A Human Factors Evaluation of Mixed Reality Technologies for Command and Control Applications

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Abstract

This paper describes research that sets out to evaluate a range of Human Factors issues of adopting Mixed Reality (MxR) technologies for advanced interaction and visualisation techniques within future cockpit environments, where the role of the occupant is envisaged to change from that of a pilot to more of a mission management specialist. Specifically, the work sets out to assess the impact on human perceptual-motor performance, cognition and workload of replacing physical display and control facilities with virtual alternatives, and if such a virtual interface can perform on a par with physical systems. The paper assesses the performance and general Human Factors issues of using various Human Machine Interface devices when conducting a series of interface selection and interaction tasks and suggests specific use cases for each device.

1 Introduction

The aim of the research reported herein is to assess general Human Factors issues arising with the use of Mixed Reality (MxR) systems for replacing physical interface and display technologies with virtual alternatives when performing representative mission systems interaction tasks within a cockpit-like environment. Part 1 addresses optimal size and placement of interface elements by evaluating aspects of current military design standards and applying them to new technologies. Part 2 assesses performance, error, usability, workload and various other objective and subjective measurements when performing fundamental interaction tasks, including selection, repositioning, resizing and zooming of user interface (UI) elements.

2 Literature Review

Augmented Reality (AR), the integration of real-world and virtual objects (e.g. Milgram *et al*., 1994), has been a common feature within combat aircraft for over a decade, in the form of the head-down display, mounted within the platform'ss instrument panel, and the head-up display within the pilot's helmet. These Human-Machine Interfaces (HMIs) can provide a vast amount of information to the user, including data from the instrument panels, navigation and terrain data, as well as advanced features such as superimposed terrain and guidance information (NASA, 2017). Wan *et al*. (2011) present an MxR cockpit system in which the cockpit instruments are displayed virtually, as a substitute for physical displays. However the system includes no interactivity and does not extend beyond the purpose of visualisation.

Extending this method of virtualisation of data from the fixed-location/fixed-function physical displays to a virtual display for integration within a helmet-worn MxR interface would have the benefit of allowing for the integration of new advanced sensor visualisation features as well as supporting the tailoring of task-oriented bespoke interface layouts to the end user's immediate (and dynamically changing) needs. Furthermore, replacing physical displays would reduce the weight of the platform and 'cost of upgrade', due to the displays being virtually implemented, thus avoiding extensive physical modifications to the platform.

As stated by the Department of Defense (2012), although the emergence of novel interface technologies presents the opportunity for higher levels of performance and capabilities, the operational benefits of these technologies may be limited due to the absence of relevant Human Factors informed guidelines and standards and out-of-date design criteria, leading to devices being used for unsuitable or inappropriate tasks. Various organisations and researchers (Department of Defense, 2012, ISO, 2010, Tulson, 2012) provide design standards and guidelines. However, when referring to emerging commercial-off-the-shelf (COTS) technologies, they often offer brief or conflicting specification for design criteria.

In order to ensure fitness of purpose when introducing these new technologies, various guidance documents have been developed which provide a methodology for the assessment of COTS devices, both in a military (Bruseberg, 2005) and non-military context (Lehn and Atkinson, 2011). Further Human Factors guidelines for interactive 3D systems have been developed (e.g. Stone, 2012) based upon lessons-learned and predominantly defence case studies.

The present experiment, therefore, assesses various guidelines and Human Factors issues relating to the use of a fully virtual cockpit interface and its effect on the human user, exploiting appropriate performance metrics.

3 Aims & Objectives

3.1 Research Questions

i. Which HMI technologies have the highest performance (highest accuracy, lowest error rate) when selecting buttons and targets?

ii. Does the distance in which distraction targets surrounding the target of interest have an effect on accuracy and response time?

iii. Which interface technologies (and technology combinations) are best suited (performance, workload and usability) for specific system interaction tasks (selecting, resizing and repositioning targets)?

iv. Which HMI technologies require the least effort with regard to physical workload, physical exertion and discomfort over prolonged intensive use?

v. Which HMI technologies have the lowest difficulty rating and highest preference when completing system interaction tasks (selecting, resizing and repositioning targets)?

3.2 Experimental Measures

The experiment was a within-subject study in which each participant completed all tasks using all HMI conditions. A Latin Square technique was used to determine the order in which each participant was tested using each technology in order to eliminate a presentation order learning effect.

A total of 20 participants were recruited from within the School of Engineering at the University of Birmingham, comprising 15 males and 4 females with a mean (M) age of 26 years and standard deviation (SD) of 8.6 years.

3.3 Assessment technologies

The HMI technologies assessed within the experiment consisted of the following publicly available Commercial off-the-shelf (COTS) devices:

HOTAS - The Hands On Throttle-and-Stick: a common feature within combat aircraft that includes placing a mouse, buttons and switches on the throttle and control sticks, allowing the user to interact with cockpit functions without removing their hands. As this method of interaction is common amongst existing generation aircraft, it represented a baseline for comparison with other technologies and was used in conjunction with other experimental interface devices. The device used was a Thrustmaster HOTAS Warthog control stick and throttle unit.

Touchscreen - Touchscreens are a common feature within the latest generation aircraft and have many benefits to the traditional input method of a HOTAS system, such as allowing for rapid, gross input selection (Tulson, 2012). However, during vehicle movement, they are affected by vibration issues, the effect of G-forces or turbulence and fatigue caused by prolonged arm extension (Savage-Knepshield, 2012). This condition represented the “advanced baseline”. The device used was a 23-inch capacitive Iiyama Touchscreen.

Mixed Reality - The MxR system consisted of an Oculus Rift CV1 Head Mounted Display (HMD) equipped with cameras and an external tracking system, allowing the user to see the surrounding environment with virtual information superimposed and overlaid over the user’s field of view. During this assessment method the touchscreen wasa deactivated, appearing black, so as to avoid user distraction. The system displayed the same interface virtually superimposed in the same position as the touchscreen in order to directly compare the virtual display to the current physical display standard.

3.4 System

The software has been developed using the Unity game engine with programming in C#, allowing for rapid integration of multiple input and display devices through modular third-party plugins. The system automatically records and logs objective user performance data, including task completion time and error analysis, and can switch between the multiple HMI technologies through a custom graphical user interface (GUI).

3.5 Environment

Gawron (2008) states that environmental conditions of an experiment can have more of an effect on performance than the independent variables in the experiment, in this case the multiple interaction tasks and HMI technologies being assessed. Therefore, in order to replicate the physically restrictive conditions of a military pilot working environment, a modular cockpit testbed has been constructed. This restricts the user's movements, limiting his/her head, hand and body, which is a natural restriction for both input devices and interaction techniques that may be used within the context of a cockpit. Additionally, the position of all input devices, including the Throttle, Stick and monitors, replicate the layout of current generation aircraft.

The participant's view of the monitor and HMD are mirrored to a secondary screen for the investigator to monitor the experiment progression, to be informed of any errors, and provide instructions to the participant. Figure 1 illustrates the Mixed Reality mode configuration, Figure 2 the touchscreen configuration, and Figure 3 illustrates the assessors display.

Figure 1: The MxR Condition with Participant Completing an Interaction Task.

Figure 2 - The Touchscreen Condition with Participant Completing a Selection Task.

Figure 3 –Mirror Display of MxR HMD View

4 Methodology

The experiment consisted of 2 parts, each with specific objectives in assessing the viability of using the 3 HMI measures when completing fundamental system interaction tasks. Part 1 aimed to address the optimal size and placement of interface elements by evaluating current military design standards and applying them to new technologies. Part 2 aimed to assess general Human Factors issues arising with the various HMI technologies by recording performance, error, usability, workload and various other objective and subjective measures.

4.1 Part 1: Selection Tasks

Part 1 of the experiment assessed the size and placement of UI elements by measuring the performance and user preferences of various HMI technologies when selecting targets of varying sizes and placement within a display, and additionally the size and placement of co-located distractor targets. The experiment focused on an ISO 9241-210 (ISO, 2010) point-and-select task as this is a common generic task that forms the basis of human-machine interaction within a manned cockpit, but may also apply to other ground, air and sea platforms for both manned and unmanned systems. The tasks were defined through discussion with test pilots and Human Factors specialists within BAE Systems Military Air & Information.

4.1.1 Button Size

When considering sizes to include within the experiment, existing standards and studies (Tulson, 2012, Department of Defense, 2012) recommend similar but different sizes for buttons on a touchscreen and other display methods. However, as the touchscreen condition is representative of the enhanced baseline condition, this will be the standard in which all other HMI conditions are tested against. Tulson (2012) recommends that when using a touchscreen interface that button sizes should be set to 3.8cm wide, 2.54cm high, with 3mm spacing. However, Def Stan 1472G (Department of Defense, 2012) states that a minimum of $1.5cm^2$ with spacing of 3mm and a maximum of $3.8cm^2$ with spacing of 5mm should be used.

	Actuation	Separation
Minimum	15mm x 15mm	3mm
Maximum	38mm x 38mm	5mm

Table 1 – Military Standard 1472G Touchscreen Button Dimensions and Separations
(US Department of Defense, 2012)

	Actuation	Separation
Preferred	38mm x 24mm	3mm

Table 2 –Touchscreen Dimensions and Separations in a Military Ground Vehicle (Tulson, 2012)

Each of these button sizes were tested against the recommended spacing sizes with both smaller and larger than the recommended measurements also included. Each of the 12 button size conditions are repeated 10 times each, to a total of 120 point-and-select actions per HMI measure, giving a total of 360 actions for all 3 HMI measures.

The task of the user was to select the button labelled "A" amongst 5 other closely co-located targets with designated letter B-I. After each button was selected, all targets moved to a different randomised position on the screen. The time taken to select the target and the error rate was measured (when users select an area of the screen which is not the target, or select an incorrect target).

When defining the point at which a user has selected a target, Tauson (2012) recommends that selection should be based upon last contact. Thus the user began by pressing down upon the button, known as first contact, in which the button has been selected but not yet activated. The item was only activated when the user removed the finger and broke the last contact with the screen. Following this the position on the screen in which the targets are displayed were randomised.

Button Size (Height x Width)	Surrounding Distractor Button Distance (mm)	Button ID
10mm x 15mma	No Distractors	1
	1	2
	2	3
	5	4
18mm x 25mm	No Distractors	5
	1	6
	3	7
	5	8
25mm x 35mm	No Distractors	9
	1	10
	3	11
	5	12

Table 3 – Button Sizes and Distractors Based on Military Standard 1472G

4.1.2 Target Size

The target size assessment method was identical to the button assessment detailed above. However, the targets ranged from 5mm to 15mm with defined distractor distances (Table 5) in order to assess a wide range of measurements. The button size experiment detailed above (Table 5) tested the size range of 10x15mm to 25x35mm sizes; the present experiment tested $5mm^2$ to $15mm^2$ and therefore covered far beyond the highest and lowest recommended sizes as suggested by multiple guidelines and standards sources.

After each target was selected, all targets moved to a different randomised position on the screen.

Each of the target sizes were tested against the recommended spacing sizes, with both smaller and larger than the recommended measurements also included. Each of the 12 target size conditions were repeated 10 times to a total of 120 point-and-select actions per HMI measure, and to a total of 360 when completing all 3 HMI measures.

	Actuation	Separation
Preferred	13mm x 13mm	-
Maximum	-	6mm

Table 4 – Military Standard 1472G Touchscreen Target Dimensions and Separations
(Department of Defense, 2012)

Target Size (Height x Width)	Surrounding Distractor Target Distance (mm)	Target ID
5mm^2	No Distractors	1
	5	2
	10	3
	15	4
10mm^2	No Distractors	5
	5	6
	10	7
	15	8
15mm^2	No Distractors	9
	5	10
	10	11
	15	12

Table 5 – Target Sizes and Distractors Based on Military Standard 1472G

4.1.3 Task and Technologies Interaction

Table 6 details the system interaction tasks undertaken by the participant for each HMI condition.

Technology/Task	Point-and-Select
Touchscreen	Touch the target on the touchscreen
HOTAS	Position cursor over target, press HOTAS "select" button
Mixed Reality	Position cursor over target, press HOTAS "select" button

Table 6 – Task & Technology Interaction Table

4.1.4 Measures

<u>Quantitative Measurements</u>

Performance measurements were collected automatically within the system; logging commenced once the assessor began the experimental task and had directed the participant to begin.

- Reaction time (speed) – The reaction time was defined as the time it takes to select a target once it appears on the interface, measured from when the user selects the target by releasing the button or removing the finger. Time measurements were recorded automatically by the system.
- Accuracy / Error rate – An error was defined by the user selecting a location on the interface that was not the target, or selected an incorrectly labelled target. Errors were recorded automatically by the system.

<u>Qualitative Measurements</u>

- Task difficulty - Rating the difficulty of each task and HMI technology on a scale of 1-10 (very easy to very hard). Completed after each button and target size task and once after each HMI measure.
- Perceived Exertion- Rating physical exertion while completing tasks using the BORG Scale (Borg, 1982). Completed after each HMI measure.
- Discomfort Rating- Rating subjective using the Discomfort Scale (Kuorinka, 1982). Completed after each HMI measure.
- Preference Rating - Rating the 4 HMI technologies in the assessment from 1-3. Completed at the end of the experiment.

4.2 Part 2: Interaction Tasks

This experiment consisted of 4 fundamental system interaction tasks, including point-and-select, repositioning, resizing and zooming. Each interaction task represented a common generic task within a manned cockpit interface but could also apply to other ground, air and sea manned and unmanned systems. Again, the tasks were defined through discussion with test pilots and Human Factors specialists within BAE Systems Military Air & Information (Warton).

4.2.1 Task 1 - Point-and-Select

The circular target represented a radar object to be selected and was repeated 10 times. The user was measured on the time it took to select the target and the error rate (when they selected an area of the screen which was not the target). As discussed previously, the selection was based upon last contact, as recommendation by Tauson (2012).

The target had a 15mm diameter as recommended within Experiment 1.

4.2.2 Task 2 - Reposition

This required the selection of a display element to reposition by moving the target until it was placed in a defined position, as dictated by a white outline. The test repeated the repositioning task 10 times by relocating the target to overlay the white rectangle and then randomly positioning the white rectangle again and repeating. The user's performance was measured by the time it took to reposition the target and the error rate in which they selected an area of the screen which was not the target.

The drag area was 15mm x 15mm as recommended within Part 1.

4.2.3 Task 3 – Resize

This required the selection of a display element to resize by increasing the scale until it reached a defined size, as dictated by a white outline. The user was tasked to drag the corner icon to increase/decrease the rectangle size, releasing it once it matched the required size. The test repeated the resizing task 10 times. The user's performance was measured by the time it took to resize the target and the error rate in which they selected an area of the screen which was not the target.

The resize corner area was 15mm x 15mm as recommended within Experiment 1. The active area for selecting the corner utilised the whole $15mm^2$. However the displayed icon was a triangle that depicted only half the area to indicate the direction in which the rectangle was resized when the user interacted and dragged the icon.

4.2.4 Task 4 - Zoom

This required the selection of a display element to perform a zoom function by using the required gesture or button function until it reached the set zoom level, as dictated by a white outline. The test repeated the zooming task 10 times by zooming in and out to a total of 10 zoom button clicks. The user's performance was measured by the time it took to reach the desired zoom level and the error rate in which they selected an area of the screen which was not the target.

2.2.5 Task and Technologies Interaction

Appendix 1 details the system interactions tasks undertaken by the participant for each HMI condition. Specific tasks require multiple steps in order to complete a task, such as having to first reposition the cursor with one dial and select the item with a different button, and is detailed within.

2.2.6 Measures

<u>Quantitative Measurements</u>

Performance measurements were collected automatically within the system and logging commenced once the assessor began the experimental task and had directed the participant to begin.

- Completion time (speed) – The completion time was defined at the time it takes to complete the task once it appeared on the interface.
- Accuracy / Error rate – An error was defined by the user selecting a location on the interface that was not the target, or selected an incorrectly labelled target.

<u>Qualitative Measurements</u>

- Workload - NASA TLX Questionnaire (Hart & Staveland, 1988)
- Usability – System Usability Score Questionnaire (Brooke,1996)
- Task difficulty - Rating the difficulty of each task and HMI technology on a scale of 1-10 (very easy to very hard). Completed after each button and target size task and once after each HMI measure.
- Perceived Exertion- Rating physical exertion while completing tasks using the BORG Scale (Borg, 1982). Completed after each HMI measure.
- Discomfort Rating- Rating subjective using the Discomfort Scale (Kuorinka, 1982). Completed after each HMI measure.
- Preference Rating - Rating the 4 HMI technologies in the assessment from 1-3. Completed at the end of the experiment

5 Results

5.1 Data Preparation

Due to the experiment requiring continuous input over a prolonged period (approx. 30 minutes per HMI condition), some users would stop for several seconds to alleviate discomfort. Therefore, in order to ensure that these periods of rest did not distort the reaction time datasets, these extraneous data points were removed using a standardised filter, in effect removing outliers which were outside the range of ± 3SD of the mean for each task. The zoom interaction task (4.2.4) has been excluded from the completion time analysis due to a data logging error. However this was included for all other analysis methods.

5.2 Statistical Analysis

Mean values are presented in a standardised format displaying mean value followed by standard deviation value, presented as (M = x ± SD value). Across all ANOVA analyses an p value of $p=0.05$ was used as a criterion for statistical significance.

5.3 Part 1 Selection Tasks: Quantitative Results

Reaction Time Analysis – A Two-Way 3 (HMI conditions) x 16 (UI conditions) Repeated Measures ANOVA was applied. The analysis shows that across all button and targets the HMI condition has a significant main effect on the reaction time ($F_{(2,296)}=1100.186$, $p < 0.001$), with the touchscreen producing the fastest response time over every condition. It was found that the presence of co-located distractor targets had no statistically significant effect on response time, as illustrated in Table 7.

	Touchscreen	Mixed Reality	HOTAS
Distractors	92 (SD=24)	171 (SD=41)	257 (SD=58)
No Distractors	94 (SD=24)	176 (SD=48)	258 (SD=57)

Table 7 – Selection Tasks Mean Reaction Time (ms)

The button sizes had a significant effect on response time ($F_{(2,306)}=1011$, $p < 0.001$), with response time decreasing as the button sizes increase (Figure 4). Similarly, the targets also had a significant effect on response time ($F_{(2,314)}=786.689$, $p < 0.001$), again with response time decreasing as target size increases (Figure 5).

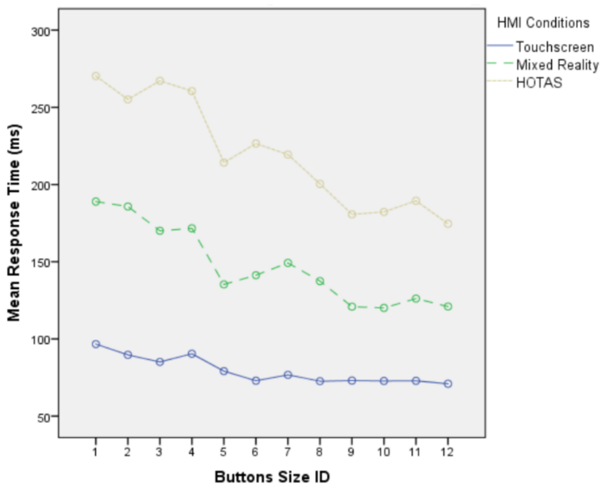

Figure 4: Button Selection Mean Response Time (ms)

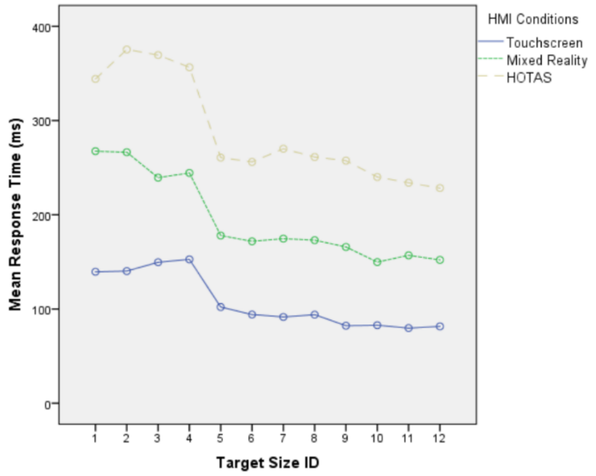

Figure 5: Target Selection Mean Response Time (ms)

Error Analysis – An error was defined by the user selecting a location on the interface that was not the target, or selected an incorrectly labelled target, and were recorded automatically by the system. A 3 (HMI conditions) x 16 (UI conditions) Repeated Measures ANOVA shown that HMI conditions elicited a significant main effect on errors ($F_{(2,34)}=11.138$, $p < 0.001$). It was found that the presence of co-located distractor targets had no statistically significant effect on error rate.

The button sizes had a significant effect on error rate ($F_{(11,187)}=5.4$, $p < 0.001$). The MxR condition had the lowest mean error score per selection input (M=.148±0.41), with the touchscreen second (M=.176±0.42), and the HOTAS condition the highest error score (M=.231±0.52), (Figure 6). Similarly, the targets also had a significant effect on error rate ($F_{(2,314)}=15.208$, $p < 0.001$) with the smaller target sizes ($5mm^2$) having a much larger effect on mean error rate (Figure 7).

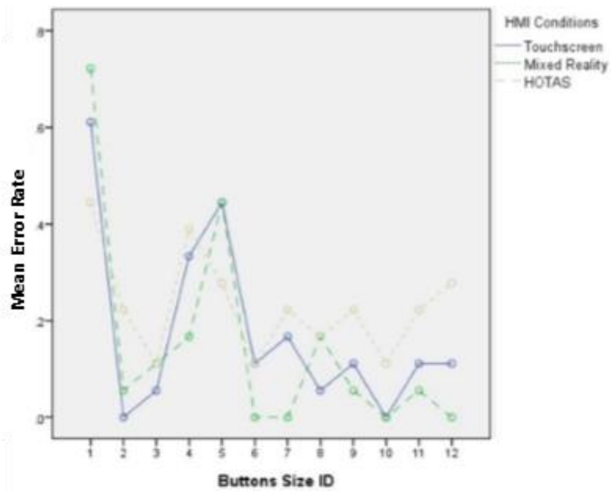

Figure 6: Button Size Mean Error Rate

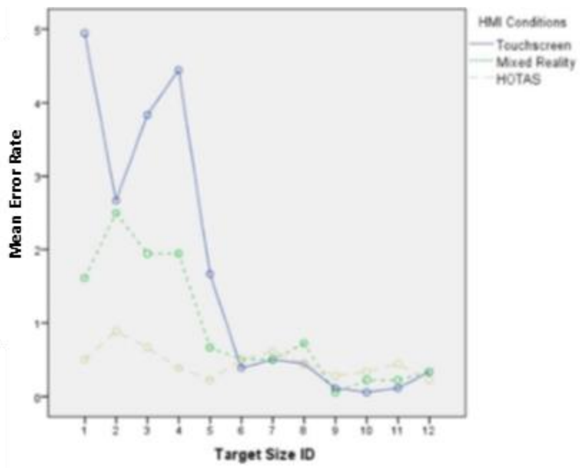

Figure 7 – Target Size Mean Error Rate

5.4 Part 1 Selection Tasks Qualitative Results

Difficulty – When rating difficulty in using the HMI conditions to complete the interaction tasks, between 1 (very easy) and 10 (very difficult), participants rated the touchscreen the easiest (M=2.35±1.42), the MxR condition second (M=3.40±2.06), and HOTAS the hardest (M=4.17±3.16). Participants commented that smaller precise movements by the thumb-controller HOTAS mouse was more difficult to achieve than the larger gestures requiring less precision, such as pressing a button with a or moving the head slaved cursor by looking at the desired location.

Exertion – When rating exertion on the BORG scale (Borg, 1982) between 6 (no exertion at all) and 20 (maximum exertion) all measured were within the “very light” bracket, with the touchscreen condition rated least exerting (M=10.40±3.16), the MxR condition second (M=10.25±3.25), and HOTAS most exerting (M=10.86±3.42). Participants commented that smaller precise movements required by the HOTAS mouse was more physically exerting than the larger gestures requiring less precision.

Discomfort – When ratings discomfort over prolonged use of each HMI conditions, all scored similarly below 3 out of 10, within the bracket denoting “minor – able to adapt to” on the scale. The MxR condition rated lowest (M=1.65±0.67), with the HOTAS scoring marginally higher (M=2.22±0.95), and touchscreen the highest (M=2.45±1.05).

Preference – When completing the continuous selection tasks the MxR condition received a marginally higher preference weighting for first preference compared to touchscreen, however the HOTAS condition was firmly placed as least preferable (Figure 8). A Friendman test indicated that this was a significant ranking ($X^2_{(2)}$ = 9.380, p=0.009).

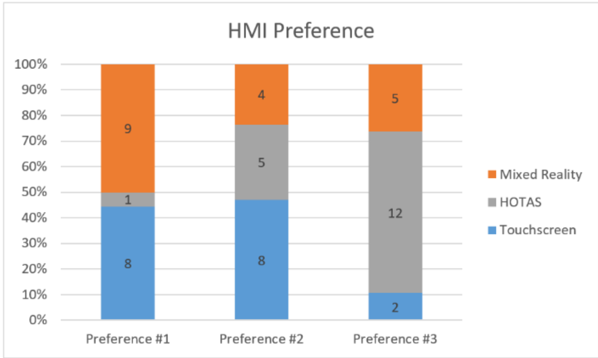

Figure 8 – Selection Tasks HMI Preference

5.5 Part 2 Interaction Tasks: Quantitative Results

Completion Time Analysis – A Two-Way 3 (HMI condition) x 3 (Tasks) Repeated Measures ANOVA found that the HMI condition had a significant main effect on task completion time ($F_{(2,290)}$=241.651, p < .001). Furthermore, the interaction tasks used had a significant effect on completion time ($F_{(2,290)}$=220.663, p < .001). This was as expected, given the varying level of steps and effort required to complete each task. Table 8 and Figure 9 further detail the completion times across each HMI and task conditions.

	Touchscreen	Mixed Reality	HOTAS
Task 1	105 (SD=55)	214 (SD=108)	334 (SD=248)
Task 2	317 (SD=93)	426 (SD=170)	739 (SD=372)
Task 3	330 (SD=155)	471 (SD=246)	601 (SD=344)

Table 8 - Interaction Tasks Mean Completion Time (ms)

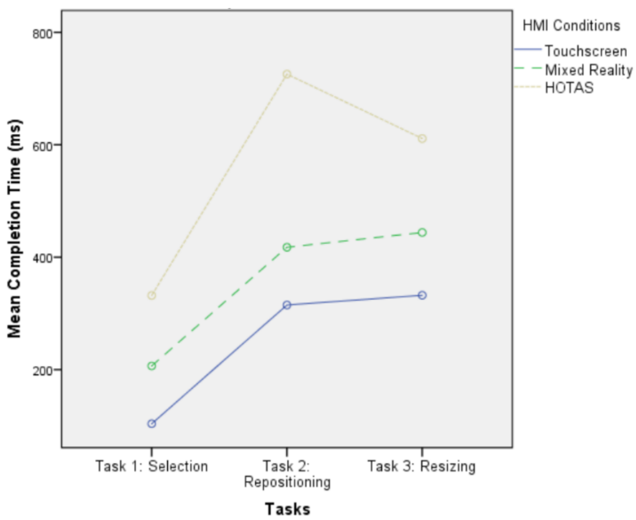

Figure 9:- Interaction Tasks Mean Completion Time (ms)

Error Analysis – Overall, participants made few errors when completing the interaction tasks. A Two-Way 3 (HMI Conditions) x 4(Tasks) Repeated Measures ANOVA was performed and did not exhibit a statistical significance in errors across HMI measures ($F_{(2,38)}$=5.441, $p < 0.08$). This is in contrast to the selection tasks which had a high error rate across all HMI measures.

5.6 Part 2 Interaction Tasks Qualitative Results

Usability – Following completing all tasks across each HMI condition participants completed a System Usability Scale (SUS) questionnaire and all conditions scored above the average of 68 as denoted by Brooke (1996). The touchscreen condition scored the highest SUS score of 92, rated "A", the MxR condition scored 79, rated "B", and HOTAS scored 71, rated "C".

Workload – Participants completed a workload questionnaire per HMI, measured on 6 sub-scales, including mental demand, physical demand, temporal demand, own performance, effort, and frustration. Workload below 50 is considered acceptable (Endsley, 1988), All 3 measures achieved overall scores below this level, with touchscreen being lowest (25.5), MxR second (32.5) and HOTAS the highest (39.1). Figure 10 illustrates rating scores across each subcategory.

Figure 10 – Workload Rating by Sub-Task

Exertion – The touchscreen condition was rated least exerting (M=8.75±3.14), the MxR condition second (M=9.63±2.76), and HOTAS most exerting (M=10.78±3.40).

Difficulty – The touchscreen was rated the easiest to use (M=2.55±1.88), the MxR condition second (M=3.75±2.10), and HOTAS the hardest (M=5.16±2.55).

Discomfort – The HOTAS condition rated lowest (M=1.45±0.51). This was as expected, given the participants only needed to move their thumbs to control the cursor and button to complete the tasks. Touchscreen scored marginally above this (M=1.60±1.05), and MxR scored the highest (M=2.44±0.98).

Preference - When ranking the preference of each HMI condition 15 out 18 participants clearly selected touchscreen as their first preference (Figure 11), in contrast to the selection tasks (5.4), in which users marginally selected the MxR condition as highest. However, the HOTAS condition was again chosen as the least preferable. A Friendman test indicated this as a significant ranking ($X^2_{(2)} = 22.4$, $p < 0.001$).

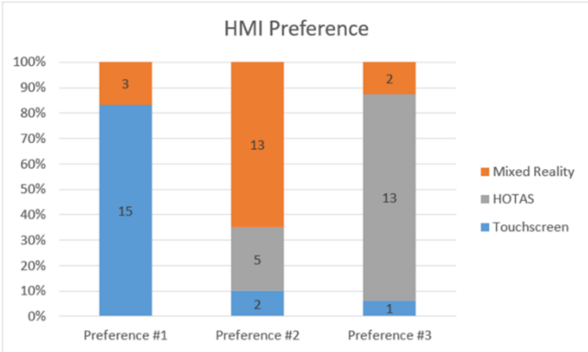

Figure 11: Part 2 Preference Ratings

6 Conclusions & Future Work

The analysis has shown that, when considering the Human Factors implications of the HMI technologies investigated in this experiment, including usability, workload, difficulty rating and perceived exertion, the touchscreen was the highest rated HMI condition amongst the majority of measures, however this was coupled with a high error rate. For simple continuous input tasks, the Mixed Reality system was the highest in preference amongst participants and provided a lower error rate compared to the touchscreen condition.

Within the scope of this project, it is suggested that although the touchscreen is best suited to more complex system interaction tasks, a Mixed Reality system may be useful for simple tasks that do not require precise and complex interactions, such as 3D object visualisation.

Further case studies have been conducted which explore defence related applications of Mixed Reality for use in command and control, and these will be published in subsequent reports. These include novel methods of visualisation for command stations, bespoke "wearable" interfaces and methods of real-time adaptive user interface systems based upon psychophysiological readings, such as eye-tracking based workload monitoring.

9 Acknowledgements

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Technology/Task	Task 1 Point-and-Select	Task 2 Resize	Task 3 Reposition	Task 4 Zooming
Touchscreen	Touch the target	Press to activate, drag corner to resize, release once required size is reached	Tap to activate, drag to reposition	Tap to activate, touch the + or – buttons to zoom in and out respectively
HOTAS	Position cursor over target, press HOTAS "select" button	Position cursor over target, select target with HOTAS "select" button, move cursor to desired position, deselect target with HOTAS "select" button	Position cursor over target, select target with HOTAS "select" button, move cursor to desired position, deselect target with HOTAS "select" button	Position cursor over target, press HOTAS "select" button,
Mixed Reality (Head Tracking) + HOTAS	Move head to target, press HOTAS "select" button	Move head to target, select target with HOTAS "select" button, move head to desired position, deselect target with HOTAS "select" button	Move head to target, select target with HOTAS "select" button, move head to desired position, deselect target with HOTAS "select" button	Move head to target, press HOTAS "select" button

Appendix 1 – Part 2 Task & Technology Interaction Matrix