A human-machine interface analysis: Under critical operation scenario

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Abstract. *This study investigates the impact of the human-machine interface (HMI) on decision-making and Command and Control for Unmanned Aerial Systems (UAS). Using a prototype HMI simulating UAS in combat scenarios, we evaluate human performance through physiological sensors to identify trends in the relationship between HMI factors, decision-making, and system performance. The objective is to develop optimized HMI designs that reduce cognitive workload, improve decision-making, and enhance situational awareness during critical operations. The findings have implications for controlling Unmanned Aerial Vehicles (UAVs) in surveillance, search and rescue, and military operations, enhancing operational effectiveness and safety.*

1. Introduction

The aviation industry is increasingly adopting unmanned systems, such as Unmanned Aerial Vehicles (UAVs) and Unmanned Aerial Systems (UAS), which offer extended flight capabilities and increased payload capacity (Fricke & Holzapfel, 2016). However, the focus on aircraft technology has sometimes overshadowed the importance of human components within the system (Rowe et al., 2017). The unique characteristics of UAS, including physical separation between the pilot and the aircraft, remote control interfaces, and radiofrequency control, introduce unconventional human factors compared to traditional aviation practices (Landry, 2018).

Human error and deficiencies in the human-machine interface (HMI) have been identified as major contributors to accidents and incidents in UAV operations (Pestana, 2011). Automation reliance without maintaining situational awareness can lead to delayed decision-making and errors when off-nominal events occur (Engsley et al., 1997).

The objective of this study is to investigate the impact of the HMI on decision-making and Command and Control in the context of UAS operations. Scenarios and tasks will be defined using a prototype HMI that simulates UAS operations in a combat environment. Human performance will be evaluated using physiological sensors to provide quantitative insights and qualitative assessments of performance and mental workload. The data collected will be analyzed to identify trends and patterns, examining the relationship between HMI factors, decision-making processes, and overall system performance.

The goal is to contribute to the development of optimized HMI designs that can reduce cognitive workload, improve decision-making, and enhance situational awareness during critical operational conditions. The findings of this research will have practical implications for the effective and safe control of UAVs in various applications, including surveillance, search and rescue, and military operations. By evaluating human performance under critical operational conditions and developing optimized HMI solutions, the aim is to enhance overall effectiveness and safety in UAV control.

2. Methodology

This study involved the participation of 24 operators and 24 pilot participants with varying levels of piloting experience, ranging in age from 20 to 50 years. Each operator performed two flights, each lasting 30 minutes, while the pilot participants underwent a simulation-based experiment. Throughout the study, four replicates were conducted for the operators, and a structured process was followed for the pilot participants.

For the operators, the flights were conducted in three different settings. In the first setting, two operators were assigned to work together, one assumes navigation while the other operates the electro-optical POD. In the second setting, only one operator was responsible for controlling the UAV, allowing for the assessment of individual performance. In the third setting, one operator used voice commands (in English) to control the UAV, investigating the impact on operation and mental workload.

Performance data (NASA-TLX and ISA), physiological measures (Eye Tracker, GSR and ECG), and subjective questionnaires were collected during the flights for the operators, while the pilot participants' data collection included physiological measurements, workload assessments, and baseline comparisons. This methodology allowed for a detailed analysis of the effects of the different settings on UAV operation and provided valuable insights for the development of guidelines and best practices in the field of unmanned aerial systems operation. Figure 1 illustrates the testing process.

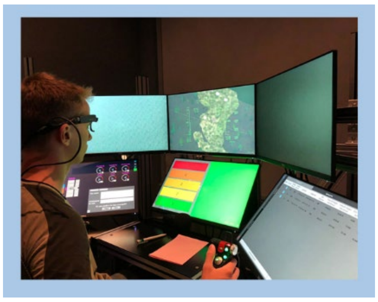

Figure 1 - Pilot in the simulation

3. Results and discussions

The main results indicated that the second flight showed a significant improvement compared to the first flight, likely due to the team's experience and familiarity with the system. The voice command configuration had the lowest performance, possibly due to inadequate optimization and language barriers.

ECG data yielded inconclusive results, while heart rate and heart rate variability (HRV) showed different conclusions. One operator experienced a higher mental workload in the first flight and when using voice commands.

Subjective questionnaires indicated no significant difference in mental workload between the flights. However, qualitative analysis revealed a higher mental workload in the second flight, likely due to task complexity and additional demands.

Operators using voice commands had a higher mental workload in both flights, suggesting increased cognitive demands. Real-time processing and interpretation of voice commands require greater attention and mental effort.

4. Preliminary conclusions

The results indicate that the operator using voice commands had the lowest performance and highest subjective mental workload. This association between performance, subjective mental workload, and physiological responses is noteworthy.

The lower performance observed in the operator using voice commands can be attributed to factors such as the additional cognitive demands and mental processing requirements introduced by voice-based interactions. The higher subjective mental workload reported by the operator using voice commands aligns with the taxing nature of voice-based interactions. The findings from physiological sensors further support the increased mental workload in this operator, indicating higher mental effort and stress during the task. These results underscore the importance of considering different interaction methods' impact on performance and mental workload to optimize user experience and system design.

5. Short biographies

Ivan de Souza Rehder: majored in Mechanical Engineering from the Federal University of Itajubá. Master's degree in Aeronautical and Mechanical Engineering from the Aeronautics Institute of Technology. During undergraduate studies, participated in the UNIFEI Formula SAE team and conducted a study on the optimization of the team's gearbox as the final project. During the master's program, focused on the use of virtual reality in the development of assistive products for the blind, using human factors as an evaluation parameter. Has experience in the use and processing of physiological sensors in human factors experiments.

Andrew Gomes Pereira Sarmento: majored in Control and Automation Engineering from the Institute of Higher Education Studies of Amazon (Brazil). In 2016 until 2017, he worked as a UAV consultant at Avanco's mining industry in Brazil. He has a master's degree in Aeronautical and Mechanical Engineering at the Aeronautics Institute of Technology, in 2020. Currently, he is pursuing his doctorate in Aeronautical Design, Aerospace Structures and Systems at Aeronautics Institute of Technology, Brazil. His interests are in systems of control, inertial navigation, identification, aerial estimation data and human factors.

Ana Carolina Russo: She has a bachelor's degree in environmental engineering from UNESP, a master's degree in Nuclear Technology from USP, and a Ph.D. in ITA. Currently, she serves as a member of the scientific committee for the International

Commission on Occupational Health, serves as a member of the technical group at the Brazilian Ergonomics Association, and teaches at the School of Engineering and Management.

Moacyr Machado Cardoso Junior: With a solid academic background acquired at ESALQ/USP, POLI/USP, IPT, and ITA, I have dedicated myself to the study and practice of Risk Analysis and Management for the past 20 years. This includes occupational and social risks arising from the impacts of industrial accidents and complex sociotechnical systems. In this regard, Over the years, this accumulated experience has enabled me to create postgraduate courses in the field of Risk Analysis, Quantitative Methods applied to Technological Risks, and Human Factors Engineering for the Technological Management Program - CTE-G at the Instituto Tecnológico de Aeronáutica in partnership with IEAv and IAE, organizations of the Aerospace Science and Technology Department - DCTA.

Emilia Villani: She holds a bachelor's degree in mechatronic engineering from the University of São Paulo, a master's degree), and a Ph.D. in mechanical engineering, also from the University of São Paulo. Since 2005, she has been a professor at the Instituto Tecnológico de Aeronáutica, working in mechatronic engineering and aerospace systems. Her research focuses on (1) specification, verification, and validation of embedded systems for critical applications, (2) design of industrial automation systems, with an emphasis on robotic applications, and (3) human factors in aeronautical applications.

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