Human-Computer Interface for Control of Unmanned Aerial Vehicles

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Abstract—Because of the limitations of human cognitive skills, judgment, decision-making, and tactical understanding in the use of Unmanned Aerial Vehicles (UAV), there is a need to redesign the current human-computer interface (HCI) to improve the interaction and communication links between operators and the UAVs. The objective is to create a system that tests the cognitive workload of the operator. The system will display information to increase situational awareness; the operator will see everything, interpret it, make appropriate decisions, and have the ability to implement the decision. Multiple interfaces are developed using MATLAB's Graphical User Interface (GUI) capabilities and embedding Satellite Tool Kit (STK) software into the GUI as a simulation environment. Both alternatives will combine buttons and place them in sequential order according to the steps needed to initialize UAVs and flight paths. One alternative will focus on a synchronous relay of information and the second will focus on an asynchronous relay of information. Usability tests with participants are conducted to measure their performance based on previously determined metrics: the time it takes to train a participant on how to use the interface, the time to complete a task, the number of errors that occur during the task, and the satisfaction level. Based on test results alternatives are redesigned and retested in order to achieve improved performance. An interface that will reduce the cognitive workload on an operator to allow better situational awareness of the environment is determined.

I. Background

Unmanned Aerial Vehicles (UAVs) are currently being used extensively for all types of military missions including, reconnaissance, stand off laser designation, autonomous scouting and relay, and crowd control or riot dispersion. Operators use Human-computer interfaces (HCI) to monitor UAVs throughout their missions. The situational awareness (SA) of the operator is important. SA is knowing about what’s going on around you and has three levels. The first level is the perception of information. Next, SA deals with the comprehension of meaning. Finally the last level is the projection of the situation over time.

II. Problem Statement

In the near future the military will rely even more heavily on unmanned vehicles, both ground and aerial, to help accomplish their missions. There is an interest to create teams consisting of troops combined with unmanned vehicles, but the current HCI for control of multiple UAVs falls short due to the poor organization of information and decision making capabilities incorporated into UAVs (i.e. recognition software). A new interface is needed to increase situational awareness so that a single operator can control multiple UAVs more proficiently. The current issue with the HCI for UAVs is that too much information is being displayed through the interface to the controller when more than one UAV is being monitored at once. This creates an information overload on operator and reduces the situational awareness of the operator.

A. Statement of Need

It is imperative that our design improves the current interface by reducing cognitive workload. There is a need to increase situational awareness and accuracy of the operator. This will lead to an overall better performance in controlling multiple unmanned aerial vehicles.

B. Scope

Throughout the scope of the project, the Team will only consider the design of the HCI. The team’s focus will be on the execution of a reconnaissn mission, and the human performance of the HCI. The human performance will be measured by training time, time to complete tasks, number of errors, and satisfaction level of the operator. Maintainability, functionality, and reliability will not be measured due to time constraints.

C. Major Assumptions

The team will have three assumptions. The first assumption is that the interface will only interact with UAVs, not unmanned ground vehicles. The next assumption is that the UAVs will be located in a rural environment, and not have payloads attached. Finally it is assumed that collision avoidance is built in so that the operator will not be responsible for preventing mid-air collisions.
III.  VALUE HIERARCHY

In order for the Team to obtain weights for the different performance measures of the HCI, an elicitation survey was distributed to sponsor Aurora Flight Sciences. This was done because Aurora Flight Sciences is most familiar with the criteria and objectives relating to the interaction between the UAVs, operator, and the interface.

The Team will focus on Human Performance and Usability, which is under System Performance. Reliability, Maintainability, and Functionality will not be the focus of the Team’s efforts.

IV.  UTILITY FUNCTION

The utility function represents the stakeholder’s values in a linear equation. The following is Aurora’s elicited utility function:

\[ U(X) = 0.50 U_{HP}(X) + 0.50 U_{SP}(X) \]

\[ U_{HP}(X) \rightarrow \text{Human Performance Utility} \]

\[ U_{SP}(X) \rightarrow \text{System Performance Utility} \]

\[ U_{HP} = 0.5U \text{User Accuracy} + 0.3U \text{User Processing Time} + 0.1U \text{Training Time} + 0.1U \text{User satisfaction} \]

\[ U_{SP} = 0.4U \text{Usability} + 0.3U \text{Reliability} + 0.2U \text{Maintainability} + 0.1U \text{Functionality} \]

The reader should note that this paper focuses only on the human performance side of the value hierarchy. This is true because the system performance covers aspects of the hardware tool that would be used. We believe that the system attributes will be achieved through assembling the right tools.

V.  EXTERNAL SYSTEMS

The external systems diagram shows the relationships between the HCI and other surrounding external systems. The system depends upon these other components to function properly. The heart of the External Systems Diagram consists of the HCI. The external systems it interacts with are the User/Controller, Unmanned Aerial Vehicles, a Command Center, and the Computer Hardware.

The HCI has the primary purpose of being the link between the Controller and the UAV’s. The Operator can control the UAV’s by entering commands into the interface. The UAVs send out specific health status information, such as fuel percentages. The HCI sends out mission Data & Highlights it receives from the UAV’s to the Controller. These packets of information include fuel percentages and other mechanical changes. Another function of the HCI is to display camera footage it receives directly from the UAVs. The HCI displays the camera footage directly to the operator, so he/she can decide how to act upon the footage received. Once the camera footage has been relayed back, the operator can decide to send out a Target Notification. These Target Notifications go directly to the Command Center.

The Command Center is another external part in which the system interacts with. The primary function of the Command Center is to send out Mission requests directly to an operator. A Mission Request is a job for the operator. It is sent from a higher command directly from the Command Center. The Command Center may have request for a reconnaissance mission, a target designation, etc. The Command Center provides essential guidance for the operator.

Finally the Computer Hardware will be an important factor in the system operating. The primary hardware component for the system to operate on will be a laptop computer. The computer will alert the user of software malfunctions and other physical computer trouble with various alerts to the screen. Also the computer acts as a database, and records mission information received from the UAVs for future use by other computer users.

The system works parallel with other systems. The dashed line shown in the figure below encompasses the following components, the HCI, the Controller, and the UAVs. These components will all be the primary focus of our modeling and simulation.

See Figure: 2 for External Systems Diagram.
VI. FUNCTIONAL ARCHITECTURE

Decomposition of HCI

The HCI is decomposed further in order to perform the three main functions of managing the UAV’s mission and current health status, controlling the UAV’s, and managing camera feeds. Typical inputs for managing UAV Mission & Health Status include different software malfunctions and Health Status Reports. Also this function has the primary responsibility of outputting Mission Data and Highlights directly to the operator. The next vital function of the HCI is the control of the UAVs. This function is designated to take inputs from the computer placed by the controller in order to directly guide UAVs. An example is if an operator wants a UAV to fly at a higher altitude, he/she must enter commands into the computer, then the commands are sent to the HCI. From the system this function accepts that command and acts upon it. This means that an output signal will go to the UAV to control it. Another key function in the HCI, involves the distribution of camera footage. The function, “Manage Camera Feeds from UAVs,” receives camera footage from the UAV. After this camera footage is received from the UAV’s, it then displays this camera feed directly to the operator.

Figure 3 shows the decomposition of the HCI.

Fig. 3. Decomposition of Human Computer Interface

Decomposition of UAVs

Functions of the UAVs are broken down further into the following, “Compiling and Managing Data,” and “Utilizing Sensors and Cameras.” The compiling and managing data function helps control the UAV as well as record incoming data. The other function that utilizes sensors and cameras helps detect changes in the environment, as well as distribute footage back to the system for display.

The Figure 4 shows the decomposition of the UAVs.

Fig. 4. Decomposition of Unmanned Aerial Vehicles

VII. MODELING APPROACH

The modeling approach the Team took towards the HCI consisted of creating two prototypes based on the two main design alternatives. The Team plans on using these two prototypes for conducting usability tests with the interface on targeted users.

A. Simulation Design

For the simulation, the Team used MATLAB and Satellite Tool Kit (STK) software. The Graphical User Interface
(GUI) capabilities from MATLAB were used to develop the interfaces for control of the UAVs while embedding STK into the GUI for the simulation environment. The STK software simulates a real world environment with terrain, vehicles, and buildings. The Team felt that this would give the simulation a more realistic feel, which would allow the operator to interact with the “real world”. The team developed eight predetermined flight paths in eight different scenarios. Predetermined targets were placed along the flight path of each UAV. Three types of facilities were used as targets, a Delta4, facility, and antenna.

In order to make design alternatives in a completely interactive environment the team chose two different formats in which to relay information to the operator: Synchronous and Asynchronous. For the synchronous relay of information all information about every UAV that is currently being controlled by the operator will be constantly relayed so that the operator will have access to any information they want at any time. For the asynchronous alternative, the information relay will be staggered and alerts will pop up to warn the operator of important information, such as low fuel and reaching target destination. After testing each design alternative, the Team will then modify the designs based on preliminary results and operator suggestion. Then each alternative will be retest and revised once again.

C. Method
The team plans to conduct a series of usability tests. In the first usability test, a group of eight participants will be asked to perform a set of tasks and encouraged to verbally describe the way they used to reach their goals. This method is known as “the thinking out loud” and is used to help the designers figure out flaws in the system. After observing the results of the first usability test, the team will recreate another set of interfaces to improve the human computer intractability. Likewise, the enhanced set of interfaces undergo testing and observations. This process of improving interfaces and retesting them stops when usability and human performance requirements are met.

Each usability test requires eight participants. Of those eight, two groups of four will be randomly selected. The first four participants will start the set of tasks on interface one, while the second group of participants starts on interface two. The two groups will then switch places. This method guarantees more reliable results since it accounts for the randomness of the samples of participants. It also assures that the learning effects, created by exposing participants to either interfaces before testing them on the other, will eventually cancel each other out.

D. Usability Test Measurements
In order to analyze and thoroughly review data from the usability test, the team determined target values for the performance measurements of the user. These measurements were essential in comparing the performance of one design alternative to the other. The first performance metric the team will use is the measurement of skill development time. The team will record and document the time it takes for a user to execute the training manual instructions successfully. Next, there will be a log of the number of error a user makes. The errors range from the simplest type such as pushing the wrong button, to more crucial ones such as crushing a UAV. The team has accounted for this range of errors by designing an error hierarchy with different weights for each type of errors. The next measurement of performance dealt with the participant’s speed. The team will use a stopwatch to measure the time elapsed through the stages of each mission. When the user completes the task assigned and moves on to the next stage, the time required to complete that stage will be documented. The final measurement consists of the satisfaction level of the interface being tested. This means that the user will have the opportunity to directly provide feedback on the usability of the interface being tested. The information will be dispersed to our group in the form of a debriefing survey.

E. The Usability Test
The usability tests will be conducted in the following order of events:
- The team will ask the participants to sit comfortably; will explain the goal of the

B. Task Analysis
The Team identified the actions to be carried out by users by determining the functions of the interface. The functions of the interface are:
- Allow selection of UAVs, assignment of flight paths, and execution of missions
- Show status of UAVs throughout mission both in summary and detailed forms
- Maneuver within maps to observe UAV locations, define routes, and designate actions
- Switch between UAV camera footages to allow operator to identify targets

![Fig 5. Screen Shot of STK](image-url)
experiments without giving away hints or show biasness towards any interface, then will provide each of the participants with a training manual.

- Each participant is then asked to follow the instructions provided in the training manual, and is encouraged to ask for help in case it is needed. Participants must verbally state that they feel comfortable with the software.
- A short test will be given to the participants to quantitatively measure their initial understanding of the software. If they pass this test, they can move on to the next step but must retake it otherwise. The aim is to train them to criterion.
- The participants will perform the tasks while time and comments are being recorded.

VIII. ANALYSIS
The analysis is the key factor in evaluating the design alternatives. The analysis depends heavily on the experiment. The output of the experiment consists of the measurements expanded on above. The team will record data from the experiment session with the users. The data will consist of skill development time, error tracking, participant speeds measured by time, comments, and satisfaction level ratings. There will be a distribution of time as a function of the different mission stages. An example of a mission stage is a simple task such as initiating the UAVs. The performance of a participant in the experiment will be represented as a function of the number of UAVs. The more UAVs a user can control then the higher the performance will be. The analysis will help in determining the maximum number of UAVs that can be controlled by the average user.

The analysis will continue with debriefing surveys and interviews from the participants. The surveys allow us to examine mental workload and situational awareness levels. This process allows for direct feedback from users regarding the interface performance.

Upon reviewing all results, the interfaces will be reconfigured in an effort to meet higher performance for our participants. After this process new participants will be selected to test the interface designs.

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BEDIS YAACOUBI is a citizen of Tunisia and he speaks three languages: English, Arabic, and French. He is a senior in systems engineering and is currently working on his accelerated masters in Operations Research. Bedis enjoys the systems engineering field especially when the topic is related to infrastructure and transportation. After graduation, Bedis would like to get a job in an American company that has branches overseas so that extensive traveling is promoted.