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Radiological and Imagery Data Enhanced Reconnaissance Swarm (RAIDERS)

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Author's Note: Cadets Trainor, Polhamus, and Brady are members of the Department of Systems Engineering at the United States Military Academy. This paper presents research performed for a Capstone Project in support of 20th Chemical, Biological, Radiological, Nuclear, Explosives (CBRNE) Command through the Defense Threat Reduction Agency (DTRA). Colonel Ricardo Morales serving as the Senior Advisor for this project provided critical expertise and advice for system integration and implementation.

Abstract: The Radiological and Imagery Data Enhanced Reconnaissance Swarm (RAIDERS) team set out to design, implement, and test a multi-unmanned aerial system to assist the 20th CBRNE in forensic collection and examination of a post nuclear blast site. The system must be deployable in a post nuclear and combat environment, able to collect data efficiently, provide the end-user with a radiation level heatmap over a ground area along with aerial reconnaissance, able to consolidate and redeploy in a timely manner, and be reconfigurable to any area or environment. Points of emphasis for the design of this project as provided by the sponsors are: rapid deployment, improved swarm behavior, enhanced sensors, aerial overwatch, and end-user integration. The RAIDERS system will be tested, validated, and implemented in a final design competition hosted by DTRA. Further development can create a working drone swarm that is ready for deployment with a 20th CBRNE unit.

Keywords: Radiological Detection, Nuclear Heatmap, Drone Swarm, System Engineering, Interdisciplinary Project

1. Introduction

When responding to notices of nuclear weapon detonation, United States Government Organizations such as the Army's 20th Chemical, Biological, Radiological, Nuclear, Explosives (CBRNE) Command are responsible for providing the government with forensic data collection of the nuclear event. In doing so, the 20th CBRNE must deploy Army soldiers near these post nuclear blasts sites in order to collect data necessary to identify information regarding the nuclear blast to include the materials utilized, possibly country of origin, and any extenuating threats that may be present. The Ground Collection Task Force (GCTF) is tasked to deploy near the settled plume of a nuclear blast to collect these forensic samples. In order to best preserve these samples and enable accurate data analysis, the team must gather and transport the samples as quickly as possible. Due to this, the GCTF maps the radiation levels of the area to determine the optimal route to certain sample collection points. Current practices for creating this radiation map is to utilize Army Aviation assets that are equipped with standard radiation detection equipment. This practice is inherently dangerous, as it places the pilots and crews of these aircraft in areas that are likely to be highly radioactive areas. One possible solution to this problem is the use of a multi-unmanned aerial system also commonly known as a drone swarm or simply, swarm.

2. Literature Review

The use of Unmanned Aerial Systems (UAS) is the next stage in advanced technology regarding military operations, specifically CBRNE operations. As of recent evaluation, UAS has found a more developed purpose "in [a] variety of operations, ranging from monitoring, surveillance and inspection to search and rescue applications" (Yamaguchi et. al.,2017). "Its inherent ability to increase situational awareness and provide a force multiplier for the soldier" will allow the military to advance in ways such as through ground troop integration as well as for complex mission sets (Barnes, Garcia, Fields and Valavanis. 2008). The use of unmanned aerial vehicles in CBRNE operations would greatly increase the capabilities of military forces' analyzing and mapping a post nuclear explosion. Areas where UAS could possibly aid CBRNE units is through, "localizing the incident, identifying the materials involved, and determining the source and amount of materials" (Murphy, Peschel, Arnett, and Martin. 2012). A multitude of different UAS variants would be necessary to effectively collect this data. Murphy suggests that, "the robots would be working independently [so that] if one fails, there is no impact on the performance of the others" (2012). More beneficial to the CBRNE community would be a multitude of drones that could work semi-autonomously with the ability to continue the mission and pick up the slack if one of the UAS links goes down. This would require some advanced interaction between drones through the use of swarm behaviors in order to mitigate risk in critical points of execution. Additionally, a current priority for military UAS application is creating a fully autonomous system in order to reduce operator skill requirements and increase the reliability of the tactical system (Williams and Michael, 2002). This will help to directly increase usability for the end user, who is limited in both training and resources.

Advanced swarming behavior, the algorithms controlling drones in a group, has developed a lot in recent years. Existing techniques involve three main methods of controlling drone behavior. Edge-following moves robots along the edge of groups by measuring distances from the robots on the edge (Rubenstein, Cornejo, and Nagpal, 2018). Gradient formation generates a gradient value message that increments as it propagates through the swarm (each robot gets a geodesic distance from the source (Rubenstein, Cornejo, and Nagpal, 2018). Finally, localization is when robots form a local coordinate system using communication with, and measured distances to, neighbors (Rubenstein, Cornejo, and Nagpal, 2018). Used in conjunction, these three techniques can be used to effectively control robots in a swarm and provide a diverse set of data to be utilized.

For these swarm behavior methods to work, effective communication must exist between the robots of the swarm. Three major forms of communication exist at the forefront of drone technology today. "Virtual individuals" is a communication technique where robots within a swarm share information with the robots in their immediate vicinity (Sterritt, Rouff, and Hinchey, 2007). This method helps robot react to new stimuli in the same way as flocks of birds. Individuals in the outer parts of the swarm detect some sort of new input and diffuse this information throughout the swarm. Another form of drone communication is "virtual targets" (Sterritt, Rouff, and Hinchey, 2007). In this information sharing scheme, points of interest are set for the drones to focus in on. Drones on approach to these targets share information with one another. Finally, "virtual pheromones" allow drones to communicate levels of traffic by other drones through areas. As drones in a swarm move, virtual pheromones are left to guide other robots into an area of interest (Sterritt, Rouff, and Hinchey, 2007). This communication can even go so far as to change the code on the robots. The genetic software framework allows a swarm of robots to evolve their code over time to adapt to scenarios (Kornienko, Kornienko, Nagarathinam, and Levi, 2018). This aspect of swarm behavior allows rapid progression of UAS technology through its utilization of dynamic technological advancement.

Swarm behavior is vital to the success of our project. It makes for the division of work necessary to accomplish complex tasks with robots. Through efficient controlling algorithms and communication, robots in a swarm can work together towards common goals. Our project requires robot to be specialized for specifics tasks. Robots will be needed for security and sensing. The coordination of these two types of robots will be done through the effective use of these swarming algorithms and communication.

3. Methodology

3.1 Background Information

The RAIDERS system is a continuation project from the United States Military Academy RAID SWARM team as outlined in "Application of the Systems Decision Process to Swarm Drone Nuclear Detection." (Girardot, Ratliff, Volpe, & Morales, 2018) The ultimate goal of the project is to provide a functioning multi-unmanned aerial system demonstration in a competition sponsored by the Defense Threat Reduction Agency (DTRA). The RAIDERS team is comprised of 13 cadets across four academic departments who work as an interdisciplinary team to design, integrate, develop, and implement a complex system to assist the 20th CBRNE in future post nuclear blast data collection. As a continuation project, the resources available to the RAIDERS team consisted of unmanned aerial vehicles that were utilized by the previous academic year capstone group. In the swarm, there are two different models of aerial vehicles: one is a fixed wing single propeller vehicle known as a zephyr while the second is a four rotor vertical lift vehicle referred to as a quadcopter. The overall budget of the project was determined by the sponsor DTRA. As a year long capstone project, the RAIDERS team had roughly eight months to produce a working multi-unmanned aerial system to detect and map radiation signatures.

3.2 Problem Definition

The problem statement as articulated by the 20th CBRNE Command is to design and test a multi-unmanned aerial system in the detection and radiation mapping of a post-nuclear blast site. The overall objective of the system is to assist forensic and surveillance data collection of a fallout region. Figure 1 depicts the overall objective along with subsequent capabilities that will drive the overall success of the system. Through stakeholder analysis, five focus areas for the RAIDERS

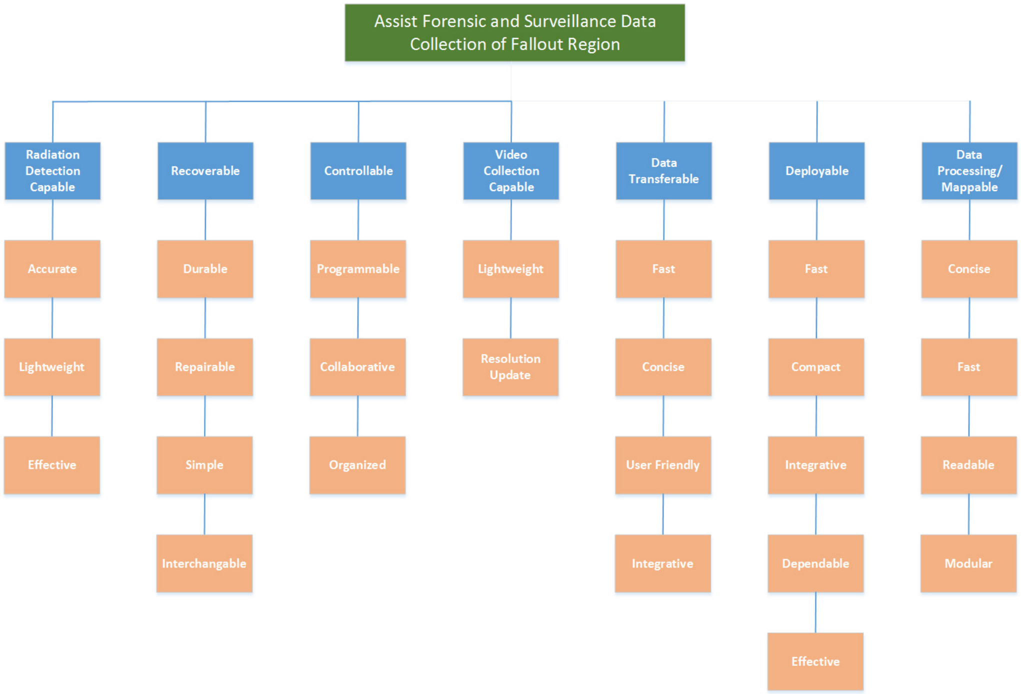

Figure 1. Objective Tree for Multi-Unmanned Aerial System

project were articulated by the 20th CBRNE Command: rapid deployment, improved swarm behavior, enhanced sensors, aerial overwatch, and end-user integration.

3.2.1 Radiation Detection

One of the primary missions of the RAIDERS project is to assist in the forensic collection and examination of a post nuclear blast site. In order for the 20th CBRNE to effectively collect soil samples and other forensic evidence in a post nuclear blast site, the GCTF must know where they are able to safely maneuver in order to minimize their radiation exposure. A multi-unmanned aerial system could provide the 20th CBRNE with an efficient method of mapping the radiation levels of an area while maintaining a safe distance for soldiers. This system needs to be deployable by an Army ground force, efficiently collect at transmit data, consolidate on completion of mission, and provide higher Army echelons with comprehendible visual analyses of the levels of radiation.

3.2.2 Overwatch

The second mission of the RAIDERS project is to provide continuous surveillance for the 20th CBRNE Command. Constant overwatch is necessary to ensure successful collection of forensic data, operation of the radiation detection swarm, and possible route planning. This system must work both independently or concurrently with the radiation detection mission. Additionally, the overwatch mission should provide the ground force commander with real-time video footage with uninterrupted updates to ensure successful completion of the GCTF mission.

3.3 Final Solution and Expectations

In designing the multi-unmanned aerial system to assist in forensic and surveillance data collection for the 20th CBRNE Command, RAIDERS focused on improving each of the five subsystem requirements outlined. Each subsystem required a multidisciplinary approach to enhance the capabilities of the overall system. Figure 2 shows how each individual subsystem focus is integrated into the functionality of the multi-unmanned aerial system.

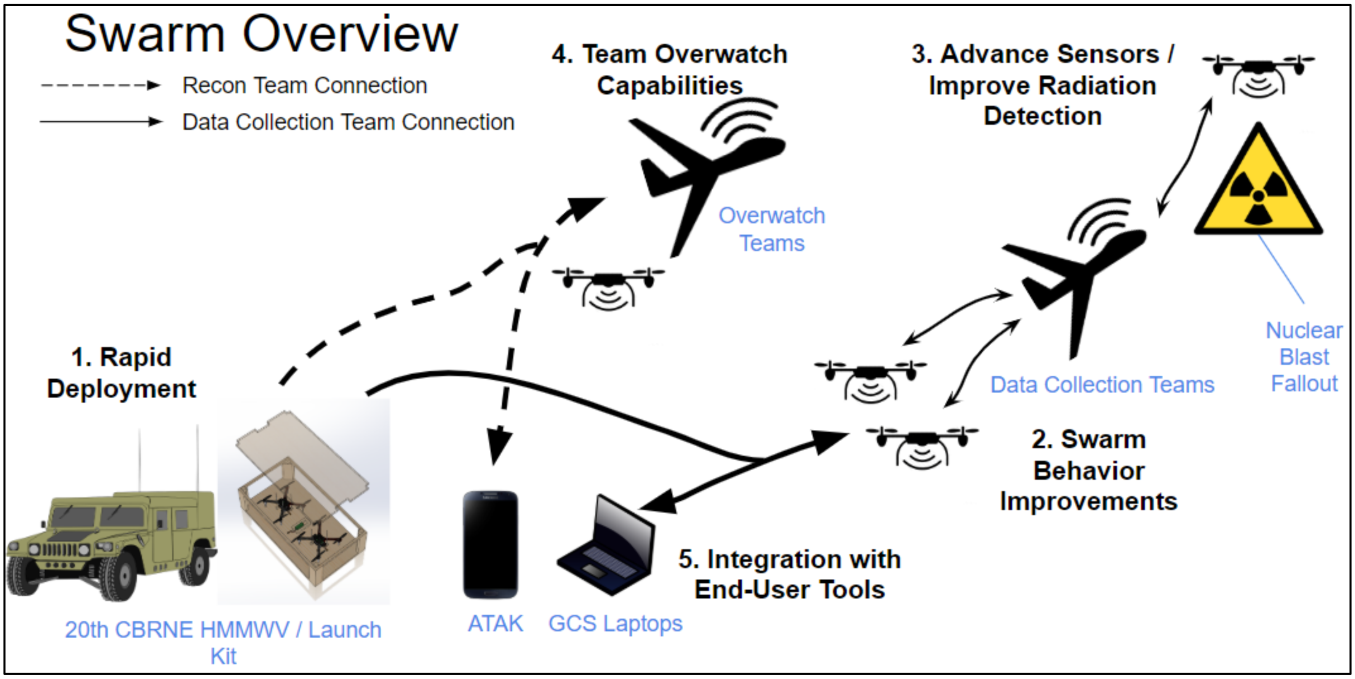

Figure 2. RAIDERS System Overview

3.3.1 Rapid Deployment

In designing improvements for the rapid deployment of the system, RAIDERS focused on the transition of the quadcopters from the GCTF High Mobility Multipurpose Wheeled Vehicle (HMMWV) to the vertical takeoff location. The previous year's project proved to have a lengthy process for transporting each individual quadcopter from the HMMWV to a specific ground control station where the vehicles would be pre-flight configured and given their mission set. RAIDERS designed a rapid deployment system that houses two quadcopters during transportation. Each container not only better protects the quadcopters during transportation, but also allows the quadcopters to be pre-flight configured in route to the takeoff location. Upon arriving at the deployment location, two soldiers will simply carry the containers from the HMMWV and set them at the specific takeoff location. From there, each quadcopter will deploy on its specific mission by using a rail guidance system incorporated in each container to prevent drone collisions.

3.3.2 Improved Swarm Behavior

Once the swarm is deployed, the speed of the data collection is primarily driven by the efficiency of the swarm behavior. The swarm behavior is defined as the manner in which the drones interact with one another to perform a given task. Projects involving this swarm in previous years utilized a greedy-go-to that assigned missions to different aerial vehicles based on their distance away from specific survey points. Although practical in some scenarios, RAIDERS utilizes a two pass method. On the initial pass through an area, radiation data is collected in a swift and abbreviated manner. Based on the results of the first pass, the points that achieve a predetermined radiation threshold will then receive a second pass through by the swarm to record more detailed data regarding the radiation signatures in that area. Both methods utilize a "lawnmower" movement pattern of searching in which an individual quadcopter will follow a linear path across an area before moving a certain distance perpendicular to that path. From here, the quadcopter will make a similar pass moving back towards the initial point. The vehicle will continue this maneuver until an entire area of prescribed length and width is surveyed or the drone runs out of battery.

3.3.3 Enhanced Sensors

The data that is collected by the radiation collection swarm is processed to produce a heat map of the radiation levels. This data is then normalized in relation to altitude to create a heat map of the surveyed area. In order to collect better results and display a higher resolution heatmap, RAIDERS aims to test and implement improved radiation detectors along with incorporating an altitude sensor. Rather than finding the altitude at a specific waypoint based on geographic data, the altitude

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sensor is able to calculate the distance from ground level while the radiation sensor is simultaneously collecting the radiation signature at that waypoint. This combination produces the clearest radiation mapping of the area.

3.3.4 Aerial Overwatch

While the quadcopters are collecting forensic data, the zephyr or fixed wing vehicles are simultaneously providing overwatch. To ensure the swarm is collecting data efficiently in the manner described by the swarm behavior, constant overwatch is necessary for the GCTF to make any real time modifications to the swarm mission. Video cameras mounted on the front of the zephyr vehicles provide the necessary overwatch for the GCTF to have command and control over the radiation detection swarm. Additionally, the zephyrs are able to provide additional surveillance outside of monitoring the quadcopters. In a post nuclear fallout zone, there will most likely be destroyed roadways and excessive debris. Video surveillance provided by the zephyrs will allow the GCTF to have a better understanding of their operating environment. This will assist the teams in moving and maneuvering to further forensic collection locations.

3.3.5 End-User Integration

All efforts in collecting this data are useful only if the end-user is able to analyze and comprehend it in a technical and tactical manner. The GCTF needs to be able to understand the data that is collected so that it assists their efforts in further forensic collection. RAIDERS integrates the Android Tactical Assault Kit (ATAK) with the swarm deployment system to display the radiation heatmap to each GCTF soldier. This software has many capabilities, one of which to using overlays to display information about the operating environment. RAIDERS uses the heatmap generated by the radiation collection swarm to create an overlay. This overlay can be put on a server where each soldier would be a client and have access to the radiation overlay.

4. Results and Conclusions

By using a Systems Engineering approach, a swarm of multi-unmanned aerial vehicles is able to successfully deploy in a simulated post nuclear environment, efficiently collect radiation data, provide the end-user with a radiation level heatmap and aerial surveillance over a ground area, consolidate and redeploy in a timely manner, and reconfigure to any area or environment. Similar systems have the potential to accomplish the needs of the 20th CBRNE Command, but due to the year-long scope of this project, the RAIDERS system is not yet ready for integration into an Army unit. However, the RAIDERS team made vast improvements to the five subsystems outlined by the client this year. The use of swarms to collect radiation information in a post nuclear blast environment is a relevant and feasible improvement upon current practices. There is a real necessity to find an alternative practice of mapping radiation levels and an extensive multi-unmanned aerial swarm has the potential to achieve that goal. Recommendations for future projects incorporating similar systems are to continue improving the overall behavior of the swarm, interpretation of radiation data to best display information for the end-user, and improved concept validation prior to implementation.

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