Proceedings of the Annual General Donald R. Keith Memorial Conference
West Point, New York, USA
May 3, 2018
A Regional Conference of the Society for Industrial and Systems Engineering

Application of the Systems Decision Process to Swarm Drone Nuclear Detection

Alfred Girardot, William Ratliff, Michael Volpe, and COL Ricardo Morales

Corresponding author's Email: william.ratliff@usma.edu

Author Note: Thank you to our teammates, advisors, and our sponsor, Defense Threat Reduction Agency (DTRA). A special thank you to COL Morales for his guidance.

Abstract: The purpose of this study is to serve as a practical application of the Systems Decision Process to the application of Unmanned Aerial Systems (UAS) Swarm Drone technology to solving the problem of post-blast nuclear forensic analysis. This study analyzes how the Systems Decision Process (SDP) was utilized in identifying problems and providing solutions to this complex, real-world problem. Additionally, this study applies Systems Engineering tools including functional and requirement analysis to our given problem. The interdisciplinary nature of this capstone project (12 members across 5 different academic disciplines) aided the focus of this paper to be on general application of Systems Thinking and problem solving rather than a focused look into one technical aspect of the problem. This project serves as an example of the interdisciplinary nature of Systems Engineering.

Keywords: Unmanned Aerial Systems, Systems Integration, Swarm Technology

1. Introduction

The United States Government has a marked interest in responding quickly and efficiently to nuclear disasters whether it be weaponized or accidental events. Part of this response is the forensic analysis of debris collected from a nuclear blast site. The data from forensic analysis of the post-blast effects and debris can reveal important aspects of the weapon to include origin and medium of detonation. A key element that facilitates forensic analysis is the rapid collection of radiological material by a National Technical Nuclear Forensics (NTNF) Ground Collection Task Force (GCTF). These task forces, composed of assets from the Department of Justice (Federal Bureau of Investigation), Department of Energy, the Department of Defense (including the 20th Chemical, Biological, Nuclear, Radiological, and high-yield explosives Command) and possible fixed and rotary wing aviation support from the US Army Aviation command, utilize a wide range of sensors and assets to assist in the collection of ground samples. Previous research has been conducted on utilizing unmanned aerial systems (UAS) to aid elements like 20th CBRNE command in the collection of ground samples. The future of UAS technology lies in multi-drone platforms commonly referred to as swarms.

2. Literature Review

The idea of utilizing UAS technology in military applications is not a new one. Current systems and UAS research focuses on “single, big, expensive, and nonexpendable platforms.” (Cevik, Kocaman, Akgul, & Akca, 2012). As technological capabilities increase, this focus will shift to systems of multiple, smaller UASs that offer distinct advantages over a single UAS. Drone swarms will have a vast array of uses, especially in the military. This technology can “provide reconnaissance for troops on the ground” or “jam enemy communications, form a wide-area flying communications network, or provide persistent surveillance of a particular area.” (Mizokami, 2017). The important aspect to the theory behind swarm technology is that the swarm operates as a unit and has the ability to coordinate (Hambling, 2016). This allows the swarm to adjust to changing conditions and continue the mission even if single drones within the system are not mission capable or are destroyed. Anti-air systems are generally used to target single planes giving swarm technology a distinct advantage.

The most popular and detailed theory on swarm use, from the Navy’s Low-Cost UAV Swarming Technology (LOCUST) program, describes a modular system that can accept different payloads for different mission sets (Hambling, 2016). This will allow for a highly adaptive system able to carry out a vast array of missions. Additionally, this type of system can be controlled by one user giving commands to the swarm rather than individual aircraft. A systems approach to UAS technology defines four layers of control within a high level framework: redundancy management, trajectory generation, path planning, and decision making (Eaton, Chong, & Maciejewski, 2016). It also identifies the fact that UAS need clear mission management functions that “provide the primary high-level decision making for the mission performance of the vehicle.”(Eaton, Chong, &

Maciejewski, 2016). The ability for a swarm system to process a mission, plan the mission, and execute the mission is critical in capitalizing on the advantages of swarm technology.

Swarm theory is the next stage in UAS development. Creating a group of highly modular drones that communicate efficiently and operate as a single entity is a key component of swarm theory. Swarms will be capable of handling a variety of mission sets, and the ability to manage missions at the system level is necessary for a successful system. As smaller, autonomous drone technology becomes wider spread, highly advanced swarm systems will become feasible (Floreano & Wood, 2015). Developing these systems for select mission sets and applying them to real life scenarios for further research will propel the development of this technology.

In order to analyze the historical context of our project it is best to study historical uses of the collection of radiation data through Unmanned Aerial Vehicles (UAVs), and the uses of Swarm Drone technology. Although UAV technology can be traced back to the 1920's, the concept of UAVs collecting radiation information was first recorded in 2009 ("Designing a Radiation Sensing UAV System," 2016). The use of UAVs for the collection of radiation data offered faster data acquisition where stationary systems were unable to reach. Additionally, UAVs can provide more detailed information without the atmospheric effects that exist with the use of traditional airborne technology. These atmospheric effects, common when using traditional helicopter and fixed-wing aircrafts, often produce less detailed and inaccurate data (Ilehag, Schenk, & Hinz, 2016). These historical issues with stationary and traditional airborne approaches have been the major driving factors towards the use of UAVs for radiation data collection.

With regards to radiation collection, UAVs have proven to be a much safer alternative to traditional approaches of collecting samples in potentially hazardous environments ("Designing a Radiation Sensing UAV System," 2016). For example, UAVs played an important role in the collection of radiation data following the 2011 Fukushima earthquake and subsequent nuclear disaster. The tsunami that hit Fukushima resulted in three reactors at the Fukushima Daiichi melting over and releasing a significant amount of hazardous beta and radiation. The Honeywell T-Hawk, a small unmanned aerial system (SUAS), was deployed following the radiation and, "was used to survey radiation levels present in the air at the disaster site and to help analysts assess visual damage and predict debris removal" ("Designing a Radiation Sensing UAV System," 2016). The Fukushima disaster provides historical evidence that the use of UAVs for radiation data collection is worth pursuing.

In addition to the practice of radiation collection, this project also utilizes Swarm Drone technology. The simple idea of "swarming" is described by Paul Scharre of the Center for a New American Security as, "large numbers of dispersed individuals or small groups coordinating together and fighting as a coherent whole," (Lachow, 2017). The application of swarming, a practice commonly found in birds and other animals in nature, has since been applied to UAVs. These swarming drones, or also known as "distributive collaborative systems", are developed to travel independently in some sort of formation and require little to no human intervention (Lachow, 2017). The application of this technology has no limitation on the number of UAVs in these swarms. However, current military applications have limited their swarm sizes from tens to hundreds of UAVs. Additionally, the swarming technology can be applied to multiple different UAV platforms ranging from completely autonomous to human-controlled (Lachow, 2017).The recent developments in swarming technology demonstrate both the endless potential and limiting factors of the technology.

3. Methodology

3.1 Background Information

The process of developing this system was based on the Systems Decision Process (SDP). "This process is a collaborative, iterative, and value based process that can be applied in any system life cycle stage." (Parnell and Driscoll, 2011) The given challenge is to modify an existing system, developed in support of the Service Academy Swarm Challenge (SASC), to fit the needs of a new sponsor. The group, composed of twelve cadets from four different academic departments, utilized a variety of skill sets to tackle the process of designing a complex system. Before going in depth into the methodology of the project, it is important to note constraints and assumptions the group was working under. First, the type of unmanned aerial vehicles (UAV) that were available were limited. The UAVs used in this project were systems remaining from the SASC project a year prior. These constraints required the modification existing system architecture to fit the needs of the stakeholder. These two vehicles, one fixed wing called a zephyr and one rotor blade referred to as a quadrotor, each had unique capabilities and mission sets. As a first year exploratory project our focus was not on costing and budgeting which are important aspects to project management. This section describes the process.

3.2 Problem Definition

Stakeholder analysis was conducted through interviews with various government and end-user personnel, including input from the 20th CBRNE Command. The original understanding for the system purpose was to aid in the data collection of radiological data following a nuclear event. Figure 1 is an OV-1 diagram that describes how the system fits within the data collection mission.

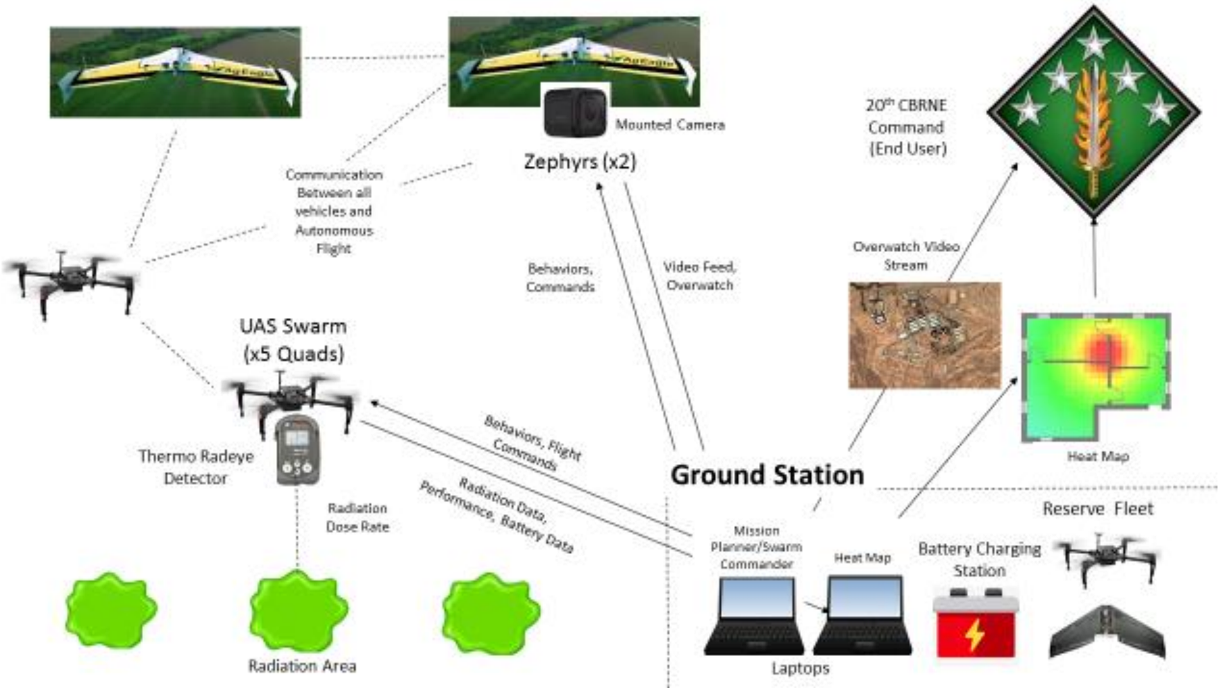

Figure 1. OV-1 Diagram.

The primary use of the system is to utilize swarm technology and radiological sensors to collect data of supposed contaminated areas and provide overwatch with live video camera feeds. The scope and requirements for the project changed throughout the developmental stages. As parts of the team began to work on solution design, it was clear that the scope of the project would need to be limited as a result of schedule and technical risk assessments. The team could not deliver a fully functional system on time for operational use. The project was scoped for a field demonstration using dispersed radioactive material. The problem statement was revised to focus on demonstrating a system that collected imagery and radiation data and presented it in the form of live camera feeds and a "heat map" of radiation levels over a given area; "Demonstrate a multi-UAS system to aid in forensic collection and analysis. This system will collect imagery and radiation data to allow the RAID Swarms to quickly locate areas that have been contaminated with nuclear/radiological debris."

The functional hierarchy in Figure 2 is derived from the top-level functions of the system and then decomposed to lower-level functions.

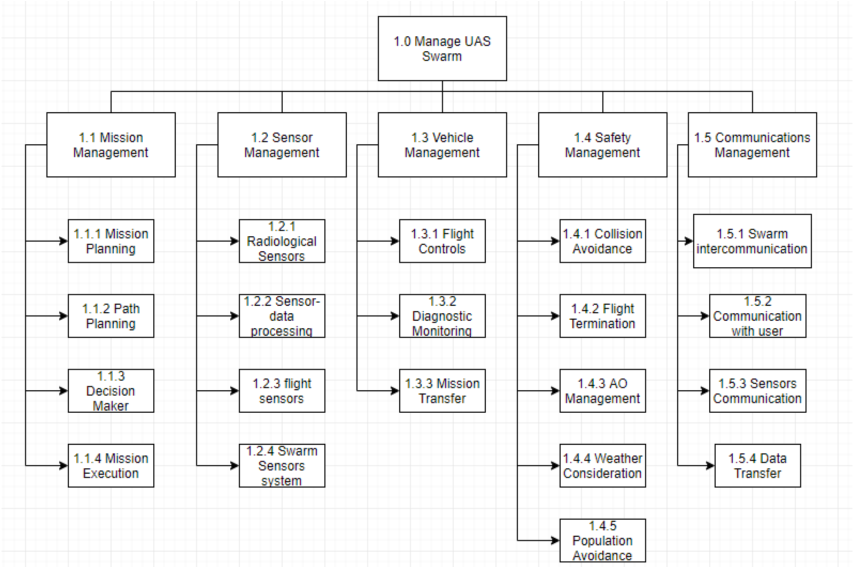

Figure 2. Functional hierarchy.

The objectives of the system are shown in Figure 3 with "Assist forensic and Surveillance Data Collection of Fallout Region" as the overall objective.

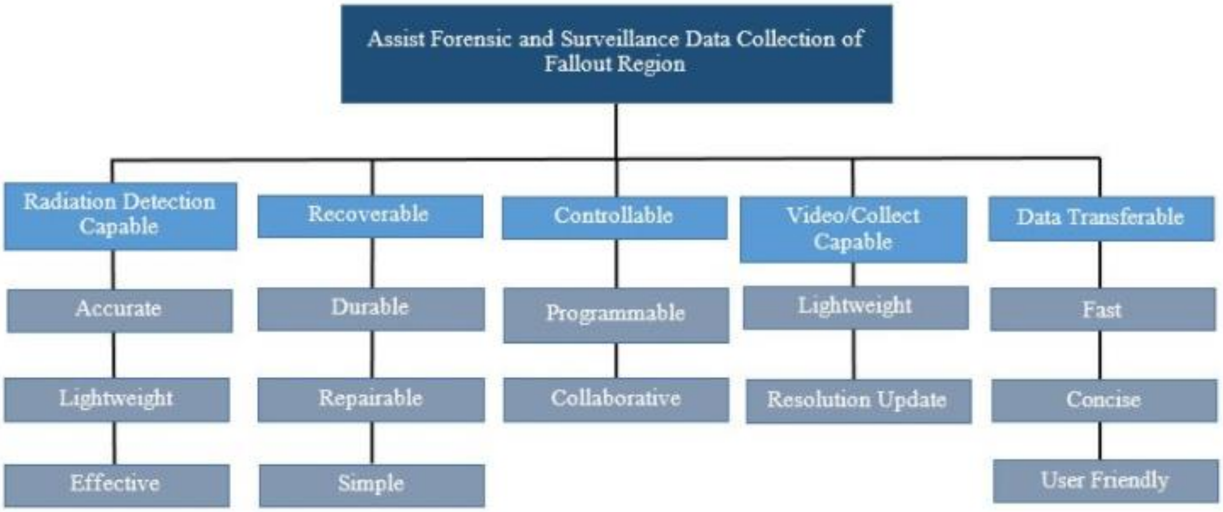

Figure 3. Objective tree.

These objectives are the driving factors in developing the value criteria for alternative design solutions. With a clear problem definition and functional analysis of the project and stakeholder needs, wants, and desires it was possible to begin designing candidate solutions.

3.3 Final Solution and Expectations

Understanding of technological capabilities changed rapidly with new testing and the solution design constantly changed with new information and iterative processes. Alternative solutions were based on type of radiological sensor and number of fixed wing and quadrotor UAVs flying in the swarm. The radiological detectors available for use were the IdentiFINDER and GN detector. The IdentiFINDER had more capabilities for transferring data and could identify a wider range of contaminated material than the GN counterpart. However, after feasibility analysis it was determined that the IdentiFINDER was too heavy to be attached to the quadrotor.

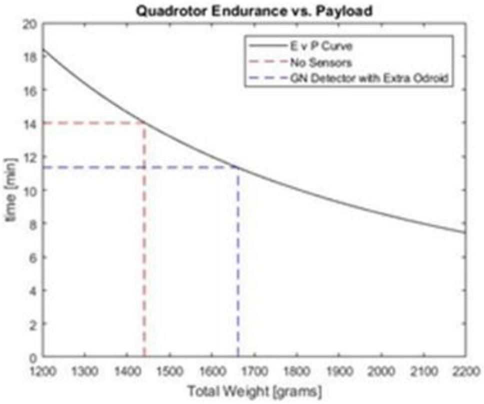

Figure 4. Quadrotor endurance in comparison to payload.

Figure 4, above, is a model for the battery of the quadrotor and reveals that the IdentiFINDER, weighing over 2200 grams with the quadrotor, would limit the vehicle to under 10 minutes of flight time which did not meet performance measures. With the IdentiFINDER screened for use, the GN detector was chosen as the detector for our system.

Selection criteria for the alternatives consisted of sensors (more is better), battery life (more is better), deployment time (less is better), autonomy (more is better), and response time (less is better). The preliminary design that scored highest consisted of 5 GN detectors each mounted on 5 quadrotors flying in a swarm with 2 zephyrs. Radiological data would be transmitted to the home station through a live video feed of the detector screen and overwatch would be provided by 2 cameras, 1 on each zephyr. The initial design was modified before the field demonstration during testing and acquisition of enabling technology.

3.3.1 Swarm Behavior and Battery Analysis

The expectations for this system involved demonstrating that swarm behavior can aid and improve collection of radiological data. Swarm behavior was expected to reduce the overall collection time. The team designed a behavior within the SASC infrastructure called “Greedy- Go- To” that assigns survey points to quadrotors based on the vehicle’s distance to the survey points. This allowed the team to overlay a collection area with a series of survey points at 5 meters apart which the quadrotors would hover over for 10 seconds in order to collect radiological data. The behavior is meant to optimize collection time by minimizing flight distance of quadrotors to survey points. An important aspect of the behavior is the survey point tracking function. As survey points are covered the home station updates which locations need to be reached. This prevents quadrotors that have swapped batteries from restarting the behavior after a battery change.

Quadrotor battery life with the mounted sensor does not allow for a full sweep of the desired collection area. The final design accounts for this by conducting battery swaps as quadrotors reach low battery. The vehicles have a feature that automatically sends them to land once a certain battery level is reached. Each quadrotor was outfitted with an adapter that enabled a battery swap without turning the quadrotor off. This enables the quadrotor to remain connected to the home station during battery exchange decreasing exchange time and allowing for survey point tracking.

3.3.3 Data Transfer

Unlike the initial design, the final design incorporated an automatic data transfer over the same network that the vehicles are connected. The GN detector was outfitted with a back plate that could read the radiological data and was also USB capable. This allowed for immediate transfer of data to the home station and creation of the gradient map of the collection area using GPS data from the survey point collection. The initial design, capturing imagery data of the GN detector screen in order to record readings, was kept as a redundant component.

3.3.4 Concept of Operation

The desired operation of the system begins with launching two zephyrs, establishing loiter routes, and connecting to the live video feed in order to provide overwatch of the collection area and avenues of approach to the collection area. The quadrotors are then launched in sequence and reach an altitude of 30 meters before maneuvering to the collection area. Once at the collection area, the greedy go to swarm behavior would be initiated and collection data at each survey point would be transmitted to the home station for processing into a gradient map. Battery analysis predicted the system would need five battery swaps per quad rotor for a collection area of 100 by 50 meters. As quadrotors reach low battery they automatically return to the home station and land as a team member swaps the battery without disconnecting the vehicle from the computer. The swarm behavior continues until each survey point is reached by one quadrotor and data is transmitted to the home station. Survey points are established prior to conducting flight operations during the mission planning phase. The swarm is constrained by a boundary which forces vehicles to return to a rally point if they breach the fence. The end result of system operation is a map containing a gradient overlay of radiological data for a given collection area.

4. Results and Conclusions

Through application of Systems Thinking and the Systems Decision Process, a feasible system was created that demonstrates the ability to identify a radiation gradient using multiple UAVs, provide overwatch of a detection area and routes and avenues of approach for 1 hour, and utilize multi-UAS Swarm behavior for efficient data gathering. Upon initial presentation of this real-world problem, it was evident that the as-is system utilized by the Army's 20th CBRNE Command could be improved through the application of multi-UAS Swarm technology. However, the constraints of this year-long project required this team to scope the problem to the pending demonstration at Idaho National Labs. The narrowed scope allowed the team to focus the effort on the demonstration of how this technology could reduce the time for radiation data to be returned to the end-user, the 20th CBRNE Command. Next, alternative generation and solution design proved to be an extremely iterative process of testing, refining, and analyzing possible solutions to this problem. Upon departure of the full-scale demonstration, the improved system demonstrated several feasible alternatives to the as-is system. The main recommendation for further study in this field would be additional testing to how best a multi-UAS Swarm should be applied to a detection area in order to reduce wait times for result times and increase radiation data accuracy. Future work will hinge on exploiting data developed after weeklong field testing to provide invaluable insights and results in to the potential design improvements for the system.

5. References

2016 IEEE Systems and Information Engineering Design Symposium (SIEDS), 2016. NExplore Digital Library, 2016, 165-169.

Allen, T. (1974). *Vanishing wildlife of North America.* Washington, D.C.: National Geographic Society.

Boorstin, D. (1992). *The creators: A history of the heroes of the imagination.* New York: Random House.

Devitt, T. (2001, August 2). *Lightning injures four at music festival*. Retrieved January 23, 2002, from The Why? Files: http://whyfiles.org/137lightning/index.html

GVU Center. (n.d.). Retrieved August 8, 2000, from 8th WWW user survy: http://www.cc.gatech.edu/gvu/usersurveys/survey1997-10/

Harlow, H. (1983). Fundamentals for preparing psychology journal articles. *Journal of Comparative and Physiological Psychology, 55,* 893-896.

Henry, W. I. (1990, April 21). Making the grade in today's schools. *Time, 135*, pp. 28-31.

Kalette, D. (1986, July 21). California town counts town to big quake. *USA Today, 9*, p. A1.

Nicol, A., & Pexman, P. M. (1999). *Presenting your findings: A practical guide for creating tables.* Washington, D.C.: American Psychological Association.

Searles, B., & Last, M. (1979). *A reader's guide to science fiction.* New York: Facts on File, Inc.

The safety of genetically modified food crops. (2002, February). Retrieved March 22, 2005, from Health Canada: http://www.hc-sc.gc.ca/english/protection/biologics_genetics/gen_mod_foods/genmodebk.html