Project Definition Document (PDD)

University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

SIVAQ - Signal **I**ntegrity **V**erifying **A**utonomous **Q**uadrotor

Approvals

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1.0 Problem or Need

The problem addressed by this project is the probable lack of GPS integrity information for future generations of autonomous vehicles. Recent tests[1] have shown the potential to capture the primary navigation system expected on these future vehicles and, as a result, induce false/misleading information regarding location and navigation. This project will be to take a current remotely piloted aerial vehicle, namely the Parrot AR.Drone 2.0 as specified by our customer, and adapt this for autonomous flight with the ability to monitor the position solution provided by GPS and assess its integrity in order to decide if GPS guided, autonomous operation can be considered safe/reliable.

Autonomy will need to be added such that the existing control algorithms of the vehicle can still be used and are not degraded significantly. The project will also add long-range data communication to the platform to enable either: (a) final position beacon signal to locate the vehicle should it not be able to return; (b) provide inflight video; and (c) downlink relevant data if the vehicle cannot be recovered. All of the previous should be possible at first with a tool-less install of a custom power/electronics package on the AR.Drone 2.0 vehicle, followed by the installation of a custom fuselage containing said electronic components that continue to use the installed control algorithms.

2.0 Previous Work

In the past year, two events have highlighted the significance of GPS radio frequency interference (RFI)/spoofing. The first involved an American unmanned aerial vehicle that was captured by the Iranian military. The Iranians claimed to have captured the vehicle by misleading it with a spoofed GPS signal. There is uncertainty in the validity of this claim, but the attack is believed to be feasible. On another occasion, students from the University of Texas at Austin successfully misled a yacht off course by half a kilometer[2]. Using a device to generate a false GPS signal and increasing its power to overtake the other signals, the students successfully deceived the crew on board.

As intentional GPS interference becomes an increasing concern, organizations such as the United States Department of Transportation and the Department of Homeland Security have begun research on the topic. One organization, the MITRE Corporation, put forth several methods for the detection of GPS spoofing, including the discrimination of amplitude, time of arrival, polarization, and angle-of-arrival. Other factors that are suggested for GPS integrity monitoring are cryptographic authentication and the consistency between navigation and an inertial measurement unit[3].

Currently, the Parrot AR.Drone 2.0 is a vehicle with many inherent capabilities such as video recording, remote-controlled piloting, and flying a distance of one kilometer. One of the aims of this project is to increase the flight range of the drone so that it can travel to a location up to three kilometers away and return.

The AR.Drone has been the subject of many user-based modifications since its introduction in early 2012. Parrot manufactures an additional GPS navigation device that interfaces with the built-in USB port on the vehicle[4]. However, this device does not have the capability to assess GPS integrity; thus a custom GPS receiver will be designed for the drone in this project, providing the capability to monitor the automatic gain control (AGC) levels that can be used to detecting RFI/spoofing. The plugin provided by Parrot allows for the user to specify the destination of the drone on a map, but does not allow for the user to specify a sequence of waypoints for the drone to traverse, a goal that this project seeks to accomplish. Presently, as the user controls the drone from an application on a device such as a smartphone, an HD camera provides a real time image. This video link will be leveraged as part of the project.

Previously, students at TU Delft attempted to fly the vehicle autonomously using open source autopilot software[5]. Others, such as those at QGroundControl[6], who fly the drone recreationally collaborate on various projects on forums[7]. There is published experimental data regarding the capability of the vehicle; Parrot has published a document describing the control algorithms it uses to maintain stable flight[8], and AR Drone users have compiled an initial list of batteries for the drone that provides specifications such as duration and weight[9].

3.0 Specific Objectives

Level 1: Autonomous quadrotor autopilot with: (a) GPS navigation system and signal integrity monitoring; (b) "return home" capability; (c) upgraded battery; (d) custom housing and mechanical interface between electronics and vehicle.

Level 2: Autonomous quadrotor autopilot with: (a) GPS navigation system and signal integrity monitoring; (b) "return home" capability; (c) upgraded battery; (d) custom housing and mechanical interface between electronics and vehicle; (e) to-be-determined long-range communications device for transmission of video, data, and last known position; (f) 2D mapping of RFI/spoofing area and photography to attempt to locate spoofer.

Level 3: Autonomous quadrotor autopilot with: (a) GPS navigation system and signal integrity monitoring; (b) "return home" capability; (c) upgraded battery; (d) custom housing and mechanical interface between electronics and vehicle; (e) to-be-determined long-range communications device for transmission of video, data, and last known position. (f) 2D mapping of RFI/spoofing area and photography to attempt to locate the RFI source; (g) interface for additional sensor packages that may be added by a future user; (h) custom fuselage that improves efficiency while preserving center of gravity and structural integrity and insures control algorithms will maintain stability. New fuselage will house (a), (c), (e), and (g).

4.0 Functional Requirements

The functional block diagram in Figure 1 shows the four main components of this project. The blocks shown in blue are components being developed for the project, while the blocks shown in orange are components that come with the AR Drone 2.0. First, the software package to be implemented onboard the UAV will: (a) leverage and assess the GPS data, programmed waypoint, and existing control system to implement autonomous flight; and (b) log relevant camera and sensor data; (c) store the route taken, using inertial sensors, so the vehicle can attempt to navigate back to the start without the aid of GPS. Second, the electronics package will be designed ~~such that it can connect to the vehicle via simple mechanical and electronic connection.~~into a custom fuselage that will be functional using the pre-existing control algorithms installed in the vehicle. The electronics package will house (a) the GPS receiver and antenna;~~,~~ (b) upgraded battery power for the mission;~~,~~ and (c) a ~~microcontroller~~ processing unit or other means of interfacing between the components. It will be designed to minimize any self-generated interference between the electronics and the GPS receiver/antenna. Third, the command station will be a laptop that can (a) running a Linux operating system (to communicate with the vehicle's operating system; ~~that can~~ (b) communicate with the vehicle wirelessly~~and~~; (c) ~~can~~ monitor the vehicle's camera output; and (d) ~~as well as~~ process telemetry ~~data~~ downlinked from the vehicle in flight. The command station is also where the user will plan the vehicle's route using a graphical user interface that allows the user to visually select waypoints and ~~communicate~~ uplink them ~~with~~ to the vehicle. Fourth, the main electronics package will also allow the addition of alternate sensors to accomplish diverse mission objectives, which is shown in gray in the functional block diagram. ~~A sample sensor payload will be designed and integrated to demonstrate this capability as the fourth and final component.~~

The vehicle will be designed to be autonomous, but for legal purposes there must be an FAA certified pilot at a control station on the ground with the ability to land the vehicle should it enter unsafe airspace or malfunction.

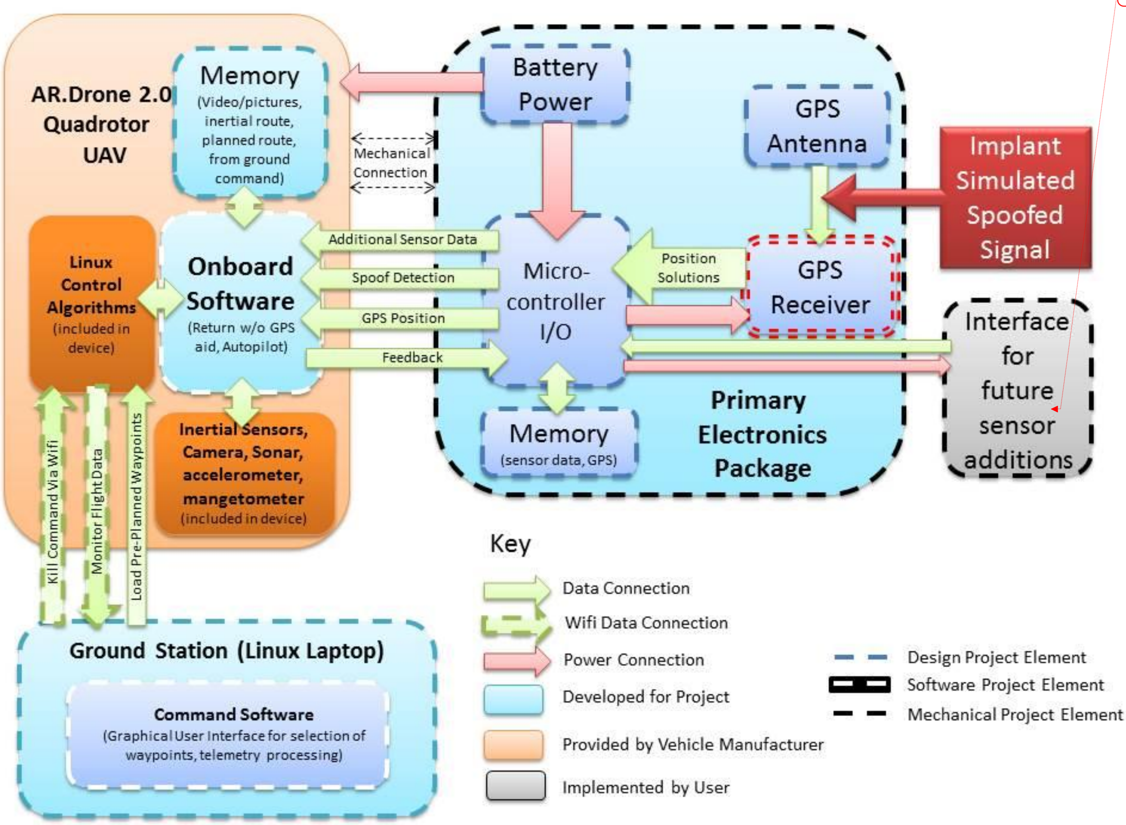

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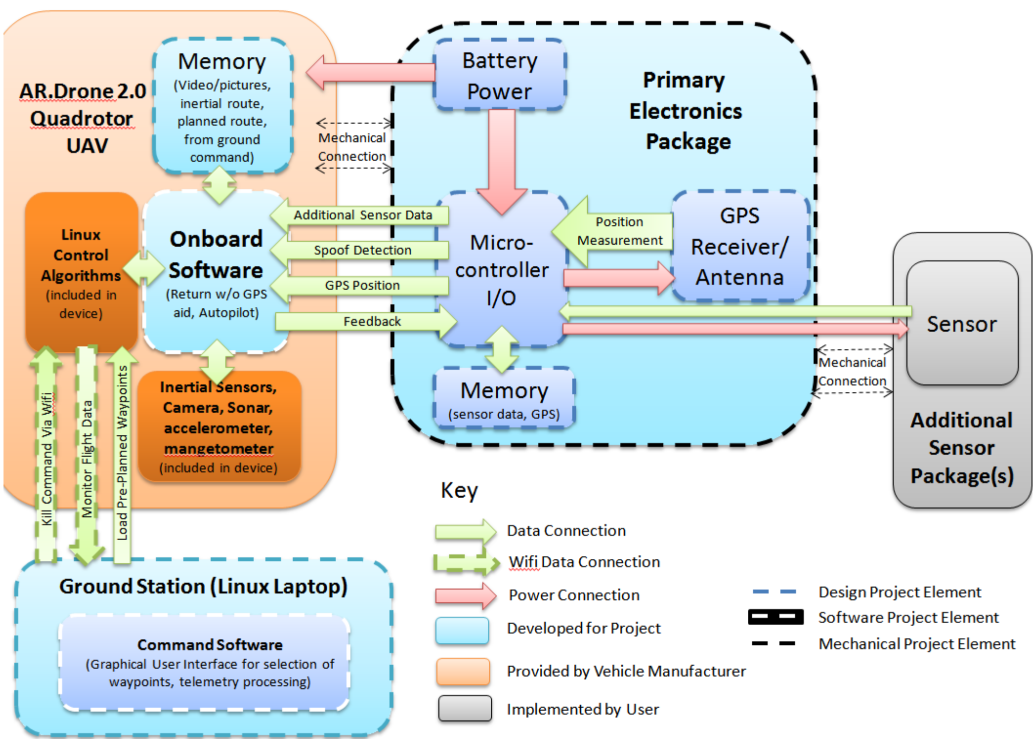
Figure 1: SIVAQ Functional Block Diagram

The project's concept of operations is shown in Figure 2, providing a general depiction of how the vehicle will function. Its mission will be to travel to a target at a location within a three-kilometer radius while using its spoof-detection capabilities, loiter and ~~take images~~capture video data for 1 minute (as if the vehicle were being used for search and rescue opperations), then return to its original starting point.



Specifically, the user will program the vehicle's route using the graphical user interface (GUI) at the ground station. This GUI will provide a map of surrounding areas and allow the user to select the desired GPS waypoints. Once the route is selected, the ground station will upload the route to the vehicle using a Wi-Fi connection. The vehicle will then act autonomously, using onboard GPS to fly

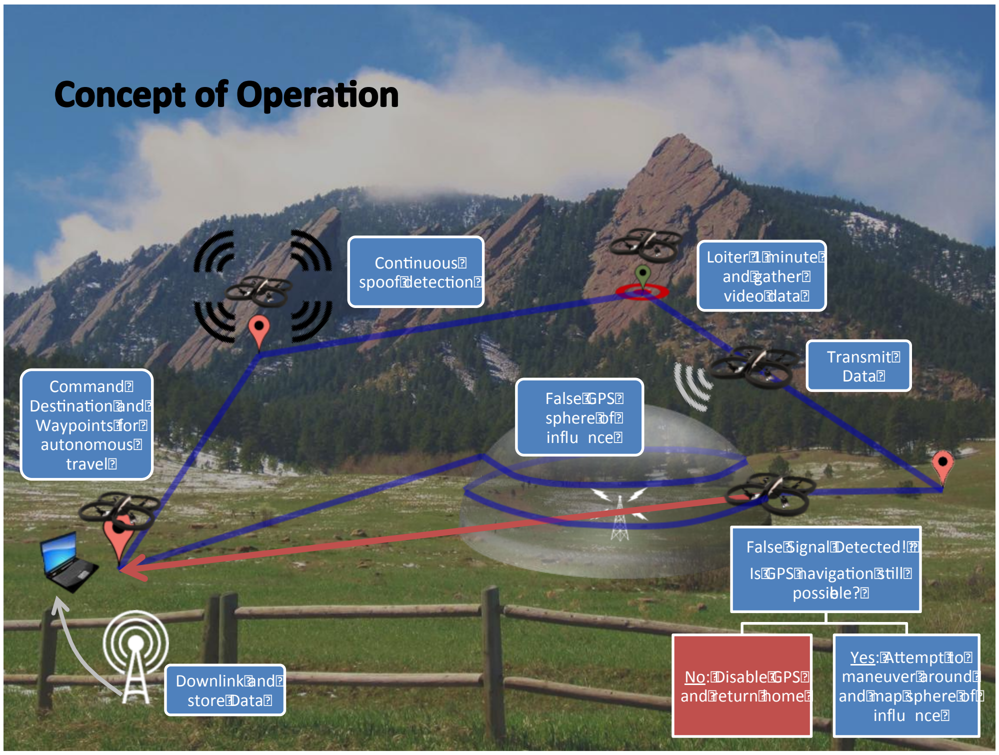


Figure 2: SIVAQ Concept of Operations

between waypoints before reaching its destination where it will loiter for one minute in order to take pictures of the ground below. During the entire duration of the vehicle's flight, it will be monitoring the integrity of the GPS signal. If the navigation information is deemed untrustworthy, the vehicle will attempt to navigate to its starting point using inertial sensors to provide guidance or provide 2D mapping of the region of degraded GPS information.

5.0 Critical Project Elements

Critical Project Elements
Vehicle Based Software/Algorithms (Linux) • Autonomous Navigation • Inertial Navigation from Memory • Additional Data Storage
Host Based Software/Algorithms (Linux) • GUI waypoints • Range Calculation • Plan/Download route to drone • Wi-Fi kill link
Mechanical • Maintain Built-in Control Integrity while adding required components • Incorporate Packages onto Vehicle
Electrical • Battery • IO/Microcontroller • GPS Receiver/ Antenna
GPS • Jamming/RFI Testing Methods • Jamming/RFI Detection Methods
COA • FAA Required Certificate Of Authorization for flight

6.0 Team Skills and Interests

Critical Project Elements	Team Member(s) and associated skills interests
Vehicle Based Software/Algorithms (Linux)	Sean Rivera (C and Linux programming), Ross Hillery (Linux Programming), Matt Zhu (C and Linux programming), Erin Overcash, Nick Brennan
Host Based Software/Algorithms (Linux)	Shane Miekle (GPS linkup), Erin Overcash, Nick Brennan
Mechanical	Geoff Sissom (Solid Works), Brett Wiesman, Steve Gentile
Electrical	Geoff Sissom, Brett Wiesman, Ross Hillery, Nick Brennan (Mechanical), Erin Overcash
GPS	Shane Miekle, Steve Gentile, Sean Rivera, Matt Zhu
COA	Steve Gentile

7.0 Resources

Critical Project Elements	Team Resources
Vehicle Based Software/Algorithms (Linux)	AR.Drone 2.0 – Parrot API/SDK
Host Based Software/Algorithms (Linux)	Linux Computer - Dennis Akos
Mechanical	Internet Vendors, University Facilities
Electrical	Internet Vendors, University Facilities
GPS	GPS receiver – Internet Vendors
COA	University Resources - James Mack

8.0 References

[1]Tippenhauer, Nils. "On the Requirements for Successful GPS Spoofing Attacks," Department of Computer Science ETH. Zurich, Switzerland. [http://www.syssec.ethz.ch/research/ccs139-tippenhauer.pdf]

[2]Zaragoza, S, "UT Austin Researchers Successfully Spoof an $80 Million at Sea," University of Texas at Austin, July 2013, [http://www.utexas.edu/news/2013/07/29/ut-austin-researchers-successfully-spoof-an-80-million-yacht-at-sea/]

[3]Wiseman, John, "A Mostly Drones Weblog," June 2013. [http://lemondronor.com/]

[4] Parrot "Flight Recorder" August 2013. [http://ardrone2.parrot.com/apps/flight-recorder/]

[5]Remes, B "TU Delft Autonomous Quadrotor" September 2012. [http://paparazzi.enac.fr/wiki/AR_Drone_2/getting_started]

[6]"QGroundControl", [http://www.qgroundcontrol.org]

[7]"Ardrone-Flyers" [http://www.ardrone-flyers.com/]

[8]Bristeau, Pierre-Jean, *"The Navigation and Control technology inside the AR. Drone micro UAV"* September 2011.

[9]"AR. Drone Battery Information" [https://docs.google.com/spreadsheet/ccc?key=0AmwVqcHo33JGdEhxOVIzT0Q0OUhhN3pIXzdqOXV4SFE#gid=0]