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Next Generation Universal Ground Control System HMI Design

Cory Anderson, Arianna Efaw, Edward Emery, John Mueller, and James Schreiner

Department of Systems Engineering
United States Military Academy
West Point, NY 10996, USA

Corresponding author's Email: Cory.anderson@usma.edu, Arianna.efaw@usma.edu, Edward.emery@usma.edu, John.mueller@usma.edu, James.schreiner@usma.edu

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Abstract: The existing Human Machine Interface (HMI) for the Army's Universal Ground Control Station (UGCS) represents a 1980s, windows-based technology which is neither intuitive nor scalable for operators. It creates high levels of cognitive load on the operators, and its closed architecture limits its adaptability for UAS missions as technologies evolve. This research presents a methodology for creating and evaluating next generation HMI designs while leveraging GNU Image Manipulation Program (GIMP) and TELLUS flight simulation software in the creation of five HMI prototype designs. A proof of concept approach in the evaluation of prototypes was performed with five UAS Aircraft Operators (15W MOS) and five USMA cadets; examination of the impact of age and experience on the perceived value of new HMI designs will influence recommendations on full experimental design. The value-focused approach to design presented in this paper and prototype designs provide a basis for full prototype development and experimental testing through PM UAS with the Intelligence and Maneuver Centers of Excellence. Results include a trade space and sensitivity analysis towards development of improved HMI designs. The methodology and high performing prototypes for HMI design will be integrated by the PM UAS CSI Project Office for further development and full experimental analysis.

Keywords: Universal Ground Control System, Human Machine Interface, Unmanned Aircraft Systems

1. Introduction and Background

The UGCS currently supports two U.S. Army UAS platforms: Shadow and Gray Eagle (SCI, 2016). The fundamental problem for PM UAS is that the command and control software is over twenty years old. The current software is a 1980s and 1990s windows-based design which has been proven less than ideal for command and control of a single Army UAS; there are currently over 1200 different screens and controls that a UGCS operator can manipulate during operation of their UAS(SCI, 2016). An overhaul is currently being conducted to update the software of the system, and in time, the hardware as well. This research is focused on presenting a methodology for the evaluation and design of the next generation UGCS HMI. The implementation goal for the new system, with the current UGCS hardware, is 2021 with an estimated 25-35 year system life cycle for the Army (SCI, 2016).

Research in Human Factors on HMI design characteristics could guide efforts in value modeling and idea generation for this research. PM UAS CSI actively employs subject matter experts in this field early on in the design process. Since PM UAS CSI has not adopted a standard to measure cognitive load or system usability, industry accepted tools could present ways to capture universal attributes to any HMI design. Prior to initial meetings with stakeholders at PM UAS, it was determined in cooperation with professors in the Engineering Psychology Department at USMA that the NASA-TLX test and the System Usability Scale (SUS) would present models of high statistical validity which should be considered for employment in evaluation of the prototypes. The NASA-TLX model measures cognitive load using Likert scale questions on six defined NASA-TLX tasks. For each of the tasks, NASA-TLX produces a value and a weight from which a composite score is generated capturing total cognitive load for the prototype (Hart et al, 1988) (Thomas, 2017); a lower composite score is better. The System Usability Scale (SUS) model measures system usability and ease of use using Likert scale questions and returns one composite score capturing total usability of the system (Brooke, 1996) (Affairs, 2013); a higher composite score is better.

With the current UGCS interface reaching the end of its life cycle, PM UAS's initial problem was to develop an intuitive, scalable HMI capable of controlling multiple UAS payloads no later than 2021 for the Army (SCI, 2016). An interface software design capability named TELLUS was identified which could transform initial prototype sketches into near-full functioning simulations for large scale testing (MCRI, 2017). While this paper focused on a 'proof of concept' design where survey data would enable evaluation of initial and improved prototypes, future work would consist of branching out to the 15W and 11B Military Occupational Specialty (MOS) communities to allow for formal, experimental testing on TELLUS-like prototypes in order to determine which HMI is best for meeting the needs of the Army.

Development of initial prototype concepts leveraged GIMP to create a visual of what the HMI of the prototype would look like and how it would function. GIMP allows for images to be imported to a single screen where graphics can be overlaid in order to create a visual of each prototypes' unique HMI (GIMP, 2017). Using the screens created in GIMP along with PowerPoint, the team was able to create a semi-interactive interface that allowed for assessment of each prototype based off of the value measures found in our qualitative value model. Techniques employed by the team in the analysis and design of the next generation UGCS HMI (GIMP prototypes) were derived from the Systems Decision Process (SDP) (Parnell et al., 2011) and will be presented in the methodology section of this paper.

2. Methodology

2.1 Problem Definition

2.1.1 Research and Stakeholder Analysis

Design of a new UGCS HMI required insights from the actual operators about current system capability flaws and what they value in a new system in order to develop a proper scope of the problem. Research was essential to framing the initial meeting with the PM UAS stakeholders. Literature reviews were performed on current UAS and UGCS technologies, UAS employment and manning, and cognitive engineering considerations. A face-to-face meeting with PM UAS 15W's at Redstone Arsenal, Alabama provided insight on the successes and failures of the current system's HMI. Although stakeholders are any persons or organizations that have a vested interest in a system (Parnell et al., 2011), the Army 15W MOS was determined as being the primary stakeholder group to be interviewed as they represent the operator and integrator of UAS capabilities for all levels of command.

The findings from this research identified a growing reliance on UAS platforms for Intelligence, Surveillance, and Reconnaissance (ISR) and kinetic attack capabilities as a combat enabler. This motivates the need for a new UGCS HMI design. The important attributes for the HMI according to the stakeholders include making the new system easily learned, intuitive and easy to use while reducing the operator's cognitive load and improving the memorability of key functions (Zimmerman & Boike, 2016). The system shall also be both horizontally and vertically scalable, meaning that the system can be operated by different levels of users while also relaying information through the chain of command (Zimmerman & Boike, 2016). The display of mission essential data shall be on the forefront of the HMI with quick access to all other information in order to improve the HMI's functionality. To capture these findings, a value model was employed as a tool to help analyze both initial and improved prototypes based off of the stakeholder's values.

2.1.2 Qualitative Value Modeling

Evaluation of next-generation UGCS HMI design prototypes would require a value focused thinking approach in order to identify decision opportunities and create better alternatives (Keeney, 2009), therefore, a qualitative value model was developed as seen in Figure 1. The team identified the fundamental objective for the Army design of the UGCS HMI with three primary functions including facilitating basic operations (launch, land and in-flight), mission operations (engagement of targets and responding to aircraft problems), and ensuring the command and control of those UAS system both vertically (from operator to observer) and horizontally (across UAS systems in support of multiple units). Development of objectives and value measures would then allow for scoring and value determination of multiple HMI prototypes. One constraint on the development of the model was the identification of four value measures not able to be tested due to full working prototypes yet to be developed. These prototypes are highlighted in Figure 1 in the color blue and include employment of eye tracking software as a way to measure cognitive load, speed of engaging targets, and speed/accuracy of properly identifying the Warnings, Cautions, and Advisories (WCA) which facilitate actions towards correcting UAS deficiencies. All other value measures would be formalized using constructed scale assessments and industry standards such as NASA-TLX and SUS models.

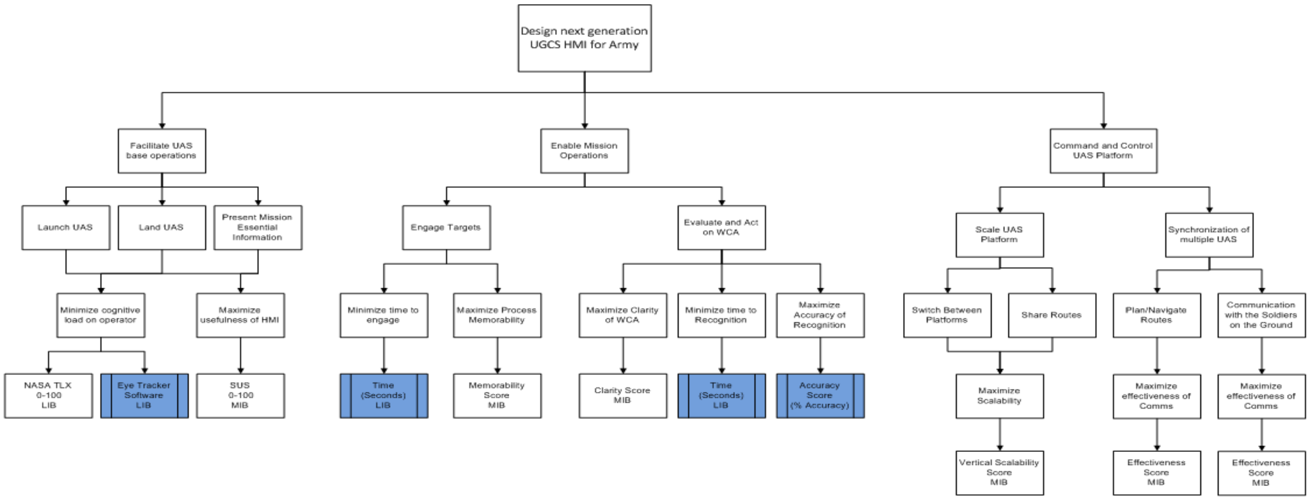

Figure 1: UGCS HMI - Qualitative Value Model

2.1.3 Quantitative Value Modeling and Redefining the Problem

To elicit the relative weights of the value measures from Figure 1, a simple series of questions were developed for the project manager at PM UAS to provide feedback on swing weights along with establishment of an initial risk attitude for each value measure (Regula, 2017). Table 1 identifies the swing weights which capture relative importance against variability of each value measure for HMI designs (Parnell et al, 2011). Risk attitude defines the return to scale of a value given a raw data score and indicates whether the decision maker is risk averse, risk seeking, or neutral (Clemen and Reilly, 2014). Integration of the four recommended (in blue) value measures from Figure 1 with swing weights would need to be implemented once the design research on HMI prototypes moves from the proof of concept phase to the full prototype experimentation phase. Total prototype value scores would be calculated using swing weights and value functions reflecting risk attitude by employing a multiple objective decision analysis (MODA) mathematical model (Parnell et al., 2011) as reflected in Equation 1.

Table 1: Quantitative Value Model – Swing Weights and Risk Attitude

Value Measures	PMUAS Swing Weight	Risk Attitude
NASA TLX (MIB, 0-100)	80	Averse
SUS (MIB, 0-100)	100	Averse
Memorability (MIB, Likert 1-5)	80	Averse
WCA Clarity (MIB, Likert 1-5)	100	Seeking
Scalability (MIB, Likert 1-5)	40	Averse
Sychronization (MIB, Likert 1-5)	40	Averse
C2 Effectiveness (MIB, Likert 1-5)	60	Averse

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i) \qquad (1)$$

The Effective Needs, or redefined problem statement, was developed at the conclusion of the problem definition phase to guide further research and design efforts: *The Army UAS community needs to design a next generation Unmanned Ground Control System (UGCS) Human Machine Interface (HMI) in order to improve simultaneous mission capacity over multiple Unmanned Aircraft Systems; design will focus on modular, multi-modal, and open-architecture characteristics that enhance the Intelligence Surveillance and Reconnaissance (ISR) and kinetic option capabilities of Army units and the warfighter.*

2.2 Solution Design

2.2.1 Idea Generation

Incorporation of the new found knowledge into prototype designs represented the next step in the research. An idea generation process consisting of a silent brain storming session and affinity diagramming was employed. Each group member spent fifteen minutes capturing design and capability ideas as needing to be improved in a next generation UAS HMI system. The group members created different characteristic or parameter 'bins'. The bins created include WCA presentation, Interface hardware/software, Communication, Layout (Presentation of material), and Information/Overlay management.

In order to reduce the biases in the initial prototype designs, it was decided to conduct a second focus group design session which allowed for those not familiar with the current system to identify design features which might be incorporated into a new HMI. In order to ensure quality in the design session, participants were chosen with different areas of expertise that would be beneficial in designing a UAS HMI; Army aviators and engineering psychologists. The diverse characteristics developed during this design session were binned alongside the group's initial work. Four unique and distinguishable initial HMI prototypes were developed from the characteristics morphology table using GIMP software; these four would represent the initial four prototypes for evaluation in the proof of concept methodology presented in this paper for PM UAS. Two other prototypes were screened out due to hardware upgrades required and available technology projections tied to PM UAS implementation target dates.

2.2.2 Method for Scoring of Prototype Designs: Proof of Concept

In order to 'score' each prototype without having the capability to simulate a mission, a questionnaire was developed to assess the testable value measures from Figure 1. It was determined that it would be valuable to understand the perceived differences in value of prototypes between a more experienced, older group of stakeholders and a lesser experienced, younger group of stakeholders. Descriptive statistics might indicate trends in perceived value of each prototype characteristic. To augment the questionnaire, two proof of concept tests were conducted; the first group consisted of five 15Ws (more experience, older) at Redstone Arsenal and the second group five USMA cadets (less/no experience, younger). Identification of trends in scores might warrant further testing upon full prototype development in order to assess impacts of experience and age demographics and assess statistical significance of those results. Two hypotheses influenced the proof of concept research:

- *H1: Less experienced users will be more accepting of the new UGCS HMI than experienced users.*
- *H2: Younger users will be more accepting of the new UGCS HMI than older users.*

In order to determine how much perceived cognitive load is needed when assessing each prototype, the NASA-TLX questionnaire was incorporated into the survey. NASA-TLX provides a breakdown of the value and weight of Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. From the value and weight of those six NASA-TLX task comes a total workload score. The objective is to minimize the total workload used for each prototype. The system usability scale is a ten question Likert scale questionnaire that provides a single value to the usability of the assessed prototype. The objective is to maximize the usability of the prototype. Measurement of value measures of memorability, clarity, effectiveness, and vertical scalability of each prototype additional Likert scale questions were emplaced into the questionnaire. The completed questionnaire enabled prototype total system value scoring to determine which prototype might deliver most value to the key stakeholders and decision maker.

3. Findings

The stacked bar charts in Figure 2 posits that the cadet evaluation group valued the new HMI's more than the 15W evaluation groups in all four prototypes as identified by a red bar above each prototype's total system value, stacked bar chart in Figure 2. Although this may indicate a level of comfort with new technologies it might also indicate that the less experienced group does not fully understand the complexity of the mission set.

The conclusion from the stacked bar chart in Figure 2 is that both the heavy interface and the glass cockpit were highly valued most by the more experienced 15W group. There were also appealing features of 3 Bin Smart Pen including cognitive load (NASA-TLX scores) and usability (SUS scores). Each prototype except the 'Desktop' candidate solution presents a large upgrade from the current UGCS HMI. Anecdotal evidence from 15Ws was collected after the survey was complete which further reinforced the appealing features of three prototypes (see dashed lines in Figure 2). A full replication of the prototype experiment was not possible for the All Star Prototype; however an estimation of its performance based off trade space analysis yields a prototype total system value score of 81.44. The anecdotal 15W data indicates that this score may be higher once a full proof of concept experiment is performed with the same participants who evaluated the first four prototypes.

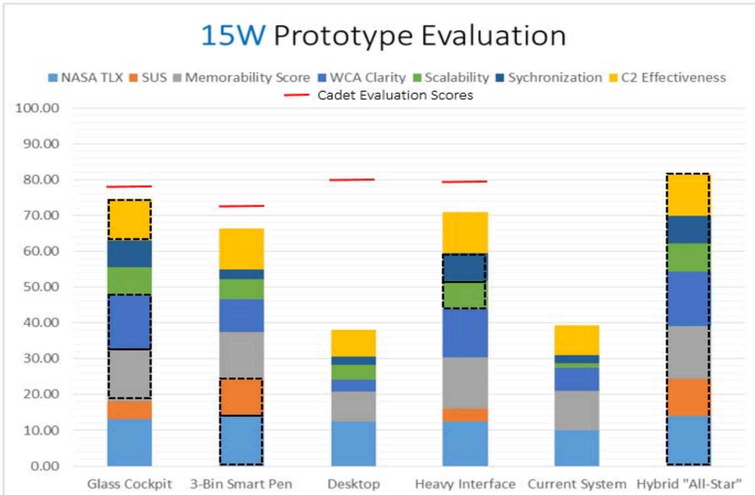

Figure 2: Value Measures Stacked Bar Chart (Cadets v. 15W Populations)

Figure 3: Value v. Cost Analysis

A top-down life cycle cost estimate (LCCE) was employed to assess each prototype. Adjusted present value labor assumptions derived from historic HMI designs and provided by PM UAS for phased software development permitted a baseline cost estimate to be developed through fiscal year 2021 (Fox, 2017). Assuming complete implementation and debugging by 2021, a baseline value of $7,781,000 in terms of FY16 dollars was utilized. For more complicated prototype designs, the cost was extrapolated using a scalar factor to develop a value versus cost analysis. Prototype total system value versus LCCE are displayed above in Figure 3. Due to the multipliers and the top down driven approach to LCCE, future work would require perhaps a bottom-up driven estimate once prototypes are fully developed to refine accuracy. It is clear that Heavy Interface score highest in value, but that an All Star hybrid solution could dominate the Glass Cockpit prototype. Employment of one-way sensitivity analysis was also completed to assess the uncertainty of the prototype decision over a range of swing weight values; it was determined that the highest value prototype was not sensitive to a change in swing weights.

Figure 4: 'All Star' Prototype #5

Collaboration with PM UAS leadership, 15Ws subjects, and MCRI staff whom shared HMI concept designs for the F35 with the team, led to the determination to develop a 5th All-Star prototype; trade space analysis is captured in Figures 2 and 3. Figure 4 illustrates the HMI controlled by mode buttons at the top, along with sub-categories and menu options on the left side of the screen which correlate to the mode the user has selected. On the two main screens, the operational screen and payload feed are displayed with 3 dimensional rendered maps, communications box, a WCA screen, and flight controls in the smaller boxes along the bottom. All these screens can be switched, minimized, and enlarged using the arrows to cater to the task at hand. Notifications will display when a screen is minimized, and specific information related to that notification will be displayed when the screen is enlarged, along with troubleshooting steps for warnings, cautions, and advisories. This prototype is currently under evaluation using the same methodology presented in this paper, and this enhanced prototype along with 'Heavy Interface' and 'Glass Cockpit' will be developed to into full prototypes using TELLUS Software.

4. Conclusions

Upon completion of the proof of concept analysis with the All Star prototype included, a transition to a full experimental design (schoolhouse testing) can test for statistical significance across demographics by employing an ANOVA to disprove the null hypotheses. Other defining operator attributes (beyond age and raw experience) should be considered to include 'type' of experience (which UAS platform and which deployed theater), years of formal schooling, and technical certifications might be considered in an ANOVA regression once prototypes move to a full experimental design.

Full integration of the additional four value measures with fully developed HMI prototypes in TELLUS will allow for simulation data which could refine total system values of each prototype while allowing for a more granular life cycle cost estimate prior to a final decision to launch the project. The ability to integrate more direct and naturally occurring value measures as suggested in the Figure 1 value model will provide a foundation to fully evaluate each of the remaining prototypes, and perhaps another iteration of sensitivity and trade space analysis to determine a further enhanced HMI design. The methodology presented in this paper, and prototypes developed represent a foundation for further evaluation and development of next generation UGCS HMI systems for the Army and could provide a model other DoD project office HMI design improvement initiatives.

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