Team 4 - Rescue Drone

Operation Manual

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1. Executive Summary

Drones used by Florida State University's Emergency Management and Homeland Security Program can autonomously scan an area, but will provide no feedback regarding image contents, nor do they have a user-friendly interface for interprocess communication. The multidisciplinary ECE Senior Design Team #4 has been tasked with creating a new, unique drone capable of scanning disaster zones and identifying unique objects of interest.

Careful research and planning has led to an innovative flight control architecture. The final product features a powerful onboard computer capable of live image processing for object detection, with distinct algorithms for color filtering and pedestrian tracking. A conversion algorithm has also been implemented for converting the drone's latitude and longitude data, which is read from the flight control hardware, into USNG format. An IP network governs all communication between the ground station and the drone.

In the pursuit of increasing autonomy and implementing computer vision, a reliable and consistent object detection remains integral to accomplishing this task. By analyzing an image in search of HSV values that satisfy a predetermined range of color, any region of pixels that comply with the given range is highlighted using the color filtering algorithm. The range is preprocessed in HTML by selecting a value in an interactive color spectrum. This value autopopulates the necessary variables on the image processing server, which results in a fluid transition between frames on the Logitech C920 as it detects the color of interest as it corresponds with the input variable data.

In order to accomplish the desired 18-minute flight time and address the sponsor's request for a portable design, the mechanical structure of the drone consists of a foldable hex frame with onboard electronics powered by a four-cell LiPo battery. Furthermore, a lightweight hexacopter frame was assembled with brushless direct current (BLDC) motors and slow-fly (SF) propellers to maximize the drone's efficiency, with the added benefit of an increased flight time. A complementary landing gear was also designed to reduce the weight and folded dimensions of the airframe. The drone is equipped with an RC transmitter which allows manual missions and acts as a fail-safe during autonomous missions. The user can plan the autonomous mission and deploy the route to the drone using any preferred mission planning software.

The resulting product increases the ability to conduct reliable and efficient search and rescue missions by eliminating manual processing in favor of increased autonomy for the drone's mechanical structure, and capable computer vision for real-time image processing.

2. Components

a. Arm Assembly

Motor - *T Motor 3506 650Kv*

- Propeller - 12x4 Slow-Fly
- Propeller nut, washer

Electronic Speed Control (ESC) - *Castle Creations Multirotor 25*

- Power wire connecting to main power bus
- Signal wire connecting to autopilot
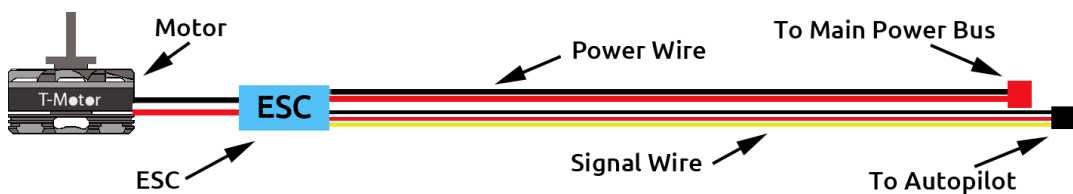
Figure 1 - Electronic Speed Control power wire and signal wire layout within the arm.

Figure 01 shows the layout within the arm of the connections between the motor, the ESC, the main power bus, and the autopilot.

Landing Gear Legs (arms 2, 4, and 5)

- The landing gear for functional purposes can be positioned on any non-consecutive arms, though it is important to position them on arms 2, 4, and 5 to avoid obstruction of the camera. See the fuselage assembly section to understand the location of arms 2, 4, and 5.

Figure 2 - Exploded view of the arm and landing gear

b. Fuselage Assembly

Autopilot - *Pixhawk PX4*

- Power meter (PM)
- GPS/compass
- Switch
- Note: These components are imperative for the autopilot, but housed separately.

Radio Control Receiver - *FrSky X8R*

- Receives the signal from the radio controller.

5 Volt Battery Eliminator Circuit - *KINGKONG UBEC*

- Divides the voltage to necessary components requiring 5 Volts.

12 Volt BEC - *Castle Creations BEC Pro*

- Divides the voltage to necessary components requiring 12 Volts.

Main Power Bus
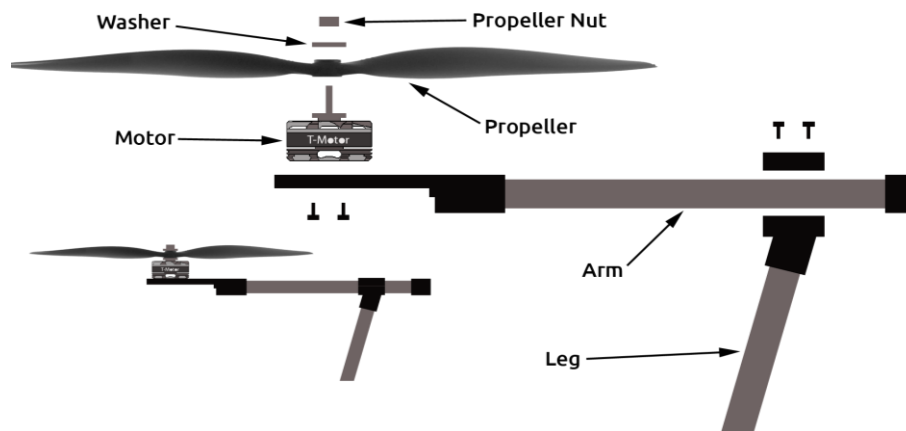
- Distributes battery power among necessary components.

Fuselage

- Carbon fiber plates that the components are secured to.
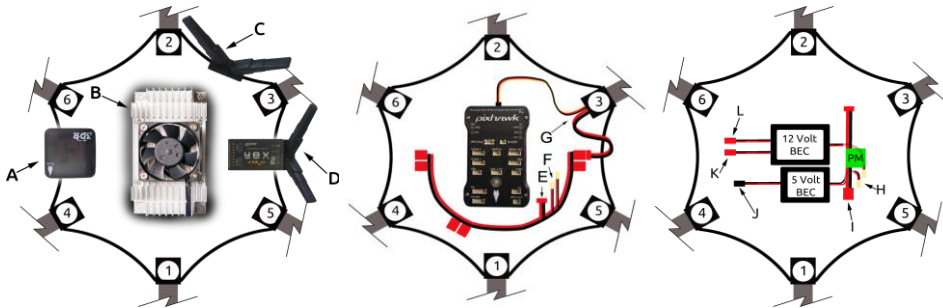
Figure 3 - From left to right are the views of the top, middle and bottom of the fuselage

In Figure 03 the top, the middle, and the bottom of the fuselage show the connections and locations of the components. A is the GPS/compass. B is Nvidia Jetson TX1 discussed in the following section. C are 2.4 GHz WiFi antennas for data transmission. D is the Radio Control Receiver which also contains an antenna. E is the input connector from the PM. F are the output connectors to BECs. G is the arm wiring coming in from the motor and the ESC. H are power inputs for the BECs. I is the output from the power meter. J is power supply for Pixhawk. K is power supply for the gimbal. L is power supply for the TX1. Wiring from the other 5 arms were omitted for clarity.

c. Payload tray assembly

Battery - *4 cell Lithium-Ion Polymer (LiPo)*

Gimbal - *Feiyu mini 3D pro*

- Stabilizes the camera to ensure a smooth footage collection.

Camera - *Logitech HD pro webcam*

- Captures images of the desired objects and environment.

Payload tray

- This holds the gimbal, camera, and battery; note depiction in Figure 04. When the arms are folded down, the payload tray must be removed by unscrewing 4 thumbscrews.
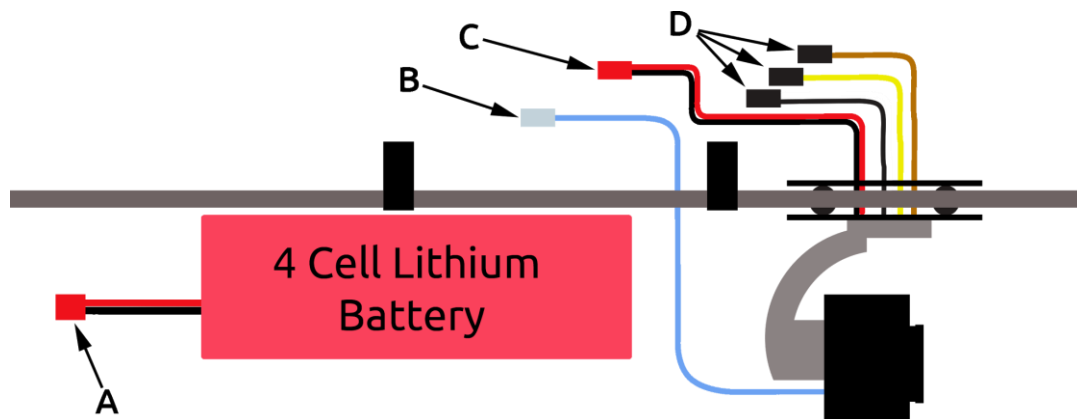
Figure 4 - Payload tray layout and connections

Figure 4 shows the layout of the payload tray: A is the power lead from the battery. B is the USB connector for the camera. C is the 12 V supply for the gimbal. D shows the gimbal's controller connections.

d. Companion computer

If the Nvidia Jetson TX1 is purchased along with the development board, it must first be removed from the development board. To separate the companion computer from the development board, first ensure the board is powered off. Unplug the fan connector and remove the screws in each of the four corners (Figure 05). Once these connections are cleared, gently pull the TX1 from the development board to remove it.
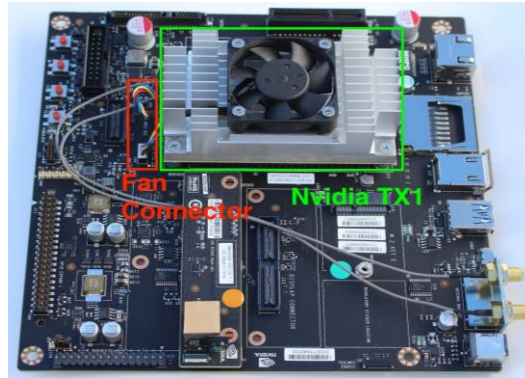
Figure 5 - TX1 and companion board

The Orbitty carrier board can then be attached through the same multi-pin connector that connects the TX1 to its development board. The carrier board and the TX1 will fit together as pictured in Figure 06. For more information, see reference 1.
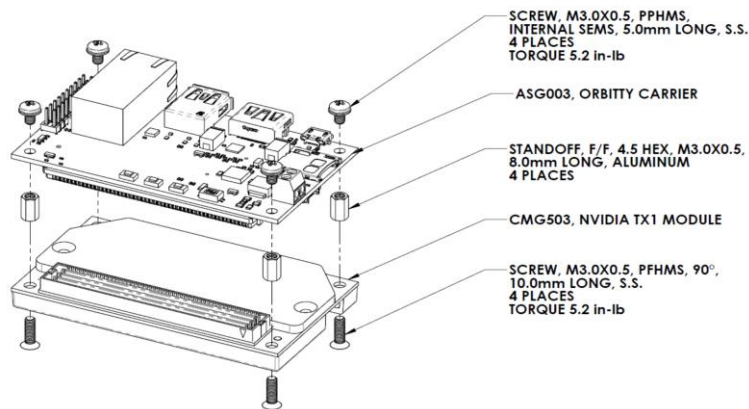
Figure 6 - Exploded view of the TX1, carrier board, and standoffs

The Orbitty carrier board connects to the Nvidia TX1 via its multi-pin connector in Figure 07.
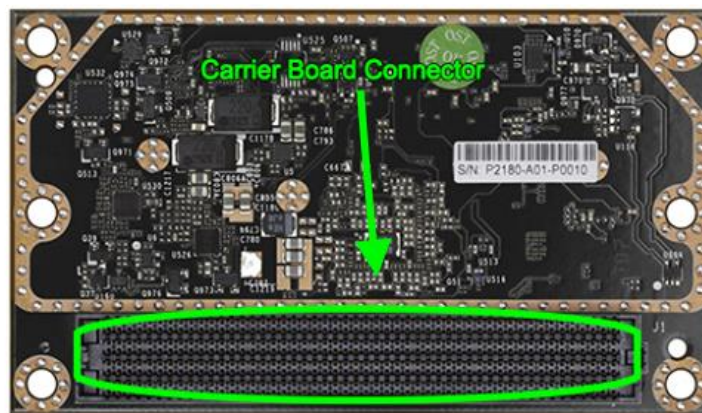
Figure 7 - Multi-pin connector of the TX1

Gently connect the TX1 and the carrier board as shown above. Install the included standoffs to secure the components and reduce the load on the electrical connection. The webcam can now be plugged into the USB port. Once the carrier board is installed, position the fan and power switches as in Figure 08.
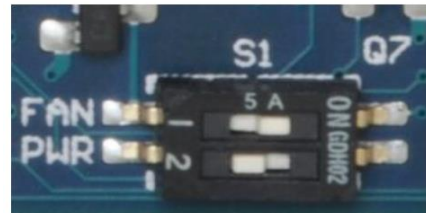
Figure 8 - Fan and power switch

Connect the positive and negative leads of the 12 V battery eliminator circuit (BEC) to the carrier board, as shown in Figure 09.

Once the power has been connected, press the power button in Figure 10 to power on the companion computer.
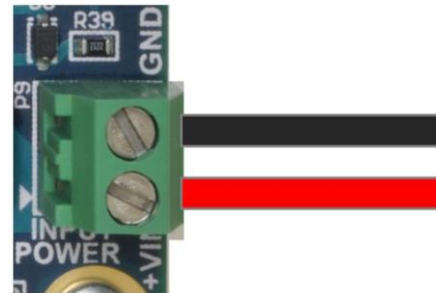

Figure 9 - Power connections to the companion computer
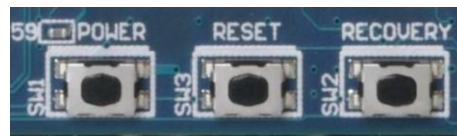
Figure 10 - Power, Reset, and Recovery buttons

The antennas located on the top of the fuselage connect to the carrier board here. These antennas are used to receive and transmit data to the ground station router. This is important in sending the processed images from the webcam.
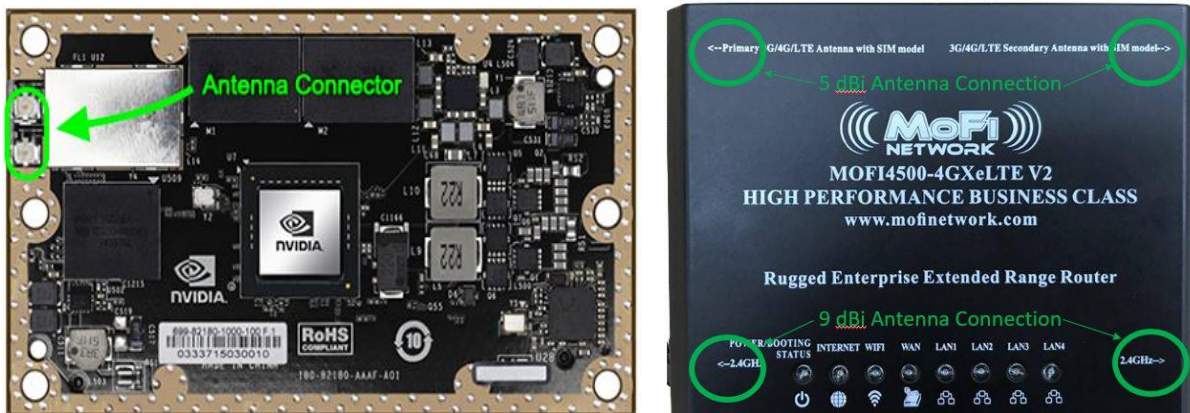
Figure 11 - Antenna connector (left) and the router for ground communication (right)

e. RC controller and wireless base station (WBS)

Extended Range WiFi Router - *MoFi 4500 4GXeLTE*
- Supports cellular data connection in addition to traditional ISP modem
- Provides 2.4 GHz signal for stable WiFi connection between drone and base station

Transmitter - *FrSky Taranis plus*
- Transmits flight control radio signal to the drone in 2.4 GHz
- Supports full telemetry with RSSI

External Antennas - *2x9 Reverse SMA Antennas*, *2x5 dBi SMA Antennas*
- 2x5 dBi Antennas extend cellular signal
- 2x9 dBi Antennas extend 2.4 GHz WiFi

3. Setup

a. Installation process

Flashing the companion computer and Installing FlytOS

JetPack, the Nvidia Jetson software development kit, is required for the initial configuration of the onboard computer. This process requires a Ubuntu x86_64 host machine for compatibility reasons. The latest version of the JetPack software (currently L4T 2.3.1) can be downloaded from Nvidia's website. The following instructions are required steps to install JetPack.

- Download most recent version of JetPack. Ensure host machine has 17 GB free space.
- Create a setup folder and put the installer inside.
- Give exec. rights to the installer by executing the following command in the setup folder:
    - ```chmod +x JetPack-${VERSION}.run```
- Launch the installer, which will bring up the component manager:
    - ```JetPack-${VERSION}.run```
- The component manager allows to customize which components are to be installed. Choose standard installation and wait for the installation to complete.

Once JetPack is installed on the host machine, it can flash the memory on the TX1. However, for this process both the host machine and the TX1 should be connected to the same router through ethernet ports. During the flashing process, the host machine will ask for the IP address of the TX1 on the network. Before continuing with the installation, obtain this information by going to the main page of the router and looking at the list of devices on the network.

To flash the OS on TX1, the device must be put into Force USB Recovery Mode. The following instructions explains the steps required to perform this action. Once the IP address is obtained, put the device in Force USB Recovery Mode (Figure 13).
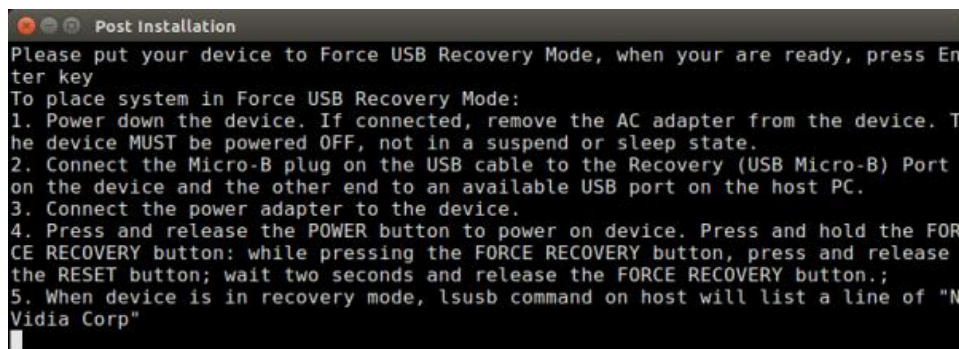
Figure 12 - Force USB Recovery Mode Instructions

- A prompt will appear to install components on the target machine.
- Wait for post-install to complete.
- Once installation tasks are completed, TX1 should be running L4T and Ubuntu 16.04.

Connect the device to a WiFi network and install an internet browser, the terminal as the default will not contain an internet browser. The following will install Google Chrome browser on TX1:

- `sudo apt-get install chromium browser`

FlytOS is built on Robot Operating System (ROS) thus for proper operation ROS needs to be installed on the TX1. The version of FlytOS that is used in this project is compatible with ROS Kinetic (desktop version). <u>Do not update/upgrade the system before installing ROS-kinetic-desktop, otherwise unresolved dependencies won't allow you to install ROS later.</u> A convenient script is available to install ROS and is used in this project. However, more detailed information regarding the Ubuntu install of ROS Kinetic can be found the ROS web page. In order the install

ROS Kinetic using the script, create a new folder on TX1 desktop and issue the following commands in the terminal:

- `git clone https://github.com/jetsonhacks/installROSTX1.git`
- `cd installROSTX1`
- `./installROSTX1`

Configuring Pixhawk and Establishing Communication

Currently, FlytOS only works when Pixhawk is loaded with PX4 flight stack. The first step of configuring the Pixhawk is to connect it to a computer through USB and to flash the flight stack. This can be done through any mission planning software but in this manual QGroundControl is used. With QGroundControl running on the computer, connect Pixhawk and it should be automatically detected. Click the firmware tab and choose PX4 flight stack. Follow the prompts until the installation is complete. The Pixhawk should now be running the PX4 flight stack.

For proper communication, there are two parameters that need to be changed on Pixhawk: `SYS_COMPANION` and `MAV_COMP_ID`. `SYS_COMPANION` which sets the baud rate of the TELEM2 port. This parameter should be set to `912600`. `MAV_COMP_ID` determines to component number and it should be set 50.

TX1 and Pixhawk communicate over UART port. To establish this communication, connect the Pixhawk's Telem2 port to TX1's UART 1 port. If using the TX1 development board, the UART1 can be found on the J17 connector. If using the carrier board, connect Pixhawk's TELEM2 port to the UART1 port on the expansion header of the Orbitty Carrier using pins in Figure 14 and 15.
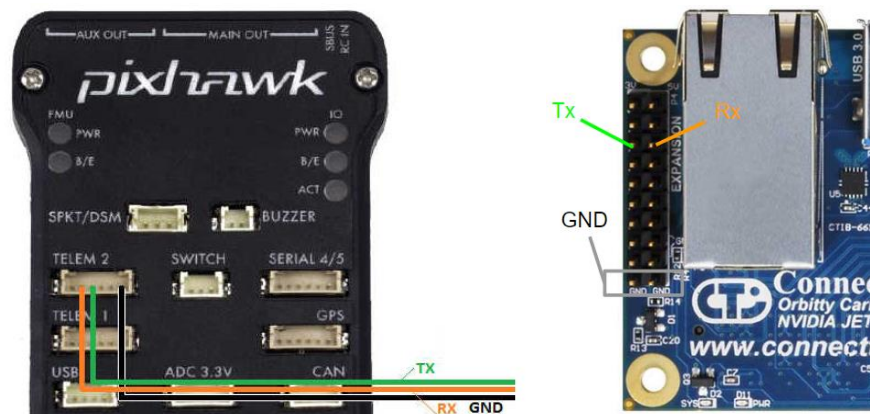
Figure 13 - Serial connection pins of Pixhawk (left) and Orbitty Carrier (right)
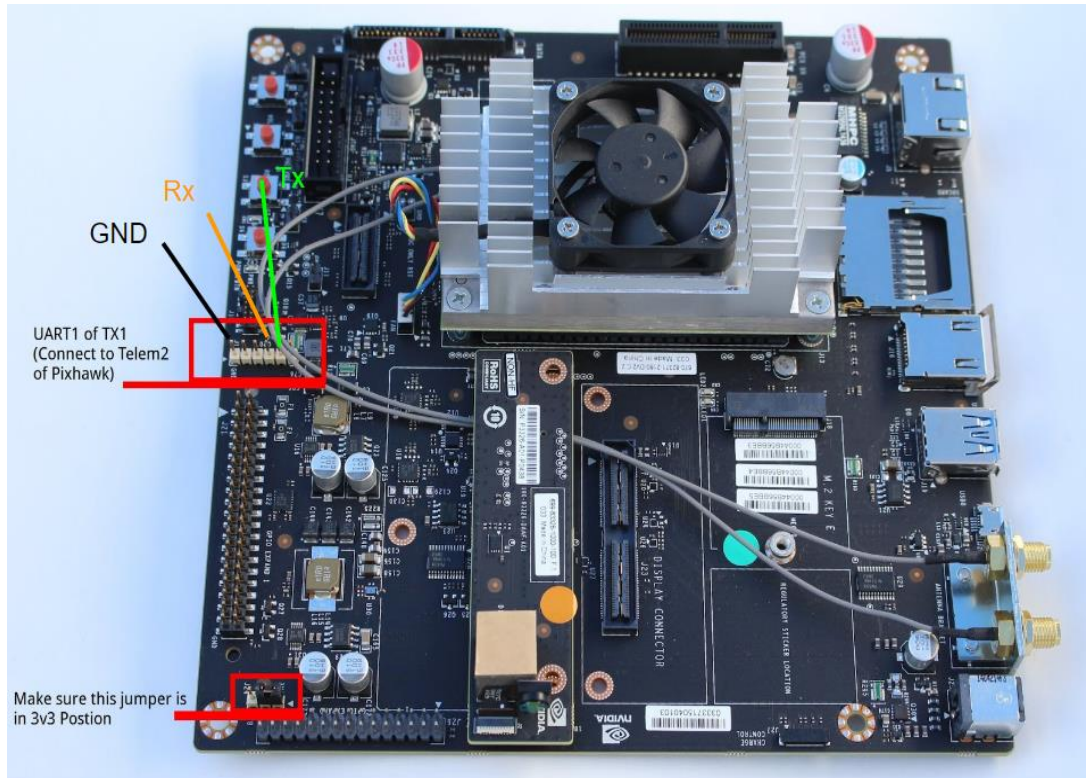
Figure 14 - Serial connection pins of TX1

Installing FlytOS

The version of FlytOS that is used for this project will be provided in the designated folder on Google Drive. Before installation, it's dependencies must be installed. On TX1, open a terminal and issue the following commands in the given order:

i.
```
sudo apt-get install -y ros-kinetic-rosbridge-suite ros-kinetic-
control-toolbox ros-kinetic-octomap-ros ros-kinetic-octomap-msgs
ros-kinetic-image-proc ros-kinetic-image-transport-plugins ros-
kinetic-image-transport ros-kinetic-eigen-conversions
```

ii.
```
sudo apt-get install -y python-serial python-flask python-wtforms
python-sqlalchemy python-concurrent.futures python-mock python-
zmq python-twisted
```

iii.
```
sudo apt-get install -y python-pip
```

iv.
```
sudo -H pip install flask_cors flask_reverse_proxy flask_restful
tblib webargs click flask_security httplib2
```

Before proceeding, the following should be added at the end of `$HOME/.bashrc` file:
- `export PYTHONPATH=$PYTHONPATH:/flyt/flytapps`
- `source /flyt/flytos/flytcore/setup.bash`

Download FlytOS into a folder on the desktop. Issue the following command and check for the "`Congratulations! FlytOS installation completed`" message:
- `sudo dpkg -i <path to debian package location>/flytcore*.deb`

Should any dependency issues raises while installing FlytOS, run the following command and execute the previous install command again:
- `sudo apt -f -y install`

Installing GeographicLib

The location conversion services are provided using the geographic library and it is essential for proper operation. This library can be compiled and installed with the following:

i. Download `GeographicLib-1.47.tar.gz` and unpack the source by issuing the following command while in the folder that contains the tar file.

```
tar xfpz GeographicLib-1.47.tar.gz
```

ii. Change directories

```
cd GeographicLib-1.47
```

iii. Create an additional build directory and enter

```
mkdir BUILD
cd BUILD
```

iv. Compile and install the software by issuing the following two commands:

```
make
make install
```

Installing the Server Files

In addition to the web server provided by FlytOS, the aircraft hosts two more servers for location data and for the live video stream. The necessary files are located in the `customapps` folder which will be provided in the designated folder on Google Drive. To incorporate these files to the setup, paste the folder in the TX1 home directory.

Calibrating the flight computer

The flight computer needs to be calibrated before the first flight and FlytOS mission control interface provides an environment to perform this calibration. Access the interface

through `192.168.1.24:9090/flytconsole.`First click on the *Frame Select* tab and inform the flight controller of the frame type of the aircraft by selecting Hexacopter + setting, shown in Figure 16.
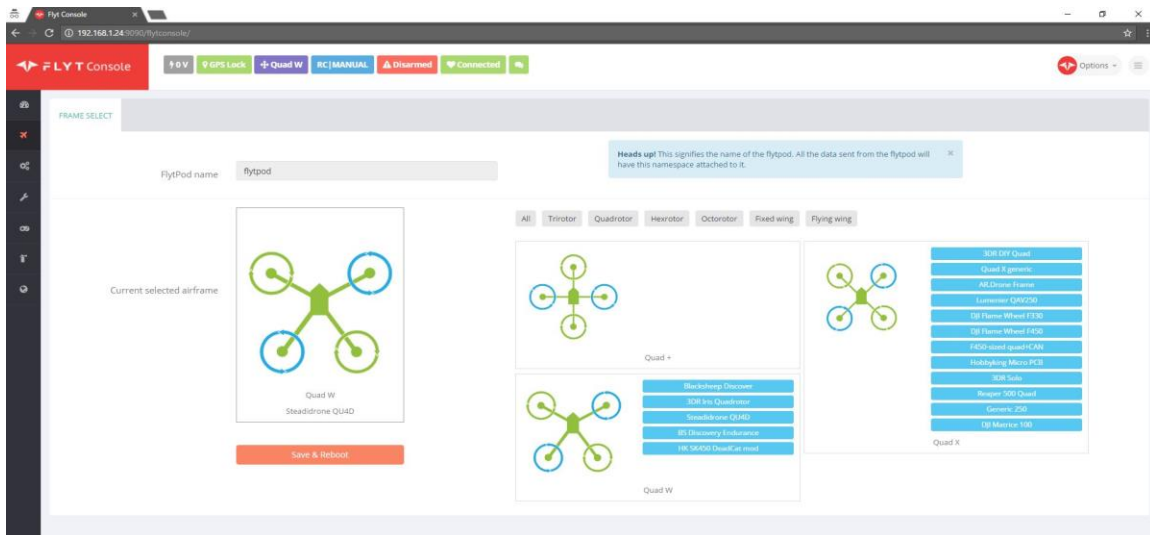
Figure 15 - FlytOS selection of frame type for calibration

The sensor calibration is consisted of four steps:
- Calibrating the accelerometer
- Calibrating the magnetometer
- Calibrating the gyroscope
- Level calibration

Click on the *Sensor Calibration* tab and complete each of the four steps, shown in Figure 17, by clicking on the respective buttons and following the prompts. Ensure that the settings are saved after completing each step.

Figure 16 - FlytOS sensor calibrations

b. Drone setup

Unfolding the arms

Assuming the drone is in folded position, the first step is to fold each of the arms and use the red aluminum screws to secure each arm in the upright position as in Figure 18. When arms are folded, the red thumbscrew screwed into the joint of the folded arm for storage.

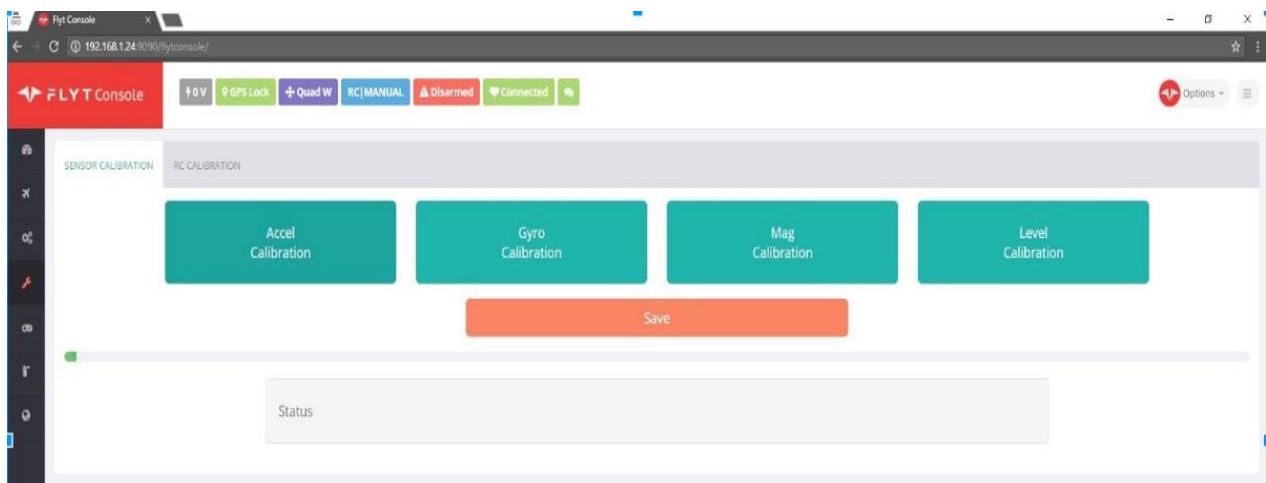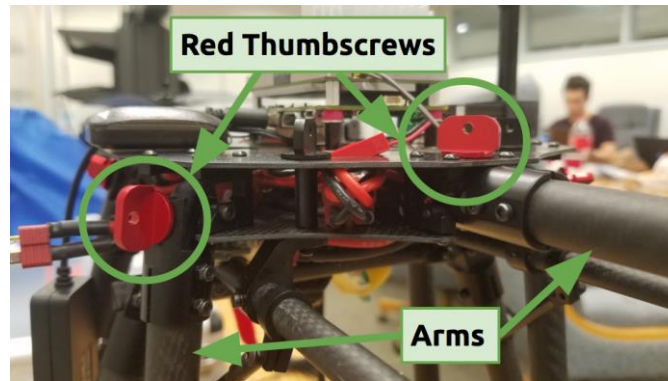*Figure 17 - Display of the red thumbscrews*

Reorienting the landing gear

On arms 2, 4 and 5 the landing gear is attached on using two screws. While the function of the landing gear permits them to be placed on any non consecutive arms, the camera limits the location to the specific arms to ensure the landing gear is placed specifically out of the view of the camera. For the folded positions, the landing gear is disoriented to avoid collision into each other, thus the screws need to be loosened enough to rotate each leg to its proper position for supporting the drone. The arm and leg connection is outlined in Figure 19.
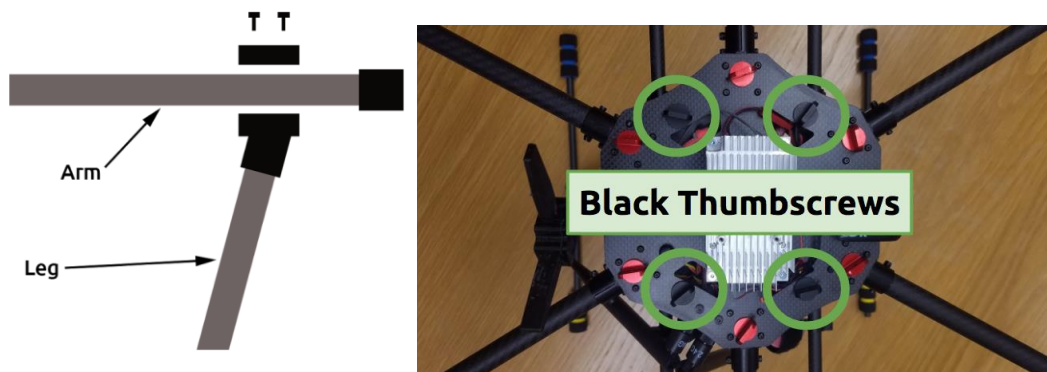

Figure 18 - Arm and leg connection (left) and Payload tray connection (right)

Connecting the payload tray

The payload tray will already have the gimbal attached. Secure the camera to the gimbal by tightening the thumbscrews on the gimbal. Connect the gimbal to the 12 BEC, and its control wires to the Pixhawk. Connect the USB wire to the camera. Strap the battery to the payload tray

using the velcro straps. The payload tray is connected to the fuselage using the black thumbscrews as in Figure 20.

4. Operation

To operate the drone, connect the battery and press the marked button on TX1 to power up the companion computer. Pixhawk will power up upon battery connection. To connect a laptop or any Wifi enabled device to the drone, the device must first be connected to the wifi base station.

   i.   Acquire wifi access to the drone's website server. To link your base station the the drone, connect to the wifi router **FsuSR**, with the password **team04#1**.

   ii.   To view the flight console, enter `192.168.1.24:9090/flytconsole` into any standard web browser. The flight console will display telemetry data, vehicle operations, and other necessary flight information.

   iii.   To access the object detection and view the live video feed as well as the USNG coordinates, enter `192.168.1.24:9090/interface` into any standard web browser.

   iv.   Verify GPS health by noting BRIGHT green, flashing LED on Pixhawk.

   v.   Verify necessary flight plan settings at this point.

   vi.   Verify data transmission by noting change in attitude, heading on the ground station laptop.

   vii.   Have qualified pilot power up the RC transmitter, select the correct vehicle, and verify connection by noting the green LED on the X8R receiver.

   viii. Press and hold the flashing red button until it stops flashing to pre-arm the vehicle.

   ix.   Make sure all persons are well clear of the multi-rotor from this point, until the drone is disarmed.

   x.   To fully arm the vehicle hold the left RC transmitter stick at its bottom, right position for more than 2 seconds. When the craft is fully armed the BRIGHT green LED will no longer be flashing.

   xi.   Test the motors to verify flight readiness by raising the throttle stick slightly, and returning it to low.

   xii.   Complete the flight mission.

xiii.   After the vehicle is on the ground hold the left stick of the RC transmitter to the bottom left position until the BRIGHT green LED on the Pixhawk begins flashing. The vehicle is now disarmed and may be approached.

xiv.   Power off vehicle by unplugging the battery.

Adjusting Color Filtering Parameters for Object Detection

The object detection relies on HTML input to adjust the criteria for the color filtering algorithm. While a default color is predetermined upon launching the server, adjusting the base color value for the filtering process requires the color of interest to be manually selected from a color picker provided on the server page. The code of the selected color will auto-populate the HSV fields. To adjust the filtering algorithm's boundaries, click submit. Note the HSV fields can also be populated manually.

5. Troubleshooting

The common problems and solutions are discussed here. For additional support, please consult the manufacturer's operation manual for respective components.

- FlytOS heartbeat not detected
    - Check connection between TX1 and Pixhawk.
    - Ensure Pixhawk parameters `SYS_COMPANION` and `MAV_COMP_ID` are set to `912600` and `50`, respectively.
- Drone cannot connect to the ground station WiFi
    - Check that both the TX1 and router are powered on.
    - Check the router interface to see if drone has been assigned a static IP address.
    - Remove saved WiFi connection settings from drone and reconnect to the network.
- Drone does not operate within the specified maximum range
    - Check for obstructions between drone and ground station
    - Place router on higher ground
- `192.168.1.24:9090/flytconsole` or `192.168.1.24:9090/interface` are unaccessible
    - Ensure ground computer is connected to **FsuSr** network
    - The drone should automatically join the network once TX1 is turned on. Make sure that TX1 is powered on and the power indicator LED is solid blue.

- Reading "16N" as the USNG coordinate
  - Ensure that the flight controller has GPS lock, which is indicated by the green flashing of the primary LED of Pixhawk. The LED is solid green if the vehicle is armed. The aircraft is designed to be operated outdoors only.
- Motors do not respond to the RC Controller
  - The aircraft is equipped with a two-step arming sequence. First, press and hold the arm button on the aircraft until the light inside the button starts blinking rapidly. Then move the throttle stick to the bottom right corner and hold until the light stops blinking and remains solid. This should enable the motors.
- No video feed available on `192.168.1.24:9090/interface`
  - Check if video feed is available on `192.168.1.24:5050/cam.mjpg`. If so, reset the FlytOS by restarting TX1. This should start the web server of FlytOS.
  - If `192.168.1.24:5050/cam.mjpg` doesn't have a video feed either, check the camera connection. After ensuring the camera is connected, restart TX1 which should relaunch the image processing server.
- USNG data not updating.
  - SSH into TX1 and check terminal for the error message: "`Waiting for master. Could not contact ROS master at [http://localhost:11311, retrying...`" If the error message is present, enter the following command or restart TX1 to automatically start ROS
    - `roslaunch home/ubuntu/flyt/flytos/flytcore/scripts/pr2.launch`
- FlytConsole does not display the battery status.
  - This is a known issue with the current version FlytOS. The battery widget is inoperative and currently the developer team does not have a solution. In order to track the battery status, employ an external battery meter that is directly connected to the balancing port of the battery or use an alternative mission planning software.

6. References

[1] "Orbitty carrier manual", Connecttech, 2015. [Online].
Available:http://www.connecttech.com/pdf/CTIM-ASG003_Manual.pdf. [Accessed: 4- April-2017].

[2] "NVIDIA Jetson TX1 Developer Kit User Guide" [Online].
http://developer.download.nvidia.com/embedded/L4T/r23_Release_v1.0/NVIDIA_Jetson_TX1_Developer_Kit_User_Guide.pdf [Accessed: 4- April- 2017].

[3] "Pixhawk Quick Start Guide" [Online]. https://3dr.com/wp-content/uploads/2014/03/pixhawk-manual-rev7.pdf [Accessed: 4- April- 2017].