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

Squad with Autonomous Teammates

Madison Teague, Luke Carpenter, Joshua Campi, and Rich Morales

Department of Systems Engineering
United States Military Academy
West Point, NY

Corresponding author's Email: madison.teague@westpoint.edu

Author Note: This project could not have been accomplished without the help of our other great teammates from the Mechanical Engineering Major and Electrical Engineering and Computer Science Major. Also, a special thanks to our team advisors: COL Morales, COL Korpela, LTC Chetcuti, and Dr. Novitzky. Without all those mentioned previously, our project would not have gotten to this point, and future projects would not be possible.

Abstract: Autonomous systems are a force multiplier on the battlefield today, however they are concentrated at high levels and primarily used for pre-mission reconnaissance. The Army has affirmed this statement with their plan for Multi-Domain Operations where they set their focus on near-peer threats, adaptation to maintain overmatch, and an increased reliance on small units. Squad with Autonomous Teams-Challenge (SWAT-C) team was challenged to design and integrate unmanned systems into a modern-day infantry squad to achieve overmatch in combat. From this overview of the challenge, the SWAT-C team developed human-drone teams capable of conducting reconnaissance and providing fire support to improve the combat effectiveness of a squad-sized element. The SWAT-C team has made steps towards the augmentation of situational awareness for squad sized elements on the battlefield. They have accomplished this with the streamlining of information relay to a squad leader, or any member of the squad, using the Android Team Awareness Kit (ATAK), which will display live video, object recognition and GPS data to the user.

Keywords: Autonomous Systems, Autonomy, Unmanned Systems, Human-Machine Teaming

1. Introduction

The SWAT-C is tasked to increase the lethality and situational awareness of a squad sized element with the aid of unmanned systems. The primary requirements, determined from stakeholder analysis, for the unmanned systems are summarized in the following needs statement; "The system needs to be able to positively identify targets, communicate that information to the squad, and provide lethal effects if necessary." The system also needs to be able to relay information to a TOC or higher command to accomplish full unit situational awareness.

Previous designs experienced difficulties with limited battery life, hardware failures, line-of-sight communication, and terrain restrictions. Furthermore, because the assets required remote piloting, they required the full attention of the end users and increased burden on the operators. This year's product addresses these challenges, specifically improving the operating range and duration while reducing the amount of distraction imposed on the members of the squad that operate and receive information from the systems.

Literature review and background research into previous SWAT-C designs revealed that both ground and aerial platforms were desirable to aid the USMA Future Applied Systems Team (FAST) in a practical exercise. USMA FAST typically participates in a competition involving a force on force scenario where teams from the United States Military Academy and the United States Naval Academy are provided offensive and defensive missions where they must incorporate unmanned systems created by cadets to aid mission success. This competition typically serves as the culminating event for the SWAT-C project. This year, the culminating event will be an individual weekend event with the SWAT-C capstone and USMA FAST.

The Department of Defense (DoD) currently employs numerous Unmanned Air Vehicle (UAV) and Unmanned Ground Vehicle (UGV) platforms. These systems aim to increase situational awareness, improve sustainment, facilitate movement, and protect the force (Robotics and Autonomous Systems Strategy). The Army primarily uses aerial drones for either delivering lethal effects or for providing intelligence, surveillance, and reconnaissance (ISR) capabilities. The Predator (U.S Air Force, 2015) and Reaper (King, 2015) drones are examples of large drones geared towards delivering lethal effects, while the BAE ARGUS is more geared towards the ISR support mission (BAE, 2020). A DoD UAS brief from 2015 detailed how the DoD further classifies drones and the typical training pipeline for UAS pilots. These systems are classified under five different groups. It is important to note that the Federal Aviation Administration (FAA) and other local and federal organizations require different permissions for designing and operating UAS systems within their jurisdiction. Table 1 outlines the five groups of the DoD UAS classifications.

Table 1. DoD UAS Classification System

UAS Group	**1**	**2**	**3**	**4**	**5**
Weight [lbs]	0 - 20	21-55	55 – 1,320	> 1,320	> 1,320
Operating Altitude [ft]	< 1,200 [AGL]	< 3,500 [AGL]	< 18,000 [MSL]	< 18,000 [MSL]	> 18,000 [MSL]
Airspeed [knots]	< 100	< 250	< 250	Any	Any
Example	Raven	Scan Eagle	Shadow, Integrator	Predator, Gray Eagle	Reaper, UCLASS

While current UAS offer incredible battlefield awareness and means of delivering devastating lethal effects, they tend to struggle with balancing relevant payloads with effective operating ranges near the class 1 level (2015). Alternatively, UGVs can support a larger relative payload. They are often used in combination with squad-sized elements to conduct reconnaissance and security operations (SBIR, 2020). Ground robots would be used in this project to provide means of delivering kinetic force against the enemy. Many of the ground vehicles that are used today, like the Titan, are highly modular, allowing for several different types of weapons to be installed. Some of these include guided missiles, 50mm weapon systems, 7.62 or .50 caliber machine guns, and 40mm grenade launchers (Judson, 2019). Limitations of ground-based systems include battery life, power allocation, environmental durability, terrain versatility, and the communication effectiveness (especially line-of-sight based radios) (Robotics and Autonomous Systems Strategy).

While many tasks have been analyzed and produced by other groups, one of the main focus areas of the SWAT-C group will be autonomy in vehicle navigation and object classification. The levels of autonomy are ranked 0-5 ranging from no autonomy to full autonomy. The goal of this project is to achieve level three autonomy. Level three autonomy provides requires that the drone will operate autonomously with human overwatch. Humans are still needed to approve and take control of the drone in certain scenarios, such as providing lethal effects (McNabb, 2019).

A key task of the SWAT-C project is target recognition. There are two approaches to learn and identify objects: machine learning and deep learning algorithms. Machine learning approach takes user-selected objects and learns its features and characteristics over time. The Tracking-Learning-Detection (TLD) algorithm from Stanford Vision Lab is an off-the-shelf machine learning approach (Kalal, 2012). It provides fast detection, but becomes unreliable if the object changes shape, color, or gets occluded for a duration of time. For SWAT-C's uses, an enemy target could "take cover" from one of the autonomous platforms and become occluded, and the TLD tracker would have difficulties recognizing the target again when it emerges from the occluded state. The deep learning approach involves training a convolution neural network (CNN) on a set of images that contain the object of interest. These images must have the location of the object in the image frame annotated so that the CNN can learn the different sides of the target. The most widely known deep learning algorithm for detection is "You Only Look Once" (YOLO), which provides superior performance compared to other deep learning algorithms (Redmon, 2018). Both TLD and YOLO generate bounding boxes around the object of interest to track and detect it successfully. The YOLO algorithm provides a default object classification dataset named "COCO" that includes human models. Improvements in YOLO's effectiveness on the battlefield can be accomplished by training the classification algorithm to recognize uniforms and rifles which will provide more information to the user and more accurately classify a human target. Using this deep learning algorithm provides autonomy to ground forces by aiding in enemy unit identification without requiring soldiers to be present on an objective.

2. Methodology

Establishing customer requirements, through interviews with advisors, members of USMA FAST, and current UAV and UGV developers, was the first step in the SWAT-C development. For a successful project customer needs had to be identified. For this project, this was done using an objectives tree. As this is a yearlong project, the scope of the SWAT-C capstone was narrowed down to five top-level objectives of the highest interest to the client: durability, lethality, versatility, portability, deplorability. These top-level objectives apply to both aerial and ground vehicles, though their relative importance varies.

A pairwise comparison was created to weight requirements for the project team. The pairwise comparison is useful in translating customer requirements into platform objectives by comparing their relative importance to one another in solving the problem. The team developed two a comparison for each platform due to as each has a different mission with different system requirements. Moving forward, these priorities will inform the team's decisions when comparing alternative solutions, and the specific tradeoffs each entail. Lower priorities will still be considered but sponsors and stakeholders are willing to accept certain loss of capability on the lower priorities if it means accomplishing the higher ones. Likewise, the ground vehicle scores low in versatility and high in deployability, so we would ensure that the drone is easily deployed and maneuverable before we focus on adding more functions for it to accomplish. The relative weights from these pairwise comparisons will be carried forward into the quality functional decomposition and ultimately the desired engineering characteristics, shown in table 2.

Further design analysis was conducted using a morphological box, alternatives chart, alternative sketches, utility curves, design matrices and system designs in order to determine were used to settle on a Clear Path Jackal as the UGV and the Tarrot 650 as the UAV which support squad operations in the scheme depicted in the operational viewpoint, figure 3. The relative weights from the pairwise comparisons were carried forward into the quality functional decomposition of the chosen platforms and ultimately the desired engineering characteristics, shown in Table 2.

Table 2. Engineering Characteristics: Target and Actual

Engineering Characteristics	**UAV**		**UGV**	
	Target	**Actual**	**Target**	**Actual**
Height [m]	< 0.30	0.46	< 3	0.66
Total Weight [kg]	< 9	3.12	< 10	27.6
Payload Weight [kg]	< 1.0	0.98	< 15	10.6
Operational Range [km] *x = horizontal, y = vertical*	> 5 (x) > 0.5 (y)	3.2 0.120	> 10 (x)	0.1
Endurance [min]	> 50	22.75	> 50	212
Size (LxW) [m^2]	< 0.5	0.97	< 0.3	0.22
Max Speed [km/hr]	> 40	54	> 80	7.2
Cost [$]	< 5,000	6,400	< 5,000	17,000

The team then analyzed the engineering characteristics and to measure the design's accomplishment of these objectives and begin constructing target values to guide the design process. In table 2, the green values are better than the target value, the yellow values are reasonably close to the target value, and the red values are far from the target values. The team is willing to accept the values far from the target values due to their low relative importance established earlier in the systems design process.

To help visualize the system an operational viewpoint, shown in figure 3, was created which depicts how the ground and air vehicles will be integrated with a squad. An operational viewpoint helps visualize the interactions of each subcomponent in the system.

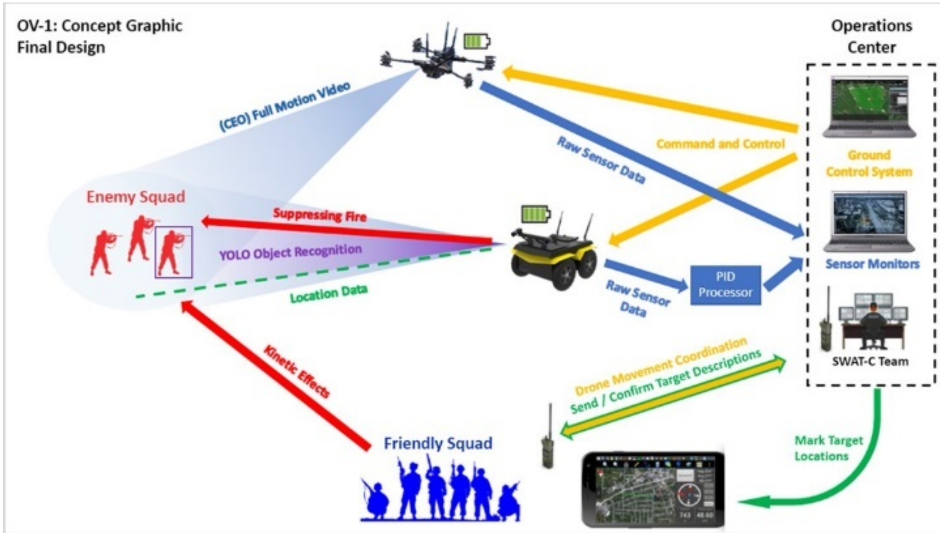

Figure 1. Operation Viewpoint 1

3. Results and Analysis

At the end of the building and testing phases, capabilities for the Tarrot 650 consist of lidar capabilities to calculate the altitude of the drone and GoPro camera will be implemented to provide a reconnaissance resource for the squad on the ground. The Tarrot 650 provides live video feed of an objective directly to a soldier, giving them the ability to visually inspect an objective without physically being on that objective. This information can be relayed to a ground station computer or Android Team Awareness Kit (ATAK) device carried by a soldier over a WiFi hotspot on the Intel NUC companion computer, which has a range of 100 meters. An example of what a soldier might see on the ATAK screen can be found in figure 4.

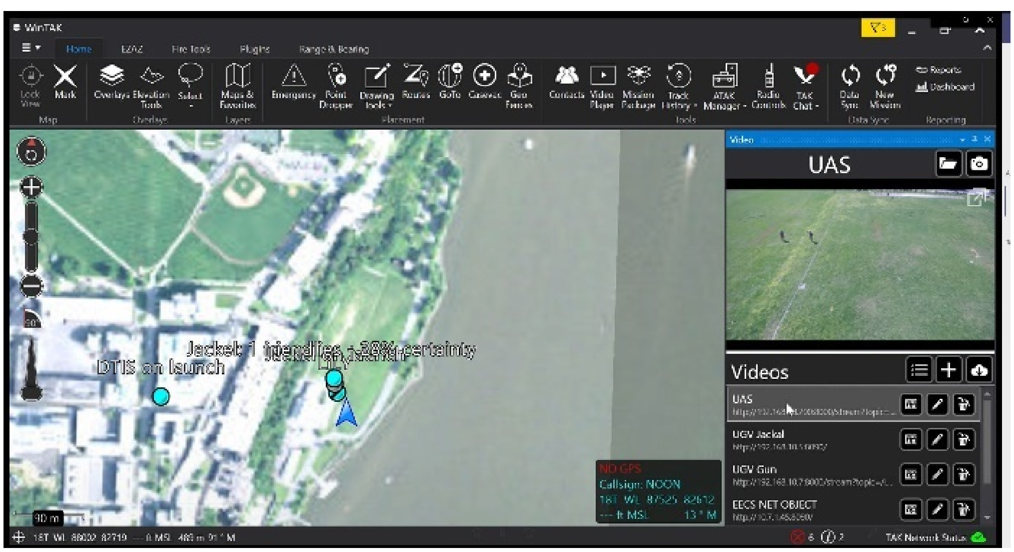

Figure 2. Example ATAK Screen with UAS Video Feed

The Jackal provides ground surveillance and payload delivery. It can be manually controlled or sent coordinates over the ATAK device to navigate to. The UGV can also relay information to the same ATAK devices and ground station computer as the UAV. The Jackal's companion computer handles all the sensory input from the Ouster OS1-64 LIDAR, Intel Realsense D435i, and FLIR BlackFly cameras which feed imagery to the infantrymen, TOC, and the object detection classifier as well as enable its autonomous navigation and obstacle avoidance. Figure 4 shows the results of two tests of the Jackal's mapping capabilities using the Simultaneous Localization and Mapping (SLAM) algorithm in a small, indoor room. The obstacle avoidance capabilities have been validated in simulation and practice, using the sensors that will be implemented on the Jackal. The Jackal can also has an attached airsoft gun which can be remote fired from a TOC or ATAK device. This feature contains a human in the loop, which is essential to maintaining ethical standards of Geneva Conventions.

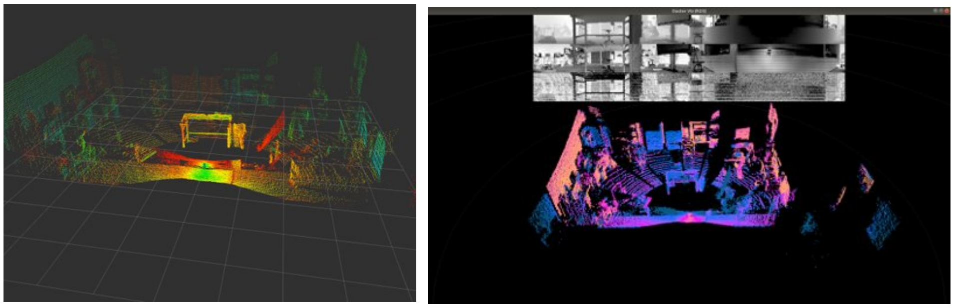

Figure 3. Image of Ouster OS1-64 LIDAR Environment Mapping

The Jackal has autonomous object detection capabilities via trained YOLOv3 models running on an on-board graphical processing unit (GPU). The GPU will achieve 17 and 50 frames per second (fps) respectively on the YOLOv3 custom light-weight dataset (yolo-tiny) and is loaded with a custom built YOLOv3 object detection dataset as opposed to the generic YOLOv3 yolo-tiny dataset. The detection model used by YOLOv3 was trained to detect friendly, classifying them based off their uniform pattern. An example of this detection can be found below in Figure 4.

Figure 4. YOLO Object Recognition of Friendly Forces

Tests were conducted on the functionality of both the UAS and UGV platforms during March and April of 2021. Tests evaluated speed, durability, network range, battery life, and autonomy capabilities. Tests were conducted indoors, outdoors, and over varying terrain. The main limitations identified in testing were the range and efficiency of the network and battery life. Since so much information travels over the network at once, the network range is limited to about 200 meters and must be line of sight. This is one of the most important features to improve in future work, as it enables the independent function of a squad. Currently, missions using the Jackal (UGV) and Tarrot (UAV) must remain close to and in direct sight of the TOC. One of the goals of this project is repeated use for a squad, which is limited due to battery life. Improving the battery life of both the ground and aerial platform would allows soldiers to conduct longer missions with the aid of the vehicles and would allow the vehicles to be deployed from much greater distances. The Jackal (UGV) speed test was somewhat concerning as it moved at walking speed which would impede soldier's movement. To improve this, the systems may need to be applied to a large vehicle. The tests of the autonomy of the both the Jackal (UGV) and Tarrot (UAV) were both successful. The UGV was able to autonomous navigate and map its movement while simultaneously running the object recognition. The UAV was able to autonomously navigate to the target point given by the ATAK system.

ISBN: 97819384962-0-2

4. Conclusion

The goal of the SWAT-C is to improve the situational awareness of infantry squads using unmanned air and ground vehicles and ATAK user interface. The systems used to achieve this goal are a UAV (Tarrot 650) and a UGV (Jackal) as extra reconnaissance and fire support resources. ATAK will provide a basis for connection and information management throughout the operation. A soldier will be able to watch live feed sent from both the UGV and UAV as well as see points on a map where a potential enemy is identified by the Jackal. The soldiers should also be able to use ATAK to dictate where these unmanned vehicles go simply by giving them a grid coordinate as a final destination. The vehicles will be equipped with an object avoidance and facial recognition software to provide an environmental aspect to autonomy. One of the greatest limitations identified through research and practice are network durability and availability. The current system relies on a Wi-Fi network developed by the SWAT-C team, but it is limited in speed of information relay, which restricts the quality of object detection and video feed that can be sent back to a squad. The project demonstrations also revealed in the teleoperation range for each of the vehicles due to network capabilities. Future goals for this project will target a system closer to level 3 drone autonomy (conditional autonomy). Since such a system could provide lethal effects, there is a requirement that a human operator remains in the loop to maintain ethical and moral standards expected for combatant engagement. Future capabilities for the SWAT-C system include an AI system built into these drones which can read and analyze different sensors to choose the most optimal action for the mission.

5. References

BAE Systems (2020). *Autonomous Real-Time Ground Ubiquitous Surveillance Imaging System*. BAE Systems. Retrieved September 22, 2020 from https://www.baesystems.com/en-us/product/autonomous-realtime-ground-ubiquitous-surveillance-imaging-system-argusis.

Automatic Target Recognition of Personnel and Vehicles from an Unmanned Aerial System Using Learning Algorithms. Retrieved September 22, 2020 from https://www.sbir.gov/sbirsearch/detail/1413823.

Downey, J., Michini, B. J., & Richman, B. (2016). *U.S. Patent No. 9,273,981*. Washington, DC: U.S. Patent and Trademark Office.

Gordon, M. S., Kozloski, J. R., Kundu, A., Malkin, P. K., & Pickover, C. A. (2017). *U.S. Patent No. 9,773,419*. Washington, DC: U.S. Patent and Trademark Office. Secretary of Defense, Unmanned Aircraft Systems Roadmap 2005-2030.

Judson, J (2019). The US and its allies are getting serious about armed ground robots. *Defense News*. Retrieved September 13, 2019 from https://www.defensenews.com/digital-show-dailies/dsei/2019/09/13/getting-serious-about-armed-ground-robots.

Redmon J., & Farhadi A. (2018), YOLOv3: An Incremental Improvement, *arXiv*:1804.02767.

McNabb, P., (2019). DroneII: Tech Talk – Unraveling 5 levels of drone autonomy. *DroneLife*. Retrieved March 22, 2021, from https://dronelife.com/2019/03/11/droneii-tech-talk-unraveling-5-levels-of-drone-autonomy/

King, L., (2015) *DoD Unmanned Aircraft Systems Training Programs.* DoD Unmanned Aircraft Systems Taskforce.

U.S. Air Force (2015). *MQ-9 Reaper Fact Sheet*. Retrieved April 24, 2021 from https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104470/mq-9-reaper/

U.S. Army (2020). *Robotics and Autonomous Systems Strategy*. Retrieved April 24, 2021 from https://www.tradoc.army.mil/wp-content/uploads/2020/10/RAS_Strategy.pdf

Kalal Z., Mikolajczyk, K., and Matas, J., Tracking-Learning-Detection, *IEEE Trans. Pattern Analysis and Machine Intelligence.*, vol. 34, no. 7

ISBN: 97819384962-0-2