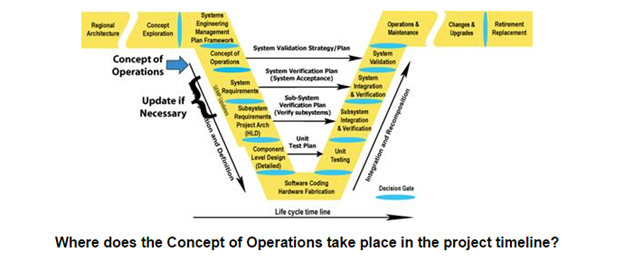
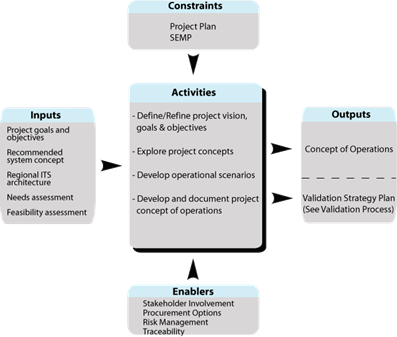
Preface Concept of Operation (CONOPS)  


**OBJECTIVE:**  
The Concept of Operations

* Documents the total environment and use of the system to be developed in a non-technical and easy to understand manner
* Presents this information from multiple viewpoints
* provides a bridge from the problem space and stakeholder needs to the system level requirements

**DESCRIPTION:**  
The Concept of Operations document results from a stakeholder view of the operations of the system being developed. This document will present each of the multiple views of the system corresponding to the various stakeholders. These stakeholders include operators, users, owners, developers, maintenance, and management. This document can be easily reviewed by the stakeholders to get their agreement on the system description. It also provides the basis for user requirements.

**CONTEXT OF PROCESS:**



**Inputs:**

**Project goals and objectives** determine how the system will be used.

The project goal is develop a drone with anti-collision, self-stabilizing, autonomous travel, and thermal reading capabilities. The system will be used to assess a transformer’s temperature state.

**Recommended system concept** describes the concept selected with the greatest cost benefit ratio. This concept will be the basis for the concept of operations.  
**Regional ITS architecture** will provide the roles and responsibilities of the primary stakeholders and the systems they operate, which may suggest features for the project concept of operations.

Needs Assessment includes the list of collected needs, their sources, and documentation of the rationale for the selection of the key needs and any constraints that exist that may limit possible solutions to the needs. The development of the Concept of Operations starts with these needs and constraints.

Feasibility assessment or FSR defines and analyzes the conceptual system and, in the process, provides operational information.

**Control:**  
The Project Plan describes the project and the SEMP describes the systems engineering effort needed for development. They both guide what may be developed.

Enablers:  
Elicitation supports continual stakeholder input and review. This is essential to developing a system that meets their needs.  
Technical reviews support continuing communications with the stakeholders, which are essential to developing a concept that reflects their needs within the stakeholders organization and operations.  
Trade studies are used for the selection and documented rational of the optimum concept.  
**Process Activities:**  
**Define project vision, goals, and objectives**  
Revisit the vision, goals, and objectives identified in Concept Exploration & Benefits Analysis [Ch. 3.3.2]. Expand and elaborate on them to capture multiple viewpoints.

Our initial vision for the drone is to develop and deploy a drone that features anti-collision, self-stabilization in air/flight and to go from point A to point B (fly a predetermined path). Our partnership with Florida Power and Light has added the objective for a nearby engineer to deploy and read a transformer’s interior/exterior as well as fly autonomously through a mapped routine.  
**Explore project concepts**  
Revisit the alternative concepts identified during Concept Exploration & Benefits Analysis [Ch. 3.3.2]. The goal is to glean just enough of a physical description of the system from the high-level system architecture to write the Concept of Operations. Perform additional trade studies as needed.

**Develop operational scenarios**  
Operational scenarios describe how the system will be operated under various conditions. For example, incident management scenarios will include normal monitoring, the sequence of events following an incident, and response to failure [e.g., sensors or communications]. These scenarios will describe the activities from the viewpoint of each of the participants. Some techniques for describing the scenarios are flow diagrams and use cases, which are part of the unified modeling language used for software development.

**Develop and document the concept of operations**  
The Concept of Operations is a document that records these findings and system characteristics from each of the multiple viewpoints of the various stakeholders. It is written in a language that they each understand. This document includes such information as vision, goals and objectives, operational philosophies, operational environment, support environment, operational scenarios, operational system characteristics, system constraints & limitations, institutional issues, external interfaces, stakeholder functions, roles & responsibilities, and capabilities.  
Stakeholder involvement is essential to ensure that the system will operate in a way that is useful to them.

**Outputs:**  
**Concept of operations** describes the operation of the system being developed from the various stakeholder viewpoints. It documents the user’s requirements for ultimate system operations. The users and other stakeholders can review the document and provide feedback and validate these key going-in assumptions.  
Traceability of scenarios to user needs, requirements, design, implementation, and verification.

**Autonomous Drone for the Electric Grid**

|  |  |  |
| --- | --- | --- |
| Submitted by: | **Brian Vu, Adam Woughter,**  **Talha Bin Amir, Joey Ellis** | \_\_\_\_\_\_\_\_\_\_\_\_\_\_ |
|  | Team Members | Date |

Technical Advisor: **Robert Tufts**

|  |  |  |
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| Endorsed by: | **Eric Schwartz** | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |
|  | Subject Matter Expert / Lead | Date |

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|  |  |  |
| Approved by: | **Wilfrido Moreno** | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |
|  | Advisor/Instructor | Date |

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# 1 Introduction

## 1.1 Client’s Need

A drone that can take off, fly a predetermined path, return back to home autonomously. The drone shall be capable of taking videos and thermal readings for electrical grid inspection. The drone shall also be able to operate in the rain and return to home autonomously when either the wind speed exceeds 20mph or the battery level is at 50%.

## 1.2 Business Need

It costs about $X to currently inspect a substation or a section of an electric grid. The high cost is due to the need of larger vehicles needed such as SUVS, helicopters, etc and man power. This cost can be significantly reduced by using a drone instead. Using a drone also allows for greater troubleshooting capabilities by the operator as it allows them to see the system from above as well. The rapid expansion of the drone industry makes a drone solution seem more pertinent as well.

# 2 Operations and Support Description

## 2.1 Missions (Primary/Secondary)

The engineering team shall develop a functional drone, design and develop the hardware and simulate its program function. The framework and physical structure shall be bought premade. The team shall develop the program to instruct the drone’s flight controller to perform certain tasks such as starting from a certain trigger, returning to the home base after the battery reaches a certain percentage or if the wind speeds are too high. The program shall also make the drone fly a predetermined path to follow electric grids.

The Primary Goal of this project is to have the drone take off from home, fly a predetermined path along electric grid lines and return back to base. The drone shall be able to avoid objects while in the air (anti-collision) and be able to remain stable while in flight.

The Secondary Goals of this project are adding a thermal and visual camera for the inspection of the electric grid lines, adding either wireless charging or some sort of charging station at the home base where the drone will charge after landing. The drone shall use the thermal and visual cameras to take pictures every second and store them on an SD card on board for reviewing later. Another feature that might be added could be a cover that could make the drone waterproof so it may be operated in the rain.

## 2.2 Users and Other Stakeholders

An example of a stakeholder is a powerlineman. For the powerlineman to inspect the power lines, he/she would need to take a helicopter to reach the line location and inspect all the lines. Using the drone, it shall make it possible to us to inspect the lines using the drone and then sending the powerlineman to inspect and repair just the ones that need repairing rather than flying in a helicopter checking all of them. This shall reduce the cost significantly and also reduce the risk for the powerlineman.

## 2.3 Operational Description

The proposed system shall be designed to fulfill the customer’s operational and business needs. The proposed system is described in the following sections.

### **2.3.1 Designs**

Design 1:

The proposed design is a hexacopter for which the frame will be bought premade. This will allow us to have a light, strong and professionally designed body for the drone. The flight controller that seems best for this design is the Pixhawk 4 flight controller. This flight controller has an open source software which allows for a lot more modifications with ease and allows future enhancements. The PixHawk flight controller works with the ArduPilot software to control the drone. The PixHawk 4 also comes with a GPS module, built in accelerometer, gyroscope, magnetometer and barometer. The ArduPilot software and the Pixhawk 4 will allow us to create predetermined flight plans and autonomous functions.

Design 2:

This design will make use of a DJI drone, either the M200 series or Mavic 2 Enterprise industrial drones. The M200 series is weather proof. The Matrice 210 RTK (Real Time Kinematic) has a built in system that avoids electromagnetic interference. The Mavic 2 Enterprise is more compact, portable and comes with 24GB of built in storage. Both the drones have a 30+ minutes flight time capability. Both the drones come with the frame, the processor, controller, motors, blades, batteries, controller and charger. Both of these drones are capable of working with the DJI Zenmuse XT1 or XT2 which are visual/thermal cameras. Both the drones also have the capability to be connected to a powerline tethered system created by the PowerLine company. This design shall also be able to fly an autonomous path just like the proposed design. This design requires use of DJI SDK (Software Development Kit) and API to modify the firmware for custom use. The DJI SDK is user friendly and allows a whole variety of customization just like the ArduPilot software used in design 1. The DJI SDK also allows us to create predetermined flight plans and missions for the drone. The DJI platforms also have room for future enhancements and add-ons. The biggest plus of this design is that DJI has been perfecting their drones for years so the basic functions such as self-balancing, obstacle detection, etc. are extremely accurate. The biggest con of this design is the cost compared to design 1, however since the engineering team is a group of students, DJI does offer educational discounts so that can be looked into. There is a cheaper alternative for this design, which would use a DJI Phantom 4. However, this alternative would not be able to use the thermal camera built by DJI so a different alternative for the camera would be needed. It would still be able to perform the autonomous tasks. The phantom 4 will also not be waterproof.

Design 3 (Possible addition to the completed design):

This design will be an addition to whichever design is chosen and completed if there is time after the completion of the main design. This design will also have a powerline tethered system capability. The powerline tethered system shall allow the drone to have a longer flight time. The powerline tethered setting can only be used when the drone is required to fly up, yaw and then land. This is because if the drone flies around, the tethered wire can come into contact with the surroundings and end up damaging the wire and possibly even the drone. If design 1 is chosen, the engineering team shall build a custom powerline tethered system, but if design 2 is chosen, then the powerline tethered system can be purchased from the PowerLine company.

Practice builds:

1. Drone:

This design’s primary objective is to get practice with the basic functions and operations of a drone. Once completed, the team will be familiar and more comfortable with the basic processes and function of drones.

The engineering team has begun working on a practice build and is working on building a drone that can perform basic functions such as take off, fly, self-balance and land.

1. Wireless charging:

A wireless charging station at the home base where the drone will charge after landing shall get rid of the need for someone to take the drone’s battery out, charge it and put it back inside. This shall make the charging process autonomous too. The type of wireless charging that would be used in this case is inductive charging and this can be implemented by having a charging dock at the home base and a receiving circuit/coil on connected to the drones battery. This is a simple circuit to implement. The downfall to this method of charging is that it is only 75-80% efficient and hence will take a little extra time to charge. The charging times and efficiency shall determine if this method will be effective enough to be added to the main design.

1. Charging dock:

In the case that wireless charging is not effective enough to be added to the main design, some sort of charging state could be designed which would still technically be wireless but charge when the contacts of the home base come into contact with the contacts of the drone’s battery. The contacts would be like the charging contacts of an electric toothbrush for example. The drone will not always land perfectly in order for the contacts to touch, but a base could be designed where the drone would land and if it is not in the exact spot, it shall mechanically be moved into place. This could be done with the use of mechanical arms or some sort of conical design where the drone would slide into place after landing.

### **2.3.2 Scheduling and Operations Planning**

1. Fall 2018 Semester (Design 1) - Building the drone (hardware)
   * Determine team, advisor, resources, company point of contact
   * Research and Order Parts (ex. motors, wires, battery, frame, fan/blades, sensors..)
   * Decide on frame, wiring, attach motors, run motors, operate by remote
2. Spring 2019 Semester (Design 2) - Develop and run program (software)
   * Develop program for autonomous flight
   * Anti-collision
   * Fly Autonomous mapping integrated with sensors and controls with user interface software developed.

### **2.3.3 Operating environment**

Power grid lines, transformer site. Open field, indoor (classroom/campus).

## 2.4 Mission Support Description

# 3 Scenarios

## 3.1 Mission Operations Scenarios

Deploy and retrieve electric grid power lines temperature reading and fly autonomously through a mapped routine at an electric grid site. Return back to a nearby engineer at site. The drone will record while in flight. The drone shall take pictures of the power lines. These pictures/videos will allow the engineer to assess the power line’s health without having to climb up to the transformer or hang off of a helicopter.

## 3.2 Mission Support Scenarios

Engineer shall go out to the field and inspect the electric grid lines. Engineers would like to collect visual data of the electric grid lines to bring back to the office for further analysis. Engineer would like to have the process automated.

# **4 System Requirements**

## 4.1 System Requirements

1. The drone shall fly in a predetermined path autonomously using GPS and a gyroscope
2. The predetermined path shall have the capability to be set by the operator.
3. The drone shall have the capability to be flown manually via a remote.
4. The drone shall remain in the line of sight of the operator at all times.
5. The drone shall take optical and thermal images of power lines.
6. The drone shall remain stable while taking aforementioned images.
7. Upon reaching 60% battery, the drone shall return to “home base”.
8. Upon sensing winds exceeding 20 mph, the drone shall return to “home base”.
9. System shall send alerts to the user if thermal readings are past a certain threshold
10. The drone shall use ultrasonic sensors to detect obstacles in front of it
    1. The drone shall stop and change course upon detecting an obstacle
11. The drone shall take thermal and optical images every one second
    1. The system shall send these images to the control center and save them into an onboard SD card
12. The drone shall be resistant to water
13. The drone shall be flown only during daylight hours (The system lacks the proper lighting to fly at night per FAA regulations)
14. The user shall be given vendor information to source parts should they need replacements
15. The flight controller shall interface with the ESC’s, transmitting speed information to the ESC’s by hardwire connection
16. The ESC’s shall hardwire connect to the motors via three wires
17. The ultrasonic sensor, GPS module and gyroscope shall connect to the flight controller via a hardwire connection

## 4.2 Primary Subsystems

Design 1:

* Motor System
  + Motor
    - Size, weight, power, blades
    - Withstand weight of payload
  + ESC (Electrical Motor Control)
    - Connects from the flight controller to the motors
* Autonomy System
  + Gyroscope sensor
  + GPS Module
    - Detect waypoints
* Communication System
  + Transmitter
* Flight Control
  + Pixhawk microcontroller
  + Ardupilot software
* Frame/Exterior
  + Hexacopter
  + Landing pad
* Battery
  + Size, weight, power
  + Withstand 4-6 motors
* Wiring
  + PCB design, soldering
  + Resistors, transistors, diodes,
* Software
  + Ardupilot

## 4.3 Secondary Subsystems

* Camera System
  + Gimbal
    - Camera stabilizer
  + GoPro
  + Runcam
* Anti-collision System
  + Ultrasonic Sensors
  + Size and weight
* Thermal Camera
  + Heat sensor
* IR Sensor



# 5 Systems Key Performance Indicator (Trade Studies)

|  |  |  |
| --- | --- | --- |
| Frame | | |
| Equipment Name | Pro | Con |
| Aluminum Alloy Pan Maker Tool Baking Mold | Already bought - comes with  2 x PCB boards  Dimensions:7.13 in x 4.65 in x 0.08 in  Weight: 8.99 oz (255 g)  Material: PU  Cost: $16 | Only Quadcopter (4 legs) |
| Tarot T960 | Hexacopter (6 legs) frame  Material:  Weight: 1050g  Dimensions: 210 x 210 x 2.0mm | Cost: $399 |

|  |  |  |
| --- | --- | --- |
| Flight Controller | | |
| Equipment Name | Pro | Con |
| Pixhawk | Weight:  Size:  Processing speed:   * Open source |  |
| Funduino UNO R3 ATMEGA328 Development Board for Arduino | Cheap - $9  Do not have to buy  Hardware platform: arduino  Weight: 27 g (0.95 oz)  Dimension: 2.95 in 2.13 in x 0.55 in.  Software: Open source | * Does not have as much capabilities as compared to other processors * Have to program/do own coding |

|  |  |  |
| --- | --- | --- |
| Motor System + Propeller/Blades + ESC | | |
| Equipment Name | Pro | Con |
| A2212 1000KV Brushless Motor + 1045 Propeller DJI F450 - Black | Material: Plastic, Metal  KV: 1000 Max  Efficiency: 80%  Max Efficiency Current: 4-10A  Current Capacity: 12A/ 60s  No Load Current @ 10V: 0.5A  No. Of Cells: 2-3 Li-Poly  Motor Dimensions: 27.5\* 30mm  Thickness of center: 9.7mm  Weight: 15 g/motor. 120 total.  550mm - 700mm | Maximum Thrust: 816g?? |
| EMAX LS2207 Lite Spec 2207 1900KV   * Spedix ES30 HV 3-6s BLHeLi\_S 30A ESC * Lumenier 6x5x3 - Gate Breaker Propeller (Sold in sets of 4) | Maximum Thrust: 1658g  KV: 1900Kv  Material: Aluminum, steel  holes:16mm\*16mm mounting holes  Wire: 18 AWG, 5% performance increase from 20AWG  Input voltage: 4-6s LiPo  Prop shaft diameter: 5mm | Diameter (total):27.5mm  Height: 31.2mm  Weight: 35.7g per motor, 214.2g total  ESC weight: 5.5g each, 33g total |
| TAROT TL96020 5008 340KV motor + Spedix ES30 HV 3-6s BLHeLi\_S 30A ESC + Quanum Carbon Fiber T-Style Propeller 18x5.5 | Kv: 340KV  Motor recommended for our frame by manufacturer | $52 per motor  $11 per 2 props ($33 for 6) |

|  |  |  |
| --- | --- | --- |
| Battery | | |
| Equipment Name | Pro | Con |
| 11.1V 2200mAh 30C Li-polymer Battery Pack for 450 Helicopter - Black | Material: Li-Polymer  Compatible: 450 helicopter / DJI Phantom 1 / 450 quadcopter  Voltage: 11.1 V  Battery Capacity: 2200mAh  Weight: 6.17 oz (175 g)  Dimension: 4.29 in x 1.38 in x 0.87 in  Cost: $17 | Can not ship to US |
| TATTU 7000mAh 6s 25c Lipo | Material: Li-Polymer  Discharge Plug: EC5  Balance plug: JST-XH  Voltage: 22.2 V  Max burst discharge: 50C  Max continuous discharge: 25C  Capacity: 7000mAh  Features: “Vibration and fire proof” (according to supplier) | Weight: 875g  Dimensions: 136\*42\*68mm  Cost: $142.99 + shipping  Supplier (getfpc) is low on stock |
| Battery Charger:  B3AC 7.4V/11.1V 2S/3S LiPo Balance Charger - Black (US Plug) | Input: AC 100~240V- 2S/7.4V- 3S/11.1V- Power cable length: 80cm  Output: 7.4V  Cost:$9 | Works with 2s/3s |

|  |  |  |
| --- | --- | --- |
| Communication System | | |
| Equipment Name | Pro | Con |
| Transmitter:  Flysky FS-T6 6-CH TX Transmitter + Radio Control System - Black | Compatibility: Flysky- Open Source  Comm: transmitter + radio control system  Material: plastic  Cost: $53  Range: |  |
| Receiver: |  |  |
| Transmitter:  FRSky Taranis X9D Plus & X8R |  | Cost: $245 |

|  |  |  |
| --- | --- | --- |
| Camera System | | |
| Equipment Name | Pro | Con |
| Camera |  |  |
| Stabilizer |  |  |

|  |  |  |
| --- | --- | --- |
| GPS System | | |
| Equipment Name | Pro | Con |
| Gyroscope Sensor:  GY-521 MPU6050 3-Axis Acceleration Gyroscope 6DOF Module - Blue | Range: | Have to implement into system |

# 6 Components

## Design 1:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Equipment** | **Name** | **Quantity** | **Price** | **Total Cost** |
| Frame | Tarot T960 | 1 | $399 | **~$2600** |
| Flight controller | PixHawk 4 | 1 | $256 |  |
| Battery | TATTU 7000mAh 6s 25c Lipo  (~24 min) | 1 | $150 |  |
| Motors | TAROT TL96020 5008 340KV motor | 6 | $312 (total) |  |
| Propellers | Quanum Carbon Fiber T-Style Propeller 18x5.5 | 3 (3 sets of 2) | $33 |  |
| Transmitter & Receiver | FRSky Taranis X9D Plus & X8R | 1 | $244.99 |  |
| Sensors | Parallax PING Ultrasonic Sensor | 5 | $150 |  |
| LEDs |  |  |  |  |
| Camera | Runcam | 1 | $80 |  |
| Camera | FLIR Duo | 1 | $799 (sale price; original $999) |  |
| Camera Stabilizer (Gimbal) | 2 Axis Runcam 2 Micro Stabilized Gimbal | 1 | $70 |  |
| ESCs | Spedix ES30 HV 3-6s BLHeLi\_S 30A ESC | 6 | $95 |  |
| Vibration Damping Mount for Pixhawk |  |  |  |  |
| Battery Voltage tester |  |  |  |  |
| Landing Pad | Qubuy Drones Landing Pad (Amazon) | 1 | $13 |  |

## Design 2:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Equipment** | **Name** | **Quantity** | **Price** | **Total Cost** |
| Drone option 1 | M200 | 1 | $4,599 | **$1,999 - $8000**  **(Depending on chosen design)**  **(Excluding thermal camera)** |
| Drone option 2 | M210 | 1 | $7,599 |  |
| Drone option 3 | Mavic Enterprise | 1 | $1,999 |  |
| Camera | Zenmuse XT2  (Program can be created with the standard drone camera and this camera can be later connected) | 1 | $11,599 |  |

## Design 3:

|  |  |  |  |
| --- | --- | --- | --- |
| **Equipment** | **Name** | **Quantity** | **Price** |
| Selected design | - | 1 | TBD |
| Tether System | PowerLine Tethered System | 1 | TBD |

## Quadcopter build:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Equipment** | **Description** | **Quantity** | **Price** | **Total Cost** |
| Arduino  -  Funduino UNO R3 ATMEGA328 Development Board for Arduino | <https://www.dx.com/p/funduino-uno-r3-atmega328-development-board-for-arduino-384207#.W9ffWUtKjic> | 1 | $8.53 | **$146.41** |
| Quadcopter frame -  Aluminum Alloy Pan Maker Tool Baking Mold | <https://www.dx.com/p/replacement-pu-quadcopter-frame-airframe-kit-for-450-500-red-beige-multi-color-398346#.W9ffWUtKjic> | 1 | $15.17 |  |
| Gyroscope Sensor  -  GY-521 MPU6050 3-Axis Acceleration Gyroscope 6DOF Module - Blue | <https://www.dx.com/p/gy-521-mpu6050-3-axis-acceleration-gyroscope-6dof-module-blue-154602#.W9ffWUtKjic> | 1 | $2.99 |  |
| Ultrasonic Sensor |  | 1 | Brian has a few |  |
| Motor  -  A2212 1000KV Brushless Motor + 1045 Propeller DJI F450 - Black | <https://www.dx.com/p/a2212-1000kv-brushless-motor-w-30a-brushless-esc-1045-propeller-dji-f450-550-413446#.W9ffWUtKjic> | 4 | $10.59 |  |
| Fan blades    -  A2212 1000KV Brushless Motor + 1045 Propeller DJI F450 - Black | <https://www.dx.com/p/a2212-1000kv-brushless-motor-w-30a-brushless-esc-1045-propeller-dji-f450-550-413446#.W9ffWUtKjic> | 4 | Included with Motors |  |
| Battery  -  11.1V 2200mAh 30C Li-polymer Battery Pack for 450 Helicopter - Black | <https://www.dx.com/p/11-1v-2200mah-30c-li-polymer-battery-pack-for-450-helicopter-dji-phantom-1-450-quadcopter-366131?Utm_rid=78761898&Utm_source=affiliate#.W9fhWUtKjid> | 1 | $16.67 |  |
| Battery Charger  -  B3AC 7.4V/11.1V 2S/3S LiPo Balance Charger - Black (US Plug) | <https://www.dx.com/p/b3ac-7-4v-11-1v-2s-3s-lipo-balance-charger-black-2-flat-pin-plug-154342#.W9ffT0tKjic> | 1 | $8.54 |  |
| Transmitter  -  Flysky FS-T6 6-CH TX Transmitter + Radio Control System - Black | <https://www.dx.com/p/flysky-fs-t6-2-4ghz-6-ch-2-9-lcd-tx-transmitter-rx-receiver-radio-control-system-black-8-x-aa-178448#.W9ffT0tKjic> | 1 | $52.92 |  |
| Soldering Kit |  |  |  |  |
| Resistors |  | 1.5kΩ & 1kΩ & 330Ω |  |  |
| 1A diode |  |  |  |  |
| LED |  |  |  |  |
| Wire |  |  |  |  |
| Thermal Cam/Sensor |  | 1 |  |  |

## Comparison of Design 1 Hexacopter vs DJI:

|  |  |  |
| --- | --- | --- |
| **SPECS** | Design 1: Hexacopter | Design 2: DJI |
| Max Flight Time | 15 - 25 min | 38 min |
| Software | ArduPilot | DJI SDK |
| Weight | 10 lbs | 9.9lbs |
| Portability | Folded: 960x210x200mm | Folded: 716x242x236mm |
| Obstacle Avoidance | Yes | Yes |
| Communication Range | 1 -1.5 miles | 4.3 miles |
| Camera | RunCam | Zenmuse XT2 |
| Future Enhancements | Yes | Yes |
| Weatherproof | No | Yes |
| Cost | ~$1600  (without thermal camera) | $1,999 - $8,000  (Depending on Chosen Drone)  (without thermal camera) |

|  |  |  |
| --- | --- | --- |
| **Exterior** | Design 1: Hexacopter | Design 2: DJI |
| Weatherproof | Yes | Yes |
| Wind Protection | No | Yes |
| EMC (electromagnetic compatibility) | No | Yes |
| Ability for future modifications | Yes | Yes |

|  |  |  |
| --- | --- | --- |
| **Exterior** | Design 1: Hexacopter | Design 2: DJI |
| Weatherproof | Yes | Yes |
| Wind Protection | No | Yes |
| EMC (electromagnetic compatibility) | No | Yes |
| Ability for future modifications | Yes | Yes |

|  |  |  |
| --- | --- | --- |
| **GPS System** | Design 1: Hexacopter | Design 2: DJI |
| Wavepoint Accuracy | Less accurate (by ~10ft) | More Accurate ~ 1 meter (3 ft) horizontal accuracy |

|  |  |  |
| --- | --- | --- |
| **Communication System** | Design 1: Hexacopter | Design 2: DJI |
| Number of Channels | 16 |  |
| Transmitter (ability for modification) | Yes | No |
| Transmitter (processing speed) | 2.4 GHz | 2.4 GHz |
| Transmitter/Receiver Distance | 1-1.5 miles | 4.3 miles |

|  |  |  |
| --- | --- | --- |
| **Camera System** | Design 1: Hexacopter | Design 2: DJI |
| Image Detection | Possibly | No |
| Quality of Picture | 1080 p | 4K |
| Ability to take pictures at different angles (4 quadrants) | Yes | Yes |
| Camera Gimbal | Yes | Yes |

|  |  |  |
| --- | --- | --- |
| **Performance** | Design 1: Hexacopter | Design 2: DJI |
| Flight time | ~20 minutes | 38 minutes |
| Weight | 4.54 kg | 3.8 kg |
| Number of props | 6 | 4 |
| Max Motor thrust (per motor) | 1658g | Unknown (proprietary motors) |

# 7 Final Design

The recommended design, by the team, for this project is Design 1: Hexacopter build. This design has a much lower cost than the other proposed designs while still meeting the requirements.

# 8 Validation

To validate that the drone meets all the requirements, it shall be flown on a short predetermined path in an area clear of obstructions or bystanders. This predetermined path shall also be flown by manual operator control to verify the manual capability of the drone. While flying the predetermined path, the camera shall take pictures of the tops of trees to simulate power lines. The drone shall also be taken out on a windy day to test the wind sensing capabilities of the system.

# 9 Maintenance

Life-cycle maintenance:

Battery:

* Check battery if it is maintaining full charge every time it charges
* Battery must deplete its charge at a normal functioning rate
* Battery must charge at full capacity

Motors:

* Keep track of motors. How many rotations, spins.
  + Is it spinning at maximum efficiency?
  + Is it operating at its maximum thrust/power?
* Check ESC’s if its at maximum efficiency
* Buy extra parts just in case one is faulty.

Firmware (OpenTX):

* Software on the transmitter and the Pixhawk need to be up to date
* Both transmitter and Pixhawk have to have compatible software

Transmitter:

* Antenna (communication) to the receiver on the drone must be connected and can operate at maximum distance
* To test this: Have regular flight tests and check the response from transmitter to drone works accordingly to expectations

# 10 Decommissioning

Parts to buy for repair:

* Motors,
  + ESC’s (electronic speed controller).
* Battery
* Firmware (OpenTX may need to be updated on the transmitter and the Pixhawk controller).

The life-cycle for the hexacopter and quadcopter drone is undetermined. The drone is more likely to crash than to die in mid-air. Our systems have alert systems to determine if a part or battery is not function correctly.   
  
The average life-cycle for drone motors is 150 hours and 450 hours for the battery (20 minute flights each flight).

# 11 Safety - Rules & Regulations

Drone - Flight (FAA rules - found in the drone registration test)

* The operator will fly below 400 feet
* The operator will fly within visual line of sight
* The operator will be aware of FAA airspace requirements: [www.faa.gov/go/uastfr](https://www.faa.gov/go/uastfr)
* The operator will not fly directly over people
* The operator will not fly over stadiums and sports events
* The operator will not fly near emergency response efforts such as fires
* The operator will not fly near aircraft, especially near airports
* The operator will not fly under the influence

Transmitter/Receiver

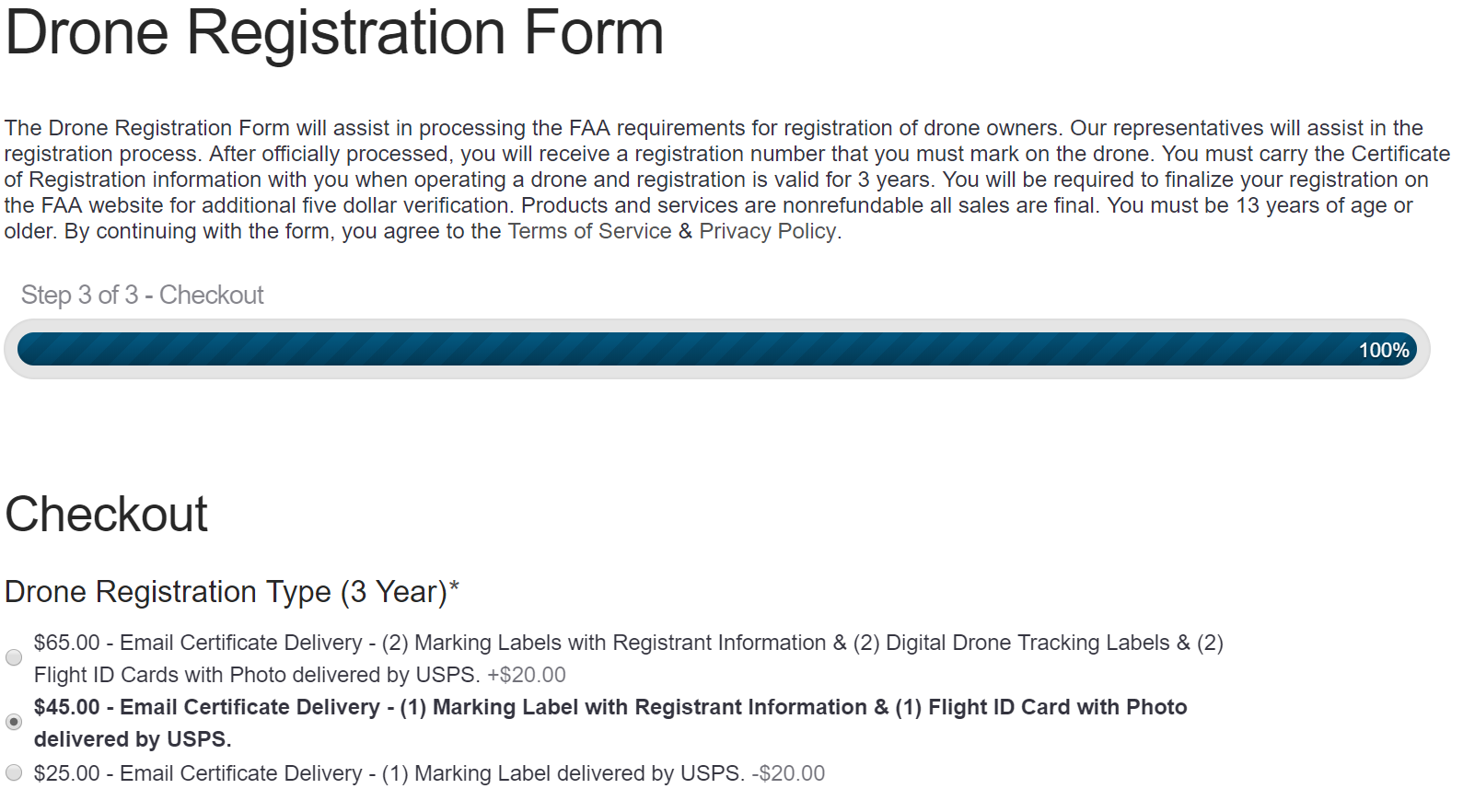
* If this equipment does cause harmful interference to radio or television reception, do the following
  + Reorient or relocate the receiving antenna
  + Increase the separation between the equipment and receiver
  + Connect the equipment into an outlet on a circuit different from that to which the receiver is connected
  + Consult the dealer or an experience radio/tv technician for help.

# 12 Drone Registration

<https://drone-registration.net/product/drone-registration-form/#_form_34>

We have registered our quadcopter and hexacopter. We have paid for $45 option of labeling both drones and receiver a flight ID card with photo. See below for more information:

**$45.00 - Email Certificate Delivery - (1) Marking Label with Registrant Information & (1) Flight ID Card with Photo delivered by USPS.**

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