System Requirements Specification for ILS/VOR Data Logger (PIGEONS)

Michael Cain

Brian Jaury

Andrew Newlon

Daniel Sommer

James Trafny


```
                          .---.
                         /  (o \_
                         | -='.'"`
                         )   (
                     _.=`     \
                 _.=`.   -.    |
            .===:._ ' '.   ;   |
 ________,.='`^~""``"====-'   ,'
'-========-""'"-=..,,,_____,.'
                      `\ `\
                     ,-'==,\
                          ,-`==;
```

Name	Date	Reason for Change	Initials	Version
Initial Release	11/8/18	Initial Release	ALL	1.0
Mission Viewer Revision	11/29/18	Made more concrete requirements for Mission Viewer.	BJ	2.0
Second Semester Revision	02/12/19	Addressed professor comments and revised requirements to fit product end goal.	ALL	3.0
Final Revisions	04/09/19	Addressed additional comments and revised requirements to fit the product end goal.	ALL	3.0

Contents

1 Introduction

This product is designed to collect and process VOR (VHF Omnidirectional Range) and ILS (Instrument Landing System) signals via drone and send the signals to a ground station. VOR is a short-range radio navigation system for aircraft by utilizing a radio signal transmitted by a fixed radio beacon. ILS is a precision runway approach aid based on two radio beams which together provide pilots with both vertical and horizontal guidance while landing. The ground station software will provide a graphical interface for the test engineers to view signal strength and location measurements while comparing them to GPS location measurements. The goal of this product is to provide a cheaper alternative of verifying ILS/VOR transmitters than current methods used.

Section 1 covers who this document and product are intended for in 1.3, the purpose of the product in 1.4, and any other useful documentation outside of this document in 1.5.

1.1 Purpose

This document intends to define all requirements and conditions associated with the ILS/VOR (PIGEONS) Data Logging System. This document covers the product itself, its interaction between software and hardware, its interaction with a user, and the requirements associated with bringing the device into regulatory standards.

This document is the most up to date as of Tuesday, 04-09-2019, revision 3.0. It is the first iteration of this document, as approved by the ILS/VOR Data Logging Team.

1.2 Intended Audience and Reading Suggestions

The intended users of this product include airport managers, FAA regulators, and test engineers. This document contains information on product functionality, requirements given by the customer, and the safety standards and regulations given by the FAA. Section 2 described to intent of the project. Section 3 describes the technical aspect of the project, most pertinent to the test engineers. Sections 4 and 5 describe the features, requirements, and standards the project follows, and should be of interest to the FAA inspectors and airport managers.

Along with reading this document, the references outlined in section 1.5 are important to know for the proper operation and testing of the project. Section 1.5.1 references the ICAO document with which the testing requirements for the project are derived from and are important for meeting FAA operation standards. Sections 1.5.2, 1.5.3, and 1.5.4 are the documentations used with the flight hardware. This is useful for the test engineer if troubleshooting is needed.

1.3 Product Scope

As equipment ages and the Earth's poles shift, the effectiveness of aircraft guidance and landing systems diminishes, such as the Instrument Landing System (ILS), and Very High Frequency Omni-Directional Range Tactical Air Navigation (VORTAC). This is drastic enough to where the FAA requires remeasurements of the systems on a timely basis to make sure they are within limits. Currently, this requires a large aircraft to fly at several approach angles around and collect data on the systems, making sure they are within tolerance limits.

The goal of this system is to replace the measuring equipment with a lightweight, standalone unit that can be mounted to a drone to collect these measurements. This could reduce operating costs (going from a large aircraft to a small drone), reduce time required to take these measurements, and allow these measurement devices to be deployed in an easier manner.

This project will be a device that has the ability to take these measurements without requiring a large aircraft. This will be done using a small, lightweight unit that can be mounted on a drone. The abilities of the measuring device must adhere to ICAO Doc 8071, Volume 1 (Fourth Edition, 2000).

1.4 References

1.4.1 Manual of Testing of Radio Navigation Aids, ICAO Doc 8071, Vol 1. Fourth Edition, 2000.

1.4.2 QGroundControl Quick Start Guide, from docs.qgroundcontrol.com

1.4.3 Digi ZigBee RF Modules User Guide, from https://www.digi.com/resources

1.4.4 Pixhawk 4 User Manual, from docs.px4.io

2 Overall Description

Section 2 covers the purpose of the product in 2.1, the product functions in 2.2, associated user information in 2.3, and the operating environment in 2.4. Sections 2.5, 2.6, and 2.7 contain additional information on the implementation of the functions outlined in section 2.2.

2.1 Product Perspective

The PIGEONS system is a new, self-contained product that replaces the need for flight tests in order to analyze the signal characteristics of the ILS and VOR transmitters. The system consists of a standalone unit from the drone to measure ILS and VOR signals.

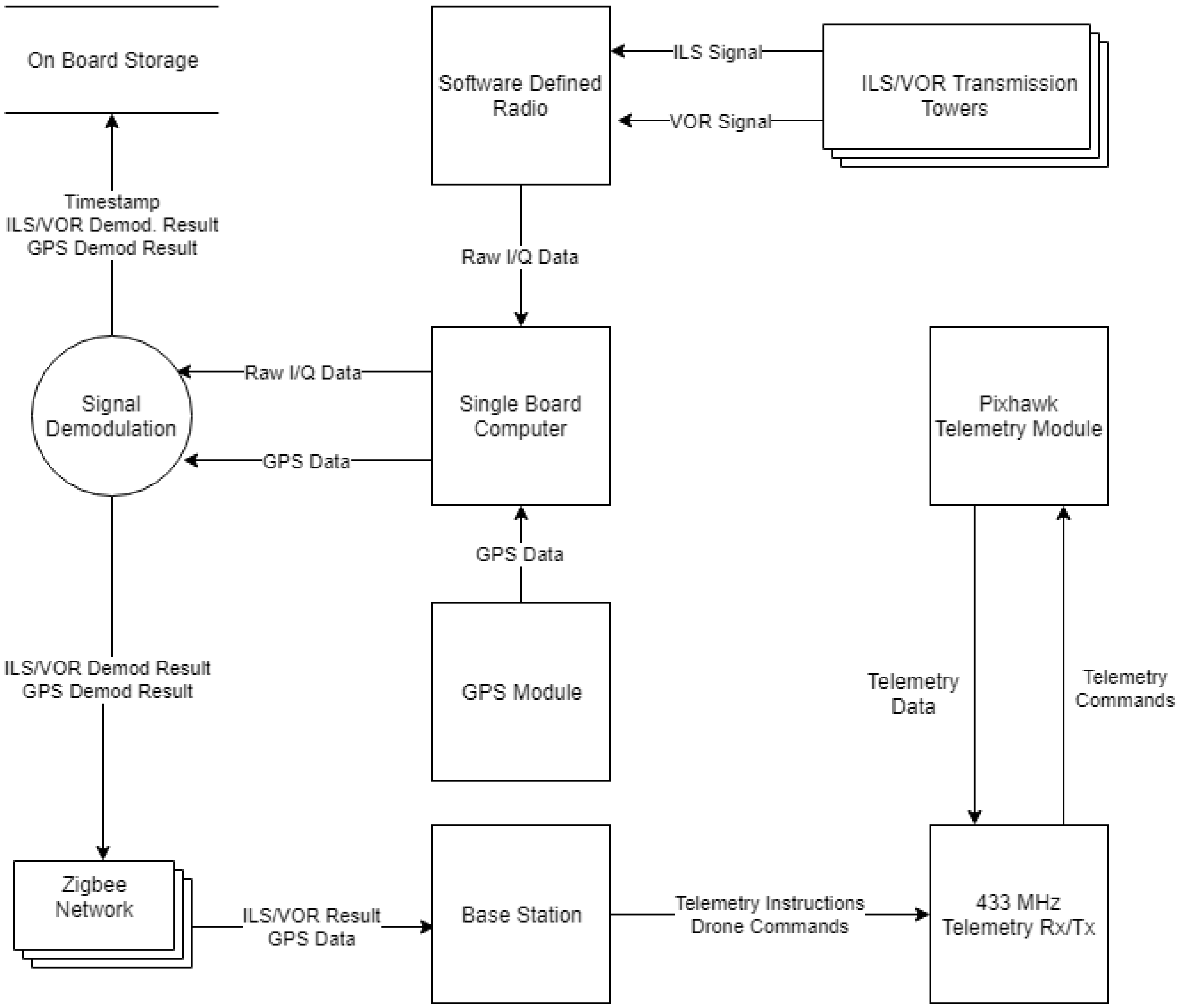


Figure 1: System Configuration Diagram

2.2 Product Functions

2.2.1 Use of SDR to receive and demodulate ILS/VOR signals for processing

2.2.2 Use ILS/VOR antenna to collect transmitted ILS and VOR signals

2.2.3 Store raw data locally (flash drive)

2.2.4 Transmit processed data to a ground station

2.2.5 Have ground station implement an overlay on QGroundControl

2.2.6 Utilize colored map on QGroundControl to indicate signal strength at location

2.3 User Classes and Characteristics

2.3.1 Remote Pilot In Command:

The Remote Pilot in Command (PIC) is an FAA Part 107 licensed remote drone operator. The PIC will be in charge of ensuring that PIGEONS missions comply with FAA Part 107 regulation to guarantee safe operating procedures. The PIC will review airspace, file any FAA waivers 90 days in advance, and review weather conditions for drone operation. During the mission, the PIC will maintain line of sight of the drone. The PIC will take manual control of the drone in the event deviations must be made to maintain the safety of the team and property.

2.3.2 Autonomous Flight Engineer:

The Autonomous Flight Engineer will work with the Remote Pilot in Command and Test Engineer to develop a QGroundControl flight path that will acquire NAVAID signal samples of points of interest. During the execution of a PIGEONS Mission, the Autonomous Flight Engineer will ensure the successful completion of the autonomous flight path by controlling and monitoring QGroundControl. In the event that a signal sample is not acquired, the Autonomous Flight Engineer will adjust the drone flight path to take a new sample.

2.3.3 Test Engineer:

The Test Engineer is a qualified individual that has proficient knowledge of the components used on the PIGEON system, as well as comprehensive knowledge of ICAO Document 8071 Volume 1. The test engineer will utilize the PIGEONS Mission Viewer to monitor

2.4 Operating Environment

2.4.1 User Interface:

QGroundControl (QGC) is the software used to interface with the drone system and relay the ILS/VOR signal information to the user. QGC requires Windows Vista or later, Mac OS X, or Linux Ubuntu 14.04 LTS or later. The system also requires Python 3 to be installed on the machine to handle wireless communication protocols.

2.4.2 Data Collection:

A software defined radio is connected to a Rami AV-525 antenna is used to collect the ILS/VOR signals on a single board computer. The signals are processed with Python 3 to extract the VOR azimuth and ILS approach offset and transferred over the Zigbee network to the ground station.

2.4.3 Data Transmission:

There are several data transmission protocols in use. User Datagram Protocol (UDP) is used to transfer data internally in the RPi, MAVlink is used to issue commands to the drone, and Zigbee is used to transfer data from the RPi to the ground station.

2.5 Design and Implementation Constraints

1. Design Constraints:
    - System shall weigh under 1 pound.
    - System must be able to operate without being mounted on drone.
    - SDR must be able to operate within ILS/VOR frequency range.
    - ILS/VOR signal analysis shall adhere to ICAO Document 8071 Volume 1.
2. Implementation Constraints:
    - XBee module was selected because of the defined transfer data rate of the module.
    - The system must transmit 10 kbps at a 9mi range, utilizing a 2.1dB antenna.
    - Signal integrity will be determined by the characteristics of the antenna used.
    - Drone range is limited by the telemetry modules transmit and receive range of 25 miles.
    - Functionality of signal collection is dependent on the functionality of VOR/ILS transmitters.

2.6 User Documentation

The following documents make up the required user documentation for the PIGEONS system. ICAO Doc 8071 contains the FAA's requirements for testing navigational aids and sets the pass/fail criteria for testing the radios. The QGroundControl Quick Start Guide gives the user a basic overview of how to plan and fly missions in QGC.

2.6.1 Manual of Testing of Radio Navigation Aids, ICAO Doc 8071, Vol 1. Fourth Edition, 2000.

2.6.2 QGroundControl Quick Start Guide, from docs.qgroundcontrol.com

2.6.3 User Manual on PIGEONS operation

2.7 Assumptions and Dependencies

2.7.1 Flight tests are shall only be performed under ideal weather conditions:

2.7.2 Wind shall not exceed 5 mph

2.7.3 Clear conditions.

2.7.4 Temperatures between 65°F and 85°F are preferred.

2.7.5 There must be a line of sight between the data measuring unit and the ILS or VOR.

2.7.6 The unit must be in the range of ILS and/or VOR transmitters for functionality.

2.7.7 There must be a line of sight between the communicating XBee modules.

2.7.8 The drone shall have enough thrust to carry all measuring equipment.

2.7.9 The user has a working laptop and is willing to download the QGroundControl software.

3 External Interface Requirements

Section 3 covers information regarding the usage of the system's interface, including both hardware and software interfaces. Sections 3.1 and 3.3 outline the software interfaces, including the user interface. Sections 3.2 and 3.44 outline the hardware interfaces, including the communication modules.

3.1 User Interfaces (Software)

The user shall interface with the PIGEONS system using QGroundControl (QGC.) The following requirements describe how the user interface shall be displayed and utilized.

The user shall use a tool bar across the top to switch between the following views:

3.1.1 View 1: Settings, shall allow the user to configure the QGroundControl application.

3.1.2 View 2: Setup, shall allow the user to configure and tune the Pixhawk 4 receiver.

3.1.3 View 3: Shall allow the user to create autonomous missions.

3.1.4 View 4: Shall allow the user to monitor the vehicle while flying.

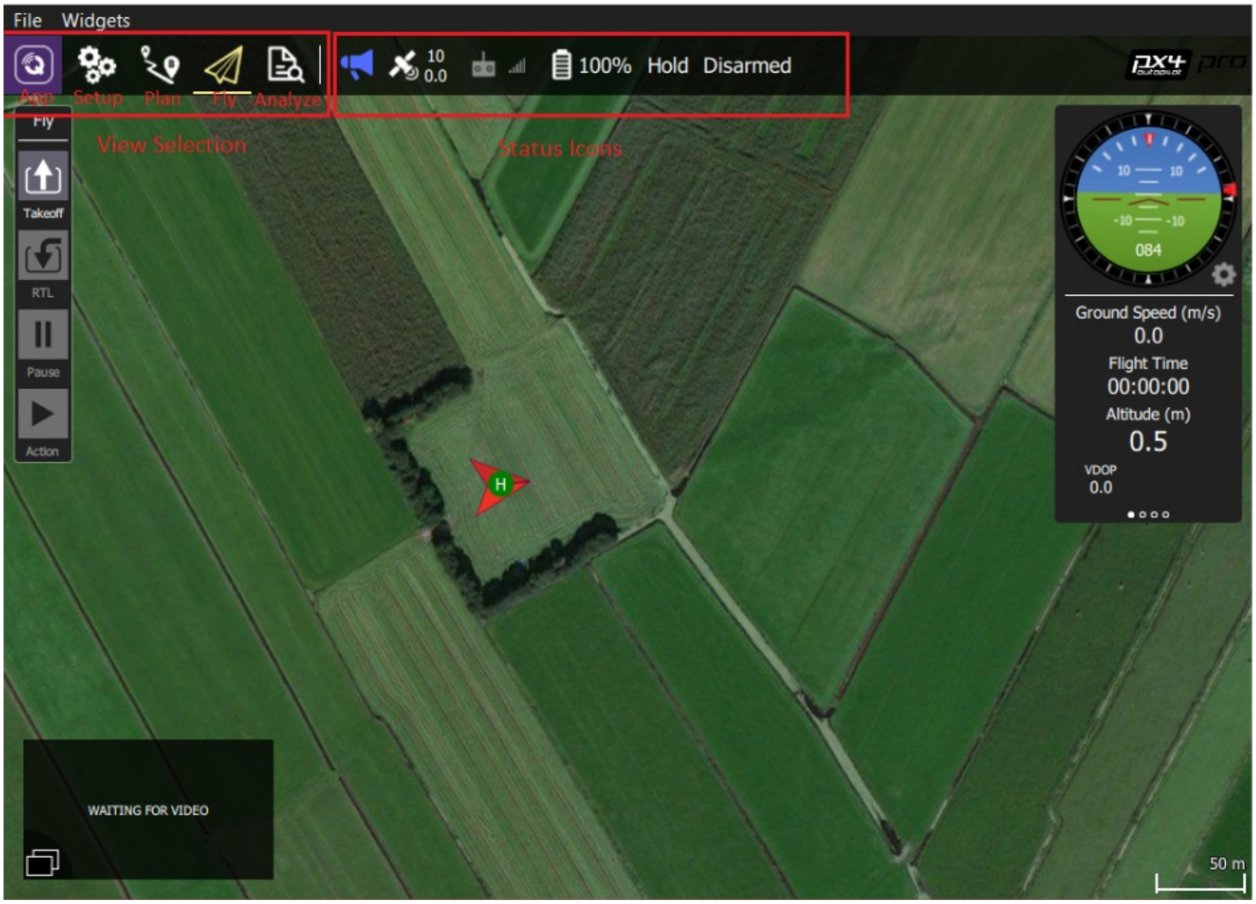


Figure 2: Toolbar Settings for QGroundControl

The main view used during missions is the “Fly” view. The instrument panel to the right shows current information about the vehicle. The center section consists of multiple pages which can be changed by clicking on them. The available pages shall be:

3.1.5 Telemetry page: The values shown within the telemetry page can be configured by clicking on the small gear icon.

3.1.6 Vehicle Health page: This page shows the health of the systems of the vehicle.

3.1.7 Vibration Clipping page: This page shows current vibration values and clip counts.

At the bottom of the view is the Guided Bar. The guided bar allows the user to interact with the vehicle directly from QGC. The following options shall be available to the user:

3.1.8 Arm, Disarm, E-Stop

3.1.9 Takeoff

3.1.10 Change altitude

3.1.11 Go to location

3.1.12 Return to location

3.1.13 Pause

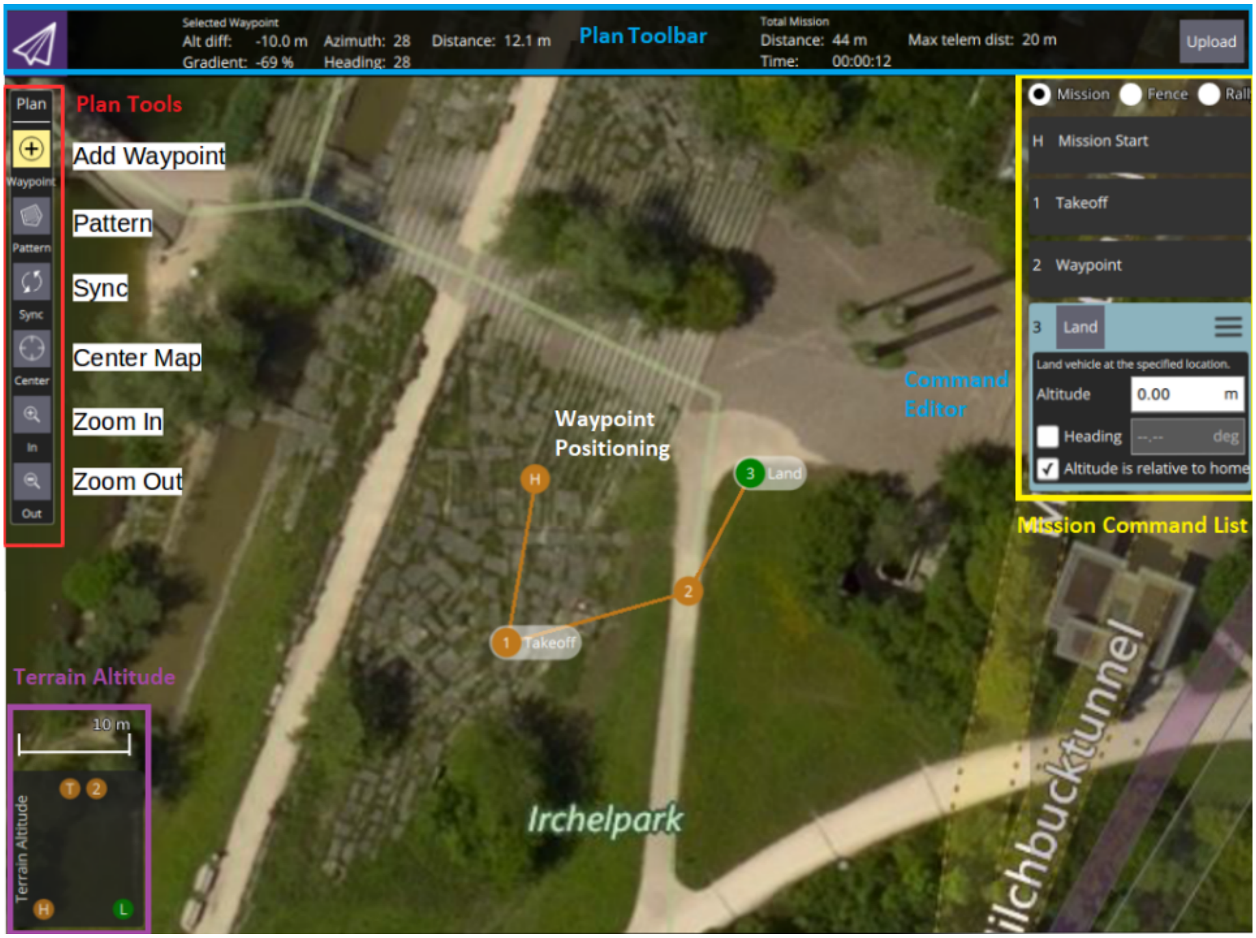


Figure 3: QGroundControl Options Locations

The screenshot above shows a simple mission plan that starts with a takeoff at the Planned Home-position (H), flies through three waypoints, and then lands on the last waypoint (i.e. waypoint 3). The elements of the UI shall be:

3.1.14 Map: Displays the numbered indicators for the current mission, including the Planned Home. Click on the indicators to select them (for editing) or drag them around to reposition them.

3.1.15 Plan Toolbar: Status information for the currently selected waypoint relative to the previous waypoint, as well as statistics for the entire mission (e.g. horizontal distance and time for mission).

3.1.15.1 Max telemetry distance is the distance between the Planned Home and the furthest waypoint.

3.1.15.2 When connected to a vehicle it also shows an Upload button, can be used to upload the plan to the vehicle.

3.1.16 Plan Tools: Used to create and manage missions.

3.1.17 Mission Command List/Overlay: Displays the current list of mission items.

3.1.18 Terrain Altitude Overlay: Shows the relative altitude of each mission command.

3.2 Hardware Interfaces

The PIGEONS hardware consists of several components working in tandem to control the drone and carry data feeds to different parts of the system. The PIGEONS hardware consists of a Laptop acting as the base-station and a drone platform carrying testing and control equipment. The base-station issues commands from QGC via the MAVlink protocol to the drone platform's Pixhawk 4 telemetry module. The drone's hardware can be broken up into two categories; command and testing.

3.2.1 The command hardware shall consists of the Pixhawk 4 telemetry module and a pair of RTK GPS modules.

3.1.2 The telemetry module shall receive commands from QGC containing coordinates of where the drone package needs to go.

3.1.3 The telemetry module shall send data back to QGC containing information regarding where it is.

3.1.4 The testing hardware shall be coordinated by a single-board computer.

3.1.5 The testing hardware shall consist of the following:

3.2.5.1 Software defined radio.

3.2.5.2 Zigbee radio module.

3.2.5.3 RTK GPS module.

3.2.5.4 USB mass storage device.

3.1.6 The data shall be passed to the base station over the the Zigbee network.

3.1.7 The base station shall consist of a laptop running QGC.

3.3 Software Interfaces

The PIGEONS system is composed of several software systems working in unison to receive, manipulate, and transfer data. The drone platform consists of a Raspberry Pi 3 model B running Raspbian Stretch Lite version 4.14. To configure the software defined radio receiver, the RPi shall run Gnu Radio Companion. I/Q data from the SDR is transferred via serial, and demodulated using Python 3. The processed I/Q data is piped to a UDP port on the RPi to get ready for packaging with a timestamp and GPS coordinates.

3.3.1 The drone platform shall utilize a Raspberry Pi 3 model B running Raspbian Stretch Lite version 4.14.

3.3.2 The RPi shall have Python 3 installed.

3.3.3 Raw I/Q data from SDR shall be piped to Python 3 for processing using Serial.

3.3.4 Post-processed data shall be piped to Python 3 for packaging using UDP.

3.3.5 Post-processed data shall be matched with timestamp and GPS coordinates, creating an I/Q Vector.

3.3.6 I/Q Vectors shall be sent to Xigbee interface via serial connection.

A GPS module is also running on the drone platform, the relevant GPS data is paired up with its corresponding ILS/VOR data points and sent over the Zigbee network back to the base-station. The base station is a portable laptop running Linux Mint 19 and hosting the QGroundControl server. QGroundControl (QGC) is an open source, extendable unmanned aircraft control platform. QGC shall display the current location of the drone package as well as the next waypoints for the current mission. A custom plugin written in QML handles receiving the ILS/VOR data from the Zigbee network and displays it on the map.

3.3.7 Base station shall be a laptop running Linux Mint 19.

3.3.8 Base station shall host the QGC server.

3.3.9 Mission viewer software shall receive I/Q Vectors via serial connection to Zigbee network.

3.4 Communications Interfaces

3.4.1 The unit shall collect VOR and ILS signals from their respective transmitters.

3.4.2 The VOR radial measurement shall be determined by referencing the phase of the of a reference signal with the phase of a variable signal

3.4.3 The ILS distance from optimal landing path shall be determined by calculating the DDM of frequency modulated signals at 90 Hz and 150 Hz.

3.4.4 Internal communications within the RPi shall be handled over UDP.

3.4.5 The base station and the drone shall interface over Zigbee network for data and measurement transfers.

3.4.6 The base station and drone shall interface over MAVLink for drone control functions.

4 System Features

Section 4 details a more specific list as put forward in section 2.2. This includes the functions associated with autonomous UAV Flight in 4.1, Navigation Aid Signal Acquisition in 4.2, and the NAVID Data Display in 4.3.

4.1 Autonomous UAV Flight

4.1.1 Description and Priority

The user shall be able to define a flight path for the UAV to execute. The user will plan flight paths by inserting navigation waypoints into a map of the airfield being evaluated. When the user is ready to execute the flight plan, the user will switch from manual to autonomous flight mode. The user will press the execute flight button to start autonomous operations. Upon completion of the user's autonomous flight plan, the UAV will return to home. High Priority.

4.1.2 Stimulus/Response Sequences

After the user draws the flight path in QGroundControl and selects "Initiate Path", the drone will begin to execute the path selected. After completion, the drone will return to the ground station.

4.1.3 Functional Requirements

4.1.3.1 The software shall give the user the ability to define a flight path in QGroundControl by drawing a flight path on the map.

4.1.3.2 A map shall be displayed after the user clicks "Display Flight Plan."

4.1.3.3 Upon clicking on map for flight path, a new waypoint shall be created.

4.1.3.4 Multiple waypoints shall have the ability to exist at the same time.

4.1.3.5 Existing waypoints shall be chronologically connected.

4.1.3.6 Flight plan shall complete once unit returns to original waypoint.

4.1.3.7 The user shall be able to define what the drone does when telemetry connection is lost.

4.1.3.8 The drone shall return to the initial location when low on battery.

4.1.3.9 The user shall be notified if telemetry connection is lost.

4.1.3.10 Should the drone lose connection with the ground station longer than 30 seconds, the drone shall return to the ground station.

4.2 Navigational Aid Signal Acquisition and Processing

4.2.1 Description and Priority

The system must be able to pick up data for the corresponding ILS and VOR signals it is trying to measure. This data is to be picked up using a dipole antenna and sent through a software defined radio module. It will enter the central processor of the device where it is to be demodulated using Python. The raw data acquired is to be saved on a local USB device while the processed data is to be sent over the XBee module, to be displayed on the NAVAID Data Display. This is a high priority function.

4.2.2 Stimulus/Response Sequences

The collection of data is done through automatically as the drone moves around, as outlined in Autonomous UAV flight, section 4.1.

4.2.3 Functional Requirements

4.2.3.1 The unit shall be able to receive ILS and VOR signals using the dipole antenna and an SDR.

4.2.3.2 The unit shall demodulate the received data from the ILS and VOR signals through an SDR.

4.2.3.3 The data shall be demodulated onboard the UAV.

4.2.3.4 The processed data shall be sent over an XBee module to a user interface.

4.2.3.5 The raw data shall be saved locally on a USB storage device.

4.2.3.6 The unit shall tag the signal data with its respective GPS location.

4.2.3.7 The user shall be notified if the unit it not picking up ILS or VOR data.

4.2.3.8 The user shall be notified if the XBee modules lose connectivity.

4.2.3.9 The user shall be notified of initial connection between UAV and ground station

4.2.3.10 The user shall be notified upon startup of collection of ILS or VOR data.

4.2.3.11 The unit shall determine a bearing measurement when measuring VOR signals.

4.2.3.12 The unit shall determine the offset from the ideal landing approach if measuring ILS signals.

4.2.3.13 The ground station shall be able to accept a reference GPS location from the user.

4.2.3.14 The ground station shall calculate the error in GPS measurement from the base station RTK GPS module.

4.2.3.15 The ground station shall send the error in the GPS measurements to the drone.

4.2.3.16 The drone shall calculate an accurate GPS location using the error measurement received by the ground station.

4.3 PIGEONS Mission Data Viewer

4.3.1 Description and Priority

The Mission Data Viewer will be built as a standalone software to display current and past PIGEONS data acquired during a mission. The XBEE module will be the means to communicate from the PIGEONS payload system and the PIGEONS Mission Data Viewer. The user will be able to control options relating XBee connection and mission types (ILS/VOR, Both). The flight path from QGroundControl will be used to create a real-time map of the flight path of the vehicle and associated data collected. The map will utilize 3D shapes and color coding scheme defined to indicate the demodulated measurements and the signal strength at any given location.

4.3.2 Stimulus/Response Sequences

When the UAV flies over a waypoint, the GPS location will be transmitted to the Mission Data Viewer. When the data packet is received, the ground station will parse the packet. The signal strength received will be displayed on the ground station with a color scheme. A cylinder of varying height will be used to denote the altitude the data point was taken. The user shall be able to click the GPS point to display the data values received.

4.3.3 Functional Requirements

4.3.3.1 The PIGEONS Mission Viewer Start screen shall be displayed upon execution.

4.3.3.2 The PIGEONS Mission Viewer Start screen shall display the Track Live Mission button.

4.3.3.3 The PIGEONS Mission Viewer Start screen shall display the Replay Previous Mission button.

4.3.3.4 Pressing the Track Live Mission button shall display the Remote Vehicle Connection Settings view.

4.3.3.5 The Remote Vehicle Connection Settings view shall allow the ability to select the COM port the XBee is connected to.

4.3.3.6 The Remote Vehicle Connection Settings view shall allow the ability to select the Baud rate the XBee is using.

4.3.3.7 The Remote Vehicle Connection Settings view shall allow the ability to select the Data Bits the XBee is using.

4.3.3.8 The Remote Vehicle Connection Settings view shall allow the ability to select the parity settings the XBee is using.

4.3.3.9 The Remote Vehicle Connection Settings view shall allow the ability to select the Stop Bits settings the XBee is using.

4.3.3.10 The Remote Vehicle Connection Settings view shall allow the ability to select the Flow Control settings the XBee is using.

4.3.3.11 The Test Connection Button shall be displayed in red.

4.3.3.12 A label shall display errors when pressing the Test Connection button results in a failed connection.

4.3.3.13 The Test Connection Button shall change colors to green when a successful connection is established over the XBee module.

4.3.3.14 The Next button in the Remote Vehicle Connection Settings shall display the PIGEONS Mission Settings Dialog when pressed.

4.3.3.15 The Mission dropdown shall display the mission types available (ILS/VOR/Both).

4.3.3.16 The user shall enter numerical frequency values for the ILS frequency.

4.3.3.17 The user shall enter numerical frequency values for the VOR frequency.

4.3.3.18 The Next button in the PIGEONS Mission Settings shall display the PIGEONS Mission Plan Upload Dialog when pressed.

4.3.3.19 Pressing the browse button shall open a file dialog for selecting .plan files.

4.3.3.20 The Next button in the PIGEONS Mission Plan Upload shall display the PIGEONS Live Mission Settings Confirmation Dialog when pressed.

4.3.3.21 The Mission label shall display the selected mission type from 4.3.3.14.

4.3.3.22 The ILS Frequency shall display the entered ILS frequency from 4.3.3.15.

4.3.3.23 The VOR Frequency shall display the entered VOR frequency from 4.3.3.16.

4.3.3.24 The Mission Plan label shall display the selected Mission Plan from 4.3.3.18.

4.3.3.25 The start button shall display the PIGEONS Live Mission View when pressed.

4.3.3.26 The top bar in the Live Mission View shall display the ILS Frequency from 4.3.3.15.

4.3.3.27 The top bar in the Live Mission View shall display the Link status as Connected in green font when connected.

4.3.3.28 The top bar in the Live Mission View shall display the Link status as disconnected in red font when disconnected from XBee module.

4.3.3.29 The map view shall display the path the drone flew with color coded cylinders.

4.3.3.30 The signal strength shall be characterized as red, yellow, green cylinders (red = unacceptable, yellow = acceptable, green = acceptable).

4.3.3.31 Cylinder height in the map view shall be determined on UAV measured altitude.

4.3.3.32 Selecting a point shall display its recorded data.

4.3.3.32.a Recorded data shall be defined as Location, Altitude, Measurement Type, Signal Strength, and Within Range

4.3.3.32.b The Location label shall display the GPS coordinates of the points recorded.

4.3.3.32.c The Altitude label shall display the Altitude in meters of the points height.

4.3.3.32.d The Measurement Type shall display the current point measurement type (ILS/Vor)

4.3.3.32.e Signal Strength shall display the signal strength in dB.

4.3.3.32.f Within Range shall display if the point recorded meets calibration criteria.

4.3.3.33 The Mission Completed dialog shall appear denoting success/failure after UAV has landed.

4.3.3.34 The user shall be able to save Mission replay to the ground station computer.

4.3.3.35 The Replay Previous Mission button shall display the PIGEONS Mission Plan Replay Selection Dialog.

4.3.3.36 Pressing the browse button for Mission plan shall open a file dialog for selecting .plan files.

4.3.3.37 Pressing the Data Recording File browse button shall open a file dialog for selecting PIGEONS Data Record Files (.pdr) files.

4.3.3.38 The Next button in the PIGEONS Mission Plan Replay Selection dialog shall display the PIGEONS Recorded Mission view when pressed.

4.3.3.39 The Recorded Mission view shall display time warp buttons to step through mission time

4.3.3.39.a The Step Backwards button shall jump the display one data point backwards.

4.3.3.39.b The Pause button shall pause the mission from displaying anymore points.

4.3.3.39.c The Play button shall continue playback of the mission.

4.3.3.39.d The Step Forward button shall just the display one data point forward.

4.3.3.40 The onboard computer shall transmit data to the ground station within 3 seconds.

4.3.3.41 The ground station shall receive data from the onboard computer within 3 seconds.

5 Other Nonfunctional Requirements

Section 5 details the current known requirements and regulations associated with this product as of the Initial Release, Version 1.0.

5.1 Performance Requirements

5.1.1 Local data writing shall not be interrupted if connection is lost.

5.1.2 Data transmission shall be performed at a speed of at minimum 10 kB/s.

5.1.3 The maximum range of data transfer from drone to base station shall exceed 1 mile.

5.1.4 The drone shall have a maximum flight time exceeding 5 minutes.

5.1.5 Transmission delay from drone to ground station shall not exceed 10 seconds.

5.1.6 Delay of updating overlay shall not exceed 10 seconds.

5.1.7 The various overlay configurations should be evident and simple to understand for the user.

5.1.8 Changing between types of overlay shall take no more than 5 seconds.

5.1.9 The user shall be informed of any connection loss during flight.

5.1.10 The user shall be notified if no signals are being collected during flight.

5.1.11 The unit shall have onboard storage that exceeds 100 gb.

5.1.12 The operating software on the Raspberry Pi shall not exceed 16 gb.

5.2 Safety Requirements

5.2.1 The system shall not be utilized in unapproved airspace unless directly approved by the FAA.

5.2.2 The drone shall not be flown within 5 miles of the airport without the airports consent.

5.2.3 The drone shall have a protocol to come back to the ground station if connection is lost.

5.2.4 All electrical connection shall be concealed.

5.2.5 No voltage line shall exceed 20 volts.

5.3 Security Requirements

5.3.1 No other device shall be able to receive the transmission unless a transmission key is provided.

5.3.2 The unit shall not measure any signals other than ILS and VOR.

5.3.3 The operator of the ground station shall possess a drone license unless flying in a designated area.

5.3.4 The drone shall not capture any images of private property or individuals without consent.

5.4 System Quality Attributes

5.4.1 The signals collected shall be within 2σ

5.4.2 The measured carrier frequency shall be within $\pm 0.002\%$ of the intended carrier frequency of the VOR transmitter as highlighted in ICAO Document 8071, Volume 1, 2.2.6.

5.4.3 Changing the polarization of the antenna shall have a variance of $\pm 2.0^{\circ}$ on VOR measurements as discussed in ICAO Document 8071, Volume 1, 2.2.34.

5.4.4 The system shall abide to all VOR bearing measurements as discussed in ICAO Document 8071, Volume 1, 2.2.7 and 2.2.8.

5.4.5 The VOR 9 960 Hz carrier shall have a modulation depth between 28% and 32% as discussed in ICAO Document 8071, Volume 1, 2.2.12.

5.4.6 The VOR 30 Hz carrier shall have a modulation depth between 28% and 32% as discussed in ICAO Document 8071, Volume 1, 2.2.12.

5.4.7 The DDM of the two ILS carriers shall be within ±2.0% when directly in line with the center line of the runway as discussed in Section 4.3.14 and 4.3.15 of ICAO Document 8071, Volume 1.

5.4.8 The average error in measurement of ILS location in the horizontal direction shall be within ±10.5 m as discussed in Section 4.3.26 to 4.3.28 of ICAO Document 8071, Volume 1.

5.4.9 The data collection unit shall not exceed 1 lb excluding the antenna.

5.4.10 The data collection unit shall be a standalone unit from the drone.

5.4.11 The data collection utilized without transmitting data if desired.

5.4.12 The ground station shall display the overlay on top of a terrain/satellite map.

5.4.13 The ground station software shall display the correct overlay selected by the user.

5.4.14 The system shall be able to be used during approved flight times by the FAA or respective airport.

5.5 Business Rules

5.5.1 Only the FAA and the airport shall be able to authorize drone testing within 5 miles of the airport.

5.5.2 A flight test engineer should determine the pre-flight path needed to verify the transmitters as described in ICAO Document 8071, Volume 1.

6 Appendix A: Glossary

DDM - Difference in depth of modulation. The percentage modulation depth of the larger signal minus the percentage modulation depth of the smaller signal, divided by 100.

ICAO - International Civil Aviation Authority

ILS - Instrument landing system

QGC - QGroundControl, software package controlling autonomous functions.

RPi - Raspberry Pi 3 model B

SDR - Software Defined Radio

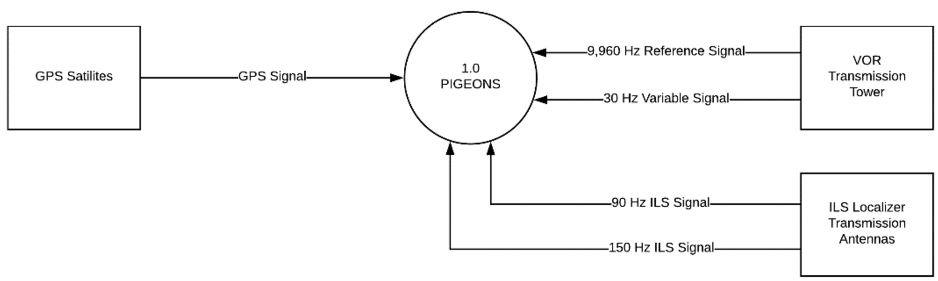
UDP - User Datagram Protocol

VHF - Very High Frequency

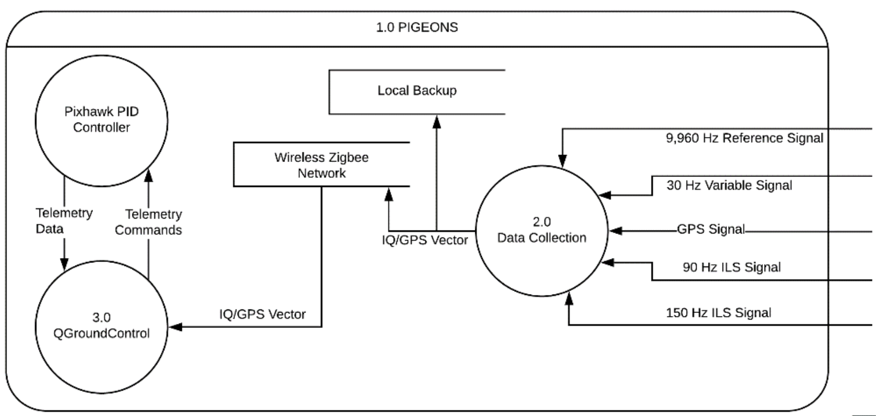
VOR - VHF omnidirectional radio range

7 Appendix B: Analysis Models

Data Flow Diagram Level 0



Data Flow Diagram Level 1



PIGEONS