**Assessment of UAV Operator Workload in A Reconfigurable
Multi-Touch Ground Control Station Environment**

Journal:	<i>Journal of Unmanned Vehicle Systems</i>
Manuscript ID	juvs-2015-0039.R2
Manuscript Type:	Article
Date Submitted by the Author:	29-Mar-2016
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Keyword:	Multi-Touch Control, Human Machine Interface (HMI), Ground Control Station (GCS), Unmanned Aerial Vehicles (UAV), Task Load Index (TLX)

Assessment of UAV Operator Workload in A Reconfigurable Multi-Touch Ground Control Station Environment

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Abstract

Multi-touch computer inputs allow users to interact with a virtual environment through the use of gesture commands on a monitor instead of a mouse and keyboard. This style of input is easy for the human mind to adapt to because gestures directly reflect how one interacts with the natural environment. This paper presents and assesses a personal computer based Unmanned Aerial Vehicle Ground Control Station that utilizes multi-touch gesture inputs and system reconfigurability to enhance operator performance. The system was developed at Ryerson University’s Mixed-Reality Immersive Motion Simulation Laboratory using Commercial-Off-The-Shelf Presagis software. The Ground Control Station was then evaluated using NASA’s Task Load Index to determine if the inclusion of multi-touch gestures and reconfigurability provided an improvement in operator workload over the more traditional style of mouse and keyboard inputs. To conduct this assessment, participants were tasked with flying a simulated aircraft through a specified number of waypoints, and had to utilize a payload controller within a predetermined area. The Task Load Index results from these flight tests have initially shown that the developed touch capable Ground Control Station improved operator workload while reducing the impact of all six related human factors.

Abbreviations

EF - Effort	M&S – Modeling and Simulation
FR – Frustration	OP – Overall Performance
FTIR – Frustrated Total Internal Reflection	PD – Physical Demands
GCS – Ground Control Station	TD – Temporal Demands
HMI – Human Machine Interface	TLX – Task Load Index
MD – Mental Demands	UAV – Unmanned Aerial Vehicle
M&K – Mouse and Keyboard	UI – User Interface

1. Introduction

In recent years there has been an increase in research towards the design of Unmanned Aerial Vehicles (UAVs). Part of the reason for this increase is the fact they are being used for both military and commercial markets. Within the civil aviation market UAVs are actively used for agricultural upkeep, film making, search and rescue, and potentially even parcel delivery. They help to reduce overall company expenditures due to the swiftness and relatively low fuel costs that small scale UAVs provide. This is contrasted by the military market where UAVs are being used for the surveillance of high value targets, intelligence gathering, and the elimination of marked targets. Military UAVs tend to be much larger than current civilian models and emphasize endurance over all else.

A commonality between all types of UAVs is that they all require some form of Ground Control Station (GCS). This station could be as simple as a tablet device or a multi-computer station housed within a complex. The majority of systems however still work off of mouse and keyboard inputs which when used for prolonged periods of time can lead to operator muscle fatigue or other repetitive strain injuries (Bachl et. al. 2010). Mouse and keyboard systems are also limited by their ability to accept only a single input at any given time, whether it be a mouse click or a button press, whereas multi-touch systems have the advantage of being able to accept multiple inputs (Nimbarte 2011). Mouse and keyboard systems also typically require the user to remove one hand from another control input such as a joystick or throttle, in order to interact with either the keyboard or mouse (Westerman et. al. 2001) which can lead to accidental control errors. However it has been found that swapping the input method to multi-touch gesture commands does not degrade the overall performance of either the user or the system itself (Keyes et. al. 2010).

Both the GCS as a whole, and the way that one interacts with it are examples of Human-Machine Interfaces (HMIs). These interfaces are what allow an individual to interact and exchange data with a machine (Hamedi et. al. 2011). As a result, a human-machine interface can either display information to the user (e.g. a monitor) or can be a system used to input data (e.g. a keyboard). However the difficulty with such systems is that they can be hard to evaluate because of their reliance on human interaction instead of mechanical reliability (Sandom 2000). With that said, these type of interactions have become possible due to advancements with computer technology that allow a system to be able to process vast amounts of information in small periods of time (Sandom 2000).

Within the aerospace industry training simulators are one of the most common HMI examples. Simulators, such as CAE's 7000XR (CAE), allow individuals to learn how to pilot aircraft within a safe environment, through the use of multiple degree of freedom machines, so that they do not put themselves or others at risk. Simulators also help to reduce training costs and time due to their ability to focus training onto specific tasks without having to partake in the lead up (e.g. landing an aircraft or learning to deal with specific system failures) (Kayayurt et. al. 2011). In addition, simulators can help military personnel to train during peace-time when they cannot gain actual combat experience, thus helping to improve their performance and training (Yoon et. al. 2011). As a result, simulators are

becoming an increasingly popular method of training individuals for a variety of HMI based systems (Jovanovic et. al. 2010).

Despite there being a variety of different HMI methods, this paper focuses solely on multi-touch gesture recognition systems as they provide an alternative to mouse and keyboard systems and have become a popular method of interacting with electronic devices. Most notably, they are found in mobile smart phone devices, such as Apple's iPhone (Apple Inc.) as well as tablet devices, such as Microsoft's Surface (Microsoft).

The majority of modern gesture based computer inputs can be recognized with one of two methods. The first is through the use of specialized infra-red cameras and computer algorithms. One of the most popular examples of this type of touch gesture recognition systems is Microsoft's Kinect 2.0, which uses a high definition dual infra-red/ colour camera to simultaneously track up to 25 independent joints on up to six unique individuals (Microsoft Kinect). However, this style of reading gesture inputs can be problematic because the standard cameras that are utilized can have a difficult time tracking the joints required to determine a gesture. This is often a result of inconsistent lighting, static background objects, and/or joint orientation (Chen et. al. 2012; Gu et. al. 2012). Despite these issues some researchers have attempted to utilize this method of gesture recognition for various aircraft related tasks. Ibanez et. al. (2014), outline a method that uses SVTs and DTs to recognize various gestures given by United States Air Force personnel while interacting with aircraft. Whereas Boudjit, Larbes and Alouache (2013), show how Microsoft's Kinect hardware and software can be used to control a Parrot AR.Drone through the use of recognized gestures.

The second method of gesture recognition is through the use of specialized computer monitors. These touch screen monitors typically use a method called Frustrated Total Internal Reflection (FTIR), shown in Fig. 2, to track the position of one's fingers as it is moved across the monitor. FTIR works by shining an infra-red beam of light through a transparent medium that makes up the monitors screen. When this beam hits the finger it is reflected back towards the rear of the screen. When the light reaches the base of the screen it is picked up by a series of small sensors which determine the location of the finger (Nimbarte 2011). This method of gesture recognition is far more common than using cameras and algorithms because they can more accurately determine gestures due to the lack of background interference. In addition, the hand is the most common body part used for personal expression, making it ideal for interacting with a computer monitor (Chen et. al. 2012). Finally, touch screens have the added advantage that they are used in the majority of mobile smart devices. This allows one to design a User Interface (UI) that will be intuitive from the start and easy for the majority of individuals to pick up and learn (Nord and Vestgöte 2010; Ponto et. al. 2011). The majority of research to date that utilizes such technology for aircraft control has focused on mobile UIs. For Android based devices, Soto-Guerrero and Torres (2013), designed and implemented a set of touch inputs that can be used to control a UAV. While Peschel and Murphy (2013), developed a program that uses touch gesture controls on devices that run off of Apple's iOS platform to control a Parrot AR.Drone. Both of these developed systems use their respective platform's touch screen display to give users control over an aircraft within a small portable device, however, they are both limited by the small screen spaces that mobile devices have.

Until recently, multi-touch monitor based systems have been limited to personal computers and mobile devices, however companies such as Thales (2013) and Garmin (2013) have begun working on glass cockpit designs that heavily utilize touch gestures for the control of maps and onboard instruments. Multi-touch inputs allow the user to interact with the system in a natural manner due to the human body's ability to keep track of its limbs kinesthetically (Forlines et. al. 2007) while providing advantages in user interfacing, specifically with regards to user customization and reconfigurability (Guerreiro et. al. 2010). Gesture commands are natural for the human body because it is typically how people express information between one another and thus, it provides a natural method of interacting with machines (Gu et. al. 2012; Jiang et. al. 2014; Fiorella et. al. 2010). These interactions can range from screen taps, to repositioning an object by dragging it, or by rescaling it with a pinching gesture. It has been found that the use of gestures can help to improve user interaction speeds by roughly 75% (Nord and Vestgöte 2010) and do not necessarily degrade accuracy (Park and Han 2010) as long as the object is larger than 11.5mm on screen (Bachl et. al. 2010). Multi-touch systems also tend to be quite easy to pick up and learn (Nord and Vestgöte 2010) and can be committed to muscle memory (Bragdon et. al. 2011) which could potentially lead to a reduction in training costs and time.

Despite the advantages that multi-touch systems can provide, they are not perfect. One of their largest issues is that they do not provide the user with any tactile feedback. As a result, a more predominate and accurate visual feedback method has to be used to show what is being affected (Bachl et. al. 2010). In addition, it is possible that key information will be concealed by the human hand that is interacting with the screen (Bachl et. al. 2010) which can lead to temporary losses in situational awareness, a necessity for pilots. Multi-touch systems can also lead to operators misusing controls more frequently because it is easier to miss-click the incorrect button (Lee and Park 2012). Lastly, like with mouse and keyboard systems, multi-touch systems are still prone to operator muscle fatigue due to the fact that they must move their arms to interact with the screen (Kim et. al. 2009; Bachl et. al. 2010; Nord and Vestgöte 2010).

Between the year 2000 and 2010 the number of UAVs that the United States military had in service increased by a factor of roughly 13 000%, going from 50 UAVs to over 7000 by the year 2010 (Weiss 2011). This increased usage of UAVs has led to a consistent increase in the risk and potential for UAV related accidents. Based upon data from the United States Department of Defense, it was found that for each type of UAV they flew, an average of 50 were lost for every 100 000 hours of operation in comparison to the approximately one accident per 100 000 hours of flight of manned aircraft (Waraich et. al. 2013). Of these accidents, 69% were attributed to human factors, and of the 69%, 24% were directly caused from a human factor issue with the GCS (Waraich et. al. 2013).

Human factors are defined as ones capabilities, limitations, and behavior while subjected to a task (Koonce and Debons 2010). Human factor research is thus used to help to improve user performance, safety, and operator well-being while they interact with an HMI (Koonce and Debons 2010). These improvements are accomplished by designing the interface around human limitations, in particular, the limitations of the individuals who will interact with the system. Ultimately designing a system around individuals can be very difficult to accomplish because all humans are unique and thus the measure of each individual's characteristics will also be unique (Hunter and Martinussen 2010).

One of the most common methods for studying the effects of human factors induced by interact systems is NASA's Task Load Index (TLX). Specifically, the TLX analyzes a user's experienced level of workload, which Sandra G. Hart of NASA Ames-Research Center described as "the cost of accomplishing mission requirements by the human operator" (Hart 2006). Workload is an important factor to look at for UI design because even though a task might seem to be simple to accomplish, an operator might still behave as if they were overloaded due to a build-up of other human factors (Hart and Staveland 1988). As a result, the TLX determines an experienced workload score based upon the individual contributions of six major factors (Anonymous 1988):

1. Mental Demands (MD) - how much thought, memory, and decision making, etc. is involved in completing a task.
2. Physical Demands (PD) - how much the user must physically use various input methods such as switches, joysticks, throttles, etc.
3. Temporal Demands (TD) - time based pressures/ stresses the user experiences based off the pace at which the task is being completed.
4. Overall Performance (OP) - how successful at the task the user believes they were.
5. Effort (EF) - how hard the user had to work to achieve the performance result.
6. Frustration (FR) - how agitated/ stressed the user felt while trying to accomplish the task

Overall this paper presents a new concept for a GCS that integrates multi-touch gesture inputs and user reconfigurability into the UI to enhance the effectiveness of UAV operators. The designed GCS will be presented, showcasing its various features and instrument panels. Finally a series of tests were conducted to gauge the benefits that the GCS has on individual users, through the use of NASA's Task Load Index. The TLX was chosen as the primary method of study because of its vast history of studying the interaction between pilots/ UAV operators and their instruments (Ruff et. al. 2002; Ryu and Myung 2005; Hart 2006; Mulder and van Paassen 2006; Bader et. al. 2010; Teo et. al. 2015), as well as how gesture inputs can enhance HMIs (Schmidt et. al. 2009; Hayes et. al. 2010; Rofouei et. al. 2012; Bruder et. al. 2013). Thus the TLX was determined to be the best method of workload analysis for the designed GCS.

2. Reconfigurable, Multi-Touch Capable, Ground Control Station

2.1. Simulation Environment

The reconfigurable GCS was developed using Presagis' M&S software package, which is utilized by over 1000 companies around the world such as Boeing, Lockheed Martin, Airbus, and CAE (Presagis). VAPS XT 4.1 Beta is a software program, used for the design of high quality human machine interfaces. These interfaces can be linked to other external programs through Presagis' nCom connection which uses various communication protocols, such as UDP or TCP, to exchange the required data. FlightSIM 14, a high fidelity fixed wing flight simulator, was then linked with VAPS XT to create the simulation environment. These two programs can also be linked to their other M&S software programs to create a high fidelity simulation environment where users can control air, ground and sea elements. These other programs include (Presagis):

1. Creator, a high quality polygon model generator, whose models can be imported into other software programs
2. STAGE, a high fidelity, virtual training simulation designer with working AI as well as programmable ground, sea, and air entities
3. Terra Vista, a high-fidelity terrain generation toolkit
4. Vega Prime, a high quality graphical visualization toolkit

Fig. 1. Presagis Modelling and Simulation Software Program Interactions

Even though all of these programs can be linked together, FlightSIM and VAPS XT can also be run separately in order to simulate the flight of a single aircraft, while also reducing the computational loads on the computer hardware.

The fidelity of the FlightSIM simulation is dependent on the amount of information that is provided about the aircraft being flown and the flight environment. The aircraft modeler requires the user to provide information on the aerodynamic properties of the aircraft, the various controls, the weight and balance, and the parameters for the power plant. In total roughly 300 to 1400 parameters need to be identified in order to get an accurate and flyable aircraft model. The GCS simulation used a stock model of an F-16 Fighting Falcon. It was used out of all the stock FlightSIM models because it had the most accurate auto-pilot system, a key component for UAVs. In addition the GCS simulation used FlightSIMs stock map of Camp Pendleton in California was used, with the aircraft starting on the ground of its primary runway.

Fig. 2. Ground Control Station Component Interactions

2.2. Ground Control Station User Interface

The final interface that was designed for the GCS is comprised of five key features, such as the ability to move and resize all of the instrument panels and how the user can operate all of the controls through common multi-touch gestures. These features are complemented by 12 instrument panels which all showcase different potential ways to integrate multi-touch gestures into how an operator controls the aircraft and perceives important flight parameters. Ultimately the combination of features and instruments creates an environment that can help enhance an operator’s performance during the course of a standard flight mission.

The first key feature of the GCS is the multi-touch input functionality. The system harnesses common taps, drags, and pinch gestures for all of its various interactions. Tap gestures are utilized for a natural method of interacting with the various and for unlocking the ability to reconfigure/ manipulate a chosen instrument panel. Drag gestures are used to move sliders and instrument panels around the screen in a natural manner. Finally, pinching gestures are used to zoom in or out of the gesture controlled map or used to change the scale of an instrument panel (i.e. making the panel larger or smaller within the screen space). All of these gestures follow the same gesture patterns as those found in mobile phones and tablets in order to help each user quickly adapt to the control scheme. This means that some operators will not have to focus as much on actually interacting with the interface as it will already be natural for them. Thus by utilizing multi-touch gestures, there will be some improvement in terms of effectiveness and performance due to the ability to focus more on their assigned task.

The second feature is the ability for the operator to reconfigure the UI they will interact with. Reconfigurability provides two major benefits. The first is that it allows the user to customize the screen and set up the instruments in a way that suits them best, thus helping to improve operator performance. The second benefit is that it allows the GCS to be used for a variety of mission types and aircraft as it can call up any panel that has been added to the system.

The third key feature is the Top Tab Bar, shown in figure 3-a, which acts in a similar manner to tabs found on modern internet browsers. It allows the user to have access to up to ten different virtual screens within the confines of one physical screen. The GCS starts up with four predefined tabs, which contain all the relevant instruments to control the aircraft (i.e. all engine related instruments, panels used to control the attitude dynamics, all navigation instruments, and any payload controllers). In addition to these four pre-set tabs, the user can add up to six other tabs that each start as a blank slate and can be named to help the operator's memory. This customization allows the user to set up the system the way that best suits their current mission, thus improving their effectiveness.

Fig. 3. Developed Ground Control Station User Interface, Featuring the: a) Top Tab Bar and b) Instrument Side Tab

The fourth feature that helps to differentiate the GCS from other designs is the Instrument Side Tab. This feature is accessed by dragging out the tab on the side of the screen labelled as "Panels", as shown in figure 3-b. This tab allows the user to quickly select and drag a desired instrument panel icon onto the screen. This feature gives the user the ability to decide what information they are shown at all times, thus helping to improve their awareness of the overall UI.

The final key feature is the alert/notification system, shown in figure 4. This system is intended to help the operator recognize and quickly deal with any problems that might arise during flight. When

an error is detected, a small, flashing red box appears in the lower right corner of the screen in order to grab the operator’s attention. If the user desires, they can further tap the initial message to get a more comprehensive description of the issue.

Fig. 4. Sample Initial Alert Pop-Up (Left) and Expanded, Detailed Alert Panel (Right)

To complement all of the key features, the reconfigurable GCS has access to a number of interactive instrument panels as well as ones that show important information. A sampling of these panels can be seen in figure 5 as well as in table 1.

Fig. 5. Visual Sampling of Included Instrument Panels

Table 1. Brief Descriptions of Included Instrument Panels

Panel Name	Description
Aircraft General Information	Shows all of the necessary flight, and atmospheric variables required to control an aircraft
Angle of Attack Gauge	Shows the aircraft's Angle of Attack – goes red when the aircraft is nearing/ in a stall
Auto Pilot Controller	Allows the operator to generate singular waypoints or a series of waypoints (a maneuver). The panel also allows the user to activate or deactivate the UAV's Auto Pilot system
Detailed Engine Monitor	Shows all of the information about each component of the aircraft's engine. This information can be accessed by tapping the specific engine component
Flap Controller	Allows the user to change the position of the aircraft's flaps
Fuel Gauge	Shows how much fuel/ battery power is remaining. The graphic appears green when the fuel level is between 30-100%, orange when between 10-30% and red when the fuel is below 10%
Gesture Map	A navigational panel that allows users to pan a map of the flyable area around along with the ability to rescale it to see more or less of the area using gesture inputs
Non-Gesture Map	Shows a larger map than the Gesture Map and has all of the same features, minus the gesture commands
Payload Controller	A fictional payload controller used for research purposes to show how gesture inputs could be used to control a camera/ weapons payload
Primary Flight Display	A standard PFD that shows the aircraft's heading, velocity, altitude and pitch rates
Simple Engine Monitor	Shows the key engine parameters (Throttle Setting, Thrust, Fuel Flow, and Compressor/ Turbine Speeds)
Throttle and Gear Controller	Allows the user to set the throttle position and retract/ extend the aircraft's landing gears

3. Testing Procedure

In order to determine the workload of the designed multi-touch GCS UI, four tests were run and evaluated with NASA's TLX. 20 participants took part in the testing. The participants had varying levels of experience in order to assess the GCS UI's effectiveness (2 had physical flight and simulator experience,

10 had simulator experience but no physical flight experience, and 8 had no prior flight or simulator experience).

Each test required the user to navigate an aircraft through a series of waypoints and to eliminate a random “high value target” using a fictional payload controller, which was only available to use within a specified region. In addition, the user was required to monitor various flight variables, (e.g., the aircraft’s remaining fuel reserve) over the course of the test to help simulate a typical UAV operator’s task and mission. Two of these tests were conducted using a mouse and keyboard version of the designed GCS, with the other two being conducted with the designed multi-touch capable GCS. The tests were completed in an alternating manner (i.e. the first and third tests utilized the mouse & keyboard GCS, and the second and fourth tests used the multi-touch GCS) to ensure that the users determined workload results were not influenced by the user becoming more adept at using the UIs as the tests proceeded. Finally, the first two tests were considered an easy flight test, requiring the user to fly through five waypoints, and utilizing the payload controller within an 8km radius circular area (a video demonstration of mouse and keyboard UI showing the easy flight test can be found at: <https://youtu.be/VvN1Z3r8uZ4>) the final two tests were considered a more difficult task, requiring the user to fly through seven waypoints and utilize the payload controller within a circular area that was only 4km in radius (a video demonstration of multi-touch UI showing the more difficult flight test can be found at: <https://youtu.be/ycCN3-zj5nk>).

Both of the tested interfaces used nearly identical instrument panels. However, the mouse and keyboard version did not have access to the gesture controlled map panel, a virtual throttle, and the flap controller. In addition, the mouse and keyboard version of the GCS had no ability to reconfigure the instrument panels. Whereas the multi-touch system allowed each participant to reconfigure their interface when the aircraft was on the ground, or while it was in the air. The panels themselves were set up in the same manner as the presets of the multi-touch system in order to best compare the effects of just the different input styles and variable reconfigurable.

The tests themselves were carried out at Ryerson University’s Mixed-reality Immersive Motion Simulation (MIMS) Laboratory. This lab was ideal for the experiment due to the extensive number of simulators that are available. The lab itself has three simulators. The first is a 2-degree of freedom full motion simulator that can rotate along both the pitch and roll axes. The second is a fixed base simulator that uses a mix of 42 inch displays and 22 inch touch panels to replicate a variety of standard cockpits. The final station was set up for the reconfigurable GCS described in this paper. It utilizes a 46 inch single touch display to show the aircraft simulation being run from Presagis’ FlightSIM 14 (Preagis), and a smaller 24 inch multi-touch display for the GCS UI.

Fig. 6. Ryerson Flight Simulator Demonstration (RyeFSD) Laboratory In The MIMS Facility: a) Ryerson's Fixed Based Simulator, b) Full Motion Simulator, and c) UAV Ground Control Station: Video Link To Lab: <https://youtu.be/Yq2XTn0M144> (Ryerson MIMS Lab 2015)

4. TLX Results

Utilizing the TLX procedure described in Sections 2 and 3, the overall workload that each participant experienced was found. Figures 7 and 8 show the averaged mouse and keyboard and multi-touch weighted human factor ratings respectively. The width of each bar represents each human factors importance/ weighting (found from part 1 of the TLX handout). Whereas the height of each bar represents the raw rating of each factor (found from part 2 of the TLX handout).

Fig. 7. Calculated Task Load Index Weighted Average Ratings for the Mouse and Keyboard Interface

Fig. 8. Calculated Task Load Index Weighted Average Ratings for the Multi-Touch Interface

From figures 7 and 8, it can be seen that the multi-touch GCS experiences lower ratings, meaning that the system outperforms the mouse and keyboard one. If one looks at the exact weighted ratings for each of the two systems, shown in table 2, this same conclusion can be drawn (the maximum score that could be achieved was the width of the bar (it’s weighting) multiplied by 100).

Table 2. Comparison of the Task Load Index Weighted Average Rating Scores

	MD	PD	TD	OP	EF	FR
M&K	104	111	129	124	129	104
Multi-Touch	95	46	99	75	75	47
Improvement Over M&K System	9%	59%	23%	40%	42%	55%

Using the results presented in table 2, it can be seen that the MD results were roughly 9% lower in the multi-touch system than the mouse & keyboard system. The reasoning for this is that users did not have to think as much to interact with the multi-touch UI. This comes from the touch UI using standard gestures that are commonly found in everyday smart devices. Users also always knew the position of every instrument due to the ability to reconfigure all of the instrument panels locations and sizes. When it came to PD values, the multi-touch UI was much less intensive, thus lowering the overall rated value by about 59%. This is because the multi-touch system used fewer hardware inputs, namely just the joystick and monitor. As a result, users did not have to constantly change which device they were interacting with. The TD results were also found to be 23% lower which stemmed from users feeling like they were reacting more rapidly to the multi-touch UI. This quicker sensation was attributed to the user not having to search for the mouse cursor on the screen, and then needing to locate and actually interact with the object. Instead the user just needed to find the object and use their hand to interact with it. This overall process allowed for a faster reaction time, and more efficient interaction procedure.

The touch gestures that the users took advantage of are believed to be the major reason for the reducing the ratings of the OP, EF, and FR results in table 2 by roughly 40%, 42%, and 55% respectively. This reduction was a result of users being able to easily utilize the gestures, due to their effective and efficient nature. In particular the majority of participants attributed the improvements in these areas to the fact that they were much more easily able to interact with the map instrument. The gestures allowed them to quickly, and accurately navigate the map, thus allowing for a more exact flight path. As a result, they could exert less effort to achieve better results in the tests, which subsequently helped to reduce their overall feelings of frustration.

If one further looks at the four tests weighted average ratings individually, as presented in figure 9, an interesting observation can be made. It was found that regardless of which of the two tests were conducted, both UIs experienced the same human factors increasing, decreasing, or staying nearly constant. It can be seen that the EF for both cases is nearly identical for each of the tests, this is likely because the “easy” and “difficult” flight tests were similar in nature (i.e. they both required users to fly the aircraft through a series of waypoints and utilize the payload controller), and thus, did not require completely different interactions.

It was also found from figure 9 that the MD, TD, and OP for both systems decreased between the “easy” and “difficult” tests. This was attributed to users learning how to utilize the various available functions. This helps to show that users likely learned to improve their performance as the tests

progressed. This was likely caused from them being able to accomplish their tasks in quicker manner, which meant they did not have to think as much.

Figure 9 also showed that the overall PD and FR ratings increased as the tests went on. Based on participant comments, this was likely because the more difficult tests required the user to interact with the interface, and hardware devices for longer periods of time (thus increasing PD). In addition, participants tended to feel increases in frustration during the final test for each system, when they missed waypoints. This was because they felt that they had progressed to the point where they could control the aircraft well enough to accomplish the tasks in one go, and as a result, when they missed waypoints they tended to get upset more easily.

Fig. 9. Comparison of the Calculated Task Load Index Average Weighted Rating Scores per Test

From figure 10 it can be seen that the addition of the multi-touch gestures and reconfigurability to the GCS helped to improve the overall workload that the operator experienced by 38%.The reason for this improvement is believed to be because the gesture interactions allowed the users to interact with the UI less awkwardly because they did not have to spend valuable time finding the mouse. The improvement is also attributed to the naturalness of gestures, and the fact that they are usually more efficient to use than mouse and keyboard systems. These two facts ultimately help to create a system that helps to improve the operator’s working conditions. Additionally the fact that users could zoom in and pan the map around with gestures helped to provide a much more accurate representation of where the aircraft was heading, which lead to a stronger feeling of performance while decreasing the amount of effort and frustration. Finally the majority of users felt the ability to customize their screens helped to limit the amount of time they had to spend trying the information they were looking for. This

allowed them to spend more time making sure the aircraft was responding the way it should, and to fine tune the flight path more frequently, thus increasing performance.

Fig. 10. Weighted Overall Task Load Index Workload Scores

5. Conclusion

A multi-touch ground control system was designed using Presagis' VAPS XT 4.1 beta that allowed the operator to interact with the GCS using common touch gestures and to reconfigure where the instruments were on screen and their size.

The system was then tested using NASA's Task Load Index to see if the addition of touch gesture inputs and reconfigurability would help to reduce operator workload. It was found that the overall workload was lowered by 38% while also reducing the impact of the all of the key workload factors. This can be attributed to the multi-touch GCS helping to lower the amount of frustration felt, the stress due to time constraints, improved user performance, and reduced the experienced physical and mental demands. All of these improvements are conducive of systems that are migrated from using mouse and keyboards to multi-touch gestures have been found to experience user improvements in various areas.

Based off of participant comments, it was determined that there are two main areas that need to be more heavily considered when it comes to multi-touch UI design. First an effort has to be made to create smooth gesture interactions, and to reduce latency as much as possible. These two factors were found to greatly increase user's feelings of effort, performance, and frustration when the UI failed to act appropriately. The second area of improvement is a result of multi-touch systems not having any form of haptic feedback. Most users felt that their interactions with slider based inputs (such as the virtual throttle) would have been much better if there was a sense of tactile resistance. This is a result of virtual sliders being very responsive and moving with very little effort, making them difficult to precisely position. Thus, having a method to provide users with a haptic feedback response could help to improve user accuracy with certain methods of input.

To conclude, it was found that the multi-touch, reconfigurable ground control station helped to improve a number of human factors over more traditional mouse and keyboard setups even though the users had limited training and experience with the system.

6. Future Work

The next step for this research is to validate whether or not the results presented in this paper are transferable to the physical control of an aircraft. This process would involve the integration of additional communication hardware into the Ryerson GCS simulator in order to allow the system to control a physical UAV. One such potential UAV candidate for this is Ryerson University's 2014 RAD plane, a student designed UAV. Once the GCS can be linked to a physical UAV, a new series of TLX Index tests can be conducted to determine if the results are comparable to the simulation.

In addition, future work will be done to improve the overall GCS. This will be accomplished by switching the aircraft simulator software from Presagis' FlightSIM 14 to STAGE. Switching to STAGE would allow the GCS to take advantage of a higher fidelity simulation environment that would be comprised of numerous air, ground, and sea entities. Finally, changing the software would also allow the GCS to take control over multiple different aircraft (or have multiple users control the same aircraft), which is becoming a more common occurrence for UAV operators.

7. Acknowledgements

The author would also like to thank Eric Simon and Presagis for providing us with access to their M&S software as well as for the inspiration for this project. The author would also like to acknowledge the National Sciences and Engineering Research Council of Canada (NSERC Grant RGPIN227747-2012). In addition, the author would like to acknowledge Ryerson University's Ethics Board for approving the research procedures adhered to within this paper (REB 2015-298).

8. References

- Apple Inc. iPhone 6. Available from <http://www.apple.com/ca/iphone/>. [accessed on 19 November 2015].
- Anonymous. 1988. NASA Task Load Index (TLX) v1.0 Paper and Pencil Package [online]. Available from the Human Performance Research Group, NASA Ames Research Center, Moffett Field. CA, USA. Available from <http://humansystems.arc.nasa.gov/groups/tlx/> [accessed 06 April 2015]
- Bachl, S., Tomitsch, M., Wimmer, C., and Grechenig, T. 2010. Challenges for designing the user experience of multi-touch interfaces [online]. *In* Proceedings of Engineering Patterns for Multi-Touch Interfaces Workshop of the ACM SIGCHI Symposium on Engineering Interactive Computing Systems, Berlin, Germany. 19-23 June 2010. Available from <http://deco.inso.tuwien.ac.at/wp-content/uploads/mt-challenges.pdf> [accessed on 06 April 2015]
- Bader, T., Heck, A. Beyerer, J. 2010. Lift-and-Drop: Crossing Boundaries in a Multi-Display Environment by Airlift. *In* Proceedings of the International Conference on Advanced Visual Interfaces. Rome, Italy. 25-29 May 2010. pp. 139-146.

- Boudjit, K., Larbes, C. and Alouache, M. 2013. Control of Flight Operation of a Quad rotor AR.Drone Using Depth Map from Microsoft Kinect Sensor. *International Journal of Engineering and Innovative Technology*. **3**(3): 15-19. ISSN: 2277-3754. Available from <http://www.ijeit.com/archive/23/volume-3-issue-3--september-2013.html> [accessed on 24 November 2015]
- Bragdon, A., Eugene, N., Li, Y., and Hinckley, K. 2011. Experimental Analysis of Touch-Screen Gesture Designs in Mobile Environments. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Vancouver, BC, Canada. 7-12 May 2011. pp. 403-412.
- Bruder, G., Steinicke, F., Stuerzlinger, W. 2013. To Touch or Not to Touch? Comparing 2D Touch and 3D Mid-Air Interaction on Stereoscopic Tabletop Surfaces. *In Proceedings of the 1st Symposium on Spatial User Interaction*. Los Angeles, CA, USA. 20-21 July 2013. pp. 9-16.
- CAE. CAE 7000XR Series Level D Full - Flight Simulator. Available from <http://www.cae.com/civil-aviation/simulation-products/cae-7000xr-series-full-flight-simulator/> [accessed on 17 November 2015].
- Chen, B.J., Huang, C.M., Tseng, T.E. and Fu, L.C. 2012. Robust Head and Hands Tracking with Occulsion Handling for Human Machine Interaction. *In IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. Vilamoura, Portugal, 7-12 October 2012. pp. 2141-2146.
- Fiorella, D., Sanna, A., and Lamberti, F. 2010. Multi-Touch User Interface Evaluation for 3D Object Manipulation on Mobile Devices. *J Multimodal User Interfaces*. **4**(1): 3-10. doi: 10.1007/s12193-009-0034-4
- Forlines, C., Wigdor, D., Shen, C., and Balakrishnan, R. 2007. Direct-touch vs. mouse input for tabletop displays. *In Proceedings of the SIGCHI conference on Human factors in Computing Systems*. San Jose, CA, USA. 28 April- 3 May 2007. pp. 647-656.
- Garmin. 2013. Garmin® Powered Glass Cockpit System Announced by Volvo Penta. Available from <http://ph.garmin.com/news/pressroom/news20130801/> [accessed 27 April 2015]
- Gu, Y., Do, H., Ou, Y. and Sheng, W. 2012. Human Gesture Recognition Through A Kinect Sensor. *In Proceedings of the 2012 IEEE International Conference on Robotics and Biomimetics*. Guangzhou, China. 11-14 December 2012. Pp. 1379-1384.
- Guerreiro, T., Nicolau, H., Jorge, J. and Gonçalves, D. 2010. Towards Accessible Touch Interfaces. *In Proceedings of the 12th International ACM SIGACCESS conference on Computers and Accessibility*. Orlando, FL, USA. 25-27 October 2010. ACM. pp 19-16.
- Hamed, M., Salleh, S.H., Tan, T., Ismail, K., Ali, J., Dee-Uam, C., Pavaganun, C., Yupapin, P.P. 2011. Human facial neural activities and gesture recognition for machine-interfacing applications. *International Journal of Nanomedicine*. **6**: 3461-3472. doi: 10.2147/IJN.S26619
- Hart, S.G. NASA-Task Load Index (NASA-TLX); 20 Years Later [online]. 2006. *In Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. Sage Publ. **50**(9): 904-908. doi:10.1177/154193120605000909. Available from <http://humansystems.arc.nasa.gov/groups/tlx/> [accessed 06 April 2015]
- Hart, S. G., and Staveland, L. E. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research [online]. *Advances in Psychology*. **52**: 139-183. Available from <http://humansystems.arc.nasa.gov/groups/tlx/> [accessed 06 April 2015]

- Hayes, S.T., Hooten, E.R., Adams, J.A. 2010. Multi-Touch Interaction for Tasking Robots. *In* IEEE International Conference on Human-Robot Interaction (HRI). Osaka, Japan. 2-5 March 2010. pp. 97-98.
- Hunter, D. R., and Martinussen, M. 2010. Aviation Psychology and Human Factors. Taylor and Francis Group, LLC. Boca Raton, FL.
- Ibanez, R., Soria, A., Teyseyre, A. and Campo, M. 2014. Easy gesture recognition for Kinect. *Advances in Engineering Software*. **76**: 171-180.doi:10.1016/j.advengsoft.2014.07.005
- Jiang, F., Wu, S., Yang, G., Zhao, D. and Kung, S.Y. 2014. Viewpoint-Independent Hand Gesture Recognition with Kinect. *SIVIP*. **8**(1): S163-S172. doi: 10.1007/s11760-014-0668-x
- Jovanovic, M., Starcevic, D. and Jovanovic, Z. 2010. Improving Design of Ground Control Station for Unmanned Aerial Vehicle: Borrowing from Design Patterns. *In* 36th EUROMICRO Conference on Software Engineering and Advanced Applications (SEAA). Lille, France, 1-3 September 2010. pp. 65-73.
- Kayayurt, B., Yayla, I., Yapici, A. and Kucukoguz, C. 2011. Ground Control Station Avionics Software Development in ANKA UAV. *In* IEEE/AIAA 30th Digital Avionics Systems Conference (DASC). Seattle, WA, USA. 16-20 October 2011. pp 5B6-1 – 5B6-7.
- Keyes, B., Micire, M., Drury, J.L., and Yanco, H.A. 2010. Improving Human-Robot Interaction Through Interface Evolution [online]. *In* Human-Robot Interaction. *Edited by* D. Chugo. InTech. Rijeka, Croatia. pp. 183-202. Available from <http://www.intechopen.com/books/human-robot-interaction/improving-human-robot-interaction-through-interface-evolution> [accessed 10 April 2015]
- Kim, J.S., Gračanin, D., Krešimir, M. and Quek, F. 2009. iPhone/iPod Touch as Input Devices for Navigation in Immersive Virtual Environments. *In* IEEE Virtual Reality Conference, Lafayette, LA, USA, 14-18 March 2009. Pp 261-262.
- Koonce, J.M. and Debons, A. 2010. A Historical Overview of Human Factors in Aviation. *In* . Aviation Human Factors. *Edited by* Wise, J.A, Hopkin, V.D., Garland, D.J. Taylor & Francis Group, LLC, Boca Raton, FL. pp. 1-1 – 1-11.
- Lee, H. and Park, J. 2012. Touch Play Pool: Touch Gesture Interaction for Mobile Multifunction Devices. *In* IEEE International Conference on Consumer Electronics (ICCE). Las Vegas, NV, USA. 13-16 January 2012. pp: 291-292.
- Microsoft. Kinect for Windows features. Available from <http://www.microsoft.com/en-us/kinectforwindows/meetkinect/features.aspx>. [accessed on 19 November 2015]
- Microsoft. Surface Pro 3. Available from <http://www.microsoft.com/surface/en-ca/products/surface-pro-3>. [accessed on 19 November 2015]
- Mulder, M., van Paassen, M.M. 2006. Haptic Feedback for UAV Tele-operation – Force Offset and Spring Load Modification. *In* IEEE International Conference on Systems, Man and Cybernetics 2006 (Volume 2). Taipei, Taiwan. 8-11 October 2006. pp. 1618-1623.
- Nimbarte, M. 2011. Multi-Touch Screen Interfaces and Gesture Analysis: A Study [online] *ACIJ*. **2**(6): 113-121. doi: 10.5121/acij.2011.2611
- Nord, M., and Vestgöte, H. 2010. Multi-Touch in Control Systems: Two Case Studies. Available from Uppsala University Publications, Uppsala, Sweden. URN: urn:nbn:se:uu:diva-144079

Park, Y.S. and Han, S.H. 2010. Touch Key Design for One-Handed Thumb Interaction With a Mobile Phone - Effects of Touch Key Size and Touch Key Location. *International Journal of Industrial Ergonomics*. **40**(1): 68-76. doi: 10.1016/j.ergon.2009.08.002

Peschel, J.M. and Murphy, R.R. 2013. On the Human-Machine Interaction of Unmanned Aerial System Mission Specialists. *IEEE Transactions on Human-Machine Systems*. **43**(1): 53-62. doi:10.1109/TSMCC.2012.2220133

Ponto, K., Doerr, K., Wypych, T., Kooker, J., and Kuester, F. 2011. CGLXTouch: A multi-user multi-touch approach for ultra-high-resolution collaborative workspaces. *Future Generation Computer Systems*. **27**(6): 649-656. doi: 10.1016/j.future.2010.11.026

Presagis. Available from <http://www.presagis.com/> [accessed 06 April 2015]

Rofouei, M., Wilson, A. D., Brush, A.J.B., Tansley, S. 2012. Your Phone or Mine? Fusing Body, Touch and Device Sensing for Multi-User Device-Display Interaction. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Austin, TX, USA. 5-10 May 2012. pp. 1915-1918.

Ruff, H.A., Narayanam, S., Draper, M.H. 2002. Human Interaction with Levels of Automation and Decision-Aid Fidelity in the Supervisory Control of Multiple Simulated Unmanned Air Vehicles. *Presense*. **11**(4): 335-351. doi:10.1162/105474602760204264

Ryerson MIMS Lab. Available from <http://www.ryerson.ca/~j3chung/> [accessed on 12 April 2015]

Ryu, K., Myung, R. 2005. Evaluation of Mental Workload with a Combined Measure Based on Physiological Indices During A Dual Task of Tracking and Mental Arithmetic. *International Journal of Industrial Ergonomics*. **35**(11): 991-1009. doi:10.1016/j.ergon.2005.04.005

Sandom, C. 2000. Operator Situational Awareness and System Safety. *In IEE One Day Seminar on Systems Dependency on Humans*. London, UK. 2000. pp.5/1-5/8.

Schmidt, D., Block, F., Gellersen, H. 2009. A Comparison of Direct and Indirect Multi-touch Input for Large Surfaces. *Human-Computer Interaction INTERACT 2009*. pp. 582-594. doi:10.1007/978-3-642-03655-2_65

Soto-Guerrero, D. and Torres, J.G.R. 2013. A Human-Machine Interface with Unmanned Aerial Vehicles. *In 10th International Conference on Electrical Engineering, Computer Science and Automatic Control*. Mexico City, 30 September – 4 October 2013. pp. 307-312.

Teo, G., Reinerman-Jones, L., Matthews, G., Szalma, J. 2015. Comparison of Measures Used to Assess the Workload of Monitoring an Unmanned System in a Simulation Mission. *Procedia Manufacturing*. **3**: 1006-1013. doi:10.1016/j.promfg.2015.07.159

Thales. 2013. Thales Unveils Avionics 2020, The Cockpit of the Future. Available from <https://www.thalesgroup.com/en/worldwide/aerospace/press-release/thales-unveils-avionics-2020-cockpit-future> [accessed 27 April 2015]

Waraich, Q.R., Mazzuchi, T.A., Sarkani, S., and Rico, D.F. 2013. Minimizing Human Factors Mishaps in Unmanned Aircraft Systems. *Ergonomics in Design: The Quarterly of Human Factors Applications*. **21**(1): 25-32. doi: 10.1177/1064804612463215

Weiss, L.G. 2011. Autonomous Robots in the Fog of War. *IEEE Spectrum*. **48**(8): 30-57. doi:10.1109/MSPEC.2011.5960163

Westerman, W., Elias, J.G., and Hedge, A. 2001. Multi-Touch: A New Tactile 2-D Gesture Interface for Human Computer Interaction. Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting. **45**(6): 632-636. doi: 10.1177/154193120104500612

Yoon, K.S., Kim, I.G. and Ryu, K.S. 2011. An Efficient Embedded System Architecture for Pilot Training. *In* IEEE/AIAA 30th Digital Avionics Systems Conference, Seattle, WA, 16-20 October 2011. pp. 8.B.5-1 – 8.D.5-6.

Draft