One-to(o)-many: Human-Machine Interfaces to Enable Multiple UAV Control by Single Operators

Kerstin S. Haring
University of Denver
Department of Computer Science, 2155 E. Wesley Ave, 80210 Denver
UNITED STATES OF AMERICA

Kerstin.Haring@du.edu

ABSTRACT

This work describes and reviews research addressing the Human-Machine-Interface challenges and potential solutions to enable a single operator to control multiple Unmanned Aerial Vehicles (UAVs) trough one interface. As a system, this is also described as Multi-Robot System (MRS). MRSs are applied to multiple areas, like environmental monitoring [1], search and rescue [2, 3], security [4], supervisory control of robot deliveries, and micro and nano-robot swarms in exploratory healthcare [5]. The advantages of one single operator controlling many robots at the same time, referred to as one-to-many relationship, are improved resource allocation, time cost, robustness, and other aspects of real-world missions [6]. However, increasing the number of robots is not necessarily a gain in system performance due to the increased cognitive workload on the single operator [7]. An early model describes the number of robots that can be controlled by a single operator using fan-out based on neglect tolerance, how the robot's effectiveness declines over time when neglected by the operator, and interaction time, the time required for task switch, establish context, plan, and communicate the plan to the robots [8]. The model has been extended to include wait times and performance metrics to model the level of fan-out for given task constraints [9].

The idea is that with appropriate automation and interface support, a single operator is able to command and control a larger number of UAVs up to hundreds of UAVs organized in swarms and subswarms. Two of the main challenges remain the appropriate and improved autonomy of current UAVs and MRSs, and the efficiency of Human-Robot Interaction interfaces appropriately representing system state and autonomy while taking into account the operator state and human cognitive resources and limitations. A third challenge presents itself in the establishment of appropriate metrics and measures for individual tasks and the overall system.

Considering the introduction of new autonomy capacities, human-machine-teaming capacities, and novel interfaces including Virtual Reality (VR) and Augmented Reality (AR) [10], this work reviews and discusses the challenges along three areas:

1. *The autonomy challenges to multi-robot system command and control from a human factors perspective,*
2. *the feasibility of novel Human-Robot Interaction user interface technologies, and*
3. *the metrics needed to appropriately determine human-machine teaming aspects necessary to achieve multiple robot control.*

Despite the continuous advances in automation and autonomy of robots and UAVs, there remains the human factors challenge of how to maintain supervisory control and shared situational awareness (SSA) of multiple robots at the same time. This multi-dimensional challenge becomes apparent when operators ask the question "What is it [the system] doing now?", expressing a large range of problems including the loss of transparency, trust, and shared situational awareness. It might even be the case that the operator at least

should be asking this question yet is not aware that there might be a problem, showing either over-trust in the system or a loss of situational awareness.

In order to control multiple robots at the same time by one operator, the operator does not only supervise and control the robots, the robots themselves need to communicate their states to the operator trough the interface. An effective interface then would enable the operator control of the robots without losing situational awareness and while maintaining a manageable cognitive workload. This requires the robots to have a certain level of autonomy as well as the interface to understand the current state of the operator, and all three entities working together as a team, forming the MRS system. Without human-machine teaming, a single operator will always be limited to a smaller number of robots to command and control.

Current multi robot command and control interfaces mainly rely on the use of a 2D display visually representing the multiple robots in addition to using other modalities for multi-modal interactions [11] (e.g. speech, audio, tactile) to support the human operator when their visual system is at capacity. This might for example include audio alerts when it is assumed that the operator does not notice the alarm on the display, a combination of visual and audio for important alerts, or the use of speech to command or group the robots. The critical point is when and how the operator should be notified about what issue, at what time, and in which order if there are several notifications.

It is crucial that the system as a whole is evaluated from a human factors perspective to enable the operator to work efficiently, to achieve all tasks and goals, to redirect their attention when needed, and to address all (including unexpected) issues appropriately and in order of criticality. A large body of research has evaluated such interfaces, especially in the area of aviation and operational tasks, however, only few research has evaluated 3D interfaces such as Virtual Reality (VR) or Augmented Reality (AR). It seems natural that a three-dimensional representation of a three-dimensional space enables operators to maintain shared situational awareness (SSA) with the robots they are controlling better than a two-dimensional representation of a three-dimensional space, as it is the case with current displays.

However, early research evaluating 3D displays found that 2D displays were not also sufficient, but also outperformed 3D displays when the tasks included line-of-sight ambiguity and even double ambiguity when an exocentric 3D tether display was used [12]. However, this research compared 2D displays to what was described as a variety of "3D" formats, a display that uses perceptual depth or distance cues to create a three-dimensional image. Creating this 3D impression on a 2D screen creates a 2 ½ dimensional effect and does not compare to the immersive environments of current VR and AR technologies. The differences observed could be attributed to the disconnect and translation between dimensions (3D real world on a 2D display that simulates 3D). It is therefore crucial to re-evaluate current 3D technology offering a true, immersive, 3D experience for the new pathways to complex command and control of multiple robots in three dimensional spaces.

This work looks at the potential metrics and measures that could compare different interfaces for single operator multi-robot systems.

[1] Roldán, Juan Jesús, et al. "Heterogeneous multi-robot system for mapping environmental variables of greenhouses." Sensors 16.7 (2016): 1018.

[2] Murphy, Robin R., et al. "Marine heterogeneous multirobot systems at the great Eastern Japan Tsunami recovery." Journal of Field Robotics 29.5 (2012): 819-831.

[3] Li, Alberto Quattrini, et al. "A semantically-informed multirobot system for exploration of relevant areas in search and rescue settings." Autonomous Robots 40.4 (2016): 581-597.

[4] Garzón, Mario, et al. "A multirobot system for distributed area coverage and signal searching in large

outdoor scenarios." Journal of Field Robotics 33.8 (2016): 1087-1106.

[5] Wang, Ben, Yabin Zhang, and Li Zhang. "Recent progress on micro-and nano-robots: Towards in vivo tracking and localization." Quantitative imaging in medicine and surgery 8.5 (2018): 461.

[6] Roldán, Juan Jesús, et al. "Multi-robot systems, virtual reality and ROS: developing a new generation of operator interfaces." Robot Operating System (ROS). Springer, Cham, 2019. 29-64.

[7] Rossi, Alessandra, Mariacarla Staffa, and Silvia Rossi. "Supervisory control of multiple robots through group communication." IEEE Transactions on Cognitive and Developmental Systems 9, no. 1 (2016): 56-67.

[8] Goodrich, Michael A., and Dan R. Olsen. "Seven principles of efficient human robot interaction." In SMC'03 Conference Proceedings. 2003 IEEE International Conference on Systems, Man and Cybernetics. Conference Theme-System Security and Assurance (Cat. No. 03CH37483), vol. 4, pp. 3942-3948. IEEE, 2003.

[9] Cummings, Mary L., Carl E. Nehme, Jacob Crandall, and Paul Mitchell. "Predicting operator capacity for supervisory control of multiple UAVs." In Innovations in Intelligent Machines-1, pp. 11-37. Springer, Berlin, Heidelberg, 2007.

[10] Haring, Kerstin S., et al. "Analysis of using virtual reality (VR) for command and control applications of multi-robot systems." Proceedings of the 1st International Workshop on Virtual, Augmented, and Mixed Reality for HRI (VAM-HRI). 2018.

[11] Chen, Jessie YC, Ellen C. Haas, and Michael J. Barnes. "Human performance issues and user interface design for teleoperated robots." IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews) 37.6 (2007): 1231-1245.

[12] Wickens, Christopher D. "The when and how of using 2-D and 3-D displays for operational tasks." Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Vol. 44. No. 21. Sage CA: Los Angeles, CA: SAGE Publications, 2000.