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December 2022

A Comprehensive Literature Review of Autonomous Surveillance Technologies Relating to Dismounted Soldiers

by Patricia M. Burcham

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1. INTRODUCTION

The development of the artificial intelligence/machine learning (AI/ML) applications for dismounted Soldier systems is paramount to defeating our adversaries, such as China and Russia, in future combat. A comprehensive AI/ML literature review is a first step toward defining what exists and what can be applied and researched for our nation's defense in future warfare. There is a clear need to use the latest AI/ML technologies in threat identification and elimination without U.S. lives lost. A comprehensive literature review is necessary to assist in defining the best path forward. In theory, networked unmanned aerial vehicles (UAVs) using onboard cameras may assist in successful navigation and threat identifications for ground troops. Furthermore, UAVs used as a surveillance and situational awareness (SA) tool may also be feasible to house weaponry to eliminate these threats.

2. METHODS, ASSUMPTIONS, AND PROCEDURES

2.1 Problem Statement

As next-generation AI/ML-enabled optical systems, visual enhancement systems, and accessories are developed for use by the Army, a comprehensive examination of the human systems integration implications for networked use of these systems for teams of Soldiers/Operators is needed to examine human performance relative to teams equipped with legacy weapons and enablers.

2.2 Approach

The U.S. Army Combat Capabilities Development Command (DEVCOM) Analysis Center, known as DAC, Human Systems Integration Division proposed a comprehensive literature review of autonomous applications, AI, ML, and networked UAVs relative to use of dismounted Soldier systems (i.e., weapon systems and enablers), to include enabling swarmed unmanned aerial systems (UASs), as a conceptual documentation of the potential for autonomous systems during operational tasks. The primary search engines used were the ARL Online Library Catalog (WebCat) and Google Scholar.

2.3 Literature Findings

2.3.1 An Exploration of Unmanned Aerial Vehicles in the Army's Future Combat Systems Family of Systems

Sulewski, C.A. (2005, December)¹

A critical part of the U.S. Army's future force will be UAVs. The future force will encompass network systems with integrated sensors and precision munitions and rely heavily on the UAVs to provide visual feedback of the battlefield. The UAVs may trigger munitions' deployment, or it may be handled by other platforms.

A simulation was built and analyzed to provide insight into the numbers and capabilities of UAVs affecting a future force Combined Arms Battalion's (CAB's) ability to secure a Northeast Asia urban objective.

Computational experiments to assess the UAV factors that affect the CAB to secure the objective with minimal losses revealed that UAVs significantly enhance the CAB's performance; UAV capabilities and their tactics outweigh the number of flying UAVs; battalion level UAVs, especially when armed, are critical in the opening phases of the battle, as they facilitate the rapid attrition of enemy high-payoff targets; and, at least one

company-level and a platoon-level UAV enhances dismounts' survivability later in the battle.

There was a 5% loss within the first 15 min of a fight when posed against a stronger enemy. This suggests that military leaders should devise a system minimizing casualties within the initial stages of a fight when up against a strong enemy situation.

It is important to keep in mind that armed UAVs change the weight and payload balance requirement of each UAV. Analysis of balance between munitions, sensors, and fuel can establish future building requirements of UAVs.

Takeaways include adding just one platoon-level UAV increases survival by nearly 1%. Having 11 or more battalion-level UAVs provides quick action and decision-making.

Lower-class UAVs provide the eyes over various terrains for dismounts. Operators need to balance the tactical flight pattern to cover essential ground while minimally loitering over detected targets.

One system consists of two UAVs and a control interface. The control interface displays the operator information and allows human interface with the UAV. The control interface is interoperable with the dismounted Soldier and the battle command system for mounted control. A networked SA capability will be provided to the UAV and small unit (platoon), in all missions, securing areas, and providing Reconnaissance, Surveillance, and Target Acquisition (RSTA).

Soldiers will employ the system and dismounted Soldiers will carry it in a container that fits within the "MOLLE pack" and protects the system from the effects of the weather and terrain.

The Class (CL) I (small 0–20 lb) UAV supports the following tasks: provides a reconnaissance and security/early-warning capability for the UAV, day or night; remotely watches over and reports changes in key terrain, avenues of approach and danger areas of open, rolling and restrictive terrain, and urban areas; provides target information for the line of sight/beyond line of sight (LOS/BLOS); provides target information for area fire munitions; performs limited communications relay (narrow band, short duration) in restrictive terrain within echelon; and does not require airfields.

Armed Robotic Vehicle-Assault Variant (ARV-A)

The ARV-A provides the infantry platoon RSTA, direct fire, and BLOS capabilities to support maneuver and dismounted operations. It responds to actions on contact, executing fire and maneuver and tactical assault to ensure lethality overmatch. It

supports cooperative engagements in the full variety of terrain sets including “point and shoot” engagements by dismounted Soldiers and designation of firing missions from other platforms or dismounted elements. ARV-A is the primary unmanned ground platform for reconnaissance and surveillance operations and the primary unmanned ground system enabler of BLOS in the infantry platoon. The ARV-A RSTA mission is threefold: 1) it provides the sophisticated onboard sensors; 2) it enables the delivery of precision BLOS fires; and 3, it detects, recognizes, and identifies targets with enough fidelity to support the use of LOS, BLOS and non-line-of-sight (NLOS) assets to support cooperative engagement.

UAV operators play a critical part in providing the eyes for the fight. The CL I and CL II UAVs have excellent sensor capabilities that provide battlefield signature patterns resulting in keeping dismounts alive.

2.3.2 Communication Architectures and Protocols for Networking Unmanned Aerial Vehicles

Li, J., Zhou, Y., & Lamont, L. (2013)²

In this paper, the pros and cons of four communication architectures for UAV networking are discussed. Some military communication standards applicable to UAV communications are reviewed. It was concluded that a UAV ad hoc network is most suitable to a UAV network team while a multilayer UAV ad hoc network is more suitable for multiple groups of heterogeneous UAVs. Through comparison of various legacy and next-generation military data link systems, one important feature of next-generation waveforms is their capability of Internet Protocol (IP) based upon ad hoc networking, allowing UAV's communications with each other in a single- or multilayer UAV ad hoc network.

A communication architecture specifies the information flow between the ground crew and a UAV or between UAVs. Four communication architectures for networking UAVs are discussed.

2.3.2.1 Centralized Communications

A centralized UAV communication architecture has a central node or ground station to which all UAVs are connected. Each UAV is connected to the ground station transmitting and receiving command and control data, and the UAVs are not directly connected to each other. A short information delay is common for data between ground crew and the UAV since all UAVs are connected to the ground station directly. Advanced radio transmission devices with high transmission power are necessary in the UAVs. This may not be feasible for medium or small UAVs due to their size and payload

constraints. The centralized UAV communication is not robust as the ground station is a UAV network vulnerability by a single point of failure. If the ground station encounters problems, so does the UAV network.

2.3.2.2 *Decentralized Communications*

In a decentralized communication architecture, a central node is not required so that two UAVs can communicate with one another directly or indirectly. Three decentralized communications are discussed.

1. **UAV Ad Hoc Network.** A UAV ad hoc network does not depend on a preexisting infrastructure. Each UAV will participate in data forwarding for other network UAVs. A backbone UAV acts as a gateway of the ad hoc network, relaying information data between the ground station and the other UAVs. The gateway UAV houses two radios: one for communications with the ground station and the other for communication with the UAVs. The coverage area by the network is significantly extended since only one UAV is needed to connect to the ground station. Also, because multiple UAVs are flying close to one another, the UAV transceiver device can be low-cost and lightweight, making it suitable for small- and medium-sized UAVs. Speeds and heading directions need to be similar for all UAVs to ensure network connectivity. This architecture is appropriate to networking similar UAVs for operations such as persistent surveillance operations.
2. **Multigroup UAV Network.** A multigroup UAV network consists of UAVs within a group that form a UAV ad hoc network with its respective backbone UAV connecting to the ground station. Intragroup communications (same group communication) are conducted within a UAV ad hoc network while intercommunications (communications involving two different groups) are performed via respective backbone UAVs and ground station. This communication architecture is suitable for a large number of UAVs with different flight or communication characteristics. It still lacks robustness due to its semi-centralized nature.
3. **Multilayer UAV Ad Hoc Network.** An individual group of UAVs form an ad hoc network that corresponds to the lower layer of the multilayer UAV ad hoc network architecture. The upper-layer UAV ad hoc network is the backbone for all UAV groups. Information exchange between any two UAV groups does not need to be routed through to the ground station. The ground station only processes data that are destined to it, resulting in a significant reduction in ground station and communication load. A multilayer UAV ad hoc network is robust since there is no single point of failure.

2.3.2.3 *Communication Protocols (Data Links)*

In military communications, a data link consists of physical devices used for transmission and reception of information data and protocols that govern the manner of information transmission and reception. A physical device is characterized by transmission range, data rate, operating frequency, link protection and security, communication mode, message format, and transceiver weight/size/cost/power.

Several next-generation data link systems have been proposed to facilitate communications in decentralized UAV networks. An overview of the current and next-generation data link standards is reviewed.

1. **Common Data Link (CDL):** CDL is a secure communications link developed in 1991 by the U.S. military as a primary military protocol allowing full duplex transmitting imagery and signal intelligence. CDL specifies a radio set providing standardized, wideband LOS communication between UAVs and ground stations.
2. **Tactical Common Data Link (TCDL):** TCDL is a U.S. military secure data link to send secure multimedia data from airborne platforms to ground stations. The data rates modulation techniques and transmission frequencies are fully interoperable with CDL.
3. **Link-11:** Link-11 is the NATO design of Tactical Digital Information Link. It employs netted communication techniques and a standard message format for exchanged digital information among airborne, land-based, and shipboard tactical data systems. Link-11 is a full-duplex, two-way, point-to-point tactical data link providing serial communications between NATO nations.
4. **Link-14:** Link-14 is a maritime data link system for broadcasting information data for ship-to-ship and ship-to-shore communications. Link-14 is used as a backup for ships not equipped to decode and use Link-11 data.
5. **Link-16:** Link-16 is a jam-resistant L-band tactical data link designed by NATO. It is mainly used for air-to-air, ship-to-air, and ground-to-air applications. It is the dominant standard for command, control, and intelligence, providing critical joint interpretability and situation awareness information. Link-16 uses the Joint Tactical Information Distribution System.
6. **Link-22:** Link-22 is a NATO secure radio system that provides BLOS communications. It interconnects air, surface, subsurface, and ground-based tactical data systems and is used for the exchange of military units' tactical data of participating nations.

2.3.2.4 *Next-Generation Data Links*

The Joint Tactical Radio System (JTRS), a next-generation data link, was proposed for tactical UAV communication. JTRS is a highly configurable tactical data link intended to replace legacy military radio standards with a faster, more flexible system. It includes encryption capabilities for secure voice and data transfer, and wideband networking software. JTRS includes two major development waveforms: Tactical Targeting Network Technology and Wideband Networking Waveform Platform.

In summary, decentralized communication architectures are suited for a one-to-many mode of operating multiple UAVs through provisioning of timely air-to-air and air-to-ground information exchange. A UAV ad hoc network is suitable for UAV single groups of similar type. A multilayer UAV ad hoc network is suited for a large number of heterogeneous UAVs. Next-generation waveforms provide IP-based ad hoc internet-working capability and will be adopted for UAV network decentralized communications.

2.3.3 Drones Weaponized with a Smart Shooter – Killers from Above

Eshel, T. (2022, January 10)³

The SMASH Dragon employs an advanced remotely controlled robotic weapon payload on drones or unmanned aerial platforms. While drones are highly versatile weaponized platforms when deploying precision-guided weapons, mounting direct-firing weapons onto drones can be challenging due to stabilizing issues. The SMASH Dragon features Smart Shooter's proprietary target acquisition and tracking algorithms while implementing computer vision to acquire the operator's target. Then, the fire control system releases the shot once the target is in sight, ensuring precise hits even in complex scenarios.

The system can be mounted with a variety of assault weapons and sniper rifles, 40-mm grenade launchers, among other weapons. The robotic system aims and fires the gun with high precision despite the unstable platform.

SMASH Dragon, a lightweight mount with a unique SMASH technology stabilization concept, allows the weapon to release accurate shots with high hit probability against stationary and moving targets during flight. It is derived from the Smart Shooter's technology, implemented in unmanned systems. Other applications include counter-drone platforms and lightweight remotely operated weapon stations for light combat vehicles, UGVs, and dismounted usages.

2.3.4 Special Issue on Unmanned Aerial Vehicle (UAV)-Enabled Green Communications and Networking

Zhao, N., da Costa, D.B., Tang, J., Wang, X., & Chambers, J.A. (2021, September)⁴

A critical challenge of 5th generation (5G) mobile networks is supporting high levels of data traffic and massive connections. To overcome this challenge, a UAV can be a promising communication platform in future wireless networks due to its flexibility, mobility, hovering, and low cost. The air-to-air and air-to-ground channels are much better than ground-to-ground channels when a UAV is used as a base station. Most often, the communication between a UAV base station and user equipment can benefit from the LOS channel in between. Millimeter wave transmission yields a higher data rate.

The most challenging issue for UAV communications and networking surrounds the limited on-board energy storage. The endurance of a battery-powered rotary-wing UAV is often less than 1 h, but it may take several hours to charge due to added propulsion energy consumption to maintain airborne and support movement. Energy efficiency could be optimized. Wireless power transfer (WPT) is a promising solution to low-power devices over long distance with fading.

UAVs can fly close to ground energy sources with excellent LOS air-to-ground channels and the WPT efficiency can be significantly improved.

As UAVs can be flexibly combined with much of the latest wireless advances to achieve better performance, it is imperative to conduct thorough investigation of UAV-enabled green communications and networks. This issue includes 14 articles of the latest research on UAV-enabled green communications and networking.

2.3.5 HMD Vision-based Teleoperating UGV and UAV for Hostile Environment using Deep Learning

Sawarkar, A., Chaudhari, V., Chavan, R., Zope, V., Budale, A., & Kazi, F. (2016, September 14)⁵

This paper discussed a novel teleoperating robot that can play a major role in combat, rescue, and reconnaissance missions while significantly reducing loss of human Soldiers in hostile environments. The proposed robotic solution consisted of a UGV equipped with an IP camera visual system broadcasting real-time video data to a remote cloud server. With the advancement of ML algorithms in computer vision, state-of-the-art deep convolutional neural networks to identify and predict individuals with malevolent intent was incorporated. The trained network in the cloud server performed

the classification on every frame of the video stream. The network-predicted output was overlaid on the video stream with specific color marks and prediction percentages. Finally, the data was resized into half side-by-side format and streamed to the head-mount display worn by the human controller, which facilitates first-person view of the scenario. The ground vehicle was also coupled with a UAV for aerial surveillance. The proposed scheme is an assistive system, and the final decision lies with the human handler.

In this paper, a robotic solution comprised of both hardware and software entities for handling hostile situations, reducing casualties, and loss of human life was presented. A teleoperating UGV and UAV were equipped with wireless vision sensor. HOG+SVM and Haar Cascade provided algorithms for human detection. State-of-the-art deep learning architecture for terrorist classification was demonstrated for maintaining safety and security and use in a hostile environment. The paper highlighted the advantages of head-mounted displays in teleoperating systems.

The system identified a person with a gun as a threat. However, it can be designed to differentiate between an armed serviceman and an armed unknown person. This capability will eventually help to counter hostile situations. The face-detection technique can be used to detect a person with a precompiled database and a match will provide valuable information.

The system can be used in various scenarios such as disaster response, rescue missions, or operations in hazardous radioactive environments. The deep convolutional network can be trained to identify humans surviving in disaster-hit areas, dangerous chemicals in decrepit chemical and radioactive plants, and biological samples in such sites. A swarm of fully autonomous or semi-autonomous teleoperating robots could prove beneficial in mitigating human loss in hostile situations.

2.3.6 Human/Machine Interface Modalities for Soldier Systems Technologies

Mulgund, S., Stokes, J., Turieo, M., & Devine, M. (2002, October 25)⁶

This report reviews human/machine interface (HMI) modalities' literature as well as guidelines for system designers to aid in choosing applicable modalities to augment human cognitive performance.

The Army's Objective Force Warrior (OFW) program seeks to create a lightweight, lethal, and fully integrated individual combat system that includes a weapon, full-coverage individual protection (head-to-toe), networked communications, Soldier-donned power sources, and enhanced human performance. To achieve this goal, the development of Soldier-centric HMIs that optimize cognitive fightability is partially

necessary. HMIs need to be designed so that the nature of human information processing and cognition are considered. In turn, this is dependent on how best to use human senses to perceive the environment and also the means by which they can affect the modalities of human–machine interaction. Traditional HMI design approaches encompass visual displays and manual inputs, not fully taking advantage of the various means that humans can perceive and interact with the environment.

There are four key areas covered in this report:

1. Models of Human Information Processing
2. Modalities for Information Presentation
3. Modalities for System Control
4. Analysis of Soldier Needs

2.3.6.1 *Models of Human Information Processing*

HMIs should be designed to optimize human performance. In particular, the following considerations motivate an appropriate high-level view of task-specific HMI design:

- A classification of human behavior based on the degree of cognitive processing
- Compatibility in stimulus-central processing-response (SCR) for display/control design
- Effects of attention-sharing and multitasking

Human behavior can be classified into three successive levels: skill-, rule-, and knowledge-based. These successive levels have a higher degree of cognitive processing and a lower automaticity than the previous.

Skill-based actions largely rely on human response speed. Accuracy is important to rule- and knowledge-based tasks. When choosing information presentation modalities, consider whether the underlying task is rule- or knowledge-based, placing top-end on the information presentation accuracy and precision.

Reaction time metrics are often optimized using auditory alerts while visual presentation is optimized when accuracy and continuous feedback is important. A key focus in modality selection is the compatibility of stimulus response (SR) pairing with relation to control/display. Visual inputs pair well with manual inputs and auditory inputs with speech output when measuring reaction time. This may be generalized as SCR.

Spatial tasks involve a judgment concerning the axes of translation and rotation, while verbal tasks involve the use of language and arbitrary symbolic coding. Spatial tasks are best associated with visual inputs and manual outputs, while verbal tasks pair well

with auditory input and speech output. Various considerations constrain these findings. Augmenting primary modalities with others can be very effective.

Finally, the effects of attention-sharing and multitasking need to be considered. The multiple resource theory of human information processing proposes that the resources for which multiple tasks compete may be defined by input and output modalities, by information processing stages, and by processing codes (verbal/spatial) (Table 1). These dimensions are considered to be independent of each another. Therefore, two tasks that share common resource demands will be time-shared less effectively than those with nonoverlapping demands.

Table 1. Modalities of Information Presentation

Modality	Methodology	Applicability and Guidelines for Use
Visual	Head-Mounted Displays (HMDs)	• Overall, visual presentation is applicable for spatial information • Visual textual displays acceptable for verbal information, particularly longer messages • HMDs particularly useful in situations where information is needed without diverting gaze, “on-the-move” operations
	Text vs. Graphic Presentation	• Graphic/symbolic presentation preferred for speed • Textual presentation preferred for accuracy • Can be combined to facilitate speed of comprehension, accuracy of interpretation, and long-term retention
Auditory	Alerts and Warnings	• Effective for rapid cueing of critical information • Alerts should be short and simple • Bi-modal (visual with auditory) warnings can elicit faster response than either uni-modal warning
	Spatial Audio Cues	• Audio signals can be spatialized to indicate direction and location and movement • Spatialized audio can help identify auditory messages in noisy conditions or could be used for navigation tasks (waypoints, object/person locations, etc.)
Haptic	Tactile Cues	• Effective for simple alerting via vibrations, pressure, etc. • More complex applications to provide sense of presence, orientation, or direction in a task environment without added cognitive burden
	Kinesthetic	• Can supplement other displays to help remember location of items in space relative to self, increasing recall • Increase usability and reduce mode error by implementing quasi-modes that are maintained kinesthetically • Typically not used alone

2.3.6.2 Modalities of System Control

Means by which humans provide input or control commands into a system must also be considered. For seamless interaction, computers should interpret all natural human actions.

The control modalities to provide input to a system via an HMI are manual, gaze, and neural (Table 2). Manual control is the most developed. Gaze- and speech-based control are becoming more viable. Neural control is relatively new.

Table 2. Modalities of System Control

Modality	Technology/Methodology	Applicability and Guidelines for Use
Manual	Simple	• Generally suited for controlling spatial elements; often paired with visual presentations • Also used for communicating verbal information, such as text entry, but not always ideal • Visual, auditory, or haptic feedback should be provided to indicate status
	Gesture	• Can be used for manipulation and communication
Gaze-based Control	Head	• Best for infrequent, non-command applications, because long or repeated movements of head can become annoying, tiresome, and distracting from other tasks • Best used for tasks where the control is closely associated with gaze, such as moving or selecting items • Can be considered in circumstances where physical impairment usage of other control modalities is limited
	Eye	• More applicable for frequently used controls because the eye can better handle frequent, repetitive movements
Speech Recognition	Speech-based Browsing	• Verbal commands and text entry can be “more natural” with speech compared to typing or handwriting recognition • Allows user to activate functions without diverting gaze
	Command and Control	• Can be used for just about any operating commands where background noise is not a cause for error • Frees hands to be used in other concurrent tasks

2.3.6.3 *Analysis of Soldier Needs*

To design a more robust, usable, and effective Soldier system, first examine the information needs and then determine the best modality or modalities combination that would best suit the information to be presented.

The types of information displayed, the actions performed, and the information being processed should lead the development of the Soldier systems' information display technologies.

This report further examines how the principles and design methodologies discussed can support task-oriented identification of HMI modalities for Soldier systems. Soldier needs are first identified, based on work conducted under the Scorpion and OFW programs to characterize Soldier tasks and activities. Tasks are then classified by the type of cognitive processing they entail. Finally, some preliminary thoughts are presented based on which HMI modalities may best support human performance in completing these tasks. This analysis is based on connecting the nature of the cognitive processing associated with a Soldier's task and the literature findings on the merits and applicability of various input/output modalities. The exact specification requires detailed consideration of tasks, context, and concurrent activity.

2.3.7 Human–Robot Interaction Design Research: from Teleoperations to Human–Agent Teaming

Barnes, M., Elliott, L.R., Wright, J., Scharine, A., & Chen, J. (2019, September)⁷

This report discusses multiyear human–robot interaction (HRI) emphasizing design principles of early teleoperation research to current human–agent teaming (HAT) research. An important principle that agents become more autonomous and increase demand of Soldier taskings is discussed.

Barnes et al. 2019⁷ stated, “AI will not only improve response time and precision of weapons but autonomous systems will act as force multipliers. Modern forces will consist of manned, unmanned, and autonomous elements controlled directly or indirectly by human supervisors.”

When evaluating displays for UAVs and UGVs, research found that Soldiers with 4-in. (diagonal) handheld or 12-in. tablet displays could interpret intelligence information from remote sensors equally well whereas helmet-mounted displays resulted in poorer performance, possibly resulting from eye strain and binocular rivalry.

Performance was improved with multiple-image displays such that the remote operators could compare UAS and UGV views. These multiples improved single-imagery displays enabling remote operators' frontal (unmanned aircraft general [UAG]) and planar (UAS) views of an ongoing mission within a map display context.

Display augmentation for Automated Navigation Systems (ANSs) implemented in a robotic version of the Stryker combat vehicle were investigated. The augmentation displayed information from the on-board ANS sensors to predict near-term and longer-projection vehicle paths and obstacles. The research demonstrated that the military operators were more likely to rely on (trust) autonomous options when they were shown projected outcomes. When comparisons are required and the amount of information to process is large, graphical visualization techniques successfully convey information to the operator without increasing their cognitive workload.

Displays with both aerial and ground views of UV sensors within geographical context will enhance the Soldier's overall SA of the battlefield.

Driver's trust of ANS increase when displays show both near- and long-term vehicle path projections.

Advantages of speech and audio:

1. Traditional Soldier–Soldier communication; generalizes to Soldier interactions
2. Lowers workload/increases comprehension in stationary settings
3. Lowers workload when used to give commands to robotic assets
4. 3-D audio cues can clarify multiple communication channels
5. 3-D can provide direction cues
6. Effective during poor visibility

Disadvantages of speech and audio:

1. Not covert when silence required
2. Not as effective in noisy context
3. Front-back cone of confusion (3-D audio)

When a tactile belt was added to a chest-mounted visual display involving waypoint navigation and incoming message receipts, missions using the tactile cueing resulted in reduced mission times, increased navigation accuracy, and lower cognitive workload, effort, and frustration. Soldiers reported increased SA and improved weapon control. Additionally, when the tactile belt was on, Soldiers rarely checked the visual display.

2.3.8 Networked Unmanned Aerial Vehicles for Surveillance and Monitoring: a Survey

Li, X., & Savkin, A. (2021)¹¹

This article classifies networked UAVs for surveillance and monitoring publications using targets of interest and analyzes common problems such as control, navigation, and deployment optimization. Research gaps and future directions are presented. There are several different methods of surveillance that include camera observation, GPS tracking, radio surveillance, and biometric surveillance. Due to the development of UAVs, computer vision, and sensor technology, UAV systems are capable of solving difficult tasks with lower cost and higher security and reliability. UAVs can quickly cover large and difficult-to-reach areas, reduce labor costs, and require little operator workspace. Because UAVs may encounter technical or other issues, networked UAV systems may still complete a mission when one fails. UAV networks work more efficiently, collecting more spatial-temporal data than a single UAV. UAV networks may be equipped with different sensor types allowing a wider range of data collection. Flight formation with combinations of sizes and configurations may conduct more complex tasks.

This paper is broken down into general target surveillance (Figure 1), traffic monitoring, wildlife monitoring, and radio surveillance. Humans or other objects in a given area of interest can be considered general targets. The classification of approaches may be organized in accordance with optimization objective, target type, operating mode, and the actual number of UAVs.

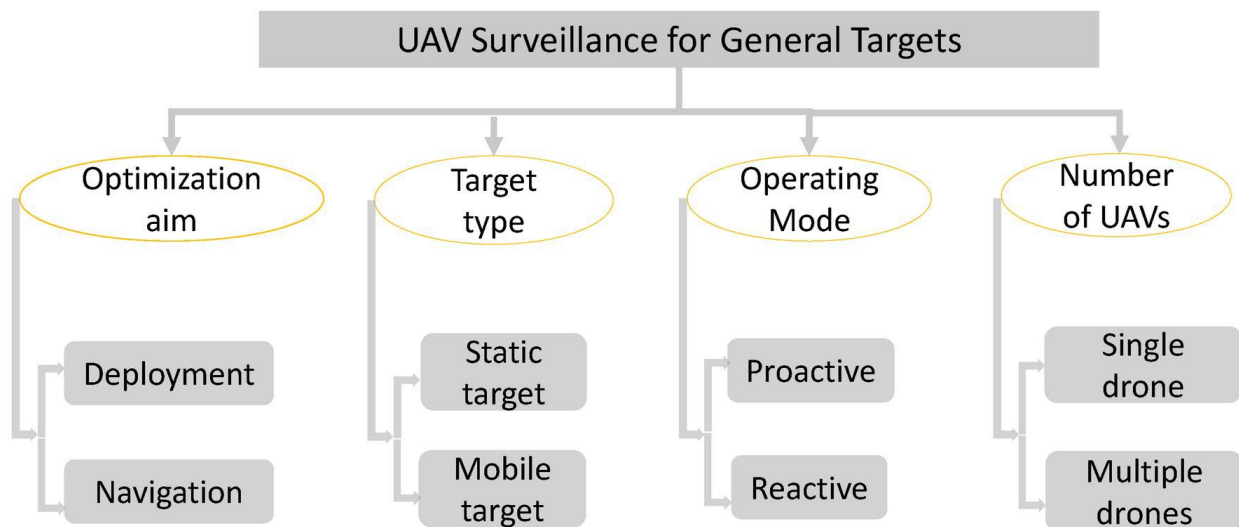


Figure 1. UAV surveillance for general targets summary¹¹

Optimization Objectives

The literature on deployment of surveillance UAVs can be divided into four categories according to the optimization objectives.

1. To minimize the number of UAVs needed to monitor an area, an algorithm based on Kershner's theorem from combinatorial geometry is used.
2. To maximize the number of covered targets for surveillance and monitoring, an energy-efficient deployment approach was presented. The vertical position or altitude of the UAV is located, providing maximal coverage, and then optimizes the UAV's horizontal position to maximize the number of covered targets while minimizing the transmission power. A mixed integer nonlinear problem involving both horizontal and vertical coordinates was used to maximize the number of targets served.
3. To maximize the quality of coverage of an area or targets for surveillance and monitoring, a reactive collision-free 3-D algorithm consisting of two control laws for horizontal and vertical submovements of the UAVs in real time was incorporated. The deployment problem for a group of UAVs to maximize the quality of coverage of an area of surveillance was considered. A distributed optimization model and coverage-maximizing algorithm to find the UAVs' locations was proposed. The model considered the constraint that a connected communication graph needs to be maintained between the UAVs and some ground nodes. The algorithm does not require global information and can converge to a local maximum within a finite number of steps. For high-quality surveillance of groups of moving pedestrians or vehicles on given paths with unknown speeds, a computationally simple algorithm to determine the deployment of multiple UAVs was proposed. The quality of coverage is calculated based on the distances between the UAVs and targets (the closer, the better). The algorithm only requires local information, with minimal involvement of the central station.
4. Joint objectives such as balancing a UAV's energy consumption and the number of covered targets were considered. A control system, containing a movement decision-maker and a decentralized algorithm, to reactively determine a fleet of UAVs' positions in 3-D space that contributes more to the coverage was designed and shown to achieve better network lifetime and target coverage. However, they only considered targets on the ground, not blockage caused by some high-rise buildings. The power received from a UAV at a target was calculated as a function of the target's horizontal distance from the UAV and the UAV's altitude. The optimal position in the horizontal and vertical dimensions was then decoupled. The horizontal position was determined using the center of the

smallest circle that covers the given set of targets, and the vertical position was determined using the least amount of transmitting power to cover that circle.

A few recent publications investigated covert surveillance for security that focused on avoiding being detected by the target. A novel metric was proposed to characterize disguising the performance of a UAV with respect to a target.

An online planning method was developed with a balance consideration of the UAV's energy efficiency, covertness, and maneuverability. A new metric was designed to quantify covertness. The UAV disguises its intention by changing the UAV target angle and distance drastically and frequently. Then, a multi-objective trajectory planning problem was formulated to maximize disguising performance and minimize trajectory length and offered a forward dynamic programming method to solve the problem. Covert surveillance is not prominent in literature. Therefore, promising future research suggests investigating multiple UAVs on covert surveillance and experiments to prove effectiveness.

In summary, the applications of networked UAVs for surveillance and monitoring were investigated. Common application problems such as the navigation, deployment optimization, and coordination of UAVs were discussed. Some representative publications were classified by targets of interest. A review was given on the use of UAVs for general target surveillance, traffic monitoring, wildlife monitoring, and radio surveillance. The main focus was on some high-level topics of surveillance UAVs. Other aspects related to surveillance UAVs, such as communication techniques between UAVs and low-level control techniques, were not discussed.

It was noted that existing publications on surveillance by UAVs did not consider the noise that UAVs produce. They can make loud noise, especially when close to targets of interest. While the noise may not impact monitoring performance in scenarios such as monitoring road traffic, it does strongly impact sound-sensitive applications such as the surveillance of wildlife animals and criminal suspects. Thus, developing low-noise UAVs would be very beneficial for future study. Additionally, there is still a need to develop highly autonomous UAVs. State-of-the-art UAVs are mainly trained for specific and well-structured environments. They are very likely to fail to operate in unstructured or new environments. Therefore, developing UAVs that are capable of learning and adapting to environments on-the-fly is necessary and challenging. Moreover, off-the-shelf UAV products, especially rotary-wing UAVs, are often restricted in operation time due to payload limitations. Therefore, the next generation of UAVs needs to be more energy efficient and able to pursue complex goals in highly dynamic and adversarial environments. Finally, the development of smarter UAVs that can avoid detection and tracking is meaningful, especially in military surveillance applications.

2.3.9 Operational Synthesis for Small Combat Teams: Exploring the Scenario Parameter Space using Agent-based Models

Chau, W., & Grieger, D. (2013, December 1–6)¹²

Combat simulations and wargames form part of a tool suite used to analyze military operations. Operational synthesis is a technique that integrates a class of models known as agent-based distillations (ABDs) into the analytical process. ABDs are an agent-based simulations subset that deliberately distill the modelling variables to focus on those important for the study. This property makes ABDs useful for the rapid exploration of large parameter spaces not typically feasible in high-fidelity military simulations due to resource and computational constraints.

In this study, the utility of the operational synthesis approach with regard to the performance of small combat teams conducting urban-setting close combat is discussed. The ability of the Map Aware Non-Uniform Automata (MANA) ABD to independently identify trends consistent with those found in a previous study that was conducted using a mix of wargaming and high-fidelity closed-loop simulation with the Close Action Environment (CAEn) tool. The CAEn study developed a scenario to assess the impact of various manned and unmanned vehicle options on the combat performance of a small combat team for the break-in and clearance of a small village. The same scenario in MANA was modelled to explore the impact of terrain density and opposition tactics, and force size on the outcomes.

The implementation in MANA results show trends consistent with the CAEn study. Some discernable differences were observed in the civilian casualties, but the results can be attributed to CAEn study known limitations and some parameters in MANA. Additional insights were observed that warrant further study with other tools and techniques. Future research is required to determine if similar outcomes can be achieved for different military scenarios. If the ABDs studies' results consistently align with other studies, then ABDs would be a valuable addition to military operations analysis tools given their ability to explore vast parameter spaces in a relatively short period of time. ABDs such as MANA could then be exploited to provide initial insights during the problem definition and design stages of relevant military studies. ABDs could also add robustness during the analysis.

2.3.10 Planning for the Next Generation of Soldier Modernization

Curtis, N.J. (2000, October)¹³

The major drivers for the long overdue modernization of dismounted Soldiers have been the advances in technology. In this paper, a requirements-based approach was taken to

predict the capability of the 2005/8 Soldier systems to undertake possible dismounted Soldier activities. Analysis was conducted to define steadfast dismounted Soldier's actions in a deconstructive manner so that each activity (such as assault or cordon and search) was examined in terms of the skills and tools (such as communications and engagement) that would be used. Deficiencies are found resulting from the inherent difficulty of the action, environmental effects, system constraints, and through enemy exploitation of the technology. The enemy exploitation of the technology was especially challenging given both direct and lateral thinking countermeasures may be expected. Study results offer research priorities to initiate development for the next generation of Soldier modernization, derived in a transparent, auditable, and credible manner.

The key critical priorities predicted are:

- the ability to provide SA tools to support trusted decision-making under stressful and information-poor environments,
- the ability to safely conduct surveillance and targeting in urban terrain, especially into buildings,
- the ability to make rapid judgements based upon a reliable “detect, recognize, and identify” process to allow trusted targeting,
- the ability to apply optimized and effective weapons to engage protected targets,
- the ability to safely engage targets at short ranges within urban terrain,
- the ability to apply selective and reliable nonlethal force, and
- the ability to move on the battlefield with a minimized risk of detection or targeting.

2.3.11 Simulation Analysis of UAV and Ground Teams for Surveillance and Interdiction

Muratone, M., Silvestrini, R.T., & Chung, T.H. (2014)¹⁴

This paper discusses use of the Situational Awareness for Surveillance and Interdiction Operations (SASIO) simulation analysis tool. The tool is used for the experimentation design and analysis to study UAVs' surveillance characteristics in reference to ground-based interdiction teams to aid in increasing the number of targets cleared from the area of interest. Different teaming strategies and coordination measures between searching and interdicting assets are investigated. The research objective is to quantify the benefit or detriment of an additional UAV asset that is a quick reaction force (QRF) in the overall surveillance and interdiction operation.

The Marine Corps has pursued UAVs' development to increase the force-multiplying capabilities to support goals of the *Marine Corps Vision and Strategy 2025*. The Navy is also advancing future UAV applications.

One of the critical UAV capabilities is autonomy, whereby autonomous systems may possess different "levels of autonomy" with some level of human interaction combined with machine automation. There is a need for a high level of automation with the UAV systems' ability to self-coordinate due to the increased difficulty of operators to control multiple UAV teams. It is crucial to maximize the integration of manned and unmanned systems to avoid missed opportunities if they are not viewed as an overall distributed force.

This paper reviews the development and analysis of a simulation model used to research manned–unmanned teaming (MUT) interactions with QRF or interdiction team to aid in Concept of Operations (CONOPS) development for UAV employment. The SASIO software is a simulation with GUI that is used to simulate real-time intelligence and aid strategic, operational, and tactical analysis development to support unmanned systems planning for specific theater scenario evaluation. The teams' effectiveness is measured by percentage of successful interdictions of targets of interest. A need exists within all services for new or improved tactics and CONOPS to effectively team ground units with organic UAVs.

The DOD "Unmanned Systems Integrated Roadmap" outlines three important areas of improvement: efficient UAV routing in the area of operations (AO), improved sensing or target acquisition, and better UAV teaming strategies.

The results show that factors with the greatest effect on MUT operation for interdiction are team type and search area. There was no indication that the QRF having an organic tracker UAV was a valuable asset. Tracker launcher and speed produced no significant effects on the response variable. It was recommended to perform an analysis with a tracker UAV of greater capability. It was discovered that the difficult part of target clearance was the search for them, which relates directly to the search area size. How we search, and asset availability, continues to be the limiting factors in target acquisition. An area for future study is the number of team types and assets available to help determine an acceptable AO size for mission accomplishment. Interdictor transit time is a limiting factor for team types with tracking capabilities. The effect of increasing or decreasing interdictor transit time is worth future study.

The QFR with an organic tracking capability had no effect on response. As search area increased, fewer targets were discovered. It was shown that a tracking capability was superior to no tracking at all.

Another area of future research is effects of multiple teams in a given AO on the response. A method may be developed to maximize the number of targets cleared by minimizing the time it takes for an interdiction team to arrive at the target location. This algorithm may solve a shortest-path problem to the target from each team, identify the closest team, and with an interface with SASIO, an order may be sent to begin the interdiction mission.

A valuable and complementary possibility of future work is a live-fly field experiment with real assets to validate the proposed CONOPS and derived insights.

2.3.12 Situational Awareness: Techniques, Challenges, and Prospects

Munir, A., Aved, A., & Blasc, E. (2022, January 29)¹⁵

This paper discusses a model for SA and dynamic decision-making that incorporates AI and dynamic data-driven application systems to adapt measurements and resources according to changing situations.

SA is often thought to encompass assessment (machine), awareness (user), and understanding (user-machine teaming). Command and control (C2) comprises SA, planning, tasking, and control. The C2 system design is aimed at presenting the situation selectively for the commander to comprehend the situation and then take the best possible action.

SA is imperative for dismounted operators to engage efficiently. They must obtain and comprehend information with regard to their environment, then use the information to predict near-future events, plan, and adapt their actions accordingly.

The winning strategy in combat is to get inside the opponent's Observe-Orient-Decide-Act (OODA) loop by having a better SA than the opponent—not only making one's own decisions quicker than the opponent but also being able to change the situation in a way that is not observable or comprehensible by the opponent in the given time. Losing SA is tantamount to being out of the loop.

- Perception—Level 1 SA: The perception of the status, attributes, and dynamics of the entities in the surroundings. Important environmental entities along with their pertinent characteristics.
- Comprehension—Level 2 SA: The comprehension of the situation, based on the integration of disconnected Level 1 SA elements. The Level 2 SA is a step further with developing an understanding of the significance of those elements in relation

to an operator's objectives. For instance, a pilot must understand the significance of the perceived elements in relation to each other.

- Projection—Level 3 SA: Relates to the ability to project the future actions of entities in the environment at least in the near term. This is achieved based on the cognizance of status and dynamics of elements in the environment and comprehension of the situation. The third level of SA is prediction or estimation of the status of entities in the surroundings in the future, at least in the near future. For example, from the perceived and comprehended information, the experienced pilots/operators predict possible future events (Level 3 SA), which provides them knowledge and time to determine the best course of action to achieve their objectives.

SA core also receives input from the commanders at strategic or operational levels regarding goals or objectives of SA. This model enhances perception, comprehension, and projection by adding support for AI-assisted decision-making and resource management. To better manage the resources according to changing situations, a dynamic data-driven application system (DDDAS) module provides input to a resource management module, which manages the environmental sensors and computing resources in the SA core. The DDDAS is a paradigm of the computation and instrumentation facets of an application system that are dynamically assimilated in a feedback control loop such that the instrumentation data can be dynamically fused into the executing model of the application, while the executing model can in turn control the instrumentation.

In Figure 2, the DDDAS module aids in steering the information fusion process of measurement instrumentation and data augmentation from physical knowledge for improved SA of the entities of interest in the environment. The DDDAS module can help guide and reconfigure sensors to increase the information content of the sensed data to enhance SA of the activities of interest in the environment.

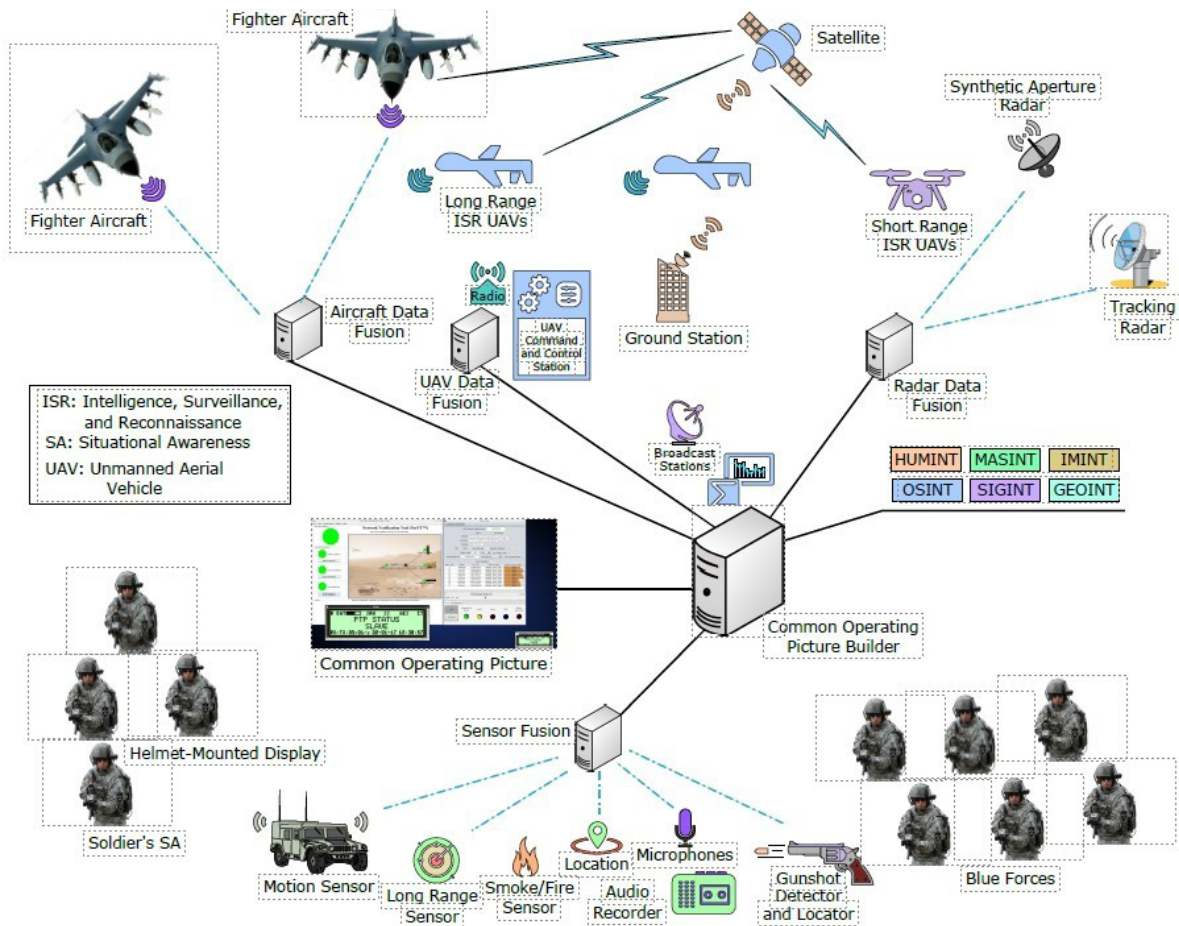


Figure 2. Overview of situational awareness¹⁵

AI has become an integral part of SA core and dynamic decision-making. AI assists operators in comprehending the situation (Level 2 SA) and then making projections about the future actions of entities in the environment (Level 3 SA). Thus, both the robustness of AI models as well as the operators' ability, experience, and training determine the level of comprehension acquired by the operators and the accuracy of future projections. Based on the acquired comprehension and projection, decisions are recommended by the AI models to the commanders, and then the commanders make the appropriate decisions by considering the input from the AI and the assessed situation. Finally, decisions are implemented at the tactical level by the operators. The decisions to be implemented have a vast range including, for example, the positioning of personnel and equipment, firing of the weapons, medical evacuation, and logistics support.

Types of constructs in assessing SA measurement validity approaches are described as face, construct, predictive, and concurrent. SA techniques are also discussed: freeze-probe, real-time, post-trial self-rating, observer-rating, performance-based rating, and process indices-based techniques.

A few of the commonly used SA measurement techniques are discussed and a comparison is made based on the assessment metrics: NASA task load index, SA global assessment technique, SA rating technique, and critical decision method.

2.3.12.1 *Artificial Intelligence*

AI advancements have had a significant impact on SA. AI can strengthen awareness of dismounted Soldiers by identifying the presence and movement of the enemy and assist in threat identification and mitigation. AI is also helpful with real-time analysis and prediction. For military applications, AI can help dismounted Soldiers with actionable intelligence and assistance with decision-making. AI can also facilitate logistics by enabling predictive maintenance, enhancing the safety operating equipment, and reducing operating costs. Further, AI can promote readiness of troops by tracking and supplying military ammunition before they are depleted. AI is integral to human-machine teaming efforts that promote efficient and effective integration of humans with complex machines. This extends beyond the usage of the standard GUI, computer keyboard, and mouse, and focuses on multimodal interaction capabilities, such as eyeglass displays, speech, gesture recognition, and other innovative interfaces. AI can accomplish military jobs that are dull, dangerous, or dirty, thereby reinforcing military strength and reducing casualties.

2.3.12.2 *Unmanned Aerial Vehicles*

UAVs can tremendously help to improve SA. UAVs are suitable for gathering intelligence from dull, dirty, and dangerous environments. With technology advancements, the next generation of UAVs will not just collect data but will also be capable of performing on-board data processing, fusion, and analytics. Context-aware UAVs outfitted with a camera can generate a high-level scene description observed in the video and identify potentially critical situations. Semantic technologies can be leveraged to identify objects and their interactions in the scene. Cognitive capabilities can be added to UAVs through fuzzy cognitive map reasoning models, deep neural networks, or other ML models.

UAVs can identify precarious and evolving situations. Furthermore, UAVs can play a pivotal role in edge SA by acting as flying fogs and thus as a sink for data from the ground sensors as they navigate above the sensors. A UAV flying fog characteristic will be the ability to process, fuse, and analyze the data on-board as well as transfer the data (whether in original or processed form depending on the nature, complexity, and context) to the ground station and/or cloud for archival and detailed analysis. Further, the UAVs can employ DDDAS methods for enabling UAVs to adapt their sensing,

processing, and navigation (routing) dynamically based on live sensor data for better monitoring and tracking of the target.

2.3.12.3 *Autonomous Vehicles*

As a result of an autonomous vehicle's (AV's) plethora of sensors, AVs are capable of always-on monitoring during operation. A network of AVs can enable mass surveillance, yielding comprehensive, detailed tracking of all AVs and their users at all times and locations. The information retrieved from the sensors on-board AVs can be collected and centrally stored. The detailed analytics of the stored information can be used to provide SA insights.

2.3.12.4 *Gunshot Location Systems*

Gunshot location systems serve as an important tool for acoustic surveillance for locating the origin of artillery fire, bullets, and snipers in urban warfare and battlefields. Acoustic SA can be interpreted as the activity used to observe environmental acoustical components at all times and in all weather conditions. Target acquisition acoustic SA refers to characterizing acoustical sources that constitute environmental noise by detection, spatial localization, reconnaissance, and identification of one or more previously identified targets.

Electro-acoustic sensors are often used to detect, localize, and identify gun fires or shooting noise. An electro-acoustic sensor consists of a piezoelectric substrate and a low-cost condenser-type acoustic transducer sensitive to acoustic pressure and having omnidirectional pickup pattern. These electro-acoustic sensors process the acoustical emissions information of gunfire events to estimate the spatial coordinates such as azimuth, elevation, range of the gunfire origin, as well as other relevant ballistic features. The electro-acoustic sensors can transmit the data using either wireless or wired communication. Modern gunshot location systems are typically able to assess the azimuth and elevation of the shooter, the range to the shooter, trajectory and caliber of the projectile, and muzzle velocity. Gunshot location systems display the gunshot localization and identification results within a few seconds after a fired shot on a user interface that is often integrated into a geographical information system.

2.3.12.5 *Internet of Things*

Internet of Things (IoT) can immensely enhance SA by their integration with military and Air Force personnel. The operators/ground Soldiers are battlefield assets and are crucial for implementing tactical decisions. An increasing number of ubiquitous sensing and computing devices are worn by military personnel and are embedded within military equipment (e.g., combat suits, instrumented helmets, weapon systems, and so on).

These sensing and computing devices are networked together to form an Internet of Military Things (IoMT) or an Internet of Battlefield Things (IoBT). IoMT/IoBT can acquire static and dynamic biometrics (e.g., face, iris, periocular, fingerprints, gait, gestures, and facial expressions), which can be used to monitor a Soldier's psychophysical and emotional conditions on the field. The IoMT/IoBT can also capture Soldiers' vital health parameters (e.g., heart rate, electrocardiogram, sugar level, body temperature, and blood pressure) in addition to monitoring Soldiers' weapons, ammunition, and location.

IoMT/IoBT can acquire tactical SA and thus gain perception of the enemy and advances of the friendly forces. The variety of statistics and parameters gathered by IoMT/IoBT have significant value for the C2 center commanders. This acquired data is sent to edge servers or the cloud where information fusion and big data analytics can be applied for SA, situation evaluation, decisional activity, and providing real-time support to Soldiers in the battlefield. The commander can become aware of Soldiers' health, weapons, equipment, and ammunition parameters and then can place orders for providing appropriate assistance.

2.3.12.6 *Graph Databases*

It has been proposed to combine IoT (IoMT/IoBT) with graph databases to provide SA about every parameter of the Soldiers in the battlefield and to yield a better decision support system. Graph databases are a new paradigm where data can be formatted in a graphical form for user-friendly searching and traversing as opposed to the traditional databases. In a graph database, data is stored in the form of nodes that are connected to each other in a graphical manner via edges. The edges represent a relationship between the connected nodes.

Graph databases are useful when attributes of the data/node are important. For example, a Soldier can be a main node with different attributes, such as equipment, ammunition, weapons, and body sensor parameters. Because IoT has multiple interconnections with other nodes and data, graph databases can be used to store and retrieve that information. The graphical representation and storage facilitates the querying of such complex data. The standard graph theory algorithms (e.g., shortest path, clustering, community detection, and so on) as well as ML methods can be used on graph databases to facilitate retrieval of the required information. The graph database can improve the visualization and SA for the commander. Information presented in a planar manner is not often adequate for clearly developing SA. The information from various sources stored in a graph database allows retrieval of the stored information graphically. This helps to better understand the relation between the attributes of different nodes in the graph. Since there is a transition from traditional map- and phone-based SA in the IoT era, the commander is able to access all of the

information remotely on an IoT-enabled device. The graphical databases can be implemented at fog/cloud level so that visual results of the query can provide situational data to assist the commander in tactical decisions. For instance, the IoMT/IoBT can collect and store the Soldiers' vital parameters in the battlefield, along with their geographical location, in graphic databases that would enable the commander to visualize this information to better gauge the health of the military assets in the battlefield.

2.3.12.7 *Fog/Edge Computing*

Fog/edge computing places applications, services, data, computing power, knowledge generation, and decision-making away from centralized nodes to the extremes of a network. Edge computing is data computation that happens at the network's edge. On the other hand, fog computing acts as a mediator between the edge and the cloud for various purposes, such as data filtering

Fog/edge computing enables computations near the edge of the network and helps in reducing the communication burden on the core network. Using biometrics, environmental sensors, and other connected IoMT/IoBT devices to send and receive data, quickly leveraging fog/edge computing will not only help improve command-and-control operations but will also permit military personnel to timely respond to potentially dangerous situations on the battlefield.

2.3.12.8 *Information Fusion*

Information fusion plays an important role in SA by assisting in deriving valuable insights from the sensed data from surveillance applications. Information fusion minimizes redundancy between the data captured by different sensors, such as views captured by different cameras. Furthermore, information fusion assists in performing handoff between cameras.

In fog/edge computing, information fusion at sensor/IoT nodes reduces the data that need to be transmitted to the edge servers, which conserves the energy for IoT devices, prolongs the battery life, and alleviates burden on the core network. Advanced computing techniques, such as parallel and reconfigurable computing, can be leveraged for real-time information fusion to provide real-time SA at IoT and edge/fog nodes.

2.3.12.9 *Automatic Event Recognition in Video Streams*

Automatic event recognition requires improvements over basic object recognition techniques as the relationship between objects need to be recognized (situation) and how these relationships evolve over time (i.e., occurrence of events). An event is

defined as a change in relationship between objects occurring over time. An example of UAV automatic event recognition is convoy surveillance.

A small UAV, like a ScanEagle, may be used to provide convoy surveillance. However, a UAV flying over the convoy will detect and track the convoy structures as well as other vehicles and objects in the convoy vicinity that may be a threat.

Event recognition approaches include Bayesian networks, hidden Markov models (HMMs), and neural networks. HMMs and neural networks require a large amount of training data for configuring the network to recognize events. Because many events of interest are deviant events whereby there is insufficient video training data, Bayesian networks can be utilized. Bayesian networks also incorporate reasoning uncertainty and provide an output indicating an event possibility or for multistate events, an event probability that is in a particular state.

With recent deep learning advancements, convolutional neural networks (CNNs) have become popular for automatic object detection, classification, and recognition in video frames. Figure 3 presents a CNN architecture for automatic object detection and classification. A CNN architecture is usually made up of an input layer, an output layer, and multiple hidden layers. The CNN hidden layers are made up of multiple convolutional layers, fully connected layers, and optional nonlinearity, pooling, and normalization layers.

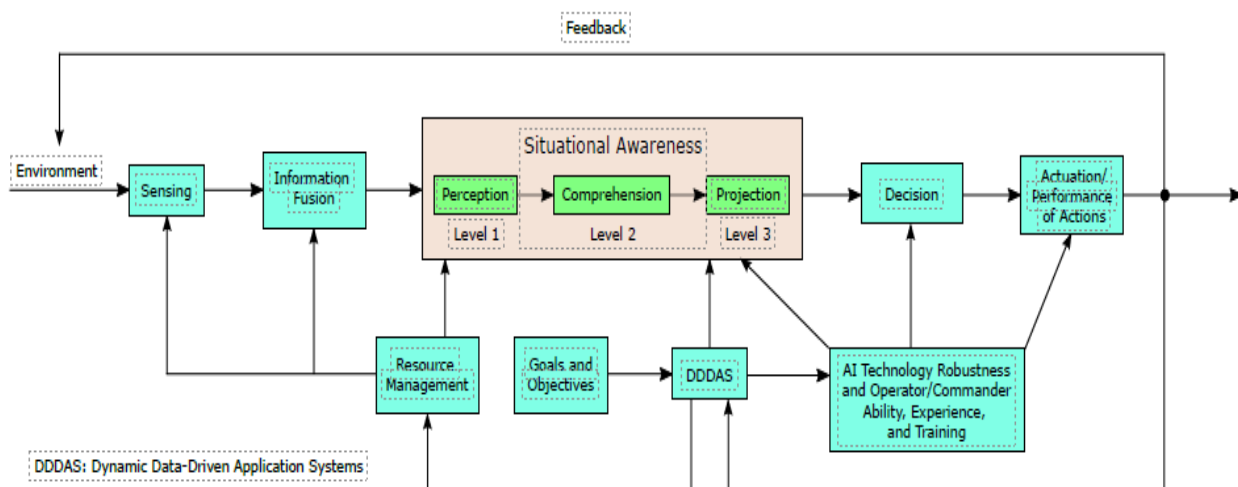


Figure 3. Model of SA and dynamic decision-making¹⁵

In Figure 4, input from an infrared camera is fed to the CNN architecture. The input is processed through multiple convolutional, nonlinearity, pooling, normalization, and fully connected layers. An output of object detection and classification at the output/classification layer is processed.

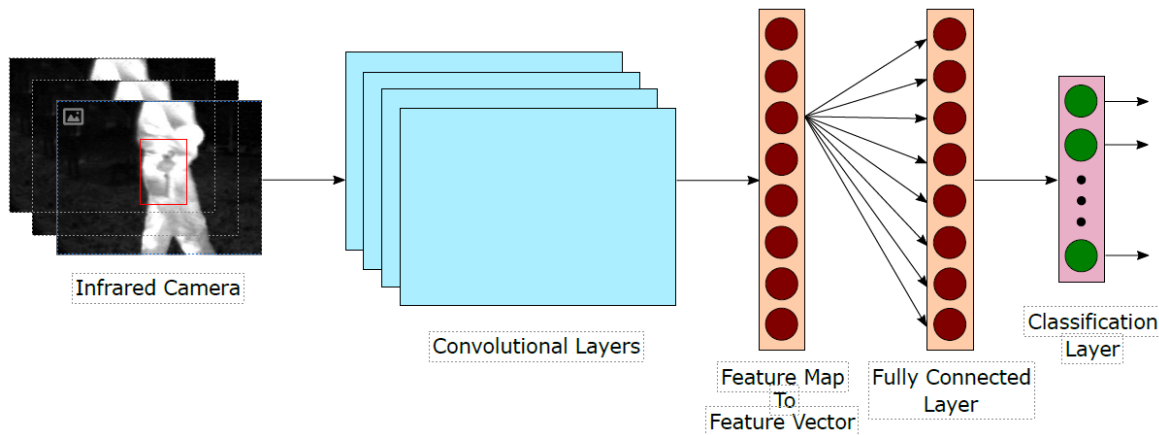


Figure 4. CNN architecture detecting a pistol from an infrared video input¹⁵

Automatic event recognition has a tremendous value for SA; however, it is a challenging problem. Other relevant research problems pertinent for SA include object detection and identification, recognition of relationships between objects, and activity recognition.

2.3.12.10 Enhanced Vision System (EVS)

An enhanced vision system (EVS) or enhanced flight vision system (EFVS) uses active and passive sensors that enhances the pilot's visibility and SA. The sensors penetrate weather conditions such as storms, fog, haze, darkness, rain, and snow.

Enhanced vision sensor performance depends on the sensor's characteristics and external environment. For example, a high-frequency radar's performance range (e.g., 94 GHz) and infrared sensors degrade in heavy precipitation and some fog types. Low-frequency (e.g., 9.6 GHz) and mid-frequency (e.g., 35 GHz) radars have improved range but have poor display resolution. Furthermore, if multiple active sensors are in close proximity, active radar sensors often experience interference.

2.3.12.11 Synthetic Vision System (SVS)

SVSs are near weather-immune displays that allow an operator/pilot to view the world as in perfect weather day and night. SVSs use a mix of sensors, GPS satellite signals, inertial reference systems, and an internal database. SVSs replace the old aircraft attitude indicators (i.e., the blue-over-brown attitude indicator that indicates where the horizon is) with an augmented reality (AR) system that overlays a real-world image on the attitude reference system. AR-based SA systems can improve aviation safety and enhance aircraft operations' efficiency. The SVS benefits include enhanced safety, improved SA, reduced pilot workload, reduced technical flight errors, and color coding for absolute altitude terrain.

An SVS example includes the Collins Aerospace's SVS that has weather-independent, high-definition image displays on heads-up displays (HUDs) with information layers including terrain, obstacles, airports, and runways that complete a solid picture of the environment. Honeywell's SmartView is another example that synthesizes flight information from various onboard databases, GPS, and inertial reference systems into a comprehensive 3-D forward terrain rendering.

2.3.12.12 *Combined Vision System (CVS)*

A combined vision system (CVS) is a future vision system that would provide pilots vision beyond what the eye can see. A CVS consists of a combination of synthetic vision (i.e., systems that create real-time rendered environments based on sensors and stored database information) and EFVSs (i.e., displays that use forward-looking infrared systems and millimeter wave radar to a live world view around the aircraft). Collins Aerospace's CVS provides a clear view through a combination of the EVS and SVS into one dynamic image. The CVS algorithms use the overlapping fields of vision from EVS and SVS to detect, extract, and display content from both sources. This yields thermal imagery of terrain at night, weather-independent virtual terrain, and the quick detection of runway and approach lighting integrated in a single system.

2.3.12.13 *Augmented Reality*

With an increased mobile device computing capability that can be carried by dismounted operators, AR holds a promising means to enhance SA. An AR system can help improve the dismounted SA by filtering, organizing, and displaying the information in a perceptible manner. AR systems need to identify the elements to be displayed and augmented in operators' HUDs. These elements include a terrain map and indication of blue and red forces. The terrain map can use a radial mini-map centered on the operator showing the operator's real-time position along with the position of allies, foes, and points of interest. Navigation data can be integrated with the terrain map by shading of the paths using AR techniques and overlaying the maps and navigation path on the operator's view. AR is also helpful when it may be difficult for the operators to maneuver their equipment and/or weapons. An AR crosshair pointing to the direction where the operator's weapon is currently engaging can improve accuracy and response time.

2.3.12.14 *Application Domains of Situational Awareness*

SA is needed in various domains such as battlefield, military- and air-bases, aviation, air traffic control, emergency and/or disaster response, industrial process management, urban areas, and critical infrastructure. An overview of SA domains is discussed. Inadequate SA can be associated with human errors resulting in adversities, relating to

military losses in the warfare, civilians' and first responders' loss of lives in emergency and disaster response, and loss of revenue in industrial control.

2.3.12.14.1 Battlefield

SA is imperative for an informed and reliable battlefield C2 system. SA enhanced by technologies, such as IoBT/IoMT and fog computing, can help the military and U.S. Air Force to fully exploit the information gathered by a wide set of heterogeneous IoBT/IoMT devices and can provide a strategical advantage over adversaries. SA in the battlefield can be provided at different levels: 1) commanders overseeing the battlefield operation, 2) dismounted Soldiers carrying out the tactical level mission, and 3) pilots providing close air support to Soldiers. Recent advancements in SA technology can help Soldiers identify the enemy, access devices and weapons systems under low-latency, and improve SA and Soldier safety.

2.3.12.14.2 Urban Warfare

Military and Air Force SA maintenance in urban environments is more challenging than in rural and open terrain. The battlespace urban environment dynamics change significantly from conventional 2-D space with the enemy in the front to a 3-D maze where the enemy can launch the offensive from any direction and from multiple directions simultaneously. Furthermore, the urban battlespace is convoluted by the increasing presence of noncombatants. Navigation aids like GPS are not as reliable in urban environments as in open terrain because the LoS to the satellite is difficult to attain. Therefore, sharing battlespace information in an urban environment to obtain the common operating picture (COP) (The U.S. DOD dictionary of military and associated terms defines COP as: "A single identical display of relevant information shared by more than one command that facilitates collaborative planning and assists all echelons to achieve situational awareness") requires a communication system/network that can maintain a link in any environment (i.e., in the presence of multipath and radio interference).

2.3.12.14.3 Gray Zone Warfare

SA is needed in gray zone warfare where it is not always simple to identify enemy combatants. Enemies can appear as civilians or could access restricted military bases with a stolen badge. To provide SA in gray zone situations, biometric sensors can scan irises, fingerprints, and other biometric data to identify individuals who might pose a danger. The use of DDDAS methods in SA systems can aid in targeted data collection on identified individuals and mobilize the responding units to diffuse the threat. The SA systems can provide real-time monitoring of sites and potential gray zone persons to

prevent or mitigate gray zone warfare negative effects, such as misinformation and disruptions of services and critical infrastructures.

2.3.12.14.4 Military- and Air-Bases

SA is needed for the safety and security of military- and air-bases. Continuous surveillance is needed because enemies can try to infiltrate the bases with stolen badges/identities. SA systems can detect unauthorized personnel in these bases and then the authorities can take the appropriate action.

2.3.12.14.5 Homeland Security and Defense

SA is required for enhancing homeland security and defense. Real-time surveillance provides timely detection and response against natural disasters and man-made events (e.g., terrorism). SA can also assist law enforcement officials in counterterrorism, anti-smuggling efforts, and apprehending fugitives.

2.3.12.14.6 Disaster Response Management

Disaster recovery operations are challenging and require support from multiple agencies including local and international emergency response personnel, nongovernmental organizations, and the military. SA plays an important role in the aftermath of a disaster so that resources, personnel, and supplies can be prioritized and directed based on the need for disaster relief. SA also needs to be continuously updated based on the changing conditions. Traditional sources of information to SA in disastrous situations includes reporting by victims; however, reporting by victims may not always be viable as communication means could be disrupted. Therefore, SA systems are required for disaster monitoring and reporting, and to aid in providing an appropriate disaster response. SA systems are also an integral part of early warning systems and can help in safety enhancement and sustainability by facilitating quick detection and response to emergency situations.

2.3.12.14.7 Critical Infrastructure

SA is needed for safety of critical infrastructures. Road networks, an essential part of transportation networks, requires SA for perceiving adverse road conditions, motorists, pedestrians, and traffic conditions. Monitoring of traffic and suspicious vehicles afforded by road SA would reduce crimes, accidents, and fatalities. Deep learning advances have helped immensely to enhance road SA. CNNs can be used to discern vehicle category and location in the road image data, and thereby assist with the situational element identification problem in the road traffic SA system. Critical infrastructure monitoring becomes more important in gray zone warfare since enemies may attempt to

create disruptions in critical infrastructure to generate favorable situations for military engagement.

In summary, research is needed to advance SA. SA will continue to advance with technology advancement. The military is still in pursuit of the perfect radios based on a software-defined radio that can accomplish secure, interoperable, and resilient multichannel communication working with different modes/waveforms. Another area pertinent to SA research is automatic event detection and recognition. Specifically, real-time automatic event detection and recognition is a demanding problem that requires AI advances as well as advanced computing techniques, such as parallel computing and reconfigurable computing. Further, hardware accelerators can be beneficial for enabling real-time automatic event detection and recognition. In addition, another area where active research is needed is safe and secure autonomous navigation of UAVs so that UAVs can accomplish missions autonomously without active remote piloting. More research in IoBT/IoMT is warranted to sense, integrate, and process a multitude of parameters related to Soldiers' health and psychophysical conditions, Soldiers' weapons, ammunition, location on the battlefield, and information about red forces. Future research in fog/edge computing is necessary to ensure the real-time processing and analytics of these sensed parameters to help enable real-time assessment and C2 decisions and respond to evolving situations. Enhanced vision systems need continuous improvement with innovation of sensing and AR technologies. New visualization techniques need to be developed based on multi-intelligence fusion results to enable a user to view a reconfigurable user-defined operating picture. New SA measurement techniques are also needed to address more assessment metrics. Finally, an urgent need exists to develop new SA assessment tools to quantify SA based on the SA requirement for a given application domain.

2.3.13 Skylord Keeps Warfighters Safe in the Heat of Battle

Eshel, T. (2020, October 6)¹⁶

Skylord performs hazardous-condition missions, allowing human operators to perform the mission remotely. The XTEND Skylord employs end technology with cognitive skills to perform dangerous missions safely. The system uses AR guidance and control technology, an AR vision system, and a single-handed controller to enable an operator to perform complex missions. The telepresence interface enables operators to immerse themselves into a remote reality and engage targets safely and effectively.

2.3.14 U.S. Army with Lockheed Martin Demonstrate 5G/UAV Capability

DEVCOM Ground Vehicle Systems Center. (2021, September 1)¹⁷

HiveStar 5G network UAV leader–follower S-band system facilitates battlefield communication on the fly. The HiveStar drone platform facilitates the autonomous delivery of a distributed mission to different nodes. It allows multiple layers of communication using LoS and S-band networking system through UAVs. HIVESTAR will distribute that mission to all assets available. During this demonstration scenario, the UAV follows a ground vehicle convoy to provide surveillance and communicate back to the ground vehicle(s) allowing supplies, and so on, to arrive safely. Point of Contact: Nikel Patel, Ground Vehicle System Center (GVSC), Warren, MI.

2.3.15 U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI): Considerations for Congress

Congressional Research Service. (2018, November 20)¹⁸

Autonomous UAV navigation is fairly straightforward as it uses maps that indicate preferred routes, height obstacles, and no-fly zones. Radars indicate what altitudes are clear of obstacles in real time. GPS coordinates convey to the UAV where it needs to go while avoiding any obstacles. In comparison, UGVs must account for many more real-time factors such as other vehicles and pedestrians in narrow time fields.

Personnel Considerations

Robots and autonomous systems (RAS) and AI led to the restructuring of how units are organized, equipped, and manned. As the Congressional Research Service stated in its report, “Autonomous systems don’t actually solve any given problem, but merely change its nature. It’s called the autonomy paradox: The very systems designed to reduce the need for human operators require more manpower to support them.”

Unmanned aircraft equipped with cameras often require multiple shifts of operators, maintainers, and intelligence analysts to extract useful data. Therefore, the question becomes, “What can robots do with us?” rather than “What can robots do without us?”

There is a greater need to recruit and retain military personnel with advanced technical knowledge as the military integrates RAS and AI. The majority of people brought into the armed forces hold a high school diploma. It will be challenging to recruit personnel with a high cognitive ability and years of advanced technical training.

There is a legal and ethical debate over the development and deployment of mobile robotic weapons systems capable of selecting and attacking targets without human intervention because that is considered by some to be inherently unlawful or unethical. Others support development of the weapon systems if they meet the international law of armed conflict, also known as the international humanitarian law, for lawful weapons. An autonomous weapon system must be able to distinguish targets and ensure that the attack is proportionate to the expected military advantage. The autonomous system can survive the “Article 36 Review” if it is programmed with sufficiently reliable targeting information to ensure it can be fired at a lawful target.

The DOD directive on the development of autonomous weapons systems states, “autonomous and semi-autonomous weapons shall be designed to allow commanders and operators to exercise appropriate levels of human judgement over the use of force.”¹⁸

The directive emphasizes effective HMI, requiring that autonomous weapon systems:

- a. Are readily understandable by trained operators,
- b. Provide traceable feedback on system status, and
- c. Provide clear procedures for trained operators to activate and deactivate system functions.

Further, the directive requires that testing and evaluation ensure that autonomous weapons systems:

- a. Function as anticipated in realistic operational environments against adaptive adversaries,
- b. Complete engagements in a timeframe consistent with commander and operator intentions and, if unable to do so, terminate engagements or seek additional human operator input before continuing the engage, and
- c. Are sufficiently robust to minimize failures that could lead to unintended engagements or to loss of control of the system to unauthorized parties.

Some ethical arguments include the concern that autonomous weapons systems may make armed conflict more prevalent. National leaders may be more likely to pursue hostilities when the risk to human Soldiers is minimized.

Another argument surrounds “automation bias,” where humans trust computer interpretations over their own senses and instincts, possibly nullifying meaningful human control over these systems.

Opponents argue that human empathy helps determine the intent of the human target as to whether they actually pose a threat. Machines may not be programmed to emulate compassion or empathy effectively. On the other hand, system proponents argue that human emotions may lead to adverse battlefields results. However, robots may not be subject to human error and unlawful behaviors stemming from human emotion. Organized groups are concerned with lethal autonomous weapons systems. Futurists Elon Musk and the late Stephen Hawking have warned that AI has the potential to be far more dangerous than nuclear weapon systems.¹⁹ The development of the U.S. RAS and AI for use by ground forces is paramount to counter foreign use of RAS and AI against U.S. ground forces.

3. RESULTS AND DISCUSSION

Having at least one company level and a platoon level UAV enhances dismounts' survivability later in battle.¹ There is a need to devise a system minimizing casualties within the initial stages of the fight when up against a strong enemy. Analysis of balance between munitions, sensors, and fuel can establish future UAV building requirements. Adding one platoon level yields a 1% survival increase. UAV operators play a critical role in providing eyes for the fight. The ARV-A provides the infantry platoon RSTA, direct fire, and BLOS capabilities to support maneuver and tactical assault to ensure lethality overmatch. The ARV-A provides sophisticated onboard sensors, enables precision BLOS fires, and detects, recognizes, and identifies targets with enough fidelity to support LOS, BLOS, and NLOS assets to support cooperative engagement.

The review of four UAV networking communication architectures revealed that decentralized communication architecture is suited for the one-to-many mode of operating multiple UAVs through provisioning of timely air-to-air and air-to-ground information exchange.² A UAV ad hoc network is most suitable to a UAV network team, while a multilayer UAV ad hoc network is more suitable for multiple groups of heterogeneous UAVs. One important feature of next-generation waveforms is their capability of IP based on ad hoc networking, allowing UAV's communications with each other in a single- or multilayer UAV ad hoc network.

The SMASH Dragon can be mounted with a variety of weapons, employs an advanced remotely controlled payload on drones or unmanned aerial platforms, and features proprietary target acquisition using computer vision to acquire targets.³ The downside is that the system experiences stabilizing issues when mounting weapons.

Communication can be a challenge with 5G networks supporting high levels of data traffic and connections when using a UAV base station, air-to-air, and air-to-ground channels.⁴ A LoS channel between the UAV base station and user equipment can be beneficial. Limited on-board energy storage is the most challenging issue for UAV communications and networking. Wireless power transfer (WPT) is a promising solution.

Another proposal surrounds the use of HMD vision-based teleoperation and a UAV using deep learning.⁵ It consisted of linking the UAV's real-time video data IP camera to a remote cloud server. Computer vision ML algorithms paired with state-of-the-art deep CNNs to identify hostile intent was incorporated. The cloud-server-based trained network classified every video frame and overlaid the video with specific color marks and prediction percentages, which was streamed to the HMD that facilitated a first-person scenario view. Aerial surveillance was accomplished using a ground vehicle coupled with a UAV.

A review of human/machine interface (HMI) modalities to augment human performance was conducted.⁶ Four main areas were discussed: models of human information processing, modalities for information presentation, modalities of system control, and analysis of Soldier needs. HMIs are needed to identify how to optimize using human senses to perceive the environment and to affect the modalities of HMI. Soldiers' needs are identified, then tasks are classified by cognitive processing type, and finally, ideas are reviewed based on which HMI modalities may best support human performance in completing the tasks. Detail to task, context, and concurrent activity are required.

Further research of these tasks and use scenarios is necessary. The following generalizations hold true⁶:

- Spatial information presentation will remain primarily visual with augmentation by spatialized (3-D) audio and directional haptic cues.
- Manual controls link favorably with visual presentations for manipulation of spatial elements.
- Simple auditory presentation can be used to acquire attention or cue alert.
- Gestures, alone or with speech, can be used to enhance communications.
- Speech recognition technologies continue to improve and be viable for browsing and other verbal software applications (limited in covert operations).
- Gaze-based control can be used for object selection and tasks such as aiming. It is best suited for object dwell time situations that are neither too short (making repeatability and accuracy of interpretation difficult) nor too long (defeating the benefits of using gaze in the first place).
- Neural controls are unlikely to be viable for real-world applications in the near term. However, they are not sufficiently robust for field use.
- Olfactory cues remain limited to emergency/notification scenarios where only presence of smell needs to be determined (e.g., detection of natural gas leaks).
- Multimodal controls offer natural communications potential between humans and machines.
- It is critical to consider tasks and modalities as a system within context of use.

Research of HRI design using teleoperation to HAT was reviewed.⁷ An important principle is that agents become more autonomous and increase Soldier tasking demand. UAV/UAG displays research revealed that 4-in. (diagonal) handheld or 12-in. tablet displays interpreted intelligence information from remote sensors equally well, whereas HMDs resulted in poorer performance, eye strain, and binocular rivalry. Performance improved with multiple displays. The multiple displays improved single-imagery displays, which enabled remote operators' frontal (UAG) and planar (UAS) views of the ongoing mission within a map display context. The research showed that military operators were more likely to trust autonomous options when shown projected

outcomes. When comparing is needed and the amount of information to process is large, graphical visualization successfully conveys information to the operator without increasing cognitive workload. Displays with both aerial and ground views of UV sensors within graphical context enhances Soldiers' overall battlefield SA. Advantages of speech and audio are listed in the article.⁷ When a tactile belt was added to a chest-mounted visual display involving waypoint navigation and incoming message receipts, missions using the tactile cueing resulted in reduced mission times, increased navigation accuracy, increased SA, improved weapon control, and lowered cognitive workload, effort, and frustration. Additionally, when the tactile belt was on, Soldiers rarely checked the visual display.

Another UAV article used targets of interest and analyzed common problems such as control, navigation, and deployment operation.¹¹ UAVs can quickly cover large and difficult-to-reach areas, reduce labor costs, and require little operator workspace. Networked UAVs can still complete a mission when one UAV fails, work efficiently, and collect more spatial-temporal data.

UAVs can make loud noises that can impact sound-sensitive applications.¹¹ Therefore, developing low-noise UAVs would be beneficial. Furthermore, developing UAVs capable of learning and adapting to environments on-the-fly is needed. Off-the-shelf UAVs, especially rotary-wing UAVs, are restricted by operation due to payload limitations. For military applications, UAVs need to be developed to avoid detection and tracking.

Although not directly related to the networked UAVs for surveillance and target acquisition, an article showed up during this search about operational synthesis for small combat teams.¹² It discussed the need to use a military operation analysis tool suite in the analysis of operational synthesis that integrates a class of models referred to as agent-based distillations (ABDs). ABDs may be a valuable addition to military operations analysis tools due to the ability to explore vast parameters space in a short timeframe. ABDs such as Map Aware Non-Uniform Automata (MANA) may provide initial insights during the problem definition and design stages of relevant military studies.

Analysis was conducted to predict the capability of 2005/8 Soldier systems to undertake possible dismounted Soldier activities.¹³ The results generated potential research priorities to initiate the development for next-generation Soldier modernization. The key priorities were provided in the paper. The idea of using networked UAVs for surveillance and target identification and acquisition touched on multiple Soldier modernization priorities.

A paper on simulation analysis of UAV and ground teams discusses SA for the surveillance and interdiction operations (SASIO) simulation analysis tool.¹⁴ The tool is used in experimental design to study UAVs' surveillance characteristics in reference to ground-based interdiction teams to increase the number of targets cleared.

Active research is needed for safe and secure autonomous navigation of UAVs to accomplish missions autonomously without remote piloting. More research is warranted for Internet of Battlefield/Military Things (IoBT/IoMT) to sense, integrate, and process parameters related to Soldiers' health and psychophysical conditions, Soldiers' weapons, ammunition, battlefield locations, and information on red forces.¹⁵ Future research in fog/edge computing is necessary to ensure the real-time processing and analytics of these sensed parameters to help enable real-time assessment and command-and-control decisions and respond to evolving situations. Enhanced vision systems need continuous improvement with innovation of sensing and AR technologies. New visualization techniques need to be developed based on multi-intelligence fusion results to enable a user to view a reconfigurable user-defined operating picture. New SA measurement techniques are also needed to address more assessment metrics. Finally, an urgent need exists to develop new SA assessment tools to quantify SA based on the SA requirement for a given application domain.

Skylord performs hazardous missions while operator perform missions remotely.¹⁶ The XTEND Skylord uses AR guidance and control technologies, an AR vision system, and single-handed controller to enable the operator to perform complex missions while engaging targets safely and effectively.

Congress faces multifaceted considerations as the military integrates RAS and AI.¹⁸ It will be challenging to recruit personnel with high cognitive ability and years of advanced technical training. There is a legal and ethical debate over the development of mobile robotic weapons with the ability to select and attack targets without human intervention. An autonomous system must be able to distinguish targets and ensure the attack is proportionate to the expected military advantage. National leaders may be more likely to pursue hostilities when human risk is minimized. It is also argued that human empathy help determine the intent of the human target as to whether or not they pose a threat. Machines may not be programmed to emulate compassion or empathy effectively. However, the U.S. RAS and AI development for use by ground forces is paramount to counter foreign use of RAS and AI against U.S. ground forces.

HMI modalities of high-level task-specific design are discussed to optimize human performance. This includes classification of human behavior defined by the degree of cognitive processing, attention sharing, multitasking, and compatibility of stimulus response (SR) pairing with relation to control/display.⁶ Guidance is provided for the

analysis of Soldier information needs and pairing with the best-suited modality given the information to be presented.

UAVs are needed to provide real-time visual feedback of the battlefield and possible munitions deployment.¹ It is important to consider armed UAVs' change of weight and payload balance.

SA that incorporates AI plays a vital role in dynamic battlefield decision-making.¹⁵ SA is imperative for dismounted Soldiers to engage efficiently. SA encompasses assessment (machine), awareness (user), and understanding (user-machine teaming). The winning strategy is obtaining the opposing force's OODA loop and having a better SA to make quicker decisions and change the situation that is not observable or comprehensible by the opposition. AI can strengthen awareness of dismounted Soldiers enemy identification and movement and assist in threat mitigation. The impact of UAVs, autonomous vehicles, gunshot location systems, IoT, graph databases, fog/edge computing, information fusion, automatic event recognition in video streams, enhanced vision system (EVS), synthetic vision system (SVS), combined vision system (CVS), and AR were discussed. SA application domains including battlefield, urban warfare, gray zone warfare, military- and air bases, homeland security and defense, disaster response management, and critical infrastructure were summarized.

Operational synthesis integrates Agent-Based Distillations (ABD) models into the analytic process.¹² The ABDs simulator subset distills modeling variables to focus on those that are important. The Map Aware Non-Uniform Automata (MANA) ABD is allowed to independently identify trends consistent with findings from a previous study that used war games, high-fidelity closed-loop simulation with the Close Action Environment (CAEn) tool. The CAEn study assessed unmanned and manned vehicles scenarios on combat performance for break-in and clearance of a small village. If ABD studies' results align with other studies, then ABDs would be valuable to military operations' tools to explore vast parameter spaces within a short timeframe. ABDs, like MANA, could yield insights during problem definition and relevant military study design stages as well as adding robust analysis.

Dismounted Soldier modernization is highly driven by advanced technology.¹³ Predicted critical priorities include SA tools to support decision-making; safely conduct surveillance and targeting especially into buildings; rapid judgements based on reliable "detect, recognize, identify, and target" processes; apply optimized and effective weapons to engage urban targets at short range; apply sensible and reliable nonlethal force; and move on the battlefield with minimal detection and targeting risk.

A UGV equipped with an IP camera visual system broadcasting real-time video data to a remote cloud server can serve in a combat, rescue, or reconnaissance mission.⁵ ML algorithms and deep CNNs were integrated to identify and predict adversaries. The cloud-server-trained network performed classification of every video frame. The network output was overlaid on the video stream. Finally, the data was resized into a side-by-side format and streamed to an HMD worn by the human controller. Aerial surveillance was attained through a ground vehicle coupled with an UAV. The human held the final decision.

4. CONCLUSION AND RECOMMENDATIONS

The main purpose of this comprehensive literature review was to provide a means to identify needed research to develop advanced ground-support technology in the area of surveillance, target identification, and target elimination to improve our dismounted Soldiers' survival and wins against adversaries.

To develop a networked UAV system to accurately identify and eliminate targets to dismounted Soldiers, the design of the HMI should be considered. HMI development considers human information processing and cognition and is necessary to optimize cognitive fightability. This is further dependent on how human senses are used to perceive the environment and how they may affect HMI modalities.

Models of information processing (human behavior classification, stimulus-central processing response, and effects of attention-sharing and multitasking), modalities of information (visual, auditory, and haptic), modalities of system control (the means by which the Soldier's input or control commands into the system), and the analysis of Soldier needs (identify information needs and implement the best-suited modality) should be reviewed when implementing or designing HMI.

UAVs will play a vital role in the U.S. Army's future force, providing visual feedback of the battlefield through the utilization of sensors, cameras, and munitions. An important factor for future building is the analysis of the balance of munitions, sensors, and fuel. UAV operators provide the eyes for the fight. The CL I and CL II UAVs provide battlefield signature patterns that keep the dismounted Soldiers alive.

To have successful wins, Soldiers must get inside the OODA by having a better SA than the threat by making quicker decisions and changing the situation in a way that is unobservable and incomprehensible by the opponent at a given time. AI can strengthen SA by identification of enemy presence, movement, identification, and mitigation.

UAVs can help improve SA with future advancements of data processing, fusion, and analytics. SA is paramount for dismounted Soldiers to engage efficiently. SA encompasses assessment (machine), awareness (user), and understanding (user-machine teaming).

To address the multifaceted problem statement concerning UAVs, visual/optic systems, AI/ML, network teaming, and the use of legacy equipment, this literature review covers many interlocking factors. Among the numerous considerations are massive communications, high-level data traffic, low on-board energy storage, network configuration, different modalities to augment human cognition, speech, and audio, and UAV navigation, deployment optimization, and coordination.

It is recommended that the GVSC Modeling, Simulation, and Software Directorate's Immersive Simulation Division be consulted in reference to supporting networked UAV development and future human-performance models for building AI/ML dismounted environments. GVSC worked with Lockheed Martin on the HiveStar 5G network UAV leader-follower S-band system to facilitate battlefield communication on the fly.¹⁷ The HiveStar drone platform facilitates the autonomous delivery of a distributed mission to different nodes. It allows multiple layers of communication using LoS and S-band networking systems through UAVs. HiveStar will distribute that mission to all assets available. During a demonstration scenario, the UAV followed ground-vehicle convoys to provide surveillance and then communicated back to the ground vehicles, which allowed supplies to arrive safely.

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LIST OF ACRONYMS

2-D	two-dimensional
3-D	three-dimensional
5G	5th generation
ABD	agent-based distillation
AI	artificial intelligence
ANS	Automated Navigation System
AO	area of operations
AR	augmented reality
ARV-A	Armed Robotic Vehicle-Assault Variant
AV	autonomous vehicle
BLOS	beyond line of sight (over 600 miles)
C2	command and control
CAB	Combined Arms Battalion
CAEn	Close Action Environment
CDL	Common Data Link
CL I, II	Class 1 (small 0–20 lb); 2 (medium 21–22 lb) UAVs
CNN	convolutional neural network
CONOPS	Concept of Operations
COP	common operating picture
CVS	combined vision system
DAC	DEVCOM Analysis Center
DDDAS	dynamic data-driven application system
DEVCOM	U.S. Army Combat Capabilities Development Command
DOD	Department of Defense
EFVS	enhanced flight vision system
EVS	enhanced vision system
GPS	global positioning system
GUI	graphical user interface
GVSC	Ground Vehicle System Center
HAT	human–agent teaming
HMD	head-mounted display

HMI	human/machine interface
HMM	hidden Markov model
HRI	human–robot interaction
HUD	heads-up display
IOBT	Internet of Battlefield Things
IOMT	Internet of Military Things
IoT	Internet of Things
IP	Internet Protocol
JTRS	Joint Tactical Radio System
LOS	line of sight
MANA	Map Aware Non-Uniform Automata
ML	machine learning
MOLLE	modular lightweight load-carrying equipment
MUT	manned–unmanned teaming
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NLOS	non-line-of-sight
OFW	Objective Force Warrior
OODA	Observe-Orient-Decide-Act
QRF	quick reaction force
RAS	robotics and autonomous systems
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SA	situational awareness
SASIO	Situational Awareness for Surveillance and Interdiction Operations
SCR	stimulus-central-processing-response
SR	stimulus response
SVS	synthetic vision system
TCDL	Tactical Common Data Link
UAG	unmanned aircraft general
UAS	unmanned aerial system
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle

UV	ultraviolet
WPT	wireless power transfer

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