Analysis of Using Virtual Reality (VR) for Command and Control Applications of Multi-Robot Systems

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ABSTRACT

With the introduction of autonomous robot swarms rapidly increasing in number and applications (e.g. multiple, heterogeneous drone swarms), command and control systems face new challenges and complexity in the human decision making processes. We propose the development of a virtual reality (VR) system to maintain a workload low enough to account for the three levels of situational awareness (SA): perception, comprehension, and projection while commanding and controlling heterogeneous robot swarms. It is hypothesized that the unique immersion qualities experienced in VR environments increases SA and reduces operator workload. We implement several human factors principles and incremental user testing to achieve an ambitious goal of a single operator controlling a swarm of 250 semi-autonomous robots through a real-time VR environment.

CCS CONCEPTS

• **Computer systems organization → External interfaces for robotics**;

KEYWORDS

Virtual Reality (VR), command and control (C2), human-robot interaction (HRI)

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1 INTRODUCTION

There is growing interest in defense, and search and rescue to design an interface with the ability to integrate a human in the loop command and control application for multiple robots. To successfully conduct multi-robot missions, several human factors (workload, situational awareness, stress, and trust) need to be addressed [7]. Traditionally air traffic control and more recently multiple-UAV (Unmanned Aerial Vehicle) control are domains that could benefit from VR swarm control. Key challenges in these scenarios are peaks of workload and in turn reduced situational awareness [1]. To control multiple-robot missions, the operator has to have a balanced workload to perceive the current status/situation, comprehend the pertinent details, and project possible future scenarios to enable informed decisions/actions. Excessive workload could lead to errors at any point in this process, resulting in decreased mission performance [2].

Past research has evaluated how to display this kind of complex information. Comparing egocentric vs. exocentric features of 3D and 2D map display has shown that 3D displays introduce high ambiguity [10] and that egocentric views support flight guidance but not situational awareness [9]. It has been pointed out that three-dimensional (3D) perspective views on flat screens for operational tasks such as air traffic control are complex [8]. And VR has only recently begun to spark interest as a multi-robot interface [7]. We therefore consider the complete immersion in a high quality three-dimensional (3D) VR space a turning point for the complex representation of multi-robot control systems.

As of 2013, no human factors analysis has been published on mobile interfaces for multi-robot single operator systems [5, 6]. We propose the development and systematic human factors analysis of a VR system to command and control multiple UAVs through a single operator. Design choices and human factors analysis will aim to mitigate high workload and loss of situational awareness,

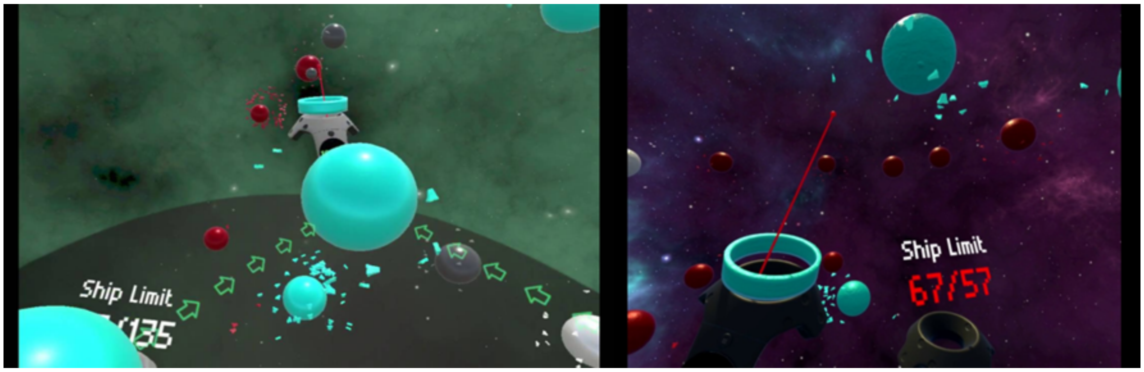

Figure 1: Screenshot of the Lazerbait VR game.

with an end goal of a system that enables a single operator to maintain control a swarm of up to 250 UAVs [DARPA OFFensive Swarm-Enabled Tactics (OFFSET) program].

With the successful implementation and testing, we will be able to answer the following research questions: Does an egocentric, exocentric, or combined view within an immersive VR environment lead to increased SA for specific control tasks? If needed, what controls inputs are appropriate to transition between views? Does a display of current and or predictive trajectory of the UAV's flight path benefit SA and workload? How do swarms, single entities, and their behaviors need to be represented in VR to maintain SA? How does that representation display their abilities in that moment without increasing workload? What kind of multimodal commands and feedback can be implemented without increasing workload onto the operator? Is a true 3-dimensional VR system ultimately superior to the 2-dimensional display for this type of task?

2 MATERIALS AND METHODS

2.1 Preliminary Task

Preliminary testing was all conducted on the commercially available HTC Vive virtual reality headset allowing the user to move in 3D space and use motion-tracked handheld controllers to interact with the environment. The preliminary testing environment is the VR game "Lazerbait". The goal of the game is to conquer the solar system, by sending your ships to capture the initially un-inhabited planets then the planets controlled by the adversary. The game is played against an AI and has multiple difficulty levels and maps. Within our preliminary test, we used the following game settings: medium difficulty, two teams in a game (participant and adversary), lowest number of ships, medium ship speed, a default 100% ship send rate (when you command your ships to travel to a new planet how many are sent), and a small map size consisting of 16 planets in a 3D virtual environment. The settings are difficult enough to create a high workload for novices in the game and to run a sufficiently long time to measure parameters. Within this environment, we are evaluating situational awareness and operator workload comparing an egocentric vs. an exocentric view in a within participant setting controlling for an order effect as all participants are new to the game.

Workload is determined through the NASA Task Load Index (NASA-TLX) [4] after each VR trial (egocentric and exocentric). Situational awareness is measured for the first two levels of SA: the *perception* of elements in the environment (level 1) and the *comprehension* of their meaning (level 2) [3]. Participants are asked 90 seconds into the game to take the headset off and account for friendly, enemy, and not yet conquered planets and their accuracy is measured. They are asked the same question a second time further into the game without removing the headset. Time to respond and accuracy in their responses are recorded. We also measure their overall performance in the game (number of captured planets) and control for previous VR experience. The intuitiveness of the controller inputs and the implemented menu are evaluated through open questions after the game interaction and will potentially influence future development of the VR multi-robot implementation.

2.2 Future Test Environment

Future research plans to replace the game of this study with a program originally developed by DARPA for a swarm control competition flying 25 heterogeneous drones against similarly equipped adversary. The original program consists of a flight tech interface (an arbiter to manage the swarm), a map, and a swarm commander (with playbook style inputs). We are integrating the latter two in our VR command and control system ultimately allowing to control a swarm in the real world in near real-time. The VR control provides the assignment of behaviors to sub-swarms and individual drones and the area the (friendly and enemy) drones. We are using the Unity game development platform (see Figure 2 for a screenshot of the current 2D display of the 3D environment). As of now, the user can freely move around in the environment along any dimension, creating confusion on the actual position in space and loss of SA. We are proposing to implement a more realistic environment representation (e.g. landmarks, terrain data), a projection trail for each sub-swarm or aircraft (future and/or past trail), an inset map, and the possibility to change between egocentric and exocentric views.

3 RESULTS

Data was submitted to a box plot analysis to look for outliers. It was decided, a priori, that any participant who has more than one score that is greater than three times the interquartile range (IQR) or two scores that are greater than one and a half times greater than the IQR would be excluded. There were no participants whose scores exceeded the criterion and thus all were included in the

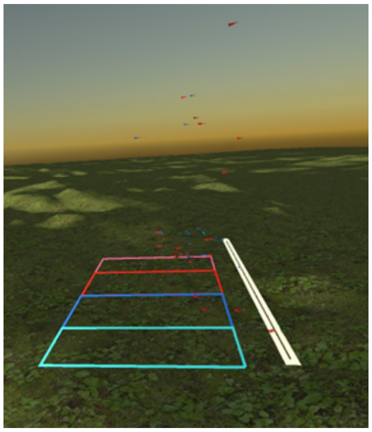

Figure 2: Screenshot of the VR environment currently under development at USAFA.

subsequent analyses. There was no significant difference between the egocentric and exocentric conditions for the number of errors in recollection of the number of their own planets, $t(8) = .887$, $p = .40$, 95% CI [-0.89, 2.00], recollection of the number of enemy planets, $t(8) = .894$, $p = .40$, 95% CI [-0.53, 1.19], or in their recollection of the total number of planets, , $t(8) = .375$, $p = .72$, 95% CI [-4.00, 5.56]. Additionally there were no significant differences between the egocentric and exocentric conditions on any of the TLX concepts (ps > .23). There were also no significant differences between conditions on self-reported control or sense of being overwhelmed (ps > .90). While not significant, difference between participants' self-reported awareness was trending towards significance, $t(6) = 1.88$, $p = .11$, 95% CI [-6.54, 49.39], such that they reported higher awareness in the exocentric condition (M = 83.57, SD = 14.06) than they did in the egocentric condition (M = 62.14, SD = 27.82). This leads to the assumption that a combined view should be implemented in the future test environment and tested again with the multi-robot task.

4 CONCLUSION

We showed that VR has the potential to become a viable user interface to observe and control multi-robot systems with a single operator. To maintain SA in a high workload task supported by an AI, it is crucial to test the human interface with the VR system for human factors concerns related to information processing and usability.

The development of a command and control system a large heterogeneous robot swarms, to enhance SA and minimize workload is challenging. However, with the available VR technology and the potential of the complete immersion in the 3-dimensional virtual world, new paradigms can now be explored to leverage these unique advantages. This work analyzed a potential impact of operator viewpoint and proposes testing additional paradigms and human factor implications for the final development of a VR multi-robot system which can be tested to optimize human factors considerations.

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REFERENCES

[1] Mary L Cummings, Sylvain Bruni, S Mercier, and PJ Mitchell. 2007. *Automation architecture for single operator, multiple UAV command and control.* Technical Report. Massachusetts Inst Of Tech Cambridge.

[2] Birsen Donmez, Carl Nehme, and Mary L Cummings. 2010. Modeling workload impact in multiple unmanned vehicle supervisory control. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans* 40, 6 (2010), 1180–1190.

[3] Mica R Endsley. 1988. Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors Society annual meeting*, Vol. 32. SAGE Publications Sage CA: Los Angeles, CA, 97–101.

[4] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, 139–183.

[5] Alan Hobbs. 2010. Unmanned aircraft systems. In *Human Factors in Aviation (Second Edition)*. Elsevier, 505–531.

[6] Joshua Michael Peschel and Robin Roberson Murphy. 2013. On the human–machine interaction of unmanned aerial system mission specialists. *IEEE Transactions on Human-Machine Systems* 43, 1 (2013), 53–62.

[7] Juan Jesús Roldán, Elena Peña-Tapia, Andrés Martín-Barrio, Miguel A Olivares-Méndez, Jaime Del Cerro, and Antonio Barrientos. 2017. Multi-robot interfaces and operator situational awareness: Study of the impact of immersion and prediction. *Sensors* 17, 8 (2017), 1720.

[8] Mark St. John, Michael B Cowen, Harvey S Smallman, and Heather M Oonk. 2001. The use of 2D and 3D displays for shape-understanding versus relative-position tasks. *Human Factors* 43, 1 (2001), 79–98.

[9] Christopher D Wickens. 1996. Situation awareness: impact of automation and display technology. *Situation awareness: limitations and enhancement in the aviation environment* (1996), k2.

[10] Christopher D Wickens, Chia-Chin Liang, Tyler Prevett, and Oscar Olmos. 1994. Egocentric and exocentric displays for terminal area navigation. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 38. SAGE Publications Sage CA: Los Angeles, CA, 16–20.