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

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About Me

- Meng Computer Systems Engineering
  - FYP Augmented Reality prototyping tool for UAV operator console design
- iCase PhD sponsored by EPSRC and BAE Systems (MAI)
  - Human Factors of introducing MR for defence application
- HIT (Human Interface Technologies) Team

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Background: Wearable Cockpit concept

- Fully virtual interface allows for:
  - Novel display methods
  - Reduced cost and time of change
  - Reduced weight in the platform
  - Platform independent
  - Bespoke task-oriented layout
  - Adaptive interface

HMI Conditions

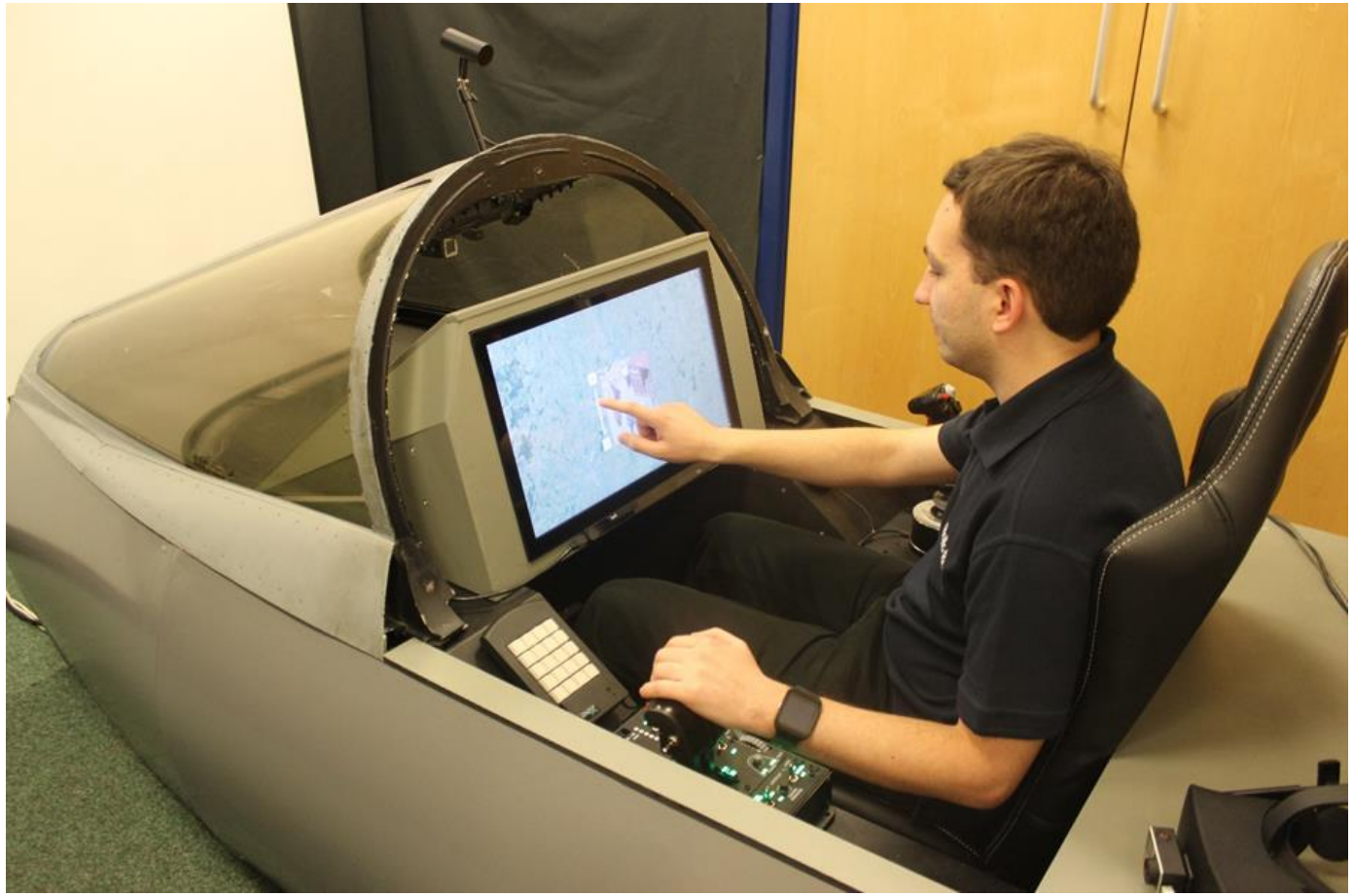
Display & Interface Devices

- Touchscreen display
- Mixed Reality system
- HOTAS

Cockpit Testbed

- Modular design to allow easy integration of new HMI devices
- Simulate physically restrictive working environment of a pilot
- Restrict users hand, arms and body movements

Condition 1: Touchscreen



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Condition 2: HOTAS Controllers

Condition 3: Mixed Reality system

Condition 3: Operator console

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Research Questions

- Can a fully virtual MR interface provide the same performance as physical systems (Touchscreen, HOTAS) for basic interaction tasks?
- When selecting UI elements does the distance in which distraction elements surrounding the target of interest have an effect on accuracy and response time?
- Which interface technologies (and technology combinations) are best suited (performance, workload and usability) for specific system interaction tasks (selecting, resizing and repositioning targets)?
- Which HMI technologies require the least effort with regard to physical workload, physical exertion and discomfort over prolonged intensive use?
- Which HMI technologies have the lowest difficulty rating and highest preference when completing system interaction tasks (selecting, resizing and repositioning targets)?

Experiment Procedure Part 1

- Optimal size of UI elements
  - 24 button and target sizes based on multiple conflicting design standards
    - Military Standard 1472G
    - Touchscreen Dimensions and Separations in a Military Ground Vehicle (Tulson, 2012)
  - Each size repeated 10 times (240 input tasks per HMI condition) to test effect on the user with prolonged intensive use
  - Location randomised after each input

- Effects of co-located distractor targets
  - Target (A)
  - Distraction targets (B-I) surrounding main target

Experiment Procedure Part 1

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

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

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Part 1: Technology/Task Matrix

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

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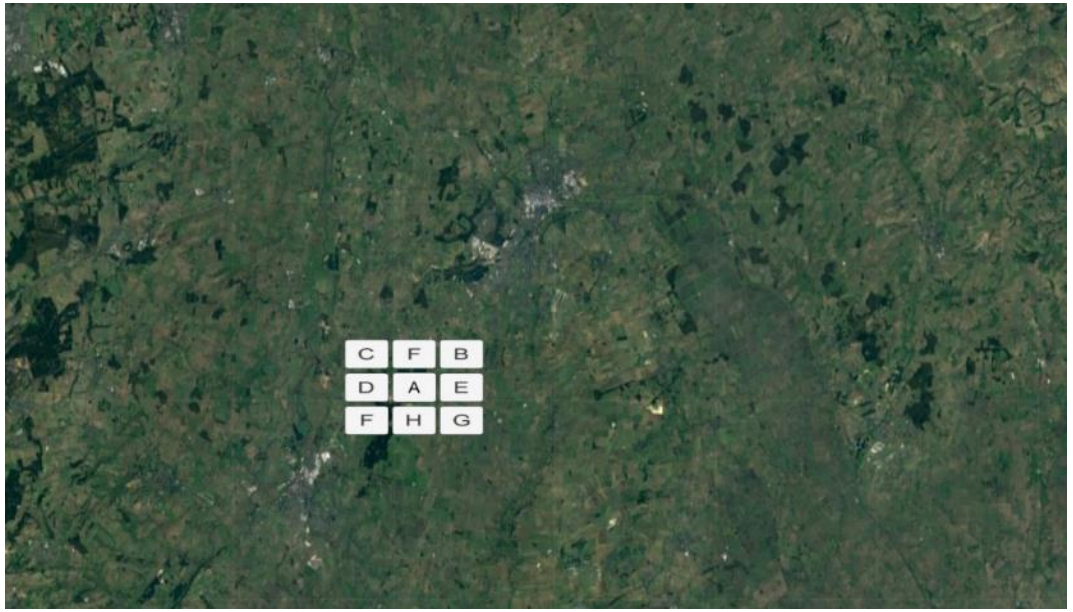
Part 1: Button Selection



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Part 1: Target Selection

Experiment Procedure Part 2

- Fundamental Interaction Tasks
  - Selection
  - Resizing
  - Repositioning
  - Zooming

Part 2: Technology/Task Matrix

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

Task 1: Selection

Task 2: Resizing

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Task 3: Repositioning

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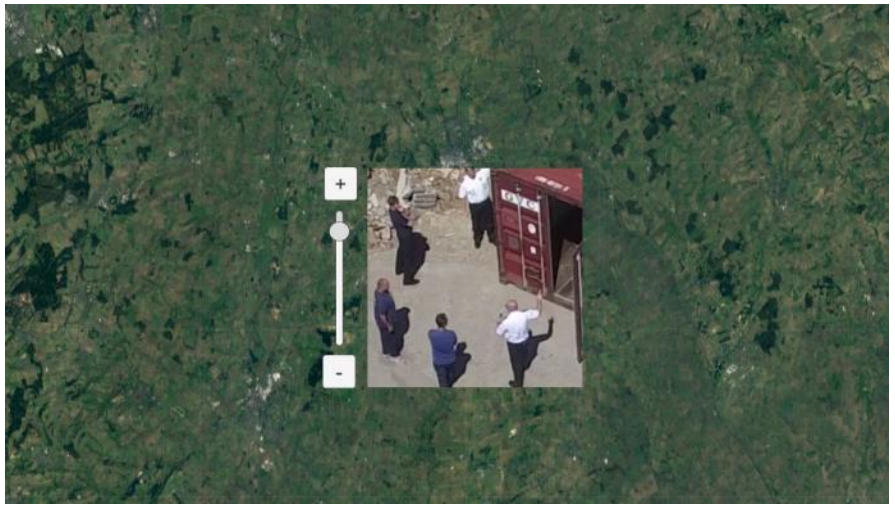
Task 4: Zooming



Measures

- Quantitative
  - Reaction Time - Time it takes participant to complete task once prompted)
  - Error Rate - Selecting an incorrect target or not completing the task)
- Qualitative
  - Workload - NASA Task Load Index questionnaire (Hart & Staveland, 1988)
  - Usability - System Usability Score questionnaire (Brooke, 1996)
  - Difficulty - Subjective rating scale between 1 (Very Easy) and 10 (Very Hard)
  - Percieved Exertion - Subjective rating scale using BORG Scale (Borg, 1982).
  - Discomfort – Subjective rating scale (Kuorinka, 1982).
  - Preference – Subjectively rating HMI preference between 1 (Most) – 3 (Least)

Results

- Part 1: UI elements size and placement
- Part 2: Fundamental interaction tasks

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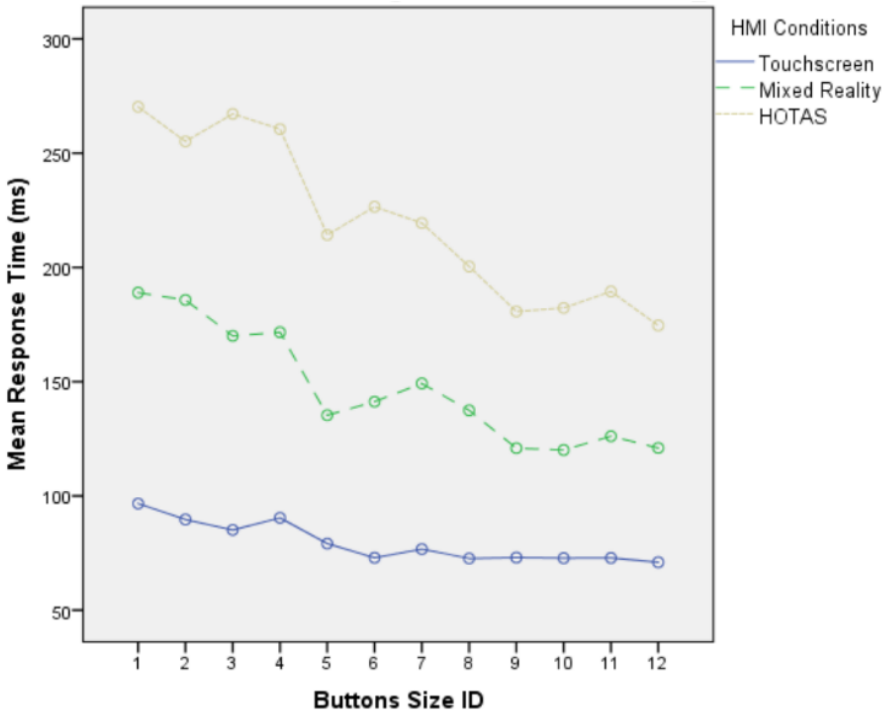
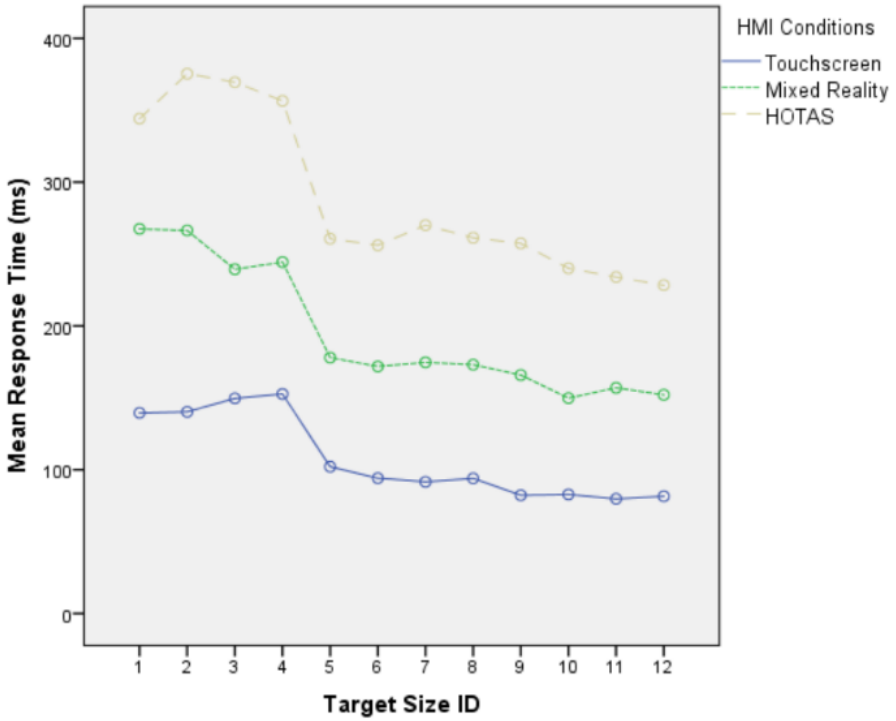
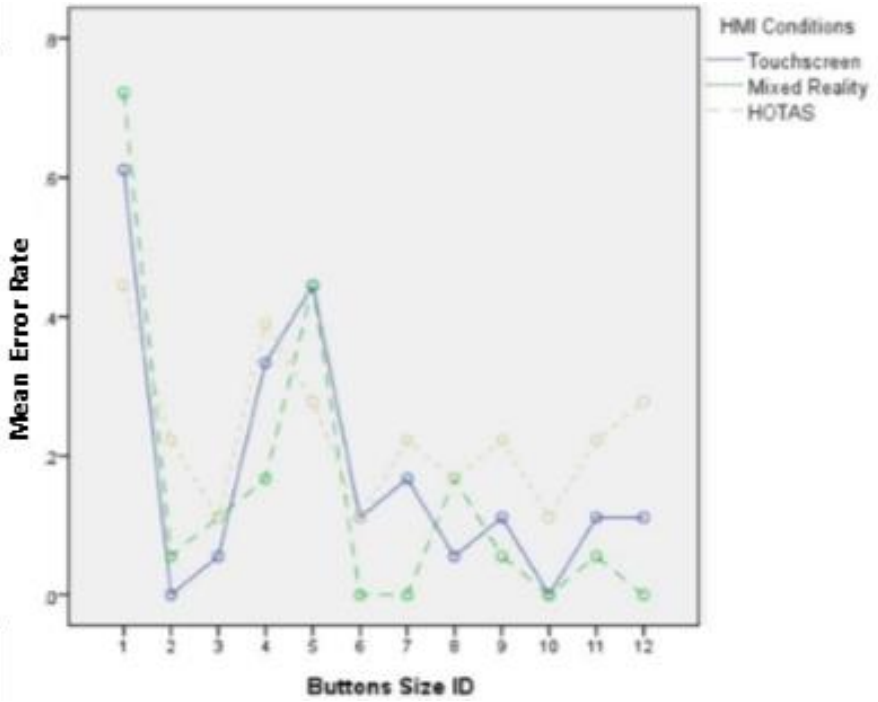
Part 1: Response Time

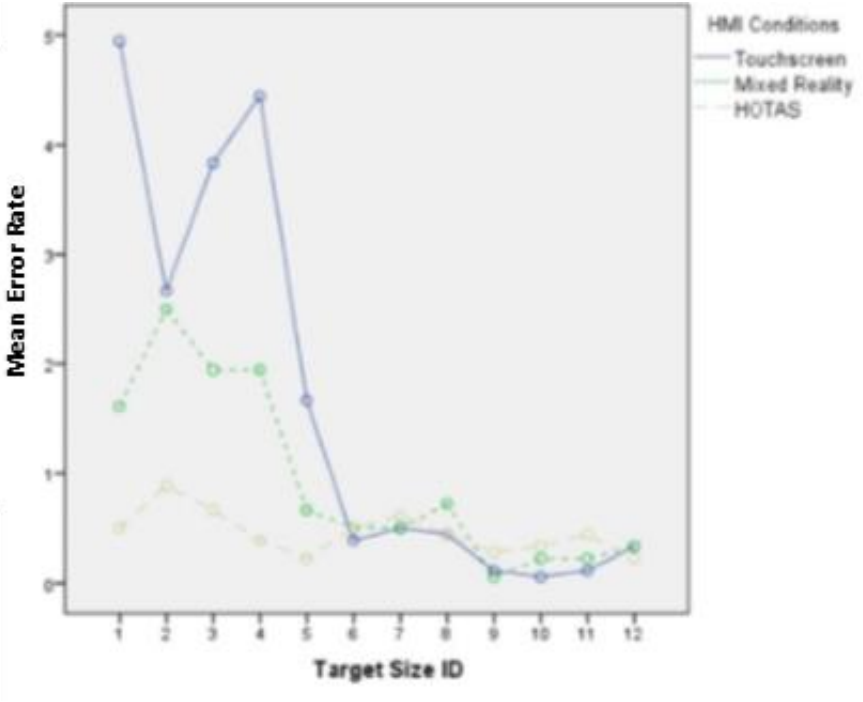




The response time was defined as the time it takes for the participant to complete a task once it appeared on the interface and the system automatically progresses to the next task

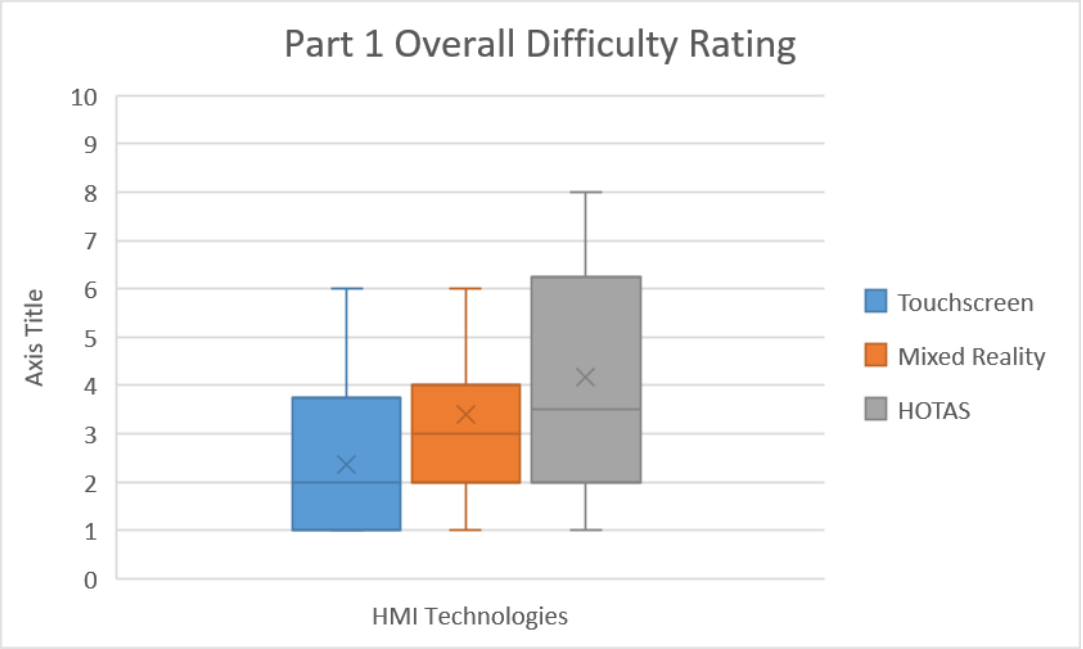
Part 1: Error rate





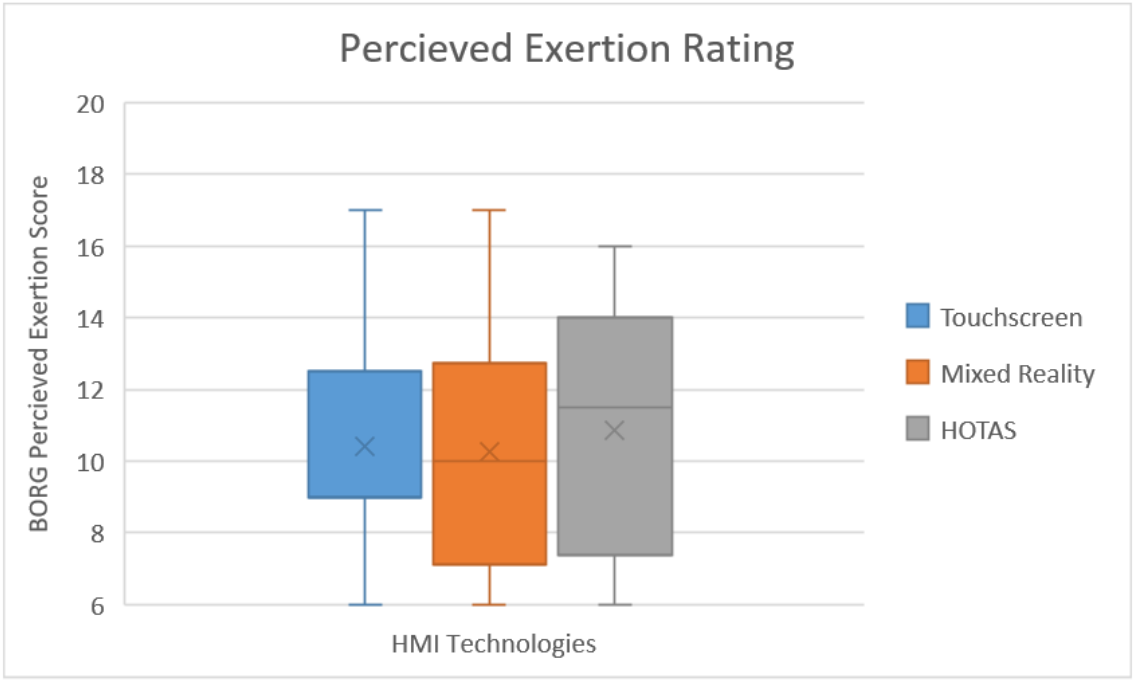
Accuracy / Error rate – An error was defined by the user selecting a location on the interface that was not the target, or selected an incorrectly labelled target.

Part 1: Subjective Ratings - Difficulty



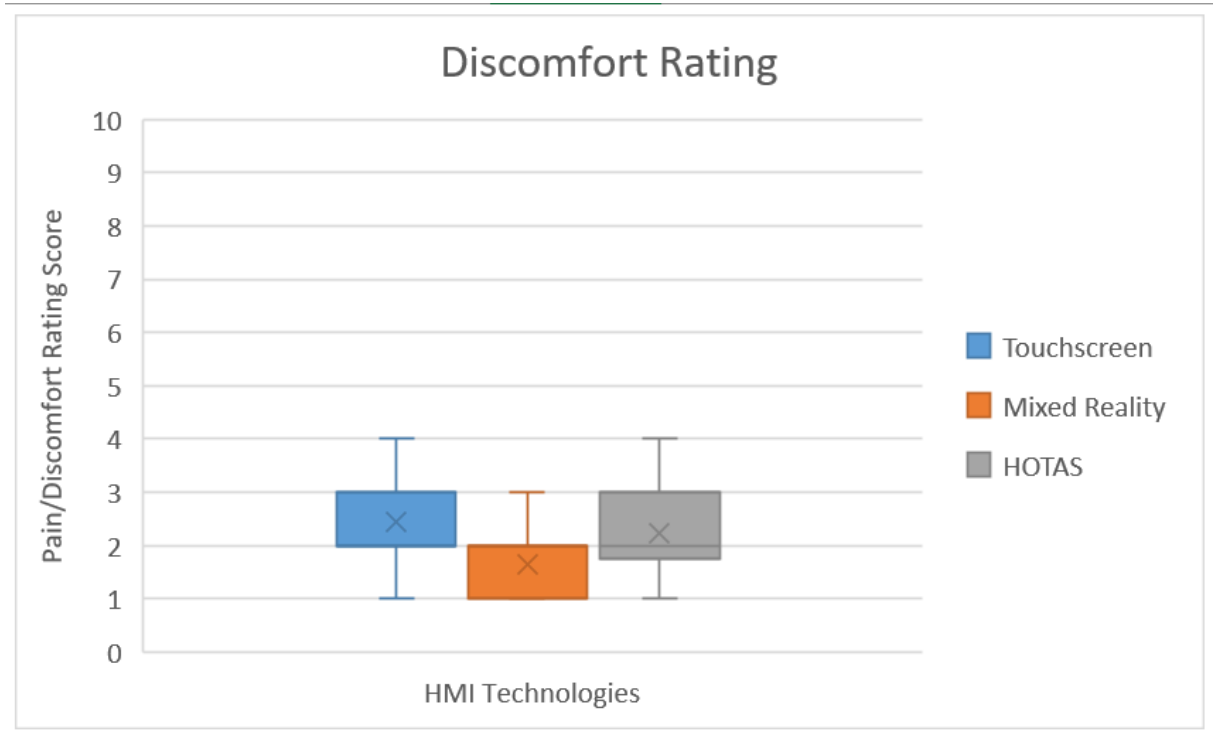
"How difficult would you rate using this HMI condition for continuous input of button and targets?"

Part 1: Subjective Ratings - Exertion



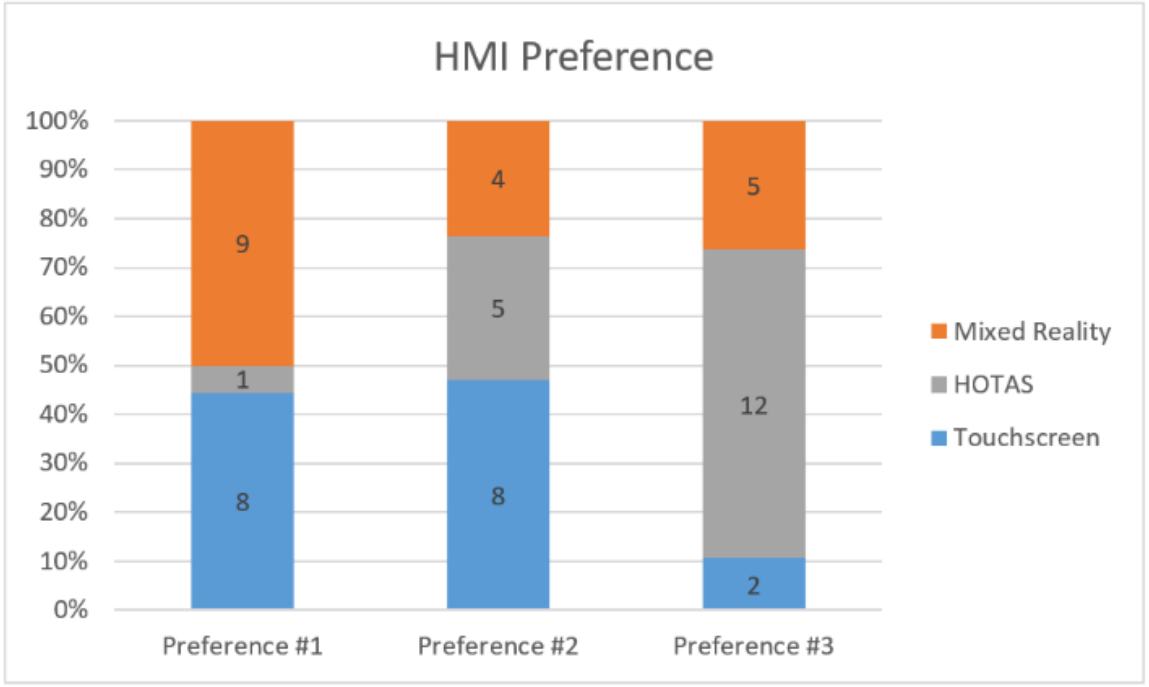
Physical exertion while completing tasks using the BORG Scale (Borg, 1982), rating between 6 (“No exertion at all”) and 20 (“Maximal exertion”)

Part 1: Subjective Ratings - Discomfort



Rating subjective using the Discomfort Scale (Kuorinka, 1982), between 0 (“Nothing at all”) and 10 (“Extremely strong”).

Part 1: Subjective Ratings - Preference



"Which of the 3 technologies in the experiment did you most prefer for continuous button and target selection? Rate the 3 technologies between 1 (most preferable) and 3 (least preferable)".

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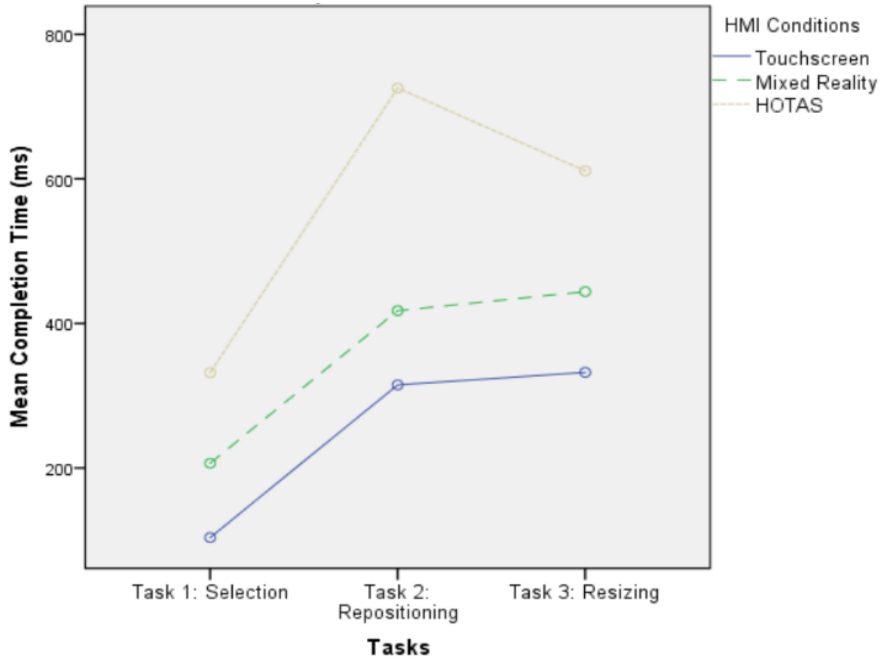
Part 2: Completion Time



The completion time was defined as the time it takes for the participant to complete a task once it appeared on the interface and the system automatically progresses to the next task

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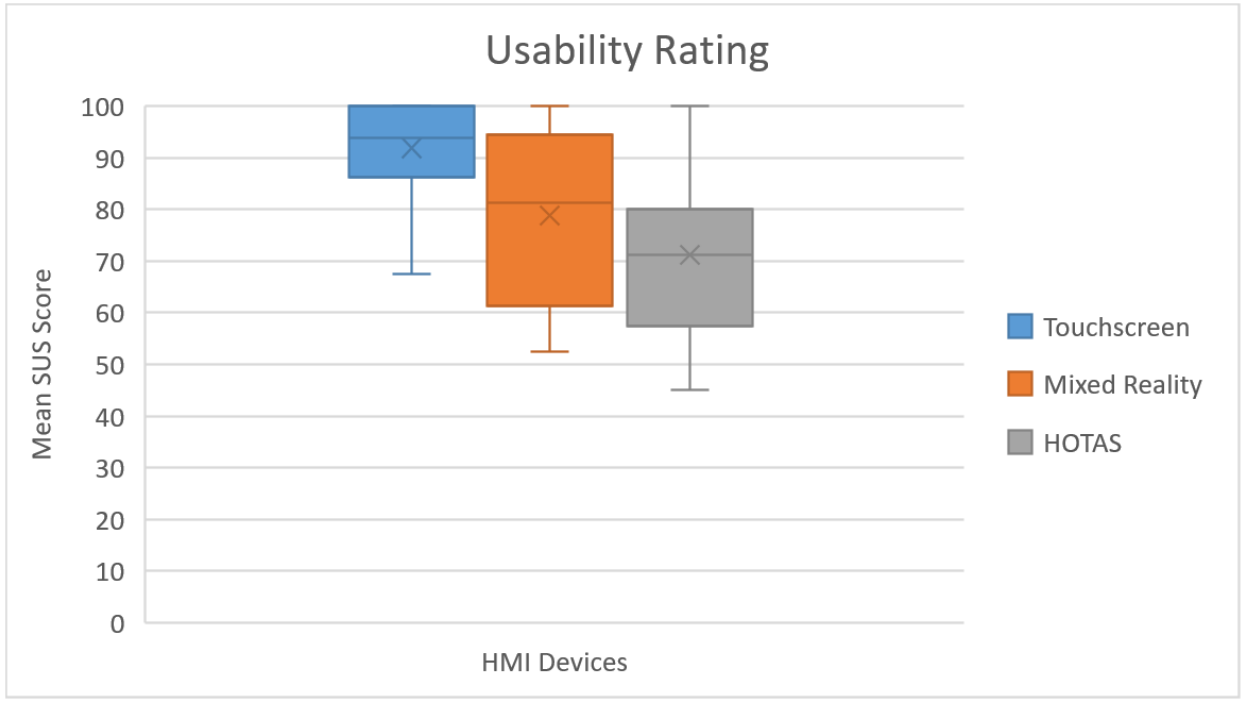
Part 2: Subjective Ratings - Workload

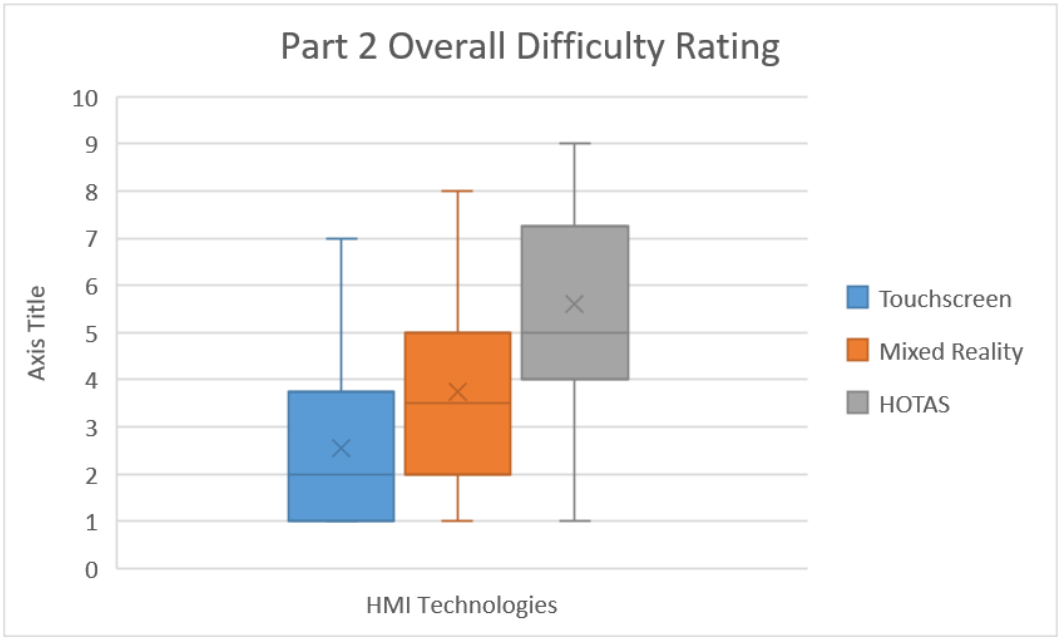
NASA TLX Questionnaire (Hart & Staveland, 1988)

Part 2: Subjective Ratings - Usability



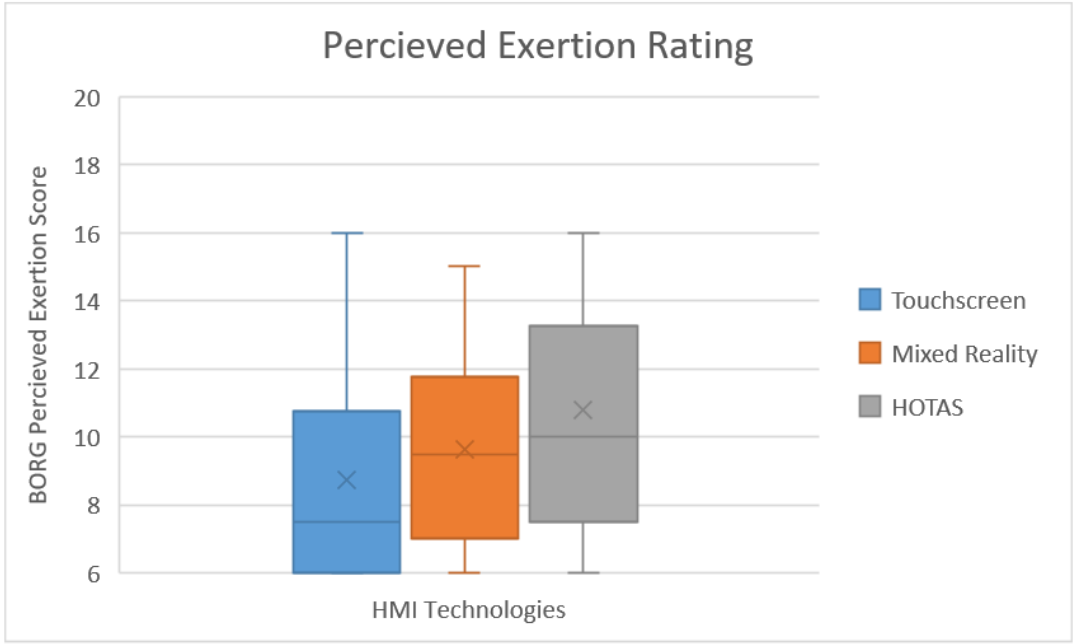
System Usability Score Questionnaire (Brooke,1996)

Part 2: Subjective Ratings - Difficulty



"How difficult would you rate using this HMI condition for continuous input of button and targets?"

Part 2: Subjective Ratings - Exertion



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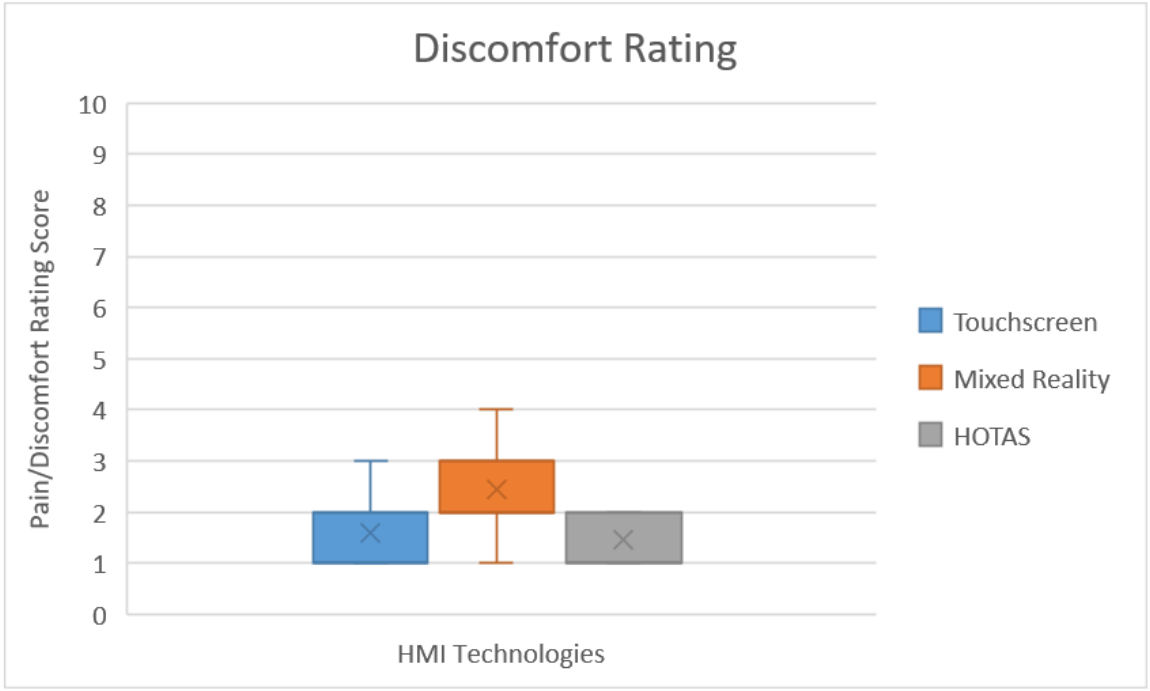
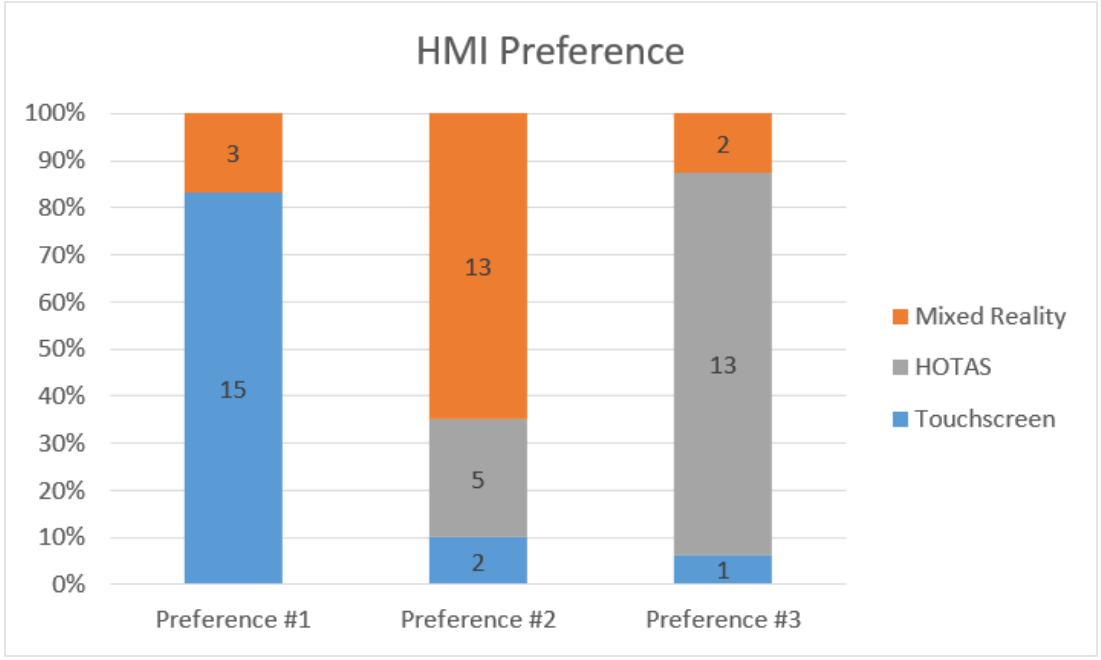


Rating subjective using the Discomfort Scale (Kuorinka, 1982), between 0 (“Nothing at all”) and 10 (“Extremely strong”).

Part 2: Subjective Ratings - Preference



"Which of the 3 technologies in the experiment did you most prefer for interaction tasks, including repositioning, resizing and zooming? Rate the 3 technologies between 1 (most preferable) and 3 (least preferable)".

Conclusions

- A Touchscreen is suitable for both simple and complex interaction tasks, but may require the HOTAS to be used in some conditions (e.g. high vibration or precise cursor positioning)

- The Mixed Reality system is suitable for simple input tasks but unsuitable for more complex interaction tasks that require precision

- The HOTAS system is a reliable input method with a high level of accuracy, but is more cumbersome and exerting over prolonged use

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Case Studies

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Case Study 2: Evaluation of Interface Devices

- Tracking Technologies
  - Infrared cameras based MoCap system
  - IMU based MoCap suit

- Interface Devices
  - Head-slaved cursor (IMU within HMD)
  - Eye gaze (FOVE HMD)
  - IR gesture recognition (LEAP Motion)
  - Gloves (MANUS VR)
  - IR tracked controllers (Vive controllers)
  - Magnetically tracked controllers (Razor Hydra)

Case Study 2: Mixed Reality Command Station Testebed

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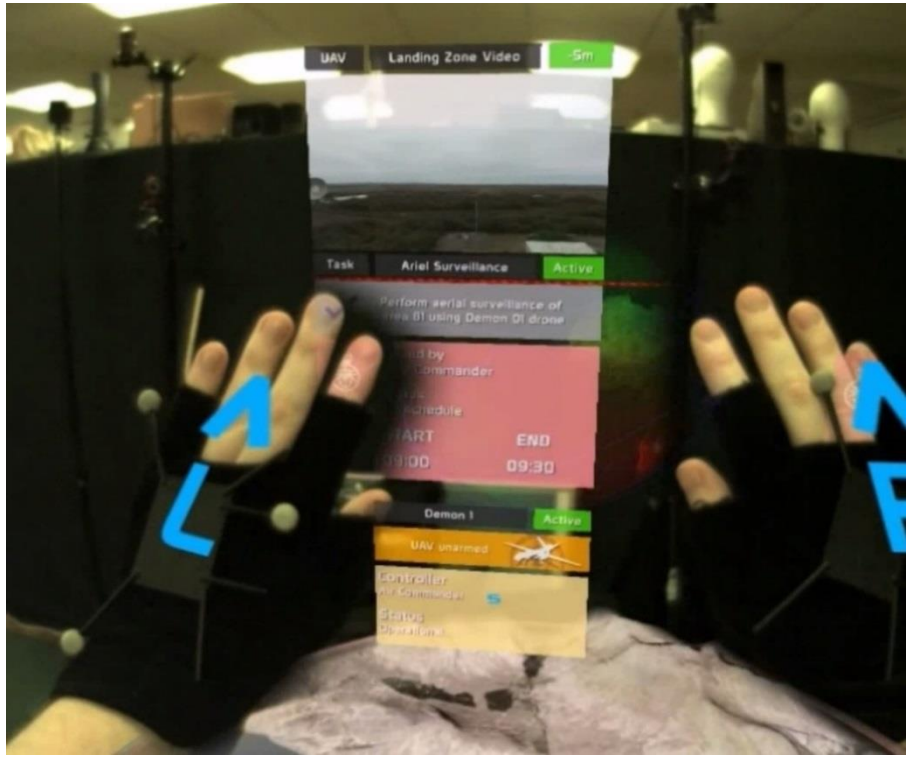
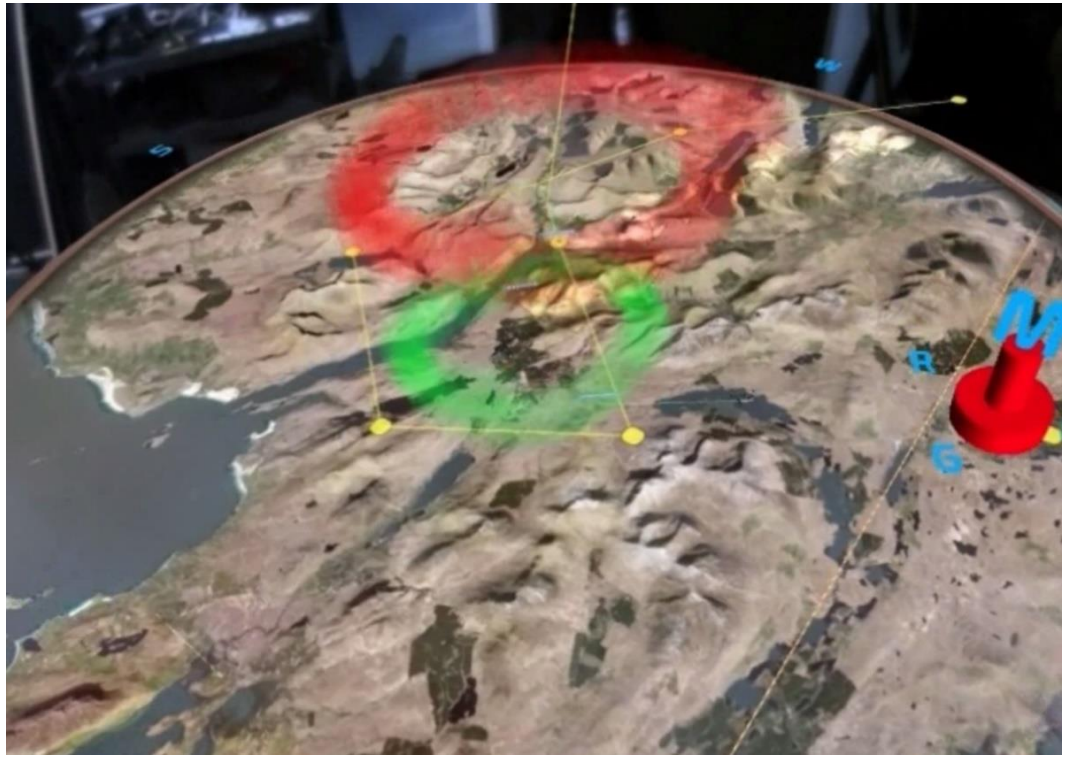
Case Study 2: Mixed Reality Command Station Testebed





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Case Study 3: User Monitoring

- Real-time psychophysiological monitoring
  - Cognitive Workload
    - HMD embedded eye-tracking (pupil dilation, fixation time, blink rate)
    - Self report workload questionnaire
  - Arousal
    - Electrodermal activity (EDA) / Galvanic Skin Response (GSR)
- Factors to trigger real-time adaptive interface actions
  - Monitor cognitive state (underload, vigilance, lock-up, overload)
    - Reduce information fidelity to core data only when in a state of cognitive overload
    - Provide tasks to occupy user when in a state of underload
  - Task performance metrics

Q&A

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