ground Control Center

In order to design an efficient MMI and exploit the potential effect of Virtual Reality visualization and interaction techniques, this system is focused on the definition of two main aspects related to Ground Support: the *Situational Awareness* features and the *Mission Planning* functions.

Fig. 3 Virtual Reality Environment

Thus, the display architecture and the mission planning modes must be provided. These depend on the list of functions that, at least, an UAV Control Center should include [9]:

1. Pre-flight mission planning;
2. Update and Reprogramming the mission plan during AV in-flight mode;
3. Remote operation of the payload;
4. Geo-rectification of data;
5. Fuel and weight & balance calculation;
6. AV programming and system checks;
7. Real time metereological condition information;

The design of the MMI is focused on the first four points in the above list.

Facing the *Situational Awareness* a primary function consists in the easy comprehension of the position of the AV in the mission air space location. The reconstruction of realistic 3D virtual sceneries on large screens allows the traditional map display to be substituted by a 3D terrain map. Basing on the use of DEM (Digital Elevation Maps), the mission is planned, checked and reprogrammed in the virtual scenery. Coupling 3D virtual scenery with the payload imagery acquired by the downward-looking camera and the payload attitude, the map display evolves into a

Mission Payload Display. As a result the operators in the Virtual Control Center observe an updated 3D perspective of the operating area.

Visual architecture in this application is based on a multiple windows deployment. The Main Window is splitted onto the projection area of the three IRR screens showing the simulation-area. The scenery can be observed by different points of view switching the camera mode and moving the virtual camera attached to the tracked right hand. This is possible due to the interaction features that allow operating on the 3D scene. The *camera modes* can be switched by means of the virtual gloves entering one of the following configurations:

1. extern following camera;
2. pilot camera;
3. "mid-camera";

The "following camera" always keeps the selected object (Air Vehicle n°1, Air Vehicle n°2, target if localized,..) at the center of the viewport while the "mid-camera" observes the scene pointing at the mid point between the two vehicles. In these modes, furthermore, one can move the point of view and zoom the pointed object by means of the fastrack receiver attached to the right hand.

Secondary Windows can be sized, positioned, activated and disabled as desired. These are the MPP (Mission Payload Panel), the IP (Instrument Panel) and the ACP (Application Configuration Panel). The MPP shows the imagery coming from the downward camera. The IP, that can be displayed onto a flat panel, contains a set of digital instruments that allows the AV attitude to be controlled. The ACP contains information on the application state, such as the list of UAVs in the scene and all the state variables needed to manage the application. It depends on the event tree that the operator is enabled to control.

Besides the aim of providing information at a glance about each class of options, the ACP leads the operator in the exploration of the tree. The ACP shows the diagram of interactions (Fig. 4) and all the functions grouped in menu. Each menu is contained at the same level in the event tree. Using the left hand pinch one can browse the options contained in the menu and activate the events or the interaction features eventually related to the events. In this system the Visualization Menu allows to access to the "camera options" and to the "visual aids options". The Mission Planning Menu, on the other hand, contains four groups of options to perform the navigation and control. In this way the event tree can be browsed by the left hand, while the right hand is utilised to manage the functions designed for single events activation such as 3D pointer handling or interactive point of view.

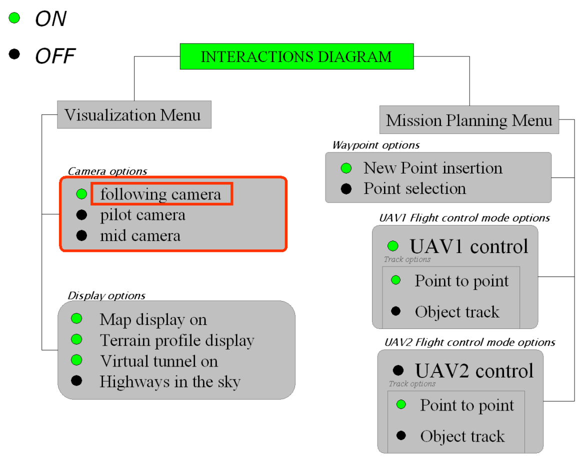


Fig. 4 Interactions diagram

3.1 Mission planning

Planning and updating the AV autonomous flight in the Virtual Control Center is based on the interactive interface for the flight navigation control assignment. Usually assignment depends on the two following control modes: trajectory following and object track. As mentioned above the first one is based on the specification of a list of waypoint and the second one depends on the specification of a target. Since the AV simulator provides both the autonomous flight tasking modes, the VR interface provides the following functions:

1. Switching one UAV to an other
2. Switching one mode to an other *(mode0: manual flight; mode1: point-to-point control; mode2: object/target track);*
3. 3D single waypoint assignement *(mode1)*;
4. 3D single waypoint catch and drag *(mode1)*;
5. target specification *(mode 2);*

The 3D map is applyed only in the narrow area and the pre flight planning consists in the creation of waypoints with the aid of a 3D pointer. The operator helds the pointer and adds single waypoints by positioning subsequent 3D shapes in the airspace. Each waypoint can be later selected and moved to a new position for the purpose of mission reprogramming.

In order to further increase situational awareness the 3D scenery can be augmented superimposing graphic elements and symbols representing the planned trajectory in detail. The desired trajectory path is displayed in the scene as a 3D curve connecting the waypoints. The actual trajectory, on the other hand, is created in real time from the actual AV attitude data received. Another path visualization feature, whose effectiveness as visual aid has been demonstrated [10], is a virtual tunnel. In human flight this feature helps to keep the assigned path, while in the autonomous flight it is particularly useful to manage from a single station more than one vehicle avoiding collisions and optimising the mission.

Visual and interactive aids have been implemented also for functional mission planning optimization.

4 Case Study

As mentioned in the previous paragraphs, the main goal of the presented case study is to perform a mission to monitor an oil slick and track the discharging ship. After an alert of slick in an approximately specified area in the sea, UAVs take off from a coastal runway under GCS control. Then the flight control is passed to the Control Center Operator (Fig.6) whose task is the waypoint list definition, based on the few situation information available. In this simulation the slick is slowly moving while the ship is bearing the south east direction, with a speed of 10 knots.

The automatic flight is enabled, so that UAVs formation starts following the path. As Fig.5 depicts, once the first UAV detects the oil slick, the point to point navigation is disabled and the aircraft tracks the target. The second UAV does not see the ship and a spiral flight around the slick is adopted to scan the sea. After some minutes also the ship is detected and the UAV2 follows the target loitering around it. The simulation is interrupted when the RTB order is sent to the vehicles: UAVs stop tracking and navigate to waypoint 1 where the GCS manages the aircrafts landing (Fig.5).

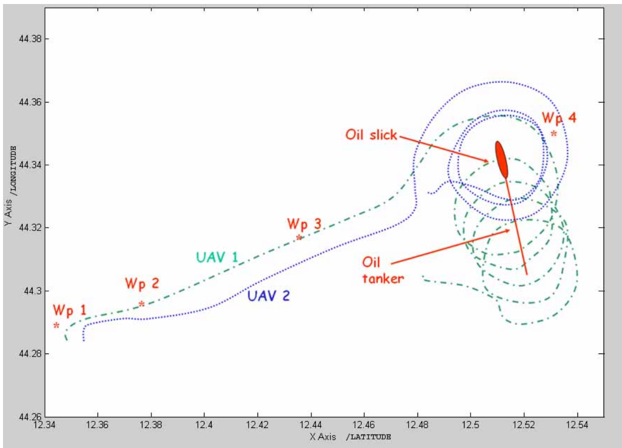


Fig. 5 Navigation Track Plot

5 Conclusions

In this paper we have described the prototype of a Virtual UAV Control Center.

One of the more interesting aspects in the use of visualization and interaction techniques is to improve the mission achievement performance. To this aim we proposed a first lay-out of graphical aids; the Man-Machine-Interface, thus, can be considered as a suitable platform to develop studies on human factors performance in a wide range of UAV missions.

Moreover in this system different objects (Air Vehicles or others) can contemporary animate the scene and the software is able to acquire data coming from different kinds of data sources, such as telemetry simulators or recorded data. This feature is particulary useful in case of event reconstruction or for training platform design, in addition to real time simulation.

More experiments are needed to further validate the interactive virtual interface in this and in other civil applications, such as fire fighting, flood monitoring, landslide, pipeline surveillance and many others.

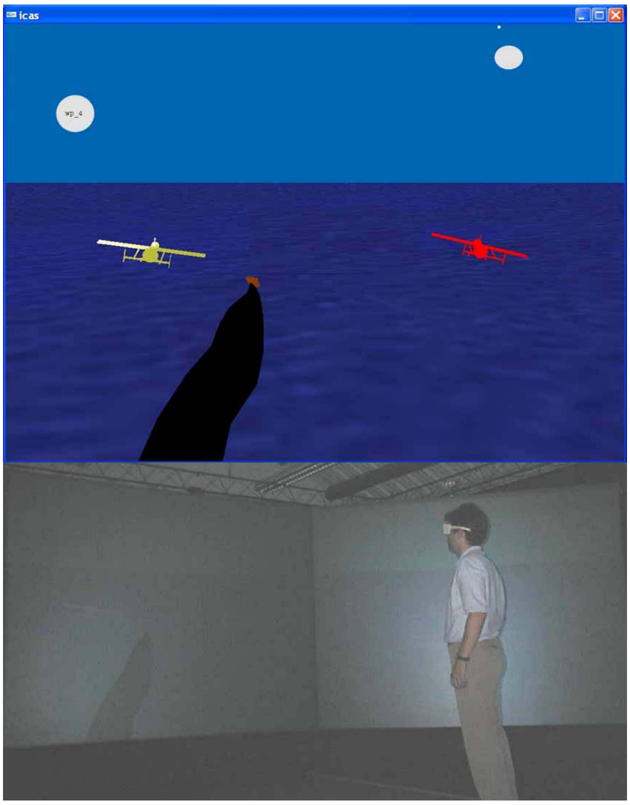


Fig. 6 Simulation in the Control Center

5 References

[1] Kam S. Tso, Gregory K. Tharp, Wayne Zhang and Ann T. Tai A Multi-Agent Operator Interface for Unmanned Aerial Vehicles, *The 18th Digital Avionics System Conference*, St. Louis, MO-USA, 1999.

[2] Mark H. Draper and Heath A. Ruff Multi-Sensory Displays and Visualization Techniques Supporting the control of Unmanned Air Vehicles Vehicle Teleoperation Interfaces, *Full-Day Workshop - IEEE International Conference on Robotics and Automation*, San Francisco, California-(28 April 2000).

[3] Ambrosia V. G., Remotely Piloted Vehicles as Fire Imaging Platforms http://geo.arc.nasa.gov/sge/UAVFiRE/.

[4] Kam S. Tso, Gregory K. Tharp, Ann T. Tai, Mark H. Draper, Gloria L. Calhoun and Heath A. Ruff A Human Factors Testbed for Command and Control of Unmanned Air Vehicles, *in Proceedings of the 22nd Digital Avionics Systems Conference*, (Indianapolis, IN), Oct. 2003.

[5] Zafrir, S., UAV Systems for Scientific Applications, *Presentation at UAVnet meeting*, Capua, 2002 www.uavnet.com/DL/Document_Library/CIRA_Meeting/UAVLAB_Zafrir.pdf

[6] Bray, Robert M., A Wind Tunnel Investigation of the Pioneer Remotely Piloted Vehicle, Monterey, *CA, Naval Postgraduate School*, June 1991.

[7] Nicololescu M., Lateral Track Control Law For Aerosonde UAV, *AIAA Aerospace Sciences Meeting and Exhibit*, Reno, NV, 8–11 January 2001

[8] Liverani A., Persiani F. and De Crescenzio F. An Immersive Reconfigurable Room (I.R.R.) for Virtual Reality Simulation, *Proceedings of the XII ADM International Conference*, Rimini, pp.E1-9/E1-15, 2001.

[9] Pretolani R, Saggiani G. And Teodorani B. RWUAV Ground Support System: Basic Requirements & First Layout Interim Technical Report UNIBO July 2003 - CAPECON Report: ID 6.1/1.

[10] Innocenti M., Pollini L. and Giulietti F. Visual Tools for Man-Machine Interface Real Time Simulation *IEEE Symposium on Information Technology in Mechatronics, ITM01*, Istanbul, Turkey, October 2001.