An Adaptive Automation Approach for UAV UI Concept Development

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Abstract

Despite decades of industry experience in the design of Unmanned Aerial Vehicle (UAV) control systems and their user interfaces, a combination of factors persist that produce a significant and unacceptable loss rate of UAVs due to poor user interfaces. One significant element is the current focus of human systems design on lower-order User Interfaces (UI) at the expense of investing in the design of an adaptive higher level integration to relieve inattentive or overtaxed operators of significant functionality as required, and to perform time-critical tactical tasks which humans cannot perform or for which they are not well suited. The approach proposed is one which defines the respective roles of user interactions with adaptive policy manager automation to address the loss of vehicles and mission failures. Specific policy manager automation elements are explored which will enable the system to flexibly assume or release UAV vehicle or systems functionality based on operator action/saturation in a number of mission areas. A notional Executive automation controller design approach is outlined to meet time critical information integration and mission task requirements.

Introduction and Historical Background

Despite decades of industry experience in the design of Unmanned Aerial Vehicle (UAV) control systems and their user interfaces, a combination of factors persist that produce a significant and unacceptable loss rate of UAVs due to poor user interfaces. By way of comparison to the progression of manned aircraft pilot vehicle interfaces, the UAV UI field has failed to progress as rapidly, being somewhat stalled at an equivalent of a 1940's state of the art with design foci on improved detailed level UI (menus, knobs, switches, screens), rather than on addressing systematic higher order user-system automation design.

In the 1940s, manned aircraft human engineering underwent a radical change in design philosophy with the work of human factors engineering pioneers such as Alphonse Chapanis, who applied engineering psychology to correct basic cockpit design flaws. The classic example of application of early engineering psychology analyses is the effort to mitigate a rash of bomber gear up crash landings. Human factors engineers redesigned landing gear handles to be shaped like wheels and reshaped flap handles shaped like flap handles for tactile discriminability by pilots who were visually focused on performing landing tasks. These were point design solutions, but were systematically applied through the cockpit and were eventually incorporated into the military standard system (Roscoe, 1995).

A systematic review in 2011 by the U.S. Air Force Scientific Advisory Board found a number of significant ergonomics and automation deficiencies in several current UAV Ground Control Systems (GCS), including poorly mechanized autopilot interfaces as well as "classic" pilot vehicle interface deficiencies. One example recalled the 1945 bomber crashes; the crash of one $4.5 million Predator UAV was directly caused by a pilot mistakenly choosing the "kill engine" switch instead of the adjacent landing gear switch (Morely, 2012). That a Predator pilot was even able to mistake (let alone be allowed to actuate in flight) the "kill engine" switch for the landing gear switch would seem to indicate the lack of a systems engineering analytical approach to user interface requirement definition.

Other studies have confirmed the apparent lack of a systematic design approach. A 2007 Air Force Research Lab study found that up to 80% of Predator mishaps alone involved human error, including poor documentation, crew coordination mistakes and training, and serious fundamental human factors design issues with GCSs. For example, it apparently took 22 key strokes to turn on the autopilot on early Predators; warning, caution and advisory messages were buried under layers of noncritical interfaces, resulting in situations where the pilot receives few if any alerting cues to emergencies. More than 400 US UAVs have crashed since 2001 (including midair collisions) and due to these causes, which contributed to lack of pilot awareness of or correct responses to weather, fuel status, data link strength, and high terrain (Craig, 2012).

Looking forward, UAV missions are expanding and multiplying into roles (such as Airborne Electronic Attack and Air to Air engagements) which stress rapidity of decision making in a complex shifting combat environment. Emergent warfighter UAV design goals are trending toward requirements for single user command and control of multiple heterogeneous UAV platforms with separate mission taskings, as well as requirements for cooperative control between a GCS and an off board user (such as a front line soldier or pilot). A Human Systems Integration (HSI) design approach limited to lower order point design switch and display issues or merely complying with military standard compliance audits does not address the systems engineering challenges from these needs. These new requirements present more challenging problems such as issues with single user task saturation and vigilance and how user system automation can augment a human user to prevent mishaps and enable mission success. This paper will summarize an approach to provide a framework for an adaptive, operator centric automation framework for future and retrofit naval UAV designs.

The approach recommended is two faceted; the first is the need for individual, adaptive automated policy managers focused on specific mission tasks (especially those needing rapid calculation or constant monitoring). The second is the need for an overarching Executive manager to provide rapid arbitration and coordination during time-critical combat operations. The end goal is to return the user to the role of tactician, automating first order calculations (e.g. fuel, terrain avoidance) but with a higher order automated process to ensure a coordinated response to human tactical direction.

Progress towards Adaptive GCS Automation

Two historically prevalent approaches to UAV GCS design have been followed. One approach focused on provision of controls duplicating manned aircraft interfaces (e.g. the approach used from 1940's designs up through the MQ-1 Predator). The other provided direction of the vehicle through graphical map cues (evolving from hard copy strip charts to present day point and click graphical interfaces to direct flight to a point). Either approach offers the potential for the uncoordinated application of multiple instances of automation (e.g., an automated route planner will disagree with an automated terrain avoidance system – and will present disharmonious results to the user from separate displays). The risk, then, is that attempts to add automation to GCS designs (within either design paradigm) will impose additional new tasks and roles on the user to monitor multiple automated systems across multiple vehicles, thus increasing the risk of significant error. For example, trending UAS human errors have been noted to include (Johnson, 2007):

1. Loss of operator situational awareness (SA) of airspace and traffic.
2. Operator-induced Air Vehicle loss of fuel/loss of link, leading to vehicle loss.
3. Loss of operator SA of altitude, airspeed, vehicle status, and clearance to terrain.

Operator Role Theory (Folds, 1995) posits a spectrum of human and automation shared roles in systems control (see Figure 1, below). Where no automation is present, the user is acting in a "Direct Performer" situation. With automation present but with the user performing information synthesis and control of the system, the system is running in a "Manual Control" region. With predominantly automated control loop processes and user monitoring and adjustment, the system is in a "Supervisory Controller" region, and finally, in the "Executive Controller" region of automation, the human is not in the control loop at all, save for a start/stop function

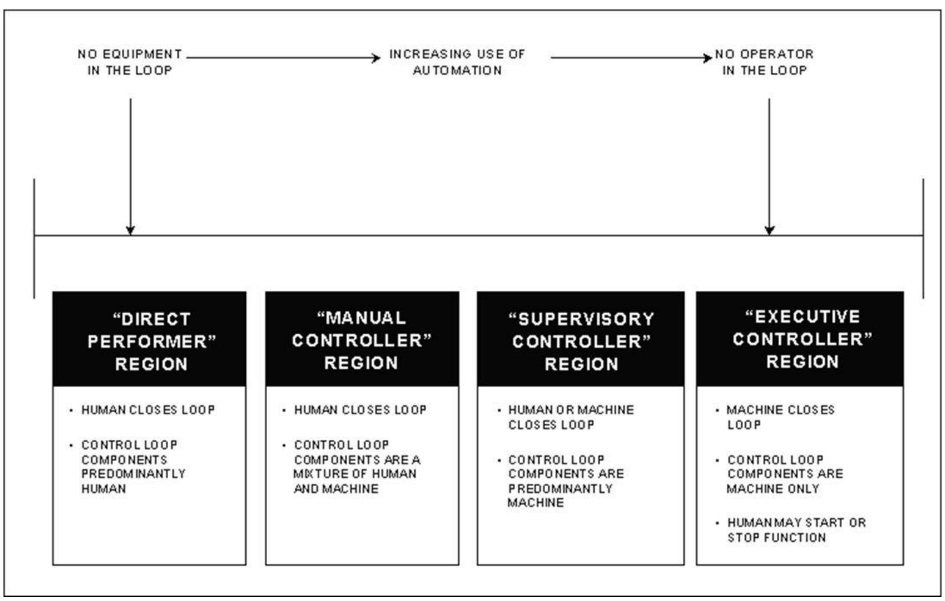

Figure 1 Continuum of Operator and Automation Roles

The classic example of Executive level control is cell phone tower switching, which takes place at an Executive level (human interaction with this automated element is generally limited to seeing the signal strength bar on their phone). Currently, GCS designs incorporate a mix of automation from in various automation control regions, with varying success. The move towards multiple UAV GCS control will only exacerbate existing problems without adoption of a new element of automation to aid the user in automation management. Newer GCS designs are undertaking to provide adaptive automaton which provides tools for automatic flight routing, route deconfliction, and calculation of weapons engagement zones, SAM shot avoidance cues, and so forth based on integrated "at a glance" presentations (Johnson, 2007).

Mission Growth Forces an Approach with an Executive

As with the cell phone example, the Executive automation role is well proven in manned combat aircraft. Airborne electronic warfare jammers react immediately, for example, to defeat incoming enemy missiles by automatically applying radar jamming techniques. The system executes the protective action because the pilot doesn't have the reaction time (let alone the surplus workload capacity) to manually employ the equipment. Particularly for pilots who may be tired or inattentive, the sudden leap in activation from being a system monitor to dealing with an emergency can lead to lapses and errors. Thus, a higher level requirement exists for a controller capability which looks across automated subsystems for multiple UAVs, accessing data to predictively analyze trends and threats in a coordinated manner, without the potential for boredom or fatigue.

To match the required UAV UI demands, a comprehensive shift to a system of systems engineering approach to adaptive automation – across applications – is recommended. With multiple UAVs aloft in a highly dynamic battlespace (where UAVs may be used not just for long counterinsurgency patrols, but as targeting and/or weapons platforms in air to air combat), automation needs to be considered as more than a family of decision making tools, but as an integrated system itself. A human systems engineering approach which applies operator role theory (Folds, 1995) to define a UAV system of systems will effect an order of magnitude improvement in combat efficiency and effectiveness. The approach proposed specifically advances the definition of multi-mission adaptive automation to address the impacts of (1) highly complex mission tasking (2) too many vehicles to manually monitor at once and (3) short engagement timelines.

Elements of the Integrated Solution: Policy Managers and an Executive

Automation should relieve humans from boring housekeeping tasks, prevent their inattention or raw information saturation from causing loss of vehicle and mission failure conditions, and allow humans to do that which they do best (make tactical judgments). Specific automation "policy" managers should be considered for collaborative integration in a fused GCS implementation. Many automation elements have already been fielded as separate tools in manned and unmanned aircraft. However, to implement enough of them, over multiple UAVs, with newly emergent requirements for tactical engagement accuracies and timelines, additional Executive level automation is needed.

Each policy manager has a role to play as individual automated elements under an Executive, which would supplement the monitoring and arbitration task set currently allocated to the human. An Executive would be able to quantitatively perform that role across multiple UAVs, and would be able to meet far tighter accuracy and speed requirements. The Executive must be able to resolve a best fit solution for the active UAV platforms given preplanned mission constraints by performing multivariate, weighted, arbitrations across the lines of the subordinate policy managers. Example potential individual automation elements include Auto Ground Collision Avoidance System (AGCAS) Protection, Auto Traffic Collision Avoidance Protection, Auto Envelope Protection, Auto Airspace Protection, Auto Datalink Protection and Auto Signature Protection (among a host of other functions). It is useful to examine how two (a Datalink Manager and a Signature Manager) interact.

The Datalink Manager monitors established UAV to GCS, UAV to UAV, and UAV to manned mission partner datalink latency and strength against calculated range limits. It then provides a real time calculated assessment of the probability of loss of link(s) as well as quality factors. (Link latency, as an example quality factor, will impact the ability of the vehicle to perform time critical tactical tasks). Based on this, as well as the availability of alternative links, this policy manager automatically shifts and configures data links In an integrated automation system, the Datalink policy manager will need arbitration with the Signature and other managers to regain signal while ensuring the "lost" AV avoids maneuvers which compromise detection or survivability.

The Auto Signature Protection manager provides real time computed signature management to ensure that the UAV remains either undetected or unengageable by threat systems. Based on preplanned settings, the Signature policy manager would provide a spectrum of adaptive actions from advisories to cautions to warnings to auto heading/alt changes based on flight paths past the minimum allowable approach range toward threats. This automation manager would consider the use of terrain and range line of sight effects in making an aspect/course/altitude change input; the signature policy manager would (in the proposed integrated system) make inputs in favor of or against course changes (whether automated or manual) to ensure that requested courses would not inadvertently generate a fatal shot solution from an enemy missile site. Yet obviously, some third party agent is necessary to perform the rapid, multivariate comparison and arbitration tasks between all these agents, if a human cannot possibly interpolate and calculate quickly enough.

The Need for an Executive Agent

While separately, individual automation elements may be useful, the emergence of far more complex combat requirements requires users to interpolate and integrate the many information variables (such as signature, envelope, and fuel as well as datalinks and weapons control) for multiple controlled UAVs, during multiple weapon engagements with hostile moving targets. USAF Colonel John Boyd, father of the Observe, Orient, Decide, and Act (OODA) loop model of tactical engagement, noted that the key to combat aircraft survival and autonomy is the ability to adapt to change rapidly and to capitalize on calculated advantages faster than one's opponent – to "get within the enemy's OODA loop" (Boyd, 1976). With such a varied range of automated policy managers, conflict arbitration via human or automated means is necessary. Because a single human cannot meet the analytical and computational requirement to comparatively perform the cross application functions for multiple UAVs within a tactically significant timeline for multiple controlled vehicles, the GCS must be equipped with an overarching Executive Agent.

Such an Executive would constantly monitor the individual policy managers for each UAV and adjudicate recommended automated actions based on preplanned algorithmic responses for most cases; the Executive would both provide more urgent advisories (would inform, then prompt, then warn) to cue user intervention based on the severity of impact of the problem within a tactically significant timeline (e.g. the UAV is headed for a threat, turn the UAV to avoid detection, and finally maneuver the UAV to defeat an engagement). In Boyd's terms, the control loop authority (human or Executive) must perform general-to-specific reasoning - deduction, analysis, and differentiation, while also performing specific-to general reasoning related to induction, synthesis, and integration tasks (Boyd, 1976).

In most cases, the Executive would employ hierarchical weightings to arbitrate between conflicting policy managers to prioritize actions emphasizing one mission aspect over another (such as a prioritizing lack of UAV detection over choosing the most fuel-efficient return route). In all cases, Executive arbitration of the policy managers would follow mission constraint settings selected during mission planning by the user (even if only for default settings) and consent for key tasks (e.g. weapons free status within approved engagement constraints) would necessarily be required.

Conclusion

By equipping proposed future multiple combat UAV controlling systems with agile, Executive level controllers which can rapidly perform multivariate, weighted, arbitrations, time critical combat tasks be met within the multiple UAV control paradigm. Significant further mission task analysis and requirements decomposition is necessary to ensure that further platform specific top level and detailed level design requirements are properly decomposed and allocated.

Works Cited

Boyd, John R. "Destruction and Creation". (3 September 1976).U.S. Army Command and General Staff College.

Folds, Dennis, and Mitta, Deborah. "Using Operator Role Theory to Guide Function Allocation in System Development", Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 1 October 1995.

Johnson, R, et al. "Testing Adaptive Levels of Automation (ALOA) for UAV Supervisory Control" (March 2007). AFRL-HE-WP-TR-2007-0068. OR Concepts Applied (ORCA) for Air Force Research Laboratory, Human Effectiveness Directorate, Wright Patterson AFB OH 45433.

Michelson, Stuart. "A survey of the human-centered approach to micro air vehicles". Chapter 90, Springer Handbook of Unmanned Aerial Vehicles 2013.

http://www.springerreference.com/docs/navigation.do?m=Handbook+of+Unmanned+Aerial+Vehicles+(Engineering)-book256

Morely, Jefferson. "Boredom, terror, deadly mistakes: Secrets of the new drone war". Salon.com, 3 April 2012.

http://www.salon.com/2012/04/03/boredom_terror_deadly_mistakes_secrets_of_the_new_drone_war/

Roscoe, Stanley. "The Adolescence of Engineering Psychology", Volume 1, 1997, Human Factors History Monograph Series, Steven M. Casey, Editor, the Human Factors and Ergonomics Society, Santa Monica CA.

Whitlock, Craig. "Drone crashes mount at civilian airports". Washington Post, 30 November 2012. http://www.washingtonpost.com/world/national-security/drone-crashes-mount-at-civilian-airports-overseas/2012/11/30/e75a13e4-3a39-11e2-83f9-fb7ac9b29fad_story.html