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VIGILANT SPIRIT CONTROL STATION: A RESEARCH TESTBED FOR MULTI-UAS SUPERVISORY CONTROL INTERFACES

Allen J. Rowe
Kristen K. Liggett, Ph.D.
Jason E. Davis
Air Force Research Laboratory
Wright-Patterson AFB, OH 45433

Since its inception, the unmanned aerial vehicle (UAV) has adapted to military life and has subsequently become an integral part of modern day warfare. Although unmanned, this technology remains dependent on human interaction for optimal function. Bridging the gap between rapidly advancing technology and the human, the Vigilant Spirit Control Station (VSCS) serves as a multi-faceted facilitator in areas ranging from research to combat missions. The result, consequentially, is an increase in the efficiency of the program by enabling a single operator to supervise multiple vehicles. Streamlining technology is tantamount to the program’s success. Developed with this in mind, VSCS effectively integrates sophisticated advancements for the purpose of strengthening the collaborative relationship between the operator and the UAV, and ultimately serves to propel this multi-purpose asset into the next decade.

Although there have been UAVs in existence since before manned flight, it was during the Vietnam era that the use of UAVs as surveillance vehicles significantly emerged (Krock, 2002). Today, UAVs have become a multi-purpose asset used by all branches of the military. In addition, UAVs are being used by state and local governments for such tasks as border patrol, search and rescue, forest fire monitoring, disaster response, and air traffic control. Commercially, UAVs are being considered for power line inspection, monitoring traffic, and filming in Hollywood (Frederick, 2006). On the military side, UAVs have become an integral part of modern-day warfare. Typical missions include intelligence, surveillance and reconnaissance (ISR), target acquisition, suppression of enemy air defenses, and combat missions. To support this wide variety of missions, UAVs carry many different payloads, from various sensors (electro-optical, short-wave infrared, etc.) to a range of armament.

Regardless of the UAV mission, the human interaction with these vehicles is of utmost importance. True, the vehicles are unmanned, but the operations of the vehicles always include a human component, and thus the need for a ground control station (GCS). It is through the interfaces in the GCS that operators perform tasks to ensure successful operations. These tasks include controlling the vehicle, to monitoring the information that the vehicle is gathering and transmitting back to the GCS. Therefore, an important link between the vehicles and the operators are the interfaces provided to execute the mission. The ratio of one operator controlling or supervising one vehicle may seem challenging enough, however, due to the high demand of qualified UAV operators (Hoffman & Kamps, 2005), current trends are moving toward a single operator supervising multiple vehicles. This adds to the importance of robust interfaces that leverage common components across various vehicles, payloads, and missions. As the services work toward interoperability, the development of a common GCS is one of the first steps (Osborn, 2009). Therefore, designing interfaces with a flexible software architecture, a standard way of communicating, a consistent look and feel for performing the majority of tasks, and a subset of tailored interfaces to support “specialty tasks” (i.e., automated aerial refueling), would facilitate this goal. The objective of this paper is to describe VSCS – a UAV GCS interface testbed. First, an overview of the VSCS philosophy will be provided, followed by examples of its implementation in a number of different programs designed to support various missions.

Vigilant Spirit Control Station Overview

VSCS originated several years ago with a primary goal of developing graphical user interface (GUI) concepts to effectively supervise up to four lethal UAVs. This thrust in the late 1990’s received attention from the Defense Advanced Research Project Agencies (DARPA) Unmanned Combat Air Vehicle (UCAV) program. A Cooperative Research and Development Agreement (CRDA) was quickly established between the Air Force Research Laboratory’s (AFRL) Human Effectiveness Directorate and the UCAV program’s prime contractor, Boeing. This relationship helped to pave the way for a series of developments over the next several years that would help VSCS gain momentum in the arena of supervisory control of multiple UAVs by a single operator. During the development of such a system to accommodate the diverse missions and vehicle payloads across multiple vehicle
platforms, it became apparent that an advanced intuitive user interface needed to be developed that provided a single common solution. VSCS was developed as a robust research testbed allowing researchers to explore a variety of supervisory control interface concepts to aid in addressing these issues. As illustrated in Figure 1, VSCS was designed around an open architecture allowing researchers access to the development tools needed to concentrate on the variety of scenarios concerning effective control and supervision of multiple UAVs. VSCS comprises a multitude of tools to aid both the researcher and UAV operator, such as a suite of advanced innovative operator interfaces; a simulation environment to aid in stimulating a synthetic environment for the modeling of various vehicle payloads, sensors, and human factors testing tools; dynamic mission planning (DMP) interfaces for interacting with vehicle supervision and control; a robust and flexible software architecture that allows for multiple configurations to accommodate diverse missions across a multitude of vehicle platforms; and finally the interoperability and communication across these vehicle platforms and the associated GCSs.

Flexible Software Architecture

VSCS has been designed to be used in various types of environments and configurations and for control of multiple vehicle platforms. Developed within a research organization, the software is required to support human-centered experimentation. These tests introduce software requirements for running participants through preplanned trials, collecting usage data, and providing mechanisms to display diverse user interface designs on the fly. More mature research can include conducting live flight tests, for which the GCS must have an ability to communicate with various commercial UAV platforms and also be implemented with concern for potential safety of flight issues. Finally, a robust modeling and simulation framework is needed to either drive laboratory-based research or to test systems prior to flight test. To meet all of these sometimes conflicting requirements, VSCS has been designed to be extremely flexible.

VSCS uses several interrelated mechanisms to achieve its required level of flexibility. The first is a set of Extensible Markup Language (XML) based configuration files that, when properly organized, define what VSCS refers to as a mission. A mission contains many items that can be configured: the UAVs under VSCS control and the payload and capabilities of those vehicles; pre-flight defined items such as points and areas of interest, real-world entities to be tracked, and imagery; symbology to be used across GUI elements; and many other settings and scenario-specific items. Closely related to a mission is the concept of a display layout, which is an XML-based specification of the types of GUI elements on the VSCS display and their sizing and positioning. Additionally, VSCS provides numerous extension points that allow for the integration of new GUI components and also various types of algorithms and non-graphical functionality. All of these can be loaded by the GCS without modifying any core source code, through the use of appropriate mission and display layout files.

The data file-driven nature of VSCS is one way that the software can easily support working with different types of UAVs in a variety of scenarios. Depending on the mission and display layout chosen by the operator at startup, any number of UAV exercises can be executed, and prosecuted efficiently by equipping the operator with a specially adapted interface toolset. Another way that these files are used is to provide an efficient means of conducting human-in-the-loop studies. For instance, in preparation for an experiment, a set of missions could be created that allow for altering aspects of the battlespace between trials, adjusting components of the GCS display, or both. Through the use of a test operator console, the person conducting the study can start and stop trials, effectively loading new missions automatically across both VSCS and simulation components, in a sequence that achieves the study’s goals.

Interoperability

Another feature of VSCS that opens it up for a wide array of uses is the way that it communicates with other systems. The primary interface that will be addressed in this discussion is the one between the GCS and the UAV that it is controlling. VSCS has adopted the data link interface defined in NATO Standardization Agreement STANAG – 4586 Standard Data Link.
(STANAG) 4586 for UAV command and control (NATO Standardization Agency, 2008). This standard states that its aim “is to promote interoperability of present and future UAV systems […]”. The STANAG 4586 aims to define a common set of functions that, when implemented on a particular unmanned aerial system (UAS), allow any similarly designed UAV GCS to control that asset to a certain degree. A complete systems architecture is also specified that allows for unobtrusive implementation of the standard in a manner that allows each UAV system to retain any proprietary or custom communications protocol while still being STANAG-compliant. This is accomplished through what is referred to as a Vehicle Specific Module (VSM).

From VSCS’s perspective, all outgoing vehicle command and control and incoming vehicle telemetry and status is conducted through the use of applicable STANAG messages. Assuming the vehicle being controlled does not natively understand these STANAG messages they must first pass through a VSM. This VSM translates the data contained in the STANAG messages into equivalent UAV-specific messages that are then sent to the vehicle for uplink commands (or vice-versa for downlink telemetry and status). While the STANAG provides the functions necessary for basic interoperability, there can still exist occasion to provide platform-specific extensions to the standard for advanced functionality and to alleviate potential safety of flight concerns. For the most part, however, VSCS has been able to leverage STANAG 4586 to achieve a high level of interoperability between several types of vehicle platforms, both virtual and physical.

The VSCS operator interface incorporates a flexible modular design that can be configured to accommodate various mission and payload requirements. The following sections will cover details regarding the core capability interface tools available within VSCS to aid the operator in these functions. As noted in previous discussions, VSCS software architecture provides developers a robust environment for the development of mission and payload specific operator interface tools for specific vehicle platforms that lie outside of VSCS core capability.

**Mission Management**

Supervisory control of multiple systems requires intuitive and robust operator interfaces to effectively perform all mission management functions. To address this need, VSCS includes a suite of tools to aid the operator during these missions. These are depicted in the vehicle Alert and Summary tool, a tactical situational display (TSD) to provide advanced mapping capability, the command and control interfaces, and dynamic mission planning (DMP) interfaces. Figure 2 depicts a typical mission management display setup. A brief description of each of these will be provided. For further detailed information, please refer to the VSCS Operator Manual (Williams, Feitshans, and Rowe, 2002)

The vehicle Alert and Summary tool provides a quick look assessment of pertinent UAV information tailored to the current mission phase (Figure 3). Each UAV is depicted in a dedicated pane providing unique features to aid the operator in quickly distinguishing the various UAVs under the operator’s control. There are four key elements used to provide cues to the operator when performing basic mission management functions. These are color, glyphs, IDs, and callsigns. Color is used throughout the system to uniquely identify each UAV and its associated data, such as flight plans, loiter locations, and sensor information. Glyphs typically indicate vehicle platform and provide basic navigation information such as vehicle heading, altitude and airspeed. Each UAV is assigned a unique ID, such as 1, 2, 3, and so forth, and compliments the glyph to provide another situation awareness (SA) measure for quickly locating a designated UAV. Finally, a unique vehicle callsign is issued based on the current mission and is used in much the same manner as typical manned aircraft missions. A quick crosscheck mechanism is also provided to show basic navigation parameters for all UAVs the operator is currently controlling in this mission phase, such as, navigation mode, airspeed, and altitude. This information is shown at the top of the Summary tool and uses many of the key indicators described to designate each UAV. Payload information, such as sensor cameras, weapons, or radar systems is also displayed for each UAV. Various alerting mechanisms are provided in this panel to indicate loss of communications, loss of global positioning system (GPS) information, low fuel/battery life, or other mission specific alerts.
The TSD provides a common mission operating context consisting of standard aviation charts and geo-referenced imagery (Figure 4). The mapping functionality of the TSD is analogous to using standard commercial tools such as Google Maps, MapQuest, or military standards such as FalconView. The TSD makes available mission information such as UAV position, air and ground tracks, airspace management aids, mission plans, sensor viewing locations (footprints) if available, and target locations. A wealth of additional information can be displayed on the TSD if source data is available for the given UAV platform given their geo-registered coordinates are known. UAV information is consistently shown with the same standard features as those found on the Summary tool as previously discussed. As mission complexity increases, overlapping symbology and clutter become an inherent problem the operator must manage. To aid the operator in dealing with this increased information management, several de-cluttering options are available to reduce this visual overload and reduce symbology clutter. Color is used extensively to aid in reducing information overload as well as techniques to filter several elements based on mission phase. As an example, UAV routes can be filtered based on phase of flight and waypoints visited to significantly reduce this clutter, as well as labels and extraneous information.

UAV command and control is accomplished through the use of a variety of standard mission and vehicle platform specific tools (Figure 5). Depending on the vehicle platforms for a particular mission configuration, the appropriate command and control tools are made available in a standard interface tightly coupled to the TSD. These tools provide vehicle navigation control, loiter management, sensor payload management, and DMP. Several techniques are used to assist the operator in accomplishing the goals of a particular mission. Standard keyboard and mouse input is always provided as a redundant input mechanism, but more intuitive techniques can be utilized for frequently used and common functions. The use of voice input, Hands on Throttle and Stick (HOTAS), gaming controllers, and touchscreens are being explored to provide an enhanced user experience. Graphical alternatives are used directly on the TSD when appropriate to aid the operator in quickly issuing a command to a particular UAV (Figure 6). Simply selecting a UAV on the TSD and gaining access to a context sensitive suite of commands and manipulating the constraints and parameters of that particular command directly on a geo-registered map simplifies the complex task of managing multiple UAV in a complex mission scenario (Williams, Hughes, Feitshans, Rowe, and Williamson, 2005).

**Payload Management**

In addition to providing effective mission management functionality, the introduction of various vehicle payloads such as electro-optical (EO) and infra-red (IR) sensors, as well as a diverse set of weapon systems, poses a unique challenge for the multi-UAV operator to maintain SA and successfully execute the desired mission. VSCS includes a suite of payload management tools in conjunction with cooperative vehicle mission planning to accomplish the dual role of air vehicle operator as well as a mission payload operator. These include the use of digital video recording (DVR) capabilities and mosaic functionality (Figure 7). Video mosaic techniques, as shown in the left side of Figure 7, have shown potential in aiding the operator during high workload situations and provide enhanced SA as well as providing a more stabilized view of the target during tumultuous conditions (Feitshans, Rowe, Davis, Holland, and Berger, 2008). Figure 8 provides a close-up view of the DVR tool. Depending on the vehicle platform, image stabilization could introduce undesirable artifacts that could be
eliminated or reduced by allowing the operator to freeze frame or “rewind” the video to inspect it more closely when searching for targets of interest. Providing an intuitive user interaction such as clicking directly in the video to designate geo-registered targets or pausing the video through the use of commonly known interfaces found on commercial digital video disk (DVD) devices can reduce operator workload while maintaining SA on several other UAV’s during a particular mission.

Weapon and stores payload management is also a challenge while trying to maintain supervisory control over multiple UAVs. Limited research has been accomplished in this area and further information can be found in the following publications (Williams et al., 2002; Williams, Venero, and Linhart, In Press). The use of DMPs has shown great promise in reducing operator workload while maintaining cooperative control of multiple UAVs. VSCS has been designed to interface with these planners through the interoperability mechanisms discussed earlier. To date, VSCS has interfaced with various cooperative control algorithms developed within the Air Vehicles Directorate, as well as Commercial off the Shelf (COTS) products such as Operations Research Concepts Applied Planning and Utility System (Williams et al., In Press).

VSCS Example Program Applications

VSCS has had many opportunities to be involved in a wide variety of unique projects. From advanced research and demonstrations to full-mission usability assessments, these programs have led to a multitude of research results and lessons-learned to further enhance the VSCS testbed. These programs include UCAV, the Joint Unmanned Combat Air System (JUCAS), Long Range Strike (LRS) (Williams, et al., In Press), Automated Aerial Refueling (AAR) of multiple UAVs (Williams, Burns, Feitshans, Rowe, and Davis, 2008), and the multi-aircraft management aspects of the Predator Program. Internal AFRL sponsored research programs such as Cooperative Operations in Urban Terrain (COUNTER) and Multi-UAV Supervisory Control Interfaces Technology (MUSCIT) have increased the VSCS sensor and mission management capabilities to include unique toolsets for effectively monitoring multiple small and micro UAVs to provide enhanced urban telepresence (Feitshans et al., 2008; Patzek, In Press).

To address more fundamental basic and applied research questions, a variety of AFRL-sponsored part-task evaluations have recently been performed. One effort is evaluating a transition aid designed to rapidly build operator SA when switching between UAV missions and their associated sensor views (Draper, Calhoun, Ruff, Mullins, Lefebvre, Ayala, & Wright, 2008). The Multi-Aircraft Video – Human/Automation Target Recognition (MAV-HATR) studies focused on effectively monitoring multiple video feeds for target identification and tracking (Carretta, Patzek, Warfield, Spriggs, Rowe, Gonzalez-Garcia, & Liggett, In Press). Another line of research is investigating the use of enhanced symbology to portray navigation and status information for multiple UAVs. This involves the development of glyphs. Finding the optimal size, information portrayal, and reduced clutter to intuitively show context sensitive mission information is the focus of a series of studies to support multi-UAV supervisory control. Figure 9 illustrates a notional glyph that could be displayed on a TSD or Summary tool to aid the operator during the course of the mission. Enhanced tools are constantly being developed and evaluated to refine their effectiveness during all phases of a diverse set of missions. One such tool includes providing terrain shading as well as a 3D perspective viewing capability directly on the TSD to enhance awareness for potential hazardous terrain (Figure 10). Another tool is a temporal display, which provides cues to upcoming events as well as visual deconfliction of potential hazards or retasking of UAVs during inherently
beneign or idle periods of time during the mission (Figure 11). The list of useful tools to aid the operator in multi-UAV control are constantly being developed and refined by the VSCS team. Combining the right mix of tools during complex and potentially stressful environments are the focus of VSCS.

Summary

The goal of VSCS is to provide the UAV community with a research testbed to continue to push the envelop of advanced multi-UAV supervisory control. This is accomplished by providing a robust software architecture and interoperability capability. It has enabled VSCS to be used throughout several research and flight test projects. The success of VSCS is evident in the wide spread utilization of this research testbed throughout several government sponsored organizations to promote multi-UAV supervisory control across diverse missions to provide one common solution.

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