University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document

Rapid Aerial Photographic Target Recognition (RAPTR)

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Approvals

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1. Problem Statement

Military personnel currently have limited means of quickly gathering real time imagery intelligence of active combat zones. The purpose of this project is to design, manufacture, and test a portable, user-deployable launch system and imaging system payload that will identify ground targets of interest and provide real time threat location and classification of said targets to the ground station within three minutes from time of deployment. The system will consist of three components: a vehicle system, a payload, and a ground station. The vehicle system shall deliver the imaging system payload to a TBD altitude while maintaining complete functionality of the payload. The imaging system must capture, compress, and downlink a TBD number of ground images at this altitude. The ground station will need to receive and process this data sent by the payload in order to identify and notify the ground station of threats as small as 5'x5'x5' in size and within at least a 2,000 foot range to the user. An interdisciplinary team made up of electrical and aerospace engineering students shall collaborate to design and build these systems; electrical engineering students will specialize on the payload while aerospace students will specialize on the vehicle system. Successfully developing this entire system will provide military users with a quicker, safer, and more cost-efficient means of attaining real time imagery intelligence of combat zones.

2. Previous Work

This project closely resembles a few previously engineered, widely used, military solutions, although with no direct relations. The size, deployment style, operating environment, and initial flight path may resemble the FGM-148 Javelin Anti-tank Missile. [2] Developed in a joint venture between Raytheon and Lockheed Martin, the Javelin missile system is a man-portable "fire-and-forget" missile that is operated by targeting and locking on with a multi-use CLU optics computer. Once a target is locked, the operator fires the Javelin missile. Then, the IR navigation system flies the missile to altitude to avoid detection. Finally, when the missile is above the intended target, it can engage the target with devastating effectiveness.

The last section of the Javelin's life cycle makes it costly to produce. For the purpose of this project, the team will attempt to imitate the Javelin's ability to be deployed and operated by a single person. After deployment, the payload vehicle might draw inspiration from the Tomahawk missile. The Tomahawk is a sub-sonic cruise missile used for deep land attacks, and is normally fired from a friendly naval ship in bordering water. [3] The missile is fired and then flies horizontally at subsonic speed over land for an extended period. Such a flight path may be beneficial for RAPTR's vehicle. Additionally, the control surfaces that allow the Tomahawk to maintain steady, level flight may be imitated to allow the payload to take higher quality images. This would lessen the need for rudimentary image processing and stabilization, which subsequently allows for quicker and more accurate target identification.

Image recognition, unlike the vehicle component, has a wide range of previous use cases. It is used frequently in both military and civilian applications for recognizing and tracking objects of various sizes. An applicable example to RAPTR would be the image recognition and tracking systems included in the (Mobile) Tactical High Energy Laser systems (THEL and MTHEL) developed by Northrup Grumman. THEL/MTHEL utilize both standard and short wave infrared cameras to acquire and track airborne targets. This system is capable of acquiring and tracking multiple airborne threats simultaneously so that they may be targeted by the THEL for destruction. Instead of tracking moving airborne threats from a stationary ground position however, RAPTR will track stationary ground threats from a moving airborne position. Despite this role reversal the overarching concept of target acquisition and tracking will be similar. By utilizing and comparing multiple images, in addition to data on the position and velocity of the payload, RAPTR should be able to locate and provide size information on threats in a similar fashion to the THEL/MTHEL systems.

3. Specific Objectives

When crafting the specific objectives RAPTR is aiming to achieve, the team took careful consideration of the scope and multitude of critical elements of the project. Due to this perceived difficulty in developing each aspect of the project to work in unison, the level I requirements are all achievable independent of the other subsystems of RAPTR. These requirements are all design and test based, and they are all achievable given the skill level of the team and the time given to design and build the project.

Level II objectives are a natural continuation of level I, with an increased emphasis on multiple systems working together to meet certain test objectives. With level II objectives met, RAPTR's subsystems will function in a more mission-focused context. All parts of the project may not be functioning correctly together and they may not have required performance measures met, however RAPTR will succeed in achieving more stripped-down mission requirements through mission simulations and tests.

The level III objectives are all dependent on the successful function of the other other subsystems of RAPTR, and they are based on fully meeting the forthcoming functional requirements designed to fulfill the problem statement.

Due to the current scope of the project and the number of separate systems vitally dependent on each other in RAPTR, there is a high likelihood that each functional requirement won't be met during a full system test given the time frame of two semesters. Thusly, these level three requirements are the most ideal and ambitious; however, if these objectives are not met, the project can still be successful by achieving the level I and II objectives.

3.1. Levels of Success

	Level I	**Level II**	**Level III**
Launch Vehicle (Aerospace Team)			
Navigation	The launch vehicle shall report location and altitude within 10 feet (TBR) of accuracy to a user interface.	Level I	The launch vehicle will send location coordinate data corresponding to payload image data in real time.
Controls	The launch vehicle shall have a mathematical control model developed and validated in a simulation for expected flight conditions.	The launch vehicle shall demonstrate flight stability during wind tunnel test using simulated payload mass.	The launch vehicle shall be able to use control actuators to execute programmed maneuvers in flight.
Vehicle Deployability	The vehicle shall be designed and built with the intent of accepting a payload.	The launch vehicle shall be deployable from the ground with a mass simulator and remain stable for up to 1 minute (TBR).	The vehicle shall be deployable from the ground within three minutes (TBR) of the user's decision to deploy and reach a desired location 500 feet (TBR) in altitude from the ground station with integrated payload.
Payload (Electrical Team)			
Communication	The payload shall wirelessly transmit image data to a receiver during a ground test.	The payload shall transmit image data to the ground station at a rate of TBD images per second at a distance of 2000 (TBR) feet during a ground test.	The payload shall transmit image data to the ground station at a rate of TBD images per second at a distance of 2000 (TBR) feet during flight while integrated into the payload.
Imaging System	The imaging system shall capture and compress an image on the command of a CPU.	Level I	The imaging system shall have the resolution and field of view to image a 5'x5'x5' object as TBD pixels from 2000 (TBR) feet.
Ground Station (Both Teams)			
Processing Performance	The processing algorithm is able to identify a high visibility 5'x5'x5' object from a simulation using the same imaging specifications as the payload.	The processing algorithm shall be shown to identify and classify a 5'x5'x5'object from 10 (TBR) different object types from 2000 (TBR) feet away during a ground test and simulation.	The processing algorithm is able to identify, classify, and provide the location of a 5'x5'x5' object on the ground from 2000 (TBR) feet in the air in real time during a flight test.
Communication	The ground station shall receive and decompress image data and send to the processing software during a ground test.	Level I	The ground station shall receive and decompress all image data and send to the processing software at a range of 2000 (TBR) feet during a flight test.
User Interface	The user interface shall display if a target has been identified by the processing algorithm during a simulation.	The user interface shall indicate which object has been identified by the software and display an image of the object to the user.	The user interface shall display the number of objects, the type of object, and the location of the object on a map to the user.

4. Functional Requirements

1. The system shall utilize image processing to detect a 5'x5'x5' stationary ground target that is TBD distance from the user.
2. The system shall be mobile and deployable in rugged or uneven terrain.
3. The system shall relay images in real time to a ground station.
4. The system shall relay threat information to the user such as identification, classification, and location in real time.
5. The system shall detect and notify the user of threats within 3 minutes of the need for deployment.
6. The system shall comply with all federal and state laws regarding testing and functionality of the system.

4.1. Concept of Operations (CONOPs)

The concept of operations is displayed in Figure 1 below and depicts RAPTR's mission and overall objectives. Upon the presence of a threat being discovered the user will launch the aerial vehicle. The aerial vehicle will climb to a cruising altitude of 400 feet TBR, along a TBD path in the vicinity of a $5' \times 5' \times 5'$ threat. The aerial vehicle will be equipped with a target detection system as the aerial vehicle's payload. This payload will scan the landscape using a TBD imaging system, compress the captured data, and relay this data to the ground station over a TBD frequency in the ISM-band. The payload must be capable of sensing the target at a range greater than 2000 feet adequately enough for the ground station to distinguish the target from its surroundings. The ground station will receive the compressed data relayed from the payload at a TBD range from the ground station. The ground station will decompress the data received and pass the data through a TBD image processing algorithm. This algorithm will extract the target's position in the image and compute the target's location relative to the aerial vehicle using the aerial vehicle's position. From here, the processing algorithm will return the position of the target relative to the ground station, and therefore the user, on a TBD GUI.

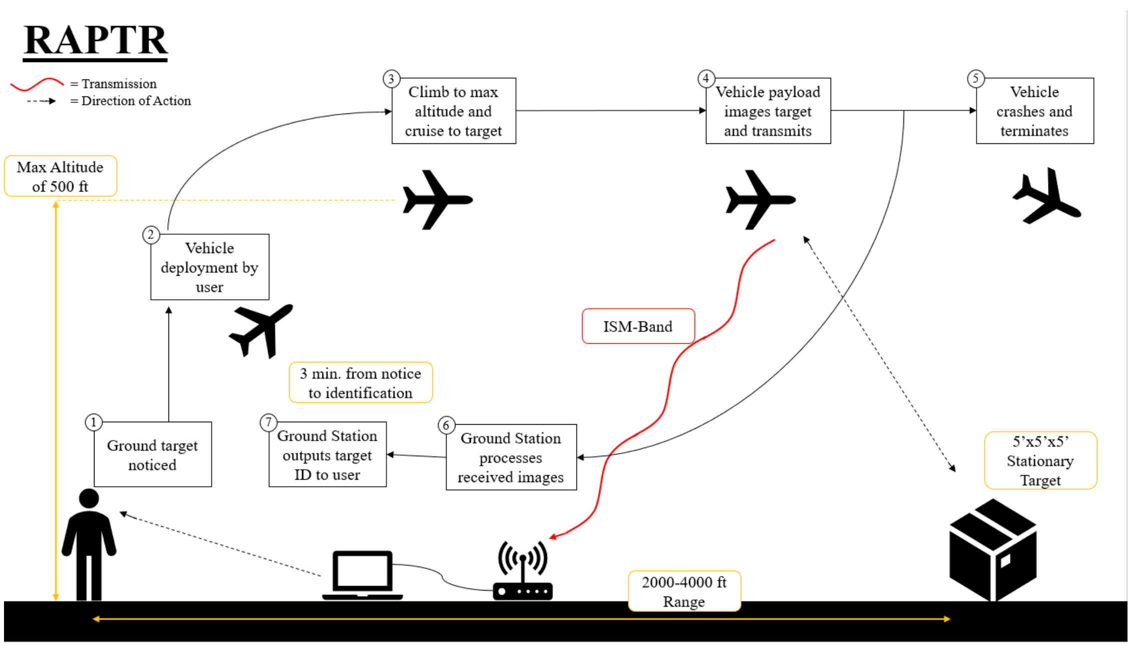

Figure 1. CONOPs Diagram

4.2. Functional Block Diagram (FBD)

The RAPTR system will be composed of 3 main components: the payload, the vehicle, and the ground station. The payload will contain the imaging system and any preprocessing associated with it as well as the communications necessary to transmit the compressed images to the ground station. The payload will primarily be designed by the

Electrical Engineering team with the Aerospace team giving input for system integration and testing. The vehicle will be designed primarily by the Aerospace Engineering team and will consist of a propulsion system, power, ADCS, and GNC system. The power system will be the main power source for all electrical equipment in the vehicle, including the payload, as well as any components related to the controls system. The GNC system on the vehicle is comprised of sensors for location, altitude, and attitude with 3-axis control capabilities (TBR). The ground station is a multi-disciplinary system that will be jointly designed by the Electrical and Aerospace Engineering teams. The ground station is comprised of a receiver and a processing unit. The receiver will receive the images that have been transmitted by the vehicle payload and send them to the processing unit. The processing unit will then decompress the images and analyze them for threats. Upon any threat being detected, the user will be alerted through the UI. The system, depending on the aerial vehicle solution, will also have user control capabilities through an RC unit that will allow the user to direct the vehicle manually towards the potential threat.

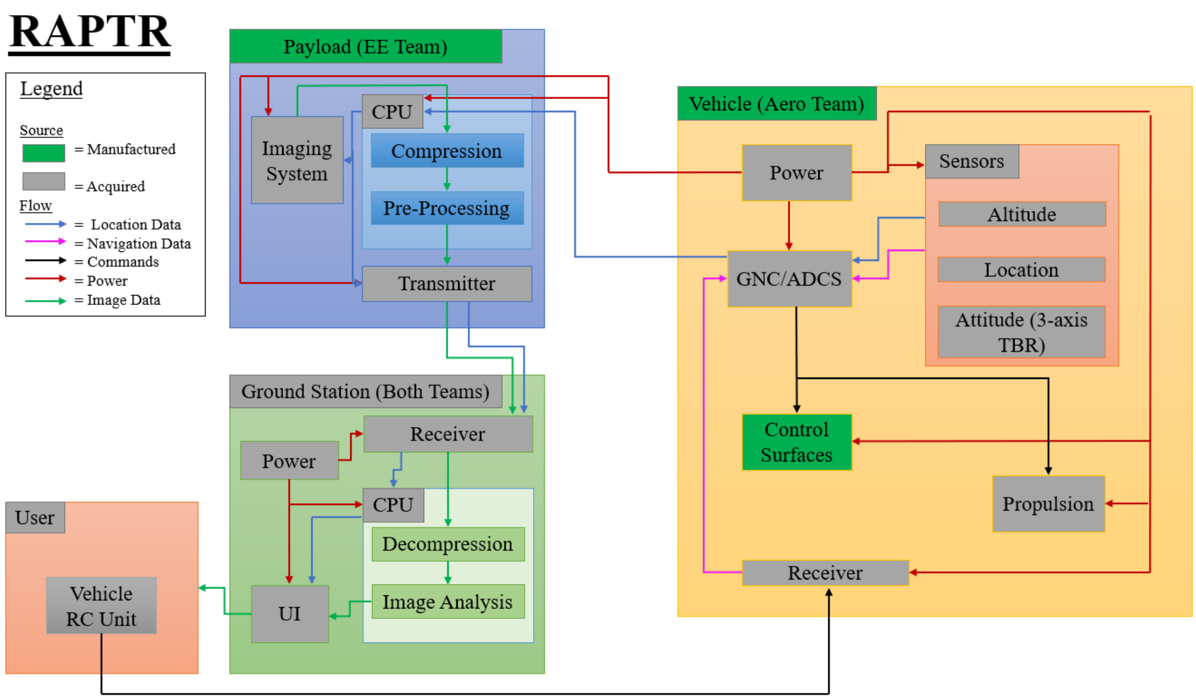

Figure 2. Project Functional Block Diagram

5. Critical Project Elements

5.1. Launch Vehicle

CPE.1 Aerial Vehicle Design

The vehicle shall have the aerodynamic properties, propulsive force, and structural strength to carry a payload, with a TBD mass and TBD volume, to a TBD altitude. Additionally, the vehicle will have rugged launch and recovery systems with minimal additional equipment.

CPE.2 Vehicle and Payload Integration

The vehicle shall have accommodations to mount the payload in a known orientation such that the camera(s) has an adequate field of view and have appropriate electrical connections to connect to the vehicle. The integration will not compromise the effectiveness of either the vehicle or payload.

CPE.3 Vehicle Electronics

The vehicle shall have a CPU that will manage the manipulation of the control surfaces, the attitude determination and control system, and the system power. The wiring will be routed in a way such that it is efficient and organized while also not interfering with any other components of the vehicle. The vehicle electronics will consist of the appropriate sensors to gather all data necessary for essential control of the vehicle.

CPE.4 FAA Approval/Compliance

The vehicle shall be operated in compliance with either FAR 107 (small unmanned vehicles) [6] or FAR 101 (amateur rocketry) [7] depending of the final vehicle design.

5.2. Payload

CPE.1 Payload Central Processing Unit

The payload CPU dictates the capture of all images using the payload's camera. The payload CPU will then compress the images for transfer. After compression, the payload CPU will pass the compressed image to the antenna for transmission to the ground station.

CPE.2 Communication System

The communication system consists of the payload antenna, ground station antenna, and information dissemination between the two antennas. Data will be transmitted in the industrial, scientific, and medical radio (ISM) bandwidth as the ISM band is open to public use. A TBD baud rate shall allow an image to be sent and received in a TBD time. The payload's antennas will be oriented to transmit data pragmatically from a TBD range.

CPE.3 Ground Station

The ground station will be comprised of an antenna for data reception over the ISM bandwidth and a user-interface that clearly and succinctly displays the target location with respect to the user. To accomplish this the ground station shall be capable of supporting the necessary image processing software.

CPE.4 Image Processing

The image processing software will first decompress the received packets. The recovered image will be run through an algorithm that filters background clutter, mathematically discerns the target, and fully identifies the target's location in the image. The target's location relative to the user will then be calculated.

CPE.5 Integration and Test

Integration and testing of the payload will consist of the assimilation of all payload hardware and software components along with functional coherence testing. This CPE will ensure the payload camera, CPU, antenna, communication, and ground station all work in unison to discover and pinpoint the target. Substantial functional testing of individual and cohesive unit payload components will be necessary to guarantee synergy between the payload and launch vehicle.

6. Team Skills and Interests

Critical Project Elements	Team Member(s) and Associated Skills/Interests
Aerial Vehicle Design	Nicholas Carvo - SOLIDWORKS experience, Aircraft Design, Manufacturing Experience Austin Abraham - SOLIDWORKS experience, precision metal/composite part fabrication Jeremiah Lane - camera mounting experience and aircraft design Logan Thompson - SOLIDWORKS and fabrication experience Greg Clements - Propulsion systems design/testing experience and interest Zach Donovan - Electrical, mechanical, aircraft, and explosive design experience Anna Tiberi - Electrical and aircraft design experience Thad Gleason - Isogeometric analysis and CFD experience
Vehicle and Payload Integration	Nicholas Carvo - Mechanical design, experience with component integration Austin Abraham - Electrical, pneumatic, and mechanical system integration experience Zach Donovan - Electrical and mechanical system integration and testing experience Tyler Faye - Fabrication, design, and electrical integration experience Anna Tiberi - Lockheed Martin Integration and Test Engineer
Vehicle Electronics	Zach Donovan - Electrical system design experience Tyler Faye - Closed loop controls system experience Austin Abraham - Ladder logic programming and PLC wiring experience Aubrey Mckelvy - Microavionics, Aerospace software Anna Tiberi - PCB buildup and integration experience
FAA Approval/Compliance	Aubrey Mckelvy - Private Pilot, FAR Exposure Nicholas Carvo - Working on private pilots license, Experience with FARs
Payload Central Processing Unit	Nelson Botsford- embedded C in the ARM architecture and FPGA development
Communication System	Nelson Botsford- antenna design and communication theory
Ground Station	Kyle Murphy- software development and interested in antennas Everett Hale- experience developing user interfaced applications Aubrey Mckelvy - Microcontroller/Data storage and C coding experience
Image Processing	Jeremiah Lane- LIDAR imaging simulation and algorithm development Everett Hale- MATLAB simulation experience and experience with C James Wells- Experience with Imaging processing using OpenCV Python Libraries and Software Development experience
Integration and Test	Yanzhi Chen- PCB design and power systems Greg Clements - Software/Hardware verification testing experience with MATLAB Logan Thompson - Integrated systems, structural, and thermal test experience Anna Tiberi - Lockheed Martin Integration and Test Engineer (mission and subsystem)

7. Resources

Critical Project Elements	Resource/Source
Aerial Vehicle Design	SOLIDWORKS, Dr. Gerren, Dr. Lopez, aerospace machine shop
Vehicle and Payload Integration	SOLIDWORKS, Bobby Hodgkinson, Trudy Schwartz, aerospace machine shop
Vehicle Electronics	Dr. Akos, Dr. Marshall, Tim May
FAA Approval/Compliance	FAR AIM Reference Book, Dr. Akos
Payload Central Processing Unit	PIC Control Board
Communication System	Dr. Akos, Dr. Sternovsky
Ground Station	Dr. Akos, Dr. Marshall, Tim May
Image Processing	Thermal Imaging Simulation Software, MATLAB and C++, Dr. Holzinger
Integration and Test	FAA Form 7711-2 (FAA Waiver)

References

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[6] "Fact Sheet Small Unmanned Aircraft Regulations (Part 107)", Federal Aviation Administration. Retrieved: 12 September 2018, from https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=20516

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