University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

ANACONDA

ANtenna with **A**utonomous, **CON**tinuous, **D**ata tr**A**nsfer

Approvals

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1.0 Problem or Need

The Research and Engineering Center for Unmanned Vehicles (RECUV) group at the University of Colorado-Boulder flies many different missions using Unmanned Aerial Vehicles (UAVs). Constant communication between the UAV and the ground station is required to receive data back from the aircraft to monitor its health and status as well as to relay high level commands from the ground station to the UAV. Up until now, the RECUV group has required an antenna to be pointed manually at the UAV while looking at a meter for signal strength. This is a draining effort for the team, especially if the mission duration is more than a few hours.

The ANACONDA project will design and construct an autonomous tracking and communication support system for an antenna or antenna array that is able to operate independent of other, preexisting systems, and keep constant communication between the ground station and the UAV up to a 30 km slant range. Antenna or antenna array shall herein be referred to as antenna system, while ANACONDA project shall refer to the deliverables of the project as a whole. This antenna system needs to be easily transportable by fitting within a 1ft^3 volume excluding support hardware, set-up easily by a single person in 10 minutes, and mountable on the ground as well as be able to be mounted on top of an unmodified vehicle. In either case, the antenna system must be raised to a minimum of 5 meters above ground level. The antenna system will need to be able to receive data at a minimum of 10 Kbits/s from the UAV and if communication is lost, it needs to be able to reacquire the link within an allotted time frame of 20 seconds. This entails that the antenna system must have 360° continuous azimuthal coverage as well as a -30° to 90° elevation range.

A successful project will eliminate the need for manual tracking and could allow the RECUV group to complete longer mission durations with a smaller crew. An autonomous system will also remove the need for human line of sight in order to communicate with the UAV and provide the potential for less error and a stronger radio signal. The ANACONDA project will be verified as successful by conducting tests to verify that its range, coverage, tacking, and signal characteristics perform as outlined above.

2.0 Previous Work

There are two main autonomous UAV tracking methods, utilizing either a combination of omnidirectional antennas and patch antennas, or a single high gain antenna mounted on a gimbal device. The latter uses a device such as radar or GPS to locate the UAV and point in its direction. Gimbal pointing antennas increase mechanical complexity, however they allow for more accurate communications and use of high gain antennas. Stationary antennas allow for mechanical simplicity, but there may be gaps in the gain pattern, which could lead to a loss in communication with the UAV.

The Marcus UAV Long Range Tracking Antenna is an example of a gimbal pointing UAV tracking system available currently. This system has the capability of autonomously tracking UAV systems using a parabolic dish antenna as well as telemetry data from the UAV. The data transfer rate is capable of streaming high quality video at a slant range of up to 30 miles with a 360° pan and 90° tilt [4]. However, this system is limited in coverage in that it only reaches an elevation angle of 0-90° and cannot extend more than six feet above the ground. Another disadvantage is that the antenna is bulky and requires extra space for transportation.

A Graduate Thesis project from Lulea University developed a UAV tracking system using a 2.4 GHz Video Transmitter. To track the UAV, one high gain dish antenna is used for communication while four Yagi-antennas are used in tandem with power detector chips and a microcontroller to detect Radio Signal Strength (RSS). Their final design uses a rotating table attached to a motor wheel and a geared tilt system capable of 1° resolution for either axis of rotation. This system is capable of tracking a UAV flying at 20 m/s at a distance of 100 m and is easily transportable in a standard car trunk [3]. This system proves the ability of using multiple antennas to track a UAV, but is limited in range and coverage.

The ANACONDA autonomous UAV tracking antenna system that will be designed in this project will push the boundaries of the products that have come before it. Accomplishing all of the various requirements at once highlights the challenges that will be faced by this project. The system must have greater coverage over a larger range, and still be easily transportable and easily set up. The greater coverage and range requirements necessitate that large gain antennas will be used, which will be difficult to accomplish in a smaller volume. This projects aims to improve existing technology to be more versatile and service a wider range of customers.

3.0 Specific Objectives

Level 1:

ANACONDA will be a completely autonomous UAV tracking system capable of maintaining communication between the ground station and the UAV. The antenna system and ground station will communicate through a USB connection, while the communication between the antenna system and the UAV will be able to operate at 2.4GHz. The antenna system will be able to be mounted from the ground to an altitude of five meters. The system will run on 9-13VDC.

Level 2:

In addition to complying with Level 1 criteria, ANACONDA will relocate and reestablish connection with the UAV if communication is lost. The system will be mountable on both an unmodified vehicle and from the ground to an altitude of five meters. The system will be able to be set up by two people within 10 minutes, or within 20 minutes by a single person. Aside from the mounting supports, the system should have a volume of less than one cubic foot.

Level 3:

In addition to complying with Level 2 criteria, ANACONDA will communicate with the UAV traveling up to 45 m/s ground speed within a specified sphere of influence. This sphere of influence consists of a 30km slant radius for 360° azimuth angle as well as a -30 to 90 degree range for the elevation angle. The communication between the antenna system and the ground station will be wireless. The communication between the antenna system and the UAV will be able to operate at both 2.4GHz and 900MHz with a transfer rate of at least 10 kbit/s. If communication is lost then the antenna system will relocate and reestablish connection within a 20 second timeframe. The system will be easily transportable and can be assembled in less than 10 minutes by a single person. The ANACONDA system will be rugged enough to withstand winds up to 30 m/s, as well as environmental impacts such as dust and precipitation.

The deliverables for the project will include working hardware and software that achieve the requirements. To determine what hardware and software have met the customer's requirements, a series of tests will be used. There will be a tracking model developed for initial software testing to ensure that ANACONDA will perform as expected in a simulated environment. Software and data tests will be run to ensure that the electronics and software developed are running as expected. There will be an initial static test where the UAV is set at a known location to verify that ANACONDA can acquire the signal from the UAV. Once the static test is complete, a dynamic test will be performed to show that ANACONDA can resolve the location of a moving ground target. Finally, a full mission test of all functional requirements will be done using either a manned or an unmanned aircraft. Additional testing will be done to verify the ruggedness and weather resistance of ANACONDA by simulating adverse weather conditions such as rain, wind, etc.

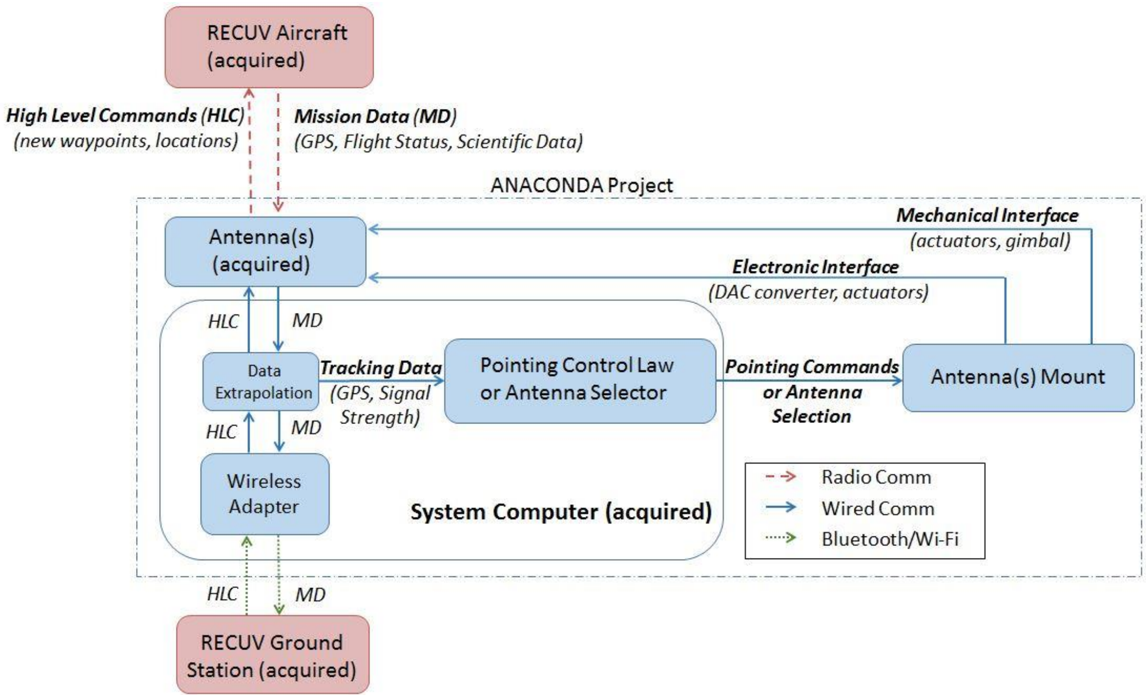

Figure 1: Functional Block Diagram (FBD)

4.0 Functional Requirements

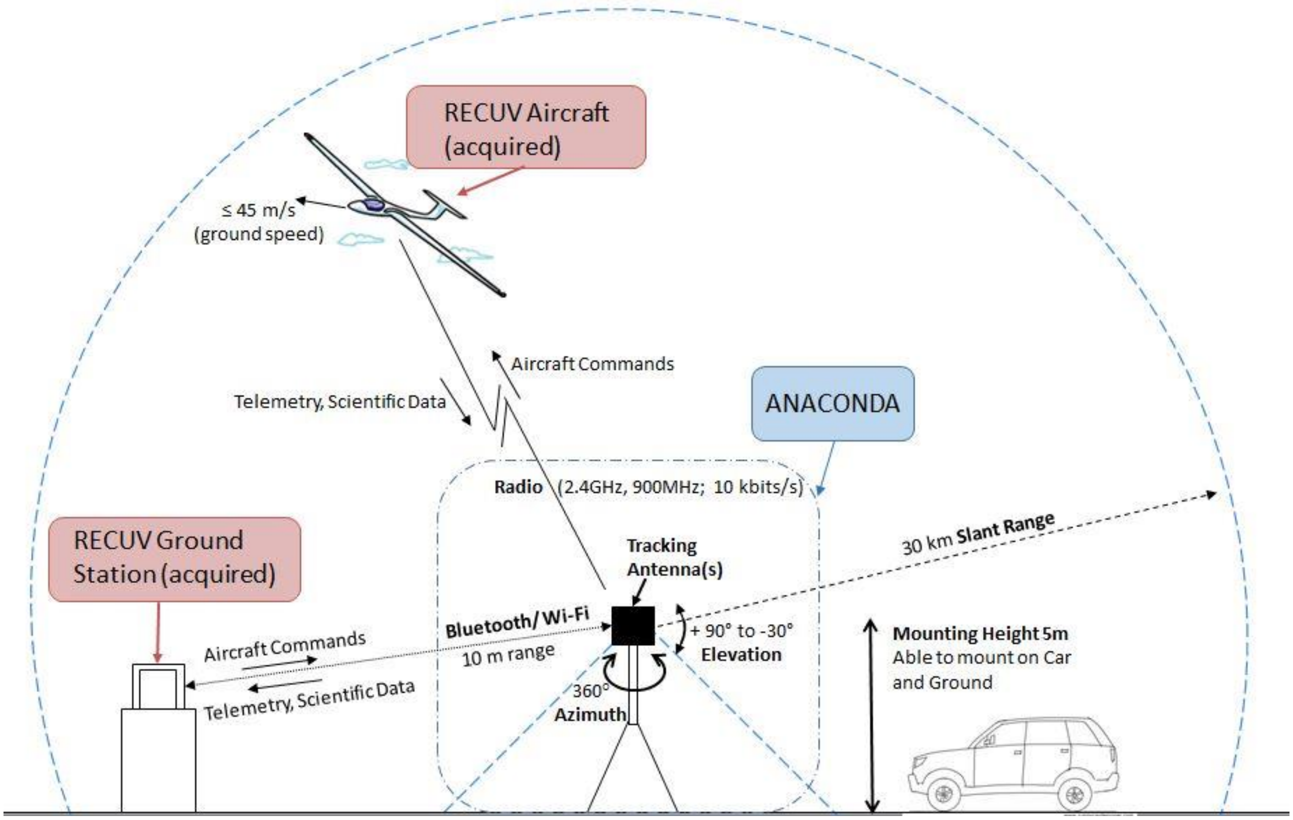

Figure 2: Concept of Operations (CONOPS) [1, 6]

5.0 Critical Project Elements

Technical:

CPE.1.1 **Have an accurate model to predict the expected gain pattern of the system if an antenna array is chosen for the design.** An accurate model of the expected gain pattern of the system must be known in order to ensure a full 360° continuous azimuthal coverage. A facility will be needed to test the gain pattern of the antenna array. First RF is a likely candidate but the team will need to seek permission.

CPE.1.2 **Develop tracking and reacquisition algorithms.** While it is not mission critical if signal is temporarily lost, it is critical that the signal is regained within 20 seconds in order to prevent lost signal flight termination. This will require time to develop and test an algorithm to reacquire the UAV position as well as time to develop and test an algorithm to track and maintain communication with the UAV.

CPE.1.3 **Be able to mount the antenna system to achieve 5m elevation.** In order to maintain communication with the UAV with a greater slant range and less signal interference, ANACONDA must be mounted 5m above the ground. This type of mount is not readily available thus will need to be designed to be easily transportable in a car and stable enough to withstand winds up to 30 m/s.

CPE.1.4 **Have a mechanical pointing system with a resolution sufficient for communication with the UAV if a high gain directional antenna is chosen for the design.** The pointing system will be comprised of off the shelf components but the overall assembly and interface between the electrical system, gimbal, and actuators will need be designed for this unique application. This will require a significant amount of time and resources for testing.

Logistical:

The ANACONDA team must:

CPE.2.1 **Acquire all legal permissions in order to test the antenna tracking system using either an unmanned or manned aircraft.** These rules are strict with regards to civilian air space, UAV restrictions, and radio communication. Without a method of testing it is impossible to validate the ANACONDA system.

CPE.2.2 **Acquire field equipment and software from RECUV in order to design for integration with existing hardware.** Access to the ground station software, UAV(s), transponders/radios, and vehicle charged power supply will be needed from RECUV for the team to fully validate the ANACONDA system.

Financial:

ANACONDA has no critical financial elements at this time.

6.0 Team Skills and Interests

Adam Kemp: Adam interned at Sierra Nevada Corporation this past summer and Veris Inc. the summer before. He has strong experience using SolidWorks for component and fixture design, as well as CFD research. He has a strong mechanical background and understands the industrial design process. He has experience in programming with MATLAB, Simulink, and is familiar with STK.

Emily Eggers: Emily interned at Raytheon's Space and Airborne Systems Division the last two summers. While there, Emily developed experience in space hardware testing for satellite sensors and mechanical design for an airborne pod. She has extensive experience in the CAD tool Pro Engineer; FEM and CFD analysis tools such as NX, STAR-CCM+; and programing experience in MATLAB and Simulink. She is interested in the mechanical, logistics and testing aspects of the project.

Gloria Chen: Gloria is currently in the microavionics course offered by University of Colorado at Boulder, so she will be developing skills with microcontrollers and controls. She has experience in SolidWorks and SolidCam, and programming experience in MATLAB and C++, and will have experience in Assembly and C. She is interested in the electrical and software side of the project, especially mechanical controllers and pointing guidance.

Kamron Medina: Kamron is in the BS/MS program and will be getting his Master's Degree in Aerospace systems with a focus in Aerospace structures. Kamron has had three years of experience working at Space Grant doing both mechanical and electrical engineering, and has also gained experience with project management and systems engineering. He is skilled at machining, SolidWorks, Altium, and engineering management. He is interested in the structural and mechanical aspects of the project.

Karsen Donati-Leach: Karsen is currently in the microcontrollers course offered by University of Colorado at Boulder, so will be developing skills with the electrical and software components in microcontrollers. Further, Karsen has built a 70ft wingspan for a sailplane, giving him manufacturing experience. He has experience in MATLAB, C++ and Python. He is interested in anything the group has to offer, but prefers the software and systems engineering components.

Sarek Lee: Sarek interned at Staples Inc. the past two summers programming several components of their new product mainframes, and built automatic build and deployment scripts for their servers. He is currently taking Naval Weapon Systems at CU Boulder, so he will be developing an understanding of radar and navigation. He has experience in MATLAB, Java, UNIX, KSH, C/C++ and SolidWorks. Sarek is interested in the electrical and software aspects of the project.

Tyler Clayton: Tyler was the electrical lead for his projects group working with microcontrollers and other electronic devices during his freshmen year. He has experience working with MATLAB, Simulink, and C programming. Tyler is interested in electrical and software integration for system control.

Tyler Herrera: Tyler worked in a co-op for Ball Aerospace over the past three summers. While there, he gained extensive experience in systems engineering, requirement management and verification, and mission operations for spacecraft. At Ball, he did work with GPS attitude determination, and is currently taking the Global Navigation Satellite System introduction course at CU Boulder. He has experience in MATLAB and Simulink. He is interested in the software and electrical aspects of the project, with a particular desire to work on the communications subsystem.

Kate Kennedy: Kate is skilled at writing and executing test plans for software and hardware components, as well as manufacturing and metal work. She has experience in MATLAB, Python, and Linux. Kate also has her private pilot license and is knowledgeable about FAA and FCC guidelines, thus can perform testing in a manned aircraft. She is interested in the software and mechanical sides, particularly for antenna pointing and control.

Critical Project Elements	Team member(s) and associated skills/interests
1.1 - Gain Pattern Model	Sarek (S), Kamron (S), Emily (S) and Tyler C. (S)
1.2 - Reacquisition	Tyler H. (I), Tyler C. (I), Adam (I), Karsen (I), Gloria (I), Kate (I), Sarek (I)
1.3 - Mounting	Kamron (S), Adam (S), Gloria (S), Emily (S)
1.4 – Pointing System	Karsen (S), Gloria (S), Tyler C. (S), Tyler H. (I), Emily (S), Kamron (S)
2.1 - Legal Permissions	Kate (S), Emily (I), and Adam (I)
2.2 - RECUV Equipment	All Team Members

7.0 Resources

The ANACONDA team has investigated professors, staff members, and industry contacts who offer expertise in critical project element areas. These resources can be sought out for help and advice throughout the design process.

Critical Project Elements	Resource/Source
1.1 - Gain Pattern Model	Dennis Akos, Eric Frew, Penina Axlerad
1.2 - Reacquisition	Dennis Akos, Eric Frew, First RF, Dale Lawrence
1.3 - Mounting	Matt Rhodes, Trudy Schwartz
1.4 – Pointing System	Matt Rhodes, Trudy Schwartz
2.1 - Legal Permissions	Donna Gerren, Eric Frew, RECUV team, James Mack, FCC, FAA
2.2 - RECUV Equipment	RECUV team; ground station software, power supply, & UAV from RECUV

8.0 References

[1] "Car Drawing Tutorial: SUV Side View." *Junior Car Designer*. [http://www.juniorcardesigner.com/car-drawing-tutorial-suv-side-view/ Accessed 9/9/14]

[2] "Dipole Antenna," Antenna-Theory.com, 2009-2011. [http://www.antenna-theory.com/antennas/dipole.php. Accessed 9/9/14]

[3] Gustafsson, J., and Henriksson, F., "UAV Tracking Device using 2.4 GHz Video Transmitter," MS Thesis, Department of Computer Science and Electrical Engineering, Lulea University, Lulea, Sweden, 2005.

[4] "Medium Range Tracking Antenna," Marcus UAV Inc., [http://www.marcusuav.com/medtrackingantenna/. Accessed 9/4/14.]

[5] "Omni Antenna vs. Directional Antenna," Cisco Systems Incorporated, Feb 27, 2007. [http://www.cisco.com/c/en/us/support/docs/wireless-mobility/wireless-lan-wlan/82068-omni-vs-direct.pdf. Accessed 9/8/14]

[6] "Out-of-This-World Summer Camps for Kids at Virginia Air and Space Center." *Insiders Passport*. 26 Apr. 2010. [http://insiderspassport.com/out-of-this-world-summer-camps-for-kids-at-virginia-air-and-space-center Accessed 9/11/14]