Proceedings of the Annual General Donald R. Keith Memorial Conference
West Point, New York, USA
April 29, 2021
A Regional Conference of the Society for Industrial and Systems Engineering

Roadmapping the Human Machine Interface between Autonomous Systems and Special Forces Operators

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Abstract: United States Special Operations Command (USSOCOM) projects that autonomous systems will play a critical role in future conflicts. As such, it is imperative that the human-machine interface (HMI) be optimized such that the autonomous systems can provide the most benefit to USSOCOM operators. Currently, the HMI simply passes commands from the operator to the autonomous system and sends data from the autonomous system back to the operator. However, the HMI can provide numerous other capabilities. For example, it can convert natural language from the operator and translate it into robotic commands to the autonomous system. Meanwhile, it can fuse and analyze data, providing the operator with actionable intelligence. This study performed an in-depth stakeholder analysis to determine what functions are necessary for the optimal HMI. It then used value modeling coupled with market research and combat modeling to develop a technology roadmap to project the evolution of the HMI.

Keywords: Human Machine Interface, Roadmap, Value Modeling

1. Introduction

Robots are on the battlefield. Over the Global War on Terror, the US Department of Defense fielded numerous robotic systems across the services to provide its warfighters with a tactical edge. These robotic systems provided numerous new capabilities especially related to situational awareness. Given that robotic systems will play a critical role in future wars, it is necessary to optimize the human-machine interface (HMI) for these systems.

This study sets out to understand the requirements associated with the HMI for United States Special Operations Command (USSOCOM). A stakeholder analysis identified the functions that the HMI must perform for Special Forces operators. These functions were aligned with technologies at varying stages of maturity to develop a technology roadmap. Value-based modeling with combat simulation provided insight into the benefits associated with the evolution of the HMI. This study further analyzed the gaps that cannot be addressed through technology.

2. Background

2.1 Robot Usage by the US Special Forces Community

USSOCOM deploys Special Operations forces on a global scale to support operations against state and non-state actors. USSOCOM operators conduct missions that include civil affairs, counterinsurgency, counterterrorism, direct action, unconventional warfare, and hostage rescue (Davidson, 2019). This broad mission set necessitates a wide array of commercial and military robots. These robots "increase situational awareness, reduce workloads, and minimize the risk to the forward deployed soldier" (Army UAS CoE, 2009), but also vary in their degree of autonomy. Semi-autonomous robots can conduct specific tasks on their own but also have functions that require a human operator (Ryan, 2019). A fully autonomous robot does not require a human operator; rather, it is pre-programmed with decision algorithms that allow it to act with a degree of independence (Hughes, 2016). Most robots are currently semi-autonomous, such that a designated operator is tasked with piloting the robot over the mission.

The HMI is the technology layer through which operators interact with these robots (Ross, 2018). Currently, the HMI is made up of a series of disparate control modules and have very limited capability. The HMI is limited to the transmission of raw data, where the operator sends controls to the robot and receives back a video feed. However, it has the potential to provide significantly more capabilities. In particular, the HMI could process data from the robots and provide actionable intelligence. Meanwhile, it could take low-level commands (e.g., "go over there") and convert them into a series of directions to the robot, allowing a semi-autonomous robot to effectively act more autonomously.

2.2 Methodology

This analysis seeks to optimize the HMI to maximize the capabilities given to the operator, following the methodology depicted in Figure 1. The methodology follows a value-based technology roadmapping approach (Mittal, 2018). In the first phase, the analysis focused on identifying and defining the problem with the existing HMI. This phase consisted of interviewing stakeholders, conducting background research into manned-unmanned teaming, and identifying the ideal HMI. The analysis then moved into the solution design phase, which determined the technologies necessary to meet the stakeholder needs. These technologies allowed for the development of an optimal HMI design. Since these technologies are at varying levels of technical maturity, some will be available before others and this is reflected in two intermediate design concepts. The roadmap analysis developed a technology roadmap to show the change in the HMI with time as new technologies become available. Value modeling was used to quantify the associated increase in value given to the user with the evolution of the HMI. This phase included modeling each design iteration in a combat simulation to better understand the operational benefit associated with each improvement.

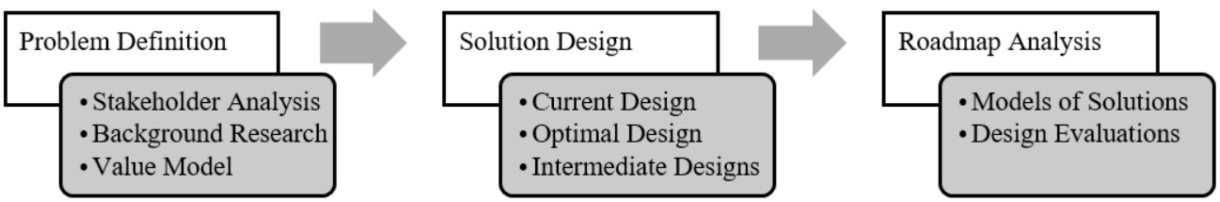

Figure 1. Methodology for this Analysis

3. Problem Definition

3.1 Stakeholder Analysis

Interviews, focus groups, and surveys with Special Forces operators of different teams, groups, and ranks provided insight into the usage of robots across the USSOCOM mission set. The stakeholders discussed the current use of robots in both kinetic and non-kinetic operations. They also extensively discussed their limitations, with a focus on what capabilities they would like to see from the system. The operational context diagrams in Figure 2 summarize the key findings from the stakeholder analysis.

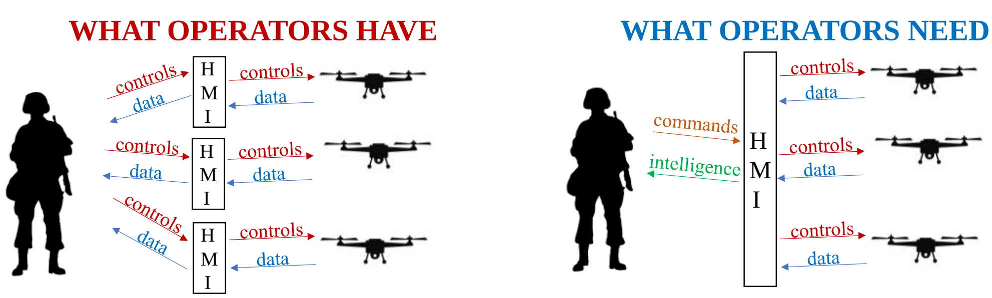

Figure 2. System Context Diagrams for the Current HMI (Left) and the Desired HMI (Right)

USSOCOM has many robots in their arsenal, most of which are semi-autonomous with stand-alone control systems. This results in teams being limited to 1-2 robots per mission due to the increased cognitive load placed on the operators.

However, these robots are critical because they provide situational awareness on the battlefield. Overall, the operators wanted the HMI to increase their survivability and lethality. They indicated that the ideal HMI would allow them to use one device to communicate with multiple ground and air robots. Also, the HMI would include processing and analysis, allowing the operator to simply give the robot a command, which the HMI converts into a series of control maneuvers. Similarly, the robot would send raw data to the HMI, which processes and fuses the data to provide the operator with actionable intelligence. In doing so, the cognitive loading from operating the robots would be reduced.

3.2 Functional Analysis

The stakeholder analysis provided insight into the functions that the HMI needs to fulfill. The fundamental objective of the system is to increase the survivability and lethality of operators through optimizing human-machine interactions. Four functions were then derived for the system to fulfill this fundamental objective, as depicted in Figure 3. The first function is retrieving data from the environment, which relates to the HMI accepting data collected by the robots. The second function is processing the data, such that the HMI software analyzes the raw data from the sensors and makes it useable for the operator. This function will rely heavily on machine learning and artificial intelligence to enable the HMI to do so. The third function is to send the processed data to the operator, which encompasses everything from sending data through radio frequencies to displaying on an interface device. The fourth function of the system is to receive and execute inputs from the operator. This encompasses the interface and the processor in taking commands from the operator and making the robot execute the commands.

A series of value measures were derived from the functional hierarchy to assess the increase in value associated with changes in the HMI design. These value measures are the number of capabilities, level of autonomy, degree of security, and the change in lethality and survivability. Each design can be evaluated and scored as it pertains to each of these five value measures. These scores are then multiplied by a weighing factor and averaged to provide a total value score between 0 and 100 for each design alternative.

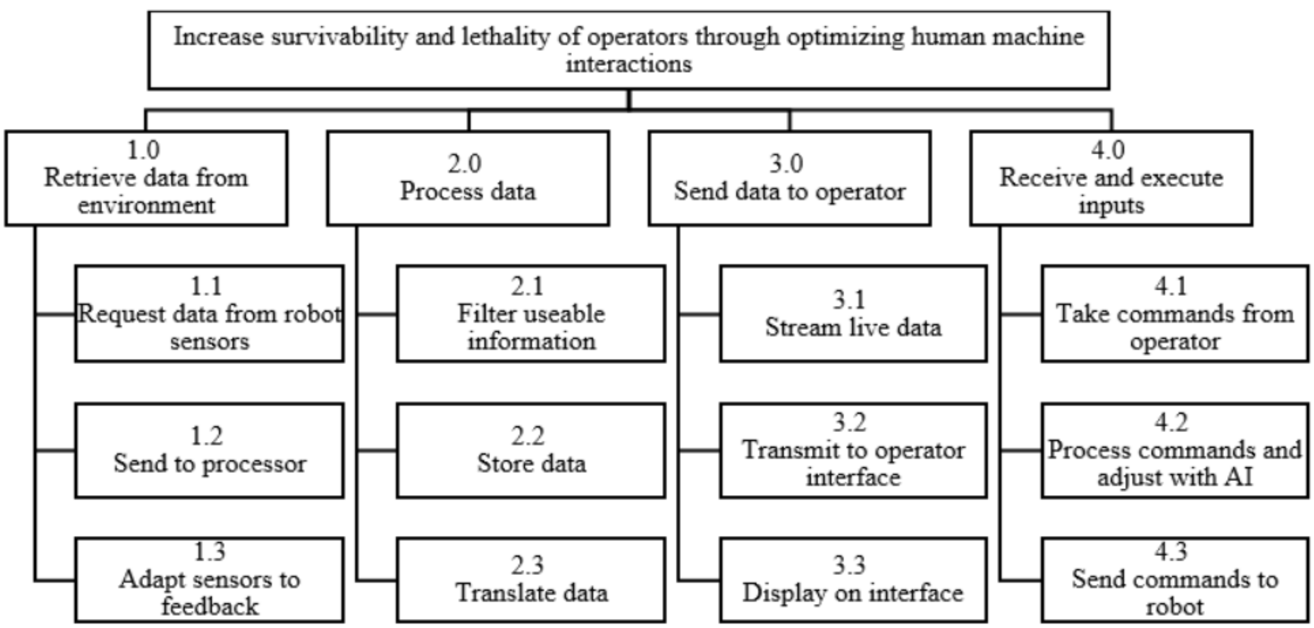

Figure 3. Functional Hierarchy

4. Solution Design

Table 1 summarizes the evolution of the HMI from its current form to allow it to perform the functions given in Figure 3. In particular, the necessary technologies are at various levels of technical maturity. HMI Increment 1 incorporates technologies that are somewhat mature, allowing for them to be integrated into the HMI by 2025. HMI Increment 2 adds technologies that are at medium levels of technical maturity that will not be available by 2030. The Optimal Solution design incorporates the immature technologies that will not be available until 2040.

Table 1. Functional Development Timeline

Functional Areas	Current	HMI Increment 1 (2025)	HMI Increment 2 (2030)	Optimal Solution (2040)
Retrieve data from environment	Regular camera, Basic GPS	IR, Night vision, Noise reduction, Radio frequency detection	Terrain analysis, Threat detection using biometrics, Standardized HMI architecture	IR, Night vision, Noise detection, Radio frequency detection, Terrain analysis, Threat detection
Process data	N/A	Identify friendly units, Identify and track objectives	Threat detection, Suggested terrain course of action, Identify and track enemies and noncombatants	Identify friendly units, Identify and track objectives, Threat detection, Suggest course of action
Send data to operator	Live video feed, Radio waves	Digital net, Encryption	Decentralized Processor	Digital net, Encryption, Decentralized processor
Receive and execute inputs	Needs manual input from operator	Maneuver based on waypoints	Digital and voice commands	Semi-Autonomous, Robot is part of the squad organization

The current HMI provides very little data from the environment aside from video feeds, which was an issue brought up during stakeholder analysis. Through continuous upgrades and the development of a standard HMI architecture, the HMI will be able to receive a large volume of data from multiple robots that will allow the operator to better understand the environment, demonstrated in Figure 2. For example, a group of robots could survey an area and collect biometric data on many people and identify possible enemy combatants.

The stakeholders indicated that current HMI systems do not process data, and provide only live camera feeds. Ideally, the HMI would be able to process the data retrieved from the environment and determine useful intelligence to the operator, including objective locations, friendly forces, noncombatants, and possible courses of actions based on terrain. Security was a key concern for our stakeholders, as they stated the future operational environment will be cyber-contested. The current HMI does not have adequate defenses from interference and attacks, making the data sent to the operators vulnerable to jamming and hacking. The optimal HMI system would have a decentralized processor to provide redundancies to the robotic system while also encrypting to block outsider interference.

When operators use the current HMI systems, they must manually control the robot movements and activities. This has a detrimental effect on the cognitive load for the operators. Current operations that involve unit organic robots remove one operator from the mission to control the robot. The optimal HMI will be more autonomous with built in functions and loops that can be received through digital and voice commands. The HMI would take simple commands from the operator and operate the robot system to carry out the sophisticated operations of the commands given. In doing so, the HMI will effectively allow the robot to function as a member of the squad.

5. Roadmap Analysis

The four designs shown in Table 1—Current, HMI Increment 1, HMI Increment 2, Optimal Solution—can be evaluated using the value model discussed in Section 3. Although the number of capabilities, level of autonomy, and degree of security can be evaluated directly from the design, survivability and lethality changes require that the solution be implemented in an operational environment. Combat simulation provides this capability.

5.1 Combat Modeling

This study utilized the Infantry Warrior Simulation (IWARS) to determine the implications of changing the HMI in a combat scenario. IWARS is an agent-based simulation package that analyzes small unit operations for small-scale, ground-

ISBN: 97819384962-0-2

based military operations. The methodologies that underly IWARS are stochastic, such that the simulation must be batch run to get a range of output parameters to include measures of survivability and lethality.

Two different models were developed in IWARS to analyze the use of robots for kinetic and non-kinetic operations. These models had been previously validated by USSOCOM (Arderi, 2020). The first mission consisted of a Special Forces team being attacked while conducting a key leader engagement. In this mission, robots supported the security detail by detecting enemy action. The second scenario modeled a hostage rescue mission, where two Special Forces teams entered and cleared a three-story building, where enemy forces were holding a hostage. For this scenario, robots provided increased situational awareness of enemy locations in addition to rear security.

Each scenario was run 100 times for each iteration of the HMI. As the HMI capability evolved, the robots were given new capabilities while the cognitive loading on the operators decreased. For the key leader engagement scenario, the average enemy deaths stayed consistent; however, the average number of blue fatalities decreased from 5.2 to 4.0. Similarly, for the raid, regardless of the HMI, the friendly forces killed all the enemy forces; however, with the improvements in the design, the number of friendly casualties decreased from 3.9 to 1.5. The average number of friendly and enemy casualties for these runs provided the data for the survivability and lethality value measures.

5.2 Value Analysis

Figure 4 shows the value score associated with each iteration of the HMI design. The value scores were calculated form the five value measures discussed in Section 3. As expected, with each increment in the design, the value score increases, approaching the score of 100, which will completely meet all the stakeholder needs.

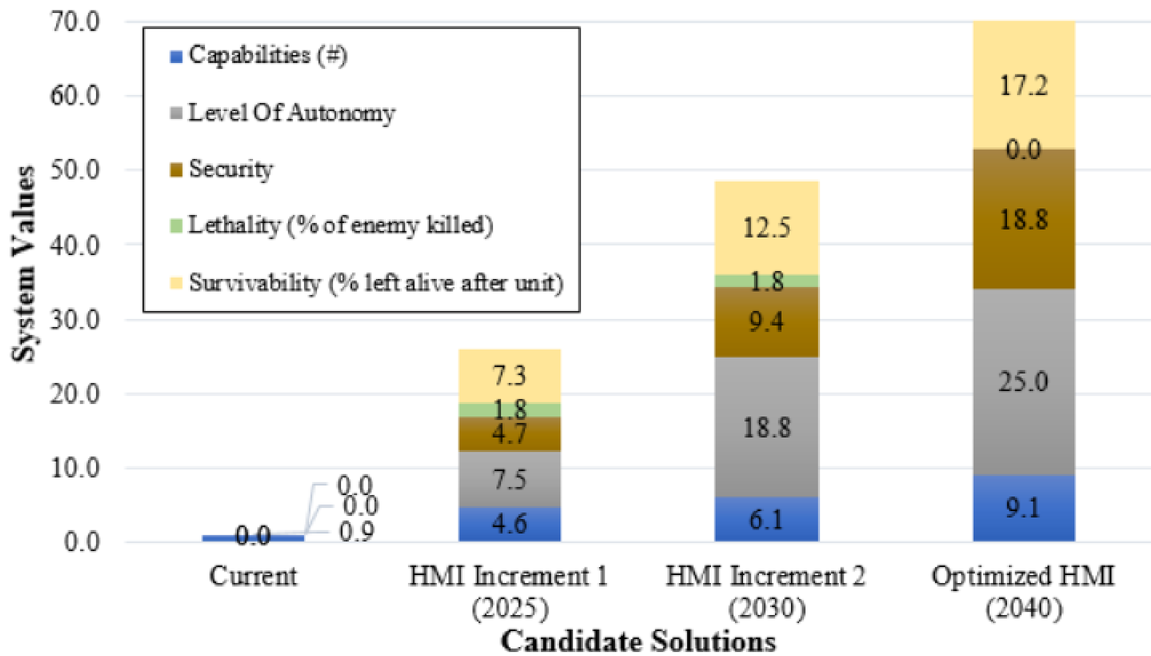

Figure 4. Value of the HMI System Over Time

ISBN: 97819384962-0-2

The current system received a score of 0.9. The first incremental design provides increases in value for all five categories, raising the value score to 25.9. This increase is primarily due to the increase of security and autonomy values with the addition of a digital network, encryption, and autonomous maneuvering through waypoints. The second incremental design further increases the value to the operator, with a score of 48.6. This increment provides several upgrades including threat detection, decentralized processing, and the capability to receive voice and digital commands. The optimized HMI, which should be available in the 2040 timeframe, has a value score of 70.1. The increase in value is due to the design synchronizing accumulated technologies from the previous increments.

Note that the score tied to lethality varied between the different designs. The combat simulations followed doctrine, where the operators had a numerical advantage over their adversaries. As such, in every scenario, they killed most of the enemies. As the HMI system evolved, the operators' heightened awareness allowed them to bypass enemies and therefore resulted in a lethality level lower than the previous increment. Additionally, as shown in Figure 4, the new technology allowed the Special Forces operators to take less casualties in the process.

It is important to note that the value scales are based on what the operators want; however, even in the optimal case, technology cannot meet all requirements. For example, the stakeholders discussed a desire for robots to be able to function completely as part of their squad and kill the enemy. Given current laws and rules of engagements this is not possible. With paradigm shifts and changes in international laws, robots can be empowered to perform more capabilities. As a result, the HMI can adjust to perform these capabilities and achieve a final value score of 100.

5.3 Key Assumptions and Limitations

The technology roadmap and value-based analysis are based on the interviews conducted with operators as well as an in-depth market survey to understand different technologies and technology trends. Numerous assumptions had to be made regarding the validity of information gathered from the market research. In some cases, companies may be over-stating their technology's level of maturity. While combat modeling with IWARS allowed for analysis of the HMI's capabilities, it did not provide insight on the design of the HMI. Additionally, the optimized HMI requires several key acquisition policy changes, including the development of a common robotics architecture. These policy changes may not necessarily be implemented. Although these limitations may change the overall value scores associated with the HMI evolution, the analysis still captured the requirements for the optimal HMI system, the likely evolution of the system, and used combat simulation to identify the operational changes associated with this evolution.

6. Conclusion

The success of USSOCOM in future war will depend heavily on the use of advanced technology. Robots will continue to play a critical role in the battlefield. As such, it is imperative that the HMI between robots and Special Forces operators be optimized to maximize the right capabilities. This study set out to understand the needs of USSOCOM operators in relation to HMI. An in-depth market research provided potential technical solutions for meeting these needs. Since the technology is at varying states of technical maturity, they will be implemented into the HMI design over time. As such, this approach allowed for the generation of a technology roadmap that identifies the evolution of the HMI from 2020 to 2040, consisting of the current HMI and three incremental improvements, with the final one being an optimized design. These designs were modeled in a combat simulation to analyze their operational benefits. The results of these models indicated that the incorporation of new technologies into the HMI provides additional value to the operators. In particular, the increased robotic autonomy and reduced cognitive load enhanced the operator's survivability. The optimized version, which would be available in 2040, is still limited from what the operators need, since some of the needs are limited by policies. Regardless, the optimized HMI will provide substantially more value to the operators than the current HMI.

7. References

Arderi, R., Chough, A., Kronschnabel, S., Rigoni, M., & Mittal, V. (2020). Hyper-Enabled Operator: Situational Awareness as Armor. *Industrial and Systems Engineering Review*, 43-49.

Army UAS CoE Staff. (2009). *Eyes of the Army. U.S. Army Roadmap for Unmanned Aircraft Systems 2010 - 2035*. Fort Rucker: U.S. Army.

Davidson, A., Flanick, S, Yoo, A., Mote, J., & Mittal, V. (2019). Expanding the Hyper-Enabled Operator Technology across the Special Forces Enterprise. *Industrial and Systems Engineering Review*, 2-8.

Hughes, C., & Hughes, T. (2016). 3. RSVP: Robot Scenario Visual Planning. *Robot Programming: A Guide to Controlling Autonomous Robots*, 47-72.

Mittal, V. (2018). The Use of Stochastic Value Models to Create Technology Roadmaps. In *2018 IEEE Technology and Engineering Management Conference (TEMSCON)* (pp. 1-6). IEEE.

Ross, L. T., Fardo, S. W., & Walach, M. F. (2018). *Industrial Robotics Fundamentals: Theory and Applications*. Goodheart-Willcox Company, Incorporated.

Ryan, T., & Mittal, V. (2019). Potential for Army Integration of Autonomous Systems by Warfighting Function. *Military Review*, 50-61.

ISBN: 97819384962-0-2