# Autonomous Health Monitoring of Transportation Infrastructure Using Unmanned Aerial Vehicle

PROJECT PLAN


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**1 Introduction** **3**

1.1 Project statement 3

1.2 purpose 3

1.3 Goals 3

**2 Deliverables** **4**

**3 Design** **5**

3.1 Previous work/literature 5

3.2 Proposed System Block diagram 9

3.3 Assessment of Proposed methods 15

3.4 Validation 16

**4 Project Requirements/Specifications** **22**

4.1 Functional 22

4.1.1 Drone 22

4.1.2 Control System 22

4.1.3 Image and Data Processing 22

4.2 Non-functional 22

4.2.1 Cost 23

4.2.3 Reliability 23

4.2.4 Reusability & Maintainability 23

4.2.5 Certifications 23

4.3 Standards 23

4.3.1 FAA 23

**5 Challenges** **24**

**6 Timeline** **24**

6.1 First Semester 25

6.2 Second Semester 25

**7 Conclusions** **27**

**8 References** **27**

**9 Appendices** **28**

# 1 Introduction

## 1.1 Project statement

Using an Unmanned Aircraft System, or UAS, it is our responsibility to evaluate the safety and effectiveness of bridges, roads, and any other infrastructure that needs inspecting. This will be done through HD visual monitoring, Infrared Thermography, LiDAR sensors, and 3D Rendering. UAS can help contribute to a new era of civil infrastructure health monitoring.

### 1.2 purpose

What drives this project is the need to provide cost-effective and efficient health monitoring management of transportation infrastructure systems. One of the benefits of this project is that this is a quick way to make sure all bridges, construction work, and roads are functioning properly so that civilians are safe when they are traveling. Some other benefits include capturing traffic movement, making sure contractors are safe, and minimizing traffic accidents. The ability to collect data with an unmanned aircraft incorporates many software and hardware challenges that can help strengthen the team. The future potential of learning these skills and applying to other industries is tremendous.

## 1.3 Goals

Our goals include:

1. A working UAS, aka drone, that flies for over 40 minutes.
   a. Can fly in 20-30 mph wind
2. Can incorporate all the sensors and cameras that are required.
   a. Have the ability to swap sensors
   b. Be able to include:
      i. LiDAR
      ii. Thermal
      iii. HD Camera
      iv. Infrared
   c. Be able to have the camera on gimbal
3. Should be able to take clear pictures and analysis when flying over, under, and near:
   a. Bridges

   b. Roads

   c. Wind Turbines

4. Have a reliable communication with the control station

   a. Can fly the drone with ease

   b. Have the correct data analysis when measuring and collecting data

5. Meet all FAA and FCC requirements.

## 2 Deliverables

| Goal | Delivarable | Expected Delivery Date |
|---|---|---|
| -A working UAV, aka drone, that flies for over 40 minutes.<br><br>-Can fly in 20-30 mph wind | To properly accomplish this we need to choose the correct drone option, like hexacopter, chose the correct parts to build the drone, and be able to tune all the hardware components to different situations. | Mid March |
| -Use our client's budget wisely when purchasing | We will research each UAV part and sensor to assure that we are getting the highest quality within our budget. Afterwards we will send the parts list to our client for approval before ordering the parts | October 20th: Goal meet |
| -Can incorporate all the sensors and cameras that are required. | Research and learn exactly what sensors and cameras are best for our particular UAS. Once that is done we plan to purchase that specific LiDAR, Thermal, HD, and Infrared cameras. | October 20th: Goal meet |
| - Have the ability to swap sensor<br><br>-Be able to have the camera on gimbal | Know how to attach and work a gimble. Have the hardware team research and learn which combinations of sensors and cameras can be put on our UAS. Then we build and operate a gimbal that can use | End of February |

| | | |
|---|---|---|
| | different combinations. | |
| -Should be able to take clear pictures and analysis when flying over, under, and near bridges, roads, and wind turbines | Once we have the correct cameras and sensors decided upon, the hardware team will work on finding the best way to be take clear pictures through building and trial and error. | Mid April |
| -Have a reliable communication with the control station<br><br>-Have the correct data analysis when measuring and collecting data | The software team will work on finding which is the best data collecting software, then in the prototyping and testing phase is where the reliability of the communication is built. We will most likely use software that already exists instead of building our own. | End of March |
| -Can fly the drone with ease | Make sure whoever is flying the drone has been properly licensed and has enough trail runs to be comfortable to fly the UAS | December 15th |
| -Meet all FAA and FCC requirements. | Read the FAA and FCC documents and follow all the guidelines. | January 20th |

# 3 Design.

## 3.1 Previous work/literature

There are many styles of drones, each with their own capabilities. However, each drone design has its own tradeoffs. The major designs that we looked at are quadcopters, hexacopters, and fixed wing designs. Each design has their trade-offs, which will be analyzed later in this assignment. The major components that make up each drone are its motors, motor controllers, flight controllers, communication receiver, battery, and various sensors to assist in flying. In addition to the aforementioned items, we will want to have the ability to have thermal sensing, video feed and capture, and lidar sensing.

Quadcopters are a UAV with four spinning blades, facing parallel to the ground, similar to a helicopter. The lift is generated from these spinning blades. To move around, the UAV will bank in a certain direction, causing the drone to move. Each blade attached to a motor, which is connected to an arm of the drone. The arm sticks out from the main body of the drone. There are four ams in total on a quadcopter. Quadcopters can achieve hovering by keeping the motors spinning at a constant rate, and is not banking. Quadcopters are also able to have vertical take offs and landings. The main electronics for a quadcopter are housed in the main body of the drone. To keep the drone in the air, the propellers that are diagonal from each other are spinning in the same directions. However, each set is spinning in a different direction. Below in figure 3-1.1 shows this concept.

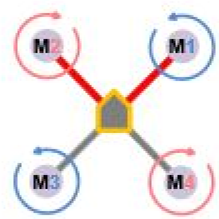



Figure 3-1.1

Hexacopters are UAV that are designed very similar to quadcopters, except that there are six blades instead of four. Like the quadcopter, each blade is attached to a motor, which is attached to an arm of the drone. There are six arms toal in a hexacopter. The main electronics are housed in the main part of the body. To keep the drone in the air, the propellers spin in different directions, as shown in figure 3-1.2. Generally, Hexacopters have the same capabilities as quadcopters, and operate in much the same way.

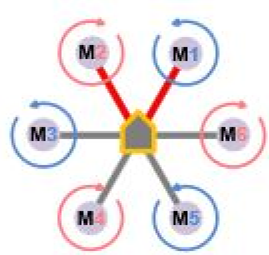



Figure 3-1.2

Fixed wing UAVs are designed very differently that quadcopters and hexacopters. Instead of blades facing the ground, they face perpendicular to the ground, like a traditional propeller airplane. Lift is not generated from the propellers, rather the wings of the aircraft. The propellers pull the plane forward. To turn, flaps on the main wings and the tail wing are adjusted. Fixed wing UAVs are not able to hover, but must circle the object they are studying if need be. Fixed wing UAVs cannot achieve vertical lift off and landings. Instead, a launchpad or runway is needed to get the UAV into the air. A runway is needed to land the plane as well.

Each drone design generally has various types of materials that they can be built out of. The most common frame materials are wood, carbon fiber, plastic, G10, and aluminum. Wood and aluminum are straightforward, and are generally available. Carbon fiber is is a tough, but lightweight material. G10 is a variation of fiberglass that can be bought in sheets

To have the drone fly in a safe manner, there are generally multiple onboard sensors and controllers. There are two main controllers on the drone, flight controller and electronic speed controllers (ESC). ESCs are circuits that take an input signal from the flight controller, and input power, and outputs a certain amount of power to the connected motor. Different models of ESCs have different input options, which can consist of pulse wave modulation (PWM), component area network (CAN), and other proprietary protocols. One example of this proprietary protocol is what DJI uses on their components, which allow for motor feedback, current draw, and voltage draw to their flight controllers. CAN is an open protocol that allows for motor feedback, current draw, and voltage draw to any flight controller that supports the protocol. PWM uses pulses to tell the motor controller what percentage to run the motor at. However, PWM does not give any feedback to the flight controller.

A flight controller is the central brain on the drone. They take in input from various sensors, communication receivers, and ESC (if supported), and sends signals to ESCs on how to run the motor. flight controllers have a range of supported sensors, protocols, and even GUI interfaces. Basic flight controllers, like the ones found in competitive drone racing or basic hobby drones, do not have a lot of onboard sensors, generally a gyroscope and accelerometer. They do have a simple GUI to tweak ESC control settings, they do not offer much more. They rely heavily on the user to control the drone, keep it steady in the air, monitor how the drone is operating. Two examples of these are the KISS FC and Lumenier LUX V2. More advanced flight controllers do have more features, such as autonomous flying, flight planning, onboard system logging, more variety of protocol support, software development kits (SDK), software simulation of hardware, gimbal support, ground station solutions, and additional onboard sensors such as inertia sensing, GPS, and barometers. Some of these flight controllers are the Pixhawk 2.1, DJI A3, and DJI N3.

With the more advanced flight controllers, there are multiple software solutions available for additional customizability. Many flight controllers, such as the Pixhawk and the LUX V2 support open source software. Other flight controllers, like the options from DJI and KISS, use proprietary software provided by the manufacture.

There are multiple communications methods that are supported by flight controllers. Examples are radio control (RC), bluetooth, WiFi and radio frequency (RF) are the most popular options. The flight controller generally does not have these modules on the controller, so a receiver/transmitter accessory needs to be purchased that will interface with the flight controller. Most controllers support most major RC and RF transmitters.

To be able to scan roads for separation, this will require the use of a thermal imaging camera. Traditionally, thermal cameras are hand held with a small screen and the ability to write the video feed to a storage device. With the rise in popularity in drones, thermal cameras are now being released in smaller form factors, which allow them to be carried by drones. One example of this is the Flir Duo. This small camera will fit in your hand, and allows you to carry it on the drone. The Duo even has a normal camera included, to allow for both thermal and regular video.

A popular method for scanning the faces of roads, buildings, and windmills is lidar. Lidar uses pulses of light to measure the distance from the sensor in a single plane. With this data, a 3D image can be created of the object. This would allow the measure of cracks length, width, and depth. Lidar systems currently are used in construction and civil applications, and are mounted on a large plane, helicopter, ground vehicle, or tripod. These lidar sensors have a range of field of view. Some can see 360 degrees around them, in a single plane. Others need to to be physically turned to reach all 360 degrees. However, with the rise in drone popularity, many lidar solutions are starting to be released in smaller form factors, and designed for drones. One example of this is the Velodyne Puck and HDL-32E.

Due to the popularity of action sport cameras, many cameras are offered with high resolution, long battery life, image stabilization, water and dust resistant, and internal video storage., With most models having existing mounting solutions, it is easy to attach these cameras to a drone. However, having a life video feed as well as storage of the video is not supported by some action sport cameras. One camera brand that does support live feed as well as storage is GoPro Hero, and Foxeer cameras

Gimbals are used to extend the range of various sensors or cameras, by allowing the connected sensor to turn on a plane. Gimbals can turn on two or three different axis, allowing for almost full coverage of the surrounding area, and image stabilization. One thing to be aware of is that if a gimbal is mounted below a drone, or on top of the drone, the drone body might block the sensor or camera from certain angles. To get full 360 degree coverage, two gimbals and two sensors/cameras will need to be used.

Once the data is collected, the data can be analyzed by open source solutions, or custom software, to bring notice to the user. Using lidar data, it is possible to identify various types of cracks and tears, and classify them for the user.

New government regulations provided by the federal aviation agency (FAA) with commercial or professional drone usage was released in 2016, which requires pilots of unmanned aerial vehicles less than 55 lbs. to have certain certifications. Pilots must be remote pilot airman certified, be 16 years or older, must keep drone below 400 feet, can only fly during the day, and fly slower than 100 mph.

While there are many drones out there for commercial usage, there are not any drones that have the ability to hold lidar, thermal, and video cameras, as well as having pre-flight planning. A drone with a single gimbal, which allows for one lidar, thermal sensor, or camera is DJI. besides providing flight controllers, DJI offers drones and gimbals. You can attach these sensors to the gimbals. Flir, the maker of thermal cameras, does offer DJI drones with their thermal cameras integrated to the drone. Phoenix Lidar Systems offers a drone with a lidar integrated in the hull. Using Phoenix software, a #D mapp of the scanned area can be created. If a 3D scan of a structure or road is desired, there are companies that offer scanning as a service, such as Infradrone. Infradrone scans and process structures or roads, and sends you the results.

There are open source option to assist in data analysis, such as Grass and BCAL LiDAR. These tools take lidar data, and create 2D and 3D images of the data. Grass markets itself as an open source geographic information system (GIS).

## 3.2 Proposed System Block diagram

Figure 3-2.1 shows a block diagram of the drone and control system interaction, where the lidar, camera, and thermal cameras are able to store their collected information locally on the device. Most flight controllers allow for a camera feed to transmit data through it.

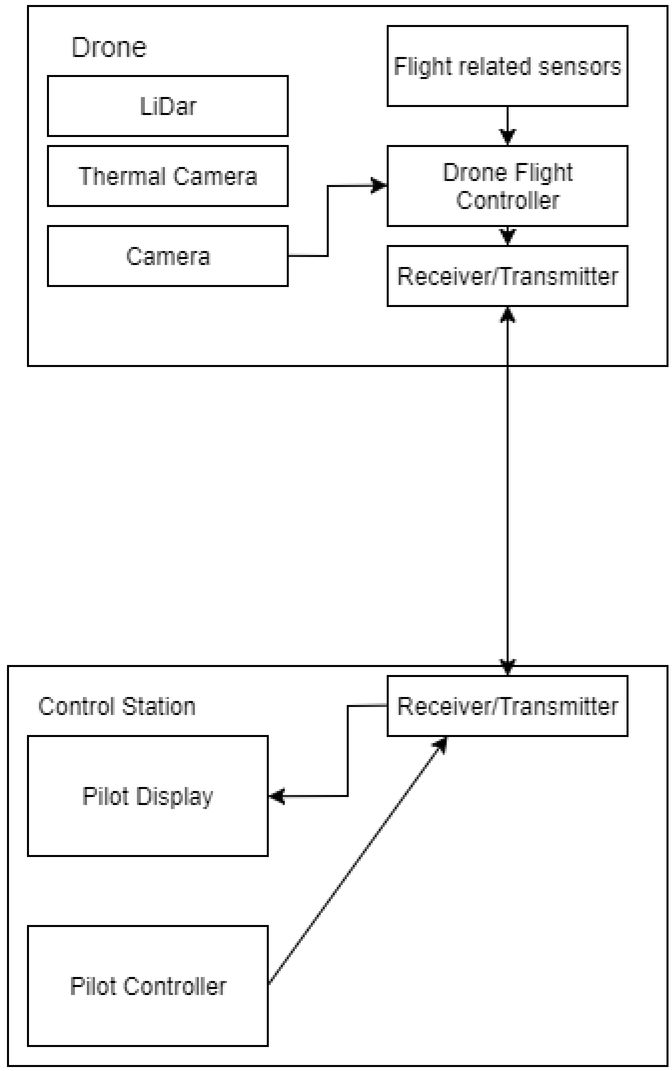



Figure 3-2.1

Figure 3-2.2 shows a block diagram if the lidar, or thermal camera cannot store the data locally on the device. It is common for lidar units to not have internal storage, so extra hardware will be needed to encode and transmit the data. The data encoder is needed because RF transmitter is generally sending data in a serial format, so the data from the thermal camera and lidar would need to be encoded, to then transmit. We would also need a decoder on the control station to decode the data, which can be used in later processing. If the camera cannot store its data locally, it can still go through the flight controller, and be captured at the control station. It would also require a storage device in the control station. If a computer is used, the internal storage device(internal hard drive, or internal SSD), or USB hard drive will suffice.

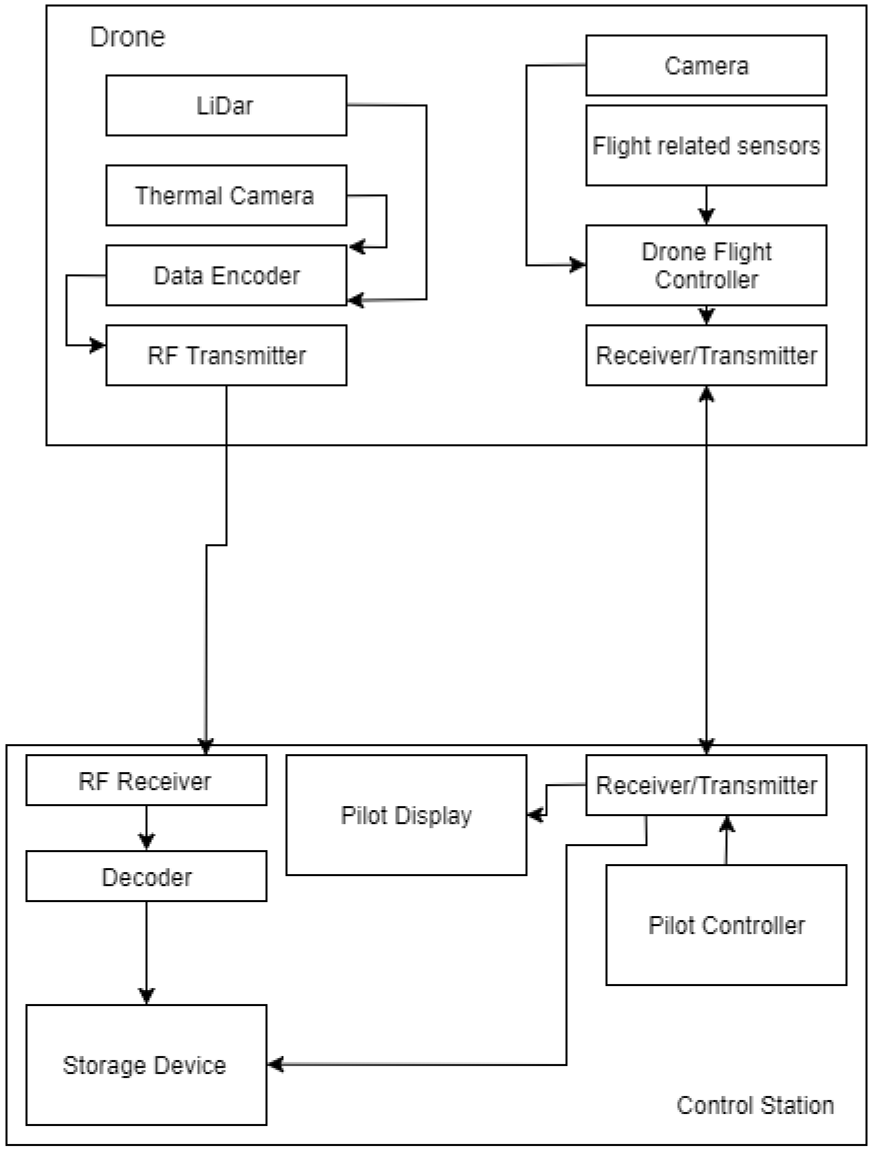



Figure 3-2.2

Figure 3-2.3 shows a revision of 3-2.2. where all data is sent through a single transmitter and receiver. This would allow for less hardware on the drone

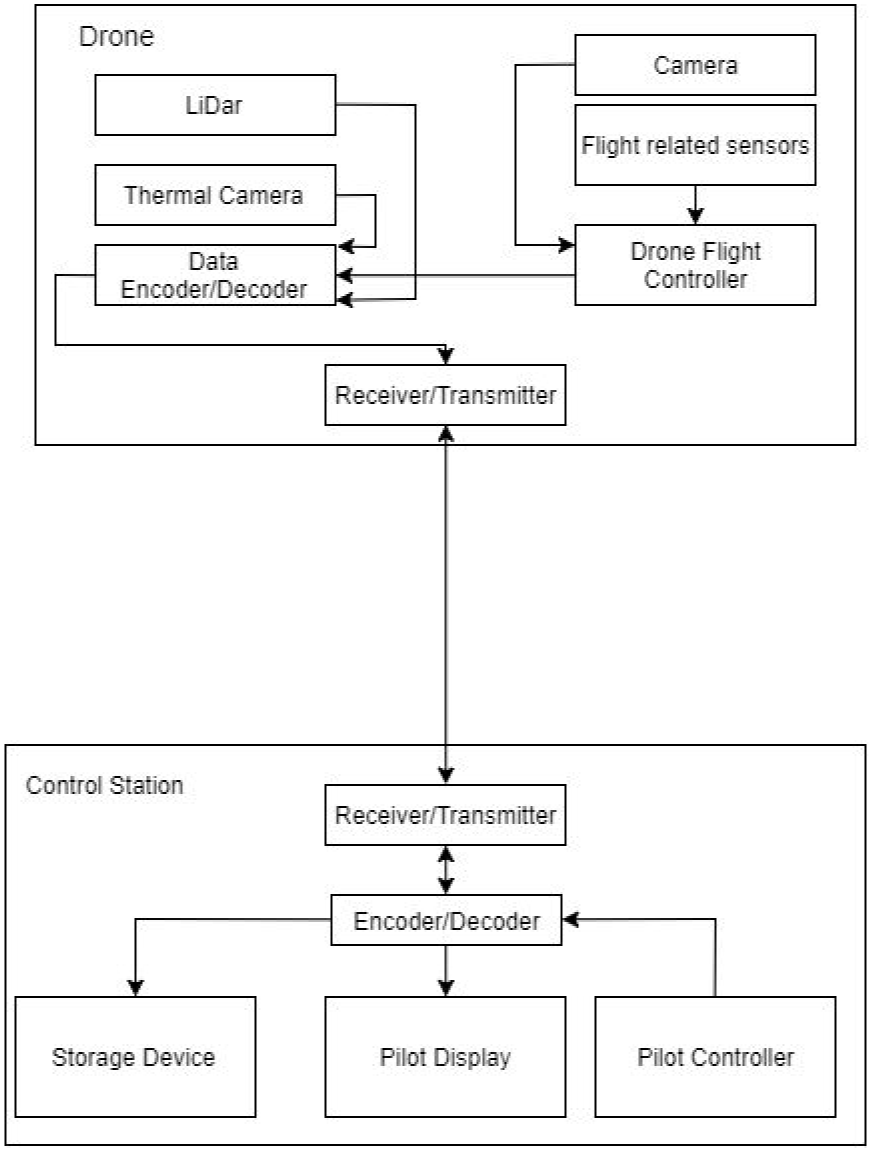



Figure 3-2.3

Below are block diagram related to drone sensors.Note that the "Data Transmission" block is just a black box representation of the various communication methods shown in above block diagrams, or the internal storage of the sensor, if applicable. Each communication method does not have an effect on the sensors and motors on the drone. The below figures would be the "Flight related sensors" and "Drone Flight Controller" blocks in the above figures.

Independent of each design, the drone will need to have a status light that will blink. The blinking light can be interpreted to allow the pilot to know what is going on with the drone if the control station is having issues. This control light is a standard feature on many flight controllers. Each design will also have a global positioning system (GPS) sensor on the drone.

Figure 3-2.4 shows the block diagram shows the drone using CAN for controlling the ESC. Note that CAN is daisy chained from one device to the next.

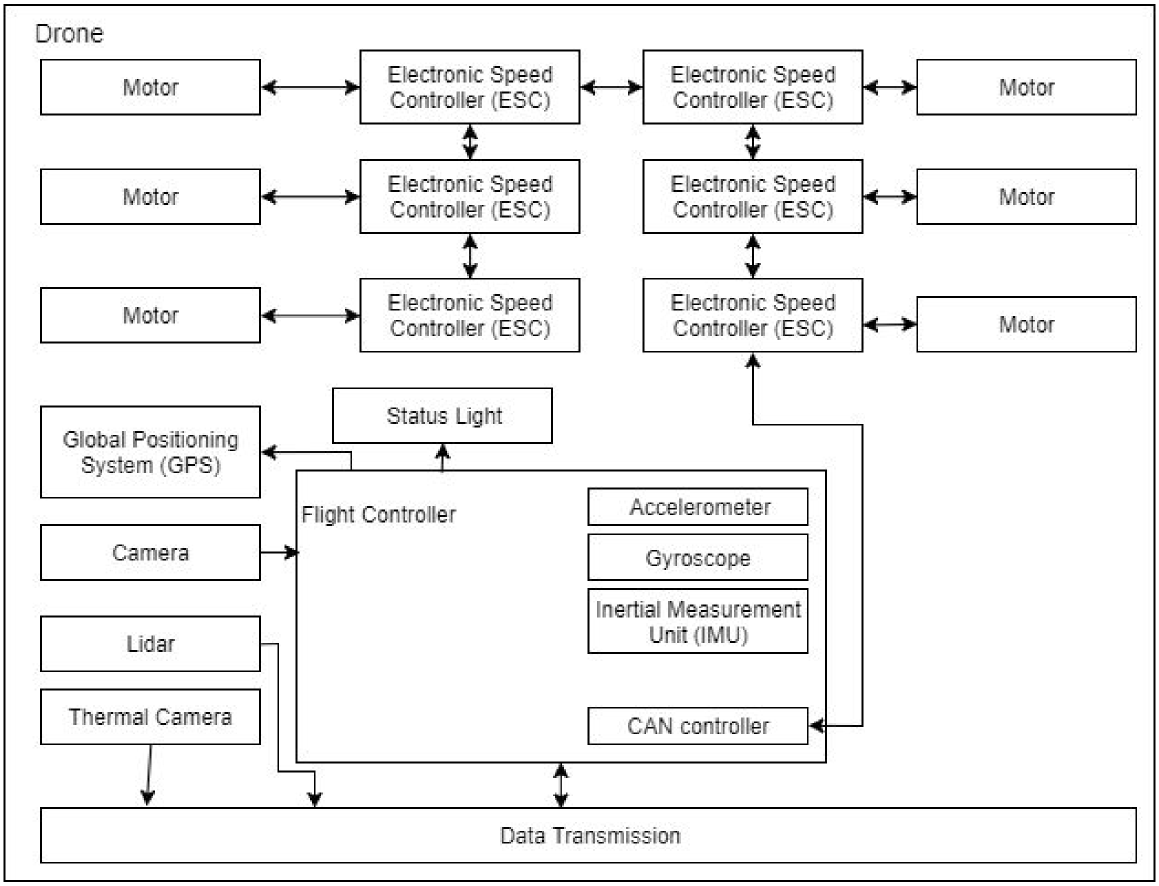



Figure 3-2.4

Figure 3-2.5 shows the block diagram  using DJI's protocol. This protocol allows for ESCs to give feedback to the flight controller, but are not daisy chained.

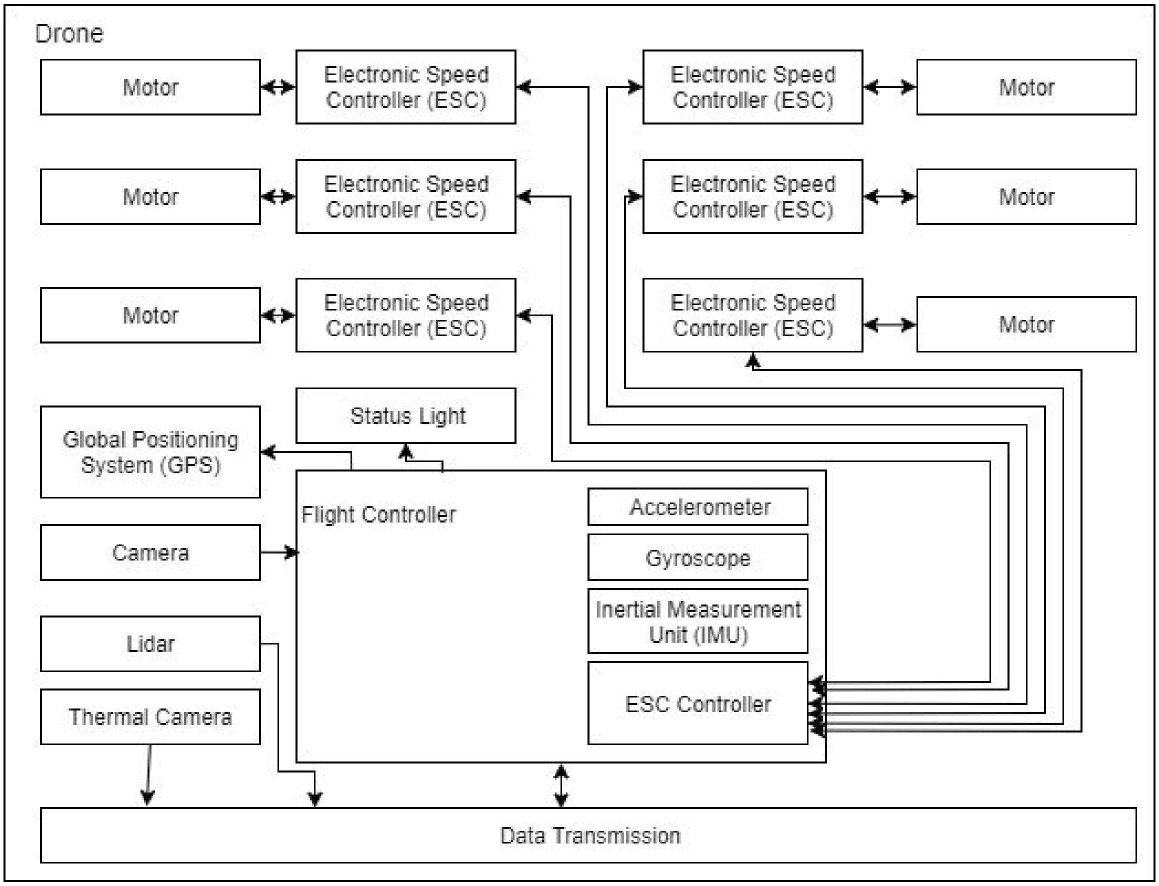



Figure 3-2.5

Figure 3-2.6 shows the block diagram using PWM. PWM data transmission requires each ESC to have its own data line. PWM does not give feedback to the flight controller.

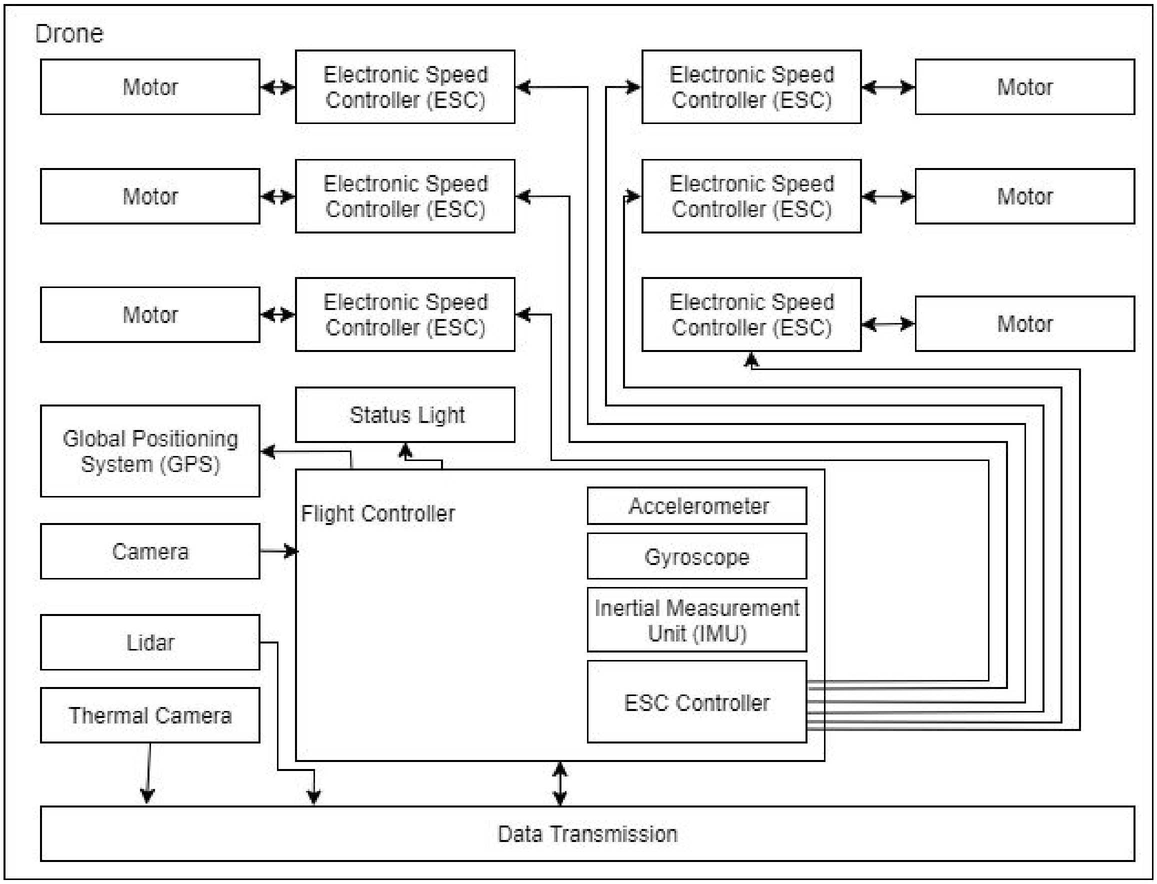



Figure 3-2.6

Once the data is captured by the drone, the data will run through data processing. During this step, it will take in the raw data, and output a couple different types of data, depending on what the user wants. The first output is 3D point cloud of lidar data, which will allow other programs to display a rotatable image that shows what was scanned. It will also allow the user to click two points, and have it calculate the measurement. This software will also classify the crack's severity using multiple criteria that can be defined by the user. The second output is the raw lidar data, which can be processed by later programs. The third output is the raw video feed of a camera. The fourth is the raw output from the thermal sensor. Figure 3-2.7 shows this process

## 3.3 Assessment of Proposed methods

The first comparison that needs to be made is the different types of drones. For this project, the three main drone types that are usable for this project is a fixed wing drone, a hexacopter drone, and a quadcopter drone. Quadcopter and hexacopter drones are very similar in design, and generally the same features. Fixed wing drone have a very different set of features

There are pros and cons when looking at a quadcopter vs a hexacopter. With only needing four motors and motor controllers, quadcopters are less expensive to make, have a longer battery life, and are easier to program. However with hexacopter six motors, it can have a heavier payload, is more stable in windy conditions, and has redundancy motors if there are motor failures which allow for graceful landing. Although it takes more battery power, a hexacopter is better suited for our purpose than a quadcopter, because of its heavier payload and motor redundancy.

Hexacopters and fixed wing drones have very different set of features. A fixed wing, when compared to a hexacopter, is much more power efficient, can have larger payload, and has a much faster linear travel speed than hexacopter. However, fixed wing drones do not have the ability to hover, require takeoff and landing runways or launchers which makes taking off and landing more complicated, are harder to control when flying, and are more expensive to build. A hexacopter is easier to control by pilots, can vertically take off and land, making it a lot easier to get in the air, have the ability to hover which makes data collection easier, have more customizability, and allow for less than perfect weight distribution. For our use, a hexacopter is a better fit. Being easier to work with, easier to fly, more customizable, and the ability to hover outweigh the increased battery efficiency and payload of the fixed wing drone.

When looking at the different communication methods laid out in figures 3-2.1, 3.-2.2, and 3.-2.3, they each try to do the same thing. The main factor when selecting a design is the feasibility given the selected hardware. The dual transmitter option of 3-2.2 is the most complex option, as there are two competing signals being sent to the drone, and allow for more points of failure. 3-1.1 would be the easiest to design, but then you are limited to the small inboard storage of the various sensors. If 3-2.3 is a feasible design, that would be the design to go with. It allows the drone to send the most data, with less points of failure. One thing to consider is drones can have redundant receivers/transmitters, which would help in the event of a receiver/transmitter failure. This would be easy to implement with figure 3-2.3

With the multiple flight controller options shown in section 3.1, it would be easiest to go with the more advanced options such as the DJI controllers, or the Pixhawk. Although they are more expensive, and slightly more complex to configure out of the box than the simpler LUX V2 or KISS FC, the additional software capabilities of the more advanced options would make controlling the drone a lot easier. The autonomous flying capabilities, advanced SDKs, inertia sensing, GPS, motor feedback capability, and preflight planning are worth the extra expense. These extra feature also enhance the predictability and safety of the camera, thermal sensor, and lidar sensors.

## 3.4 Validation

To verify that the UAS system is properly working, and meets product deliverables, the following test cases are defined.

1. Have the drone fly with a weight if 55lbs
    a. Test steps
        i. With required software and hardware for the drone to be usable and human controlled, , attach extra weight securely to the drone so drone is 55 lbs
        ii. Conduct vertical takeoff procedure
        iii. Hover drone for 5 minutes
        iv. Bank drone bank left
        v. Bank drone bank right
        vi. Have drone fly forward
        vii. Have drone fly backward
        viii. Turn drone counterclockwise 180 degrees
        ix. turn drone clockwise 180 degrees
        x. Conduct vertical landing procedure
    b. Goal of testing
        i. With the maximum load allowed by FAA regulations, have the drone be able to be flown and easily controlled
    c. Defined success:
        i. Drone is able to safely and smoothly take off vertically
        ii. Drone is able to hover in the same spot for 5 minutes
        iii. Drone is able to bank left and right
        iv. Drone is able to fly forward and backward
        v. Drone is able to turn 180 degrees in both directions
        vi. Drone is able to safely land without damage to the drone
        vii. Drone flies in a predictable manner by the pilot
2. Flight Time
    a. Test steps
        i. With required software and hardware for the drone to be usable and human controlled, , attach extra weight securely to the drone so drone is 55 lbs
        ii. Conduct vertical takeoff procedure
        iii. Hover for 40 minutes, or until critically low battery percentage
        iv. Conduct landing procedure
    b. Goal of testing
        i. With maximum allowed weight, the drone should have a 40 minutes best case flight time.
    c. Defined success
        i. Drone is able to hover for 40 minutes
        ii. Drone is able to safely land after hovering
3. Windy Conditions
    a. Test steps

i. Find conditions with 20-30 mph sustained winds. Gusts above 20-30 are okay
ii. With required software and hardware for the drone to be usable and human controlled, , attach extra weight securely to the drone so drone is 55 lbs
iii. Conduct vertical takeoff procedure
iv. Hover drone for 5 minutes
v. Bank drone bank left
vi. Bank drone bank right
vii. Have drone fly forward
viii. Have drone fly backward
ix. Turn drone counterclockwise 180 degrees
x. turn drone clockwise 180 degrees
xi. Conduct vertical landing procedure

b. Goal of testing
   i. The state of Iowa can be very windy at times. The drone still wants to be flown in these windy conditions.

c. Defined success
   i. Drone is able to safely and smoothly take off vertically
   ii. Drone is able to hover in the same spot for 5 minutes
   iii. Drone is able to bank left and right
   iv. Drone is able to fly forward and backward
   v. Drone is able to turn 180 degrees in both directions
   vi. Drone is able to safely land without damage to the drone
   vii. Drone flies in a predictable manner by the pilot

4. Sensing
   a. Test steps
      i. Attach camera, thermal sensor, and lidar units to drone
      ii. Conduct vertical takeoff procedure
      iii. Select object to scan
      iv. Scan selected object with all three sensors
      v. Conduct landing procedure
   b. Goal of testing
      i. To verify that each sensor works properly, and data that is generated is captured
   c. Defined success
      i. Data from each sensor is captured in a way that can be processed at a later time

5. 360 degree coverage
   a. Test steps
      i. Attach camera to drone
      ii. Conduct vertical takeoff procedure
      iii. Start video recording
      iv. Conduct procedures to video record 360 degrees around the drone, with the drone hovering in one spot, and is not turning
      v. Conduct vertical landing procedure

b. Goal of testing
    i. Have the drone be able to record every angle around it, without the need to run the drone
c. Defined success
    i. Video recording(s) shows all angles around the drone

6. Sensor Swap
    a. Test steps
        i. Attach video camera to gimbal
        ii. Conduct vertical takeoff procedure
        iii. Start video recording
        iv. Record for 1 minute
        v. Stop video recording
        vi. Conduct vertical landing procedure
        vii. Take video camera off of gimbal
        viii. Attach thermal sensor to gimbal
        ix. Conduct vertical takeoff procedure
        x. Start thermal sensing
        xi. Record for 1 minute
        xii. Stop thermal sensing
        xiii. Conduct vertical landing procedure
        xiv. Take thermal camera off of gimbal
        xv. Attach lidar to gimbal
        xvi. Conduct vertical takeoff procedure
        xvii. Start lidar sensing
        xviii. Record lidar data for 1 minute
        xix. Stop recording lidar data
        xx. Conduct vertical landing procedure
    b. Goal of testing
        i. Verify that all sensors can attach to the drone's gimbal
        ii. Verify that all sensors can properly recorded data, and be captured that allow for later data processing
        iii. Verify that all sensors can be used without major software reconfiguration
    c. Defined success
        i. All sensors can attach to the drone's gimbal
        ii. All sensors can interface with drone electronics
        iii. All sensors can record without the need for major software configuration between sensor switches
7. Communication stress
    a. Test steps
        i. Set up drone transmitter(s)/receiver(s)
        ii. Set up control station transmitters) and receiver(s)
        iii. Connect to a microcontroller that is able to emulate data to be transmitted, and can receive data
        iv. Move transmitters and receivers 100 feet from each other, but can maintain line of sight

        v. Using the microcontroller, send as much data at the max transfer rate for 5 minutes
    b. Goal of testing
        i. Under max transferring rate, make sure the communication system can maintain communication
    c. Defined success
        i. Communication is maintained, and the data is that was sent is the same data that was received on the other end
8. User Controllable
    a. Test steps
        i. With required software and hardware for the drone to be usable and human controlled, , attach extra weight securely to the drone so drone is 55 lbs
        ii. Conduct vertical takeoff procedure
        iii. Hover drone for 5 minutes
        iv. For 30 minutes, let the pilot fly around, raising, lower, banking, flying forward, and backward as the pilot feels.
        v. Conduct vertical landing procedures
    b. Goal of testing
        i. Pilot feels comfortable controlling the drone
    c. Defined success
        i. When conducting the test steps, pilot maintains complete control, and drone flies as the pilot predicts it should based off of the input from the pilot.
9. Motor Feedback
    a. Test steps
        i. Have  drone in production hardware configuration
        ii. Conduct vertical takeoff procedure
        iii. Hover for 5 minutes
        iv. During hovering, observe motor current draw, voltage draw, and RPM.
        v. Conduct vertical landing procedures
    b. Goal of testing
        i. Verify motor health can be monitored while drone is flying
    c. Defined success
        i. motor current draw, voltage draw, and RPM viewed in real time
10. FAA requirements
    a. Test steps
        i. Locate FAA drone requirements for commercial use
        ii. Verify drone follows all requirements
    b. Goal of testing
        i. Drone is FAA compliant for flying
    c. Defined success
        i. Drone passes all FAA requirements
11. FCC requirements
    a. Test steps
        i. Locate FCC rone requirements for commercial use

        ii. Verify drone follows all requirements
    b. Goal of testing
        i. Drone is FCC compliant for flying
    c. Defined success
        i. Drone passes all FCC requirements
12. Data Analysis human readable output
    a. Test steps
        i. Locate already captured data from the drone
        ii. Run data through data analysis programs Run data through data analysis so output is in a raw, human readable format
        iii. Open output
        iv. Have human analyze the data
    b. Goal of testing
        i. Data from the drone can be read by a human
    c. Defined success
        i. Human can analyze data
13. Data Analysis computer assisted output
    a. Test steps
        i. Locate already captured data from the drone
        ii. Run data through data analysis so output is in a computer assisted human readable format
        iii. Open output
        iv. Have human analyze the data
    b. Goal of testing
        i. Output from this part of the data analysis makes sense to a human
    c. Defined success
        i. Output from this part of the data analysis makes sense to a human
14. Communication failure
    a. Test steps
        i. Have  drone in production hardware configuration
        ii. Conduct vertical takeoff procedure
        iii. Hover for 5 minutes
        iv. Turn off communication on the driver station
        v. Observe results
    b. Goal of testing
        i. In the event of a communication failure, drone will safely land
    c. Defined success
        i. After 5 minutes, or critical battery level (whichever is first), the drone will land itself
        ii. In the time before the drone lands, the drone hovers in the same spot
15. Motor Failure
    a. Test steps
        i. Have  drone in production hardware configuration, with the additional ability to have motor loose connection to the system
        ii. Conduct vertical takeoff procedure
        iii. Hover for 5 minutes

iv. Remotely cut off one motor from the drone system
v. Hover for 1 minute
vi. Conduct vertical landing procedure

b. Goal of testing
   i. In the event of a motor failure, the drone be able to recover ,and safely land

c. Defined success
   i. Drone is able to hover for 1 minute when a motor has failed
   ii. Drone is able to land with one failed motor

# 4 Project Requirements/Specifications

## 4.1 Functional

Our functional requirements overlap with most of our goals. The goals that were defined above do go into strict detail on non-functional requirements. Our client is less concerned about non-functional requirements, and is more focused on functional requirements.

### 4.1.1 Drone

- Drone will be able to fly for 40 minutes at a time.
- Drone will be able to fly in winds up to 30 mph.
- Drone will have a modular design. A modular design (for this project) is defined as:
  - Being able to operate and collect data with any permutation of optical, thermal, and lidar sensors.
  - Every part on the drone must be able to be easily removed and installed.
- Drone will be able to capture images of the underside of bridges. This will be done by attaching a camera to a gimbal.
- Drone will be able to follow preprogrammed flight plans
- Drone will be able to hover in a single place without operator control.
  - While hovering, the operator shall be able to operate the gimbal in a controllable and predictable manner.
- Done will be able to safely land when one motor fails.
- Drone will have redundant flight critical sensors.

### 4.1.2 Control System

The control system will need to be able to:

- Control the drone in a predictable manner.
- Respond to the pilot's input in a predictable manner.
- Give near real time information on the drone's various health attributes. These health attributes include:
  - Battery health and percentage
  - Ground Station to drone connection status
  - RC controller to drone connection status
  - Pitch and Yaw of the drone
  - Altitude
  - Motor health
- Store sensor and drone health information. This can be achieved by a combination of storage on the drone, and storage on the ground.

### 4.1.3 Image and Data Processing

- Data will be able to be analyzed offline, and independent of the status of the drone ( as long as the data has been collected and transferred to an appropriate storage solution).
- Analyze cracks and other faults by their:

- width
- depth
- length
- severity
- location

- Ability to create topographic map from sensor and camera data
- Ability to assist in the detection of pavement delamination.

## 4.2 Non-functional

### 4.2.1 Cost

There are two major categories for spending, non flight related hardware, and flight related hardware. All software will be developed, or built on an open source library, and will not be factored into the cost.

Non flight related hardware covers any sensor that is used for civil structure monitoring, which include the thermal sensor, camera(s), and lidar, as well as any gimbals or accessories for these sensors. These sensors are very expensive. Because of this, all non flight related sensors are combined into their own categories. Camera(s) and thermal sensor will be bought for this project, while the lidar, which is more than the thermal and lidar sensor combined, will be bought at a later time. No hard limit has been set on how much will be sent on non flight related hardware, but we have set a soft goal of $5,000. Our client has stressed that they are willing to spend a little extra for a better value sensor if applicable, but wishes to keep sending low.

Flight related hardware is any hardware needed to operate the drone in a safe manner. This includes a flight controller, flight related sensors, RC controller/transmitter, RC receiver, ESCs, motors, propellers, frame, and any other needed hardware. These parts are generally much cheaper than non flight related sensors. With purchasing spare parts, such as extra batteries, we will be spending less than $5,000. However, this price will increase if the client wishes to purchase more spare batteries that what we have budgeted.

### 4.2.3 Reliability

Because this drone will be fairly expensive to build, we need it to be reliable during flight so as not to crash. To achieve this, the drone is designed with hardware redundancy, software fail safes and graceful degradation. The flight controller that is used has two to three times redundant flight related sensors, allowing for sensor failure. The drone configuration is a hexacopter, allowing for a theoretical two motors to fail, while still maintaining control of the drone. The software system will have multiple different communication redundancy, allowing for the RC controller, ground station, or a software time out safely land the drone the event of any communication failure. The software will also be able to sense health status, and possible failures. If possible critical failure is sensed, the software will gracefully degrade and land the drone, minimizing further damage to the drone or other hardware.

Often times, our client will travel for multiple hours to collect data on civil structures. Thus, the UAS system must be able to operate in less than ideal weather conditions, so multiple hours are not wasted. The system must be able to be operated in light rain, and as stated in our goals, up to 30 mph wind. It also must be able to follow all goals and functional requirements while in these conditions.

#### 4.2.4 Reusability & Maintainability

This drone and system will need to be used after the student team has graduated. Therefore, the parts should be durable and cheap but easy to replace if they do break. This means we will elect to purchase off the shelf components as opposed to creating custom components when possible. In the case of the gimbal, which we will likely need to 3D print or fabricate ourselves. Any part(s) that we create will be clearly documented to allow for our client to re-create the part. The rest of the system will also be well documented, to allow for future projects to build on the system.

#### 4.2.5 Certifications

Each member will become certified to fly the drone. While not needed for “flying for fun”, we would be flying the drone to test for a research team. This is not explicitly stated in FAA regulations as needing a license. However, Iowa State University requires a FAA airman's license to fly in campus airspace. Thus, each member will need to become certified to fly the drone.

### 4.3 Standards

#### 4.3.1 FAA

Our drone will fall in the category Fly for Fun under the Special Rule for Model Aircraft. We will elect to register our drone in case it gets lost. The following requirements will be followed, as specified by the Special Rule for Model Aircraft:

- Fly at or below 400 feet
- Be aware of airspace requirements and restrictions
- Stay away from surrounding obstacles
- Keep your UAS within sight
- Never fly near other aircraft, especially near airports
- Never fly over groups of people
- Never fly over stadiums or sports events
- Never fly near emergency response efforts such as fires
- Never fly under the influence of drugs or alcohol

From these standards, these affect how we will design our drone, and what features we will design into the system. The two biggest restrictions put on us is the altitude restriction of 400 ft, and keeping the UAS within line of sight. These affect our ability to automate the drone. We have less airspace to fly in, and the distance that can be scheduled in a flight plan. It also means that the ground station will need to move more often when unscanned areas want to be covered. Thus, the ground station must be extremely portable. This portability provides design challenges, because it limits storage space limitations, screen size limitations, and limits what platform the ground station can be built on.

Due to the Ames airport, we will need to travel to the north side of campus to test our drone, so we are not near the airport. This will affect our ability to test the hardware of the drone. We will need to plan ahead when testing the drone, as we will need to travel with all the equipment.

We alre also limited to a 55 lbs maximum weight for the drone. Thus, all sensors and flight hardware will need to be under 55 lbs. While we have the ability to fly with that payload, our drone is significantly under that limit with normal sensor configurations. However, high definition lidar sensors, and even non destructive evaluation equipment, can be heavy and will increase the drone's total weight towards the maximum weight capacity. Thus, the user will need to think and plan weight accordingly when attaching sensors and other hardware.

### 4.3.2 FCC and Frequency

The FCC limits what bandwidths are open in the US for public use. The spectrums that are available to us are 915 Mhz, 2.4 Ghz, and 5.8 Ghz. Most drone components are designed to operate in these frequencies. These frequencies are well defined by the FCC, which allowed the industry plenty of time to fit the FCC regulations.

Generally, the higher the frequency, the higher the transfer rate, but lower the penetration power. Thus, data transferred at higher frequencies may be obstructed by trees, buildings, or even longer distances. We also will need to spread our data transfer over these three frequencies, so we do not get interference with our own equipment. Thus, we have elected to send high bandwidth data, such as video, over the 5.8 Ghz spectrum. We elect pilot input over the 2.4 Ghz, which allows for a good mix of distance, low latency, moderate penetration through trees and other surroundings, and bandwidth. The 915 Mhz spectrum will be used to transfer health information, flight plans, and emergency pilot control in the case of controller failure. This spectrum is not very responsive, and is limited on data transfer rate. All data transferred over this spectrum is either for human consumption, or does not have a strict low latency need, thus it is okay to transfer it at this frequency. The pilot control is only used in case of emergency, and will only be used to bring the drone back to the pilot for safe landing.

# 5 Challenges

The biggest concern for our team is the possibility of crashing the drone. If we happened to crash the drone we would experience a major setback in our project. The cost of rebuilding a drone and the possible cost of replacing any broken sensors from a crash would be in the thousands of dollars. Not to mention the time that would be wasted rebuilding the drone and ordering replacement parts and sensors which can take weeks to months to arrive. It is definitely an outcome that our team wants to avoid at all costs. To help mitigate this, we need to be very careful that our design for the drone has no flaws and that the load it carries is balanced to help stability of the drone's flight. In addition, everyone on our team who will be flying the drone will be FAA drone pilot certified. This involves taking a practical and written test about how to fly a drone and relevant safety protocols involved. This will also be another challenge since in order to fly the drone legally, the pilot must pass this test. Studying and practicing for the FAA pilot certification test will also take time to accomplish, and must be done before we can start testing our project.

In addition to learning drone flight protocols, our team will also have to expand our knowledge about data collection and processing relating to infrastructure and drones. Will we need to learn about thermal sensors, LIDAR sensors, and visual cameras specs. Information such as stabilizing on a moving drone, distance from which the sensors are effective, and how accurate the readings of the sensor can be in various weather conditions are all factors that will need to be taken into account. Then once we have collected the data, we will need to have knowledge over how to process the raw information into useful statistics and data. This process may be simplified significantly by implementing pre-existing open source softwares. Our team will then need to coordinate with the client and the client's provided resources in order to gain understanding on what processed data is relevant to the infrastructure health and should be highlighted in our data processing software.

The major challenges faced by our team have the potential to create large, significant, time delays. However, as long as we remain vigilant and start preparations to avoid these pitfalls now as we already have, our plan should be able to run smoothly without a hiccup.

Here is some information about the challenges we faced when ordering the parts. These include cost and making sure each part fits the requirement for our project. Here are two examples of parts that we ordered, and the work we put into each part :

Lidar Sensors:

| **Lidar Sensors** | Phoenix AL3-16 | Lidar USA Snoopy A-Series | Velodyne Puck VLP-16 |
|---|---|---|---|
| Price | $100,000 | $49,000 | $8,000 |
| Weight | 2.5 kg / 5.5 lb | 2 kg | 0.83 kg |
| Spatial Resolution | 35 mm | 46 mm | 30 mm |
| Laser Range | 107 m | 50 m | 100 m |

HD Camera

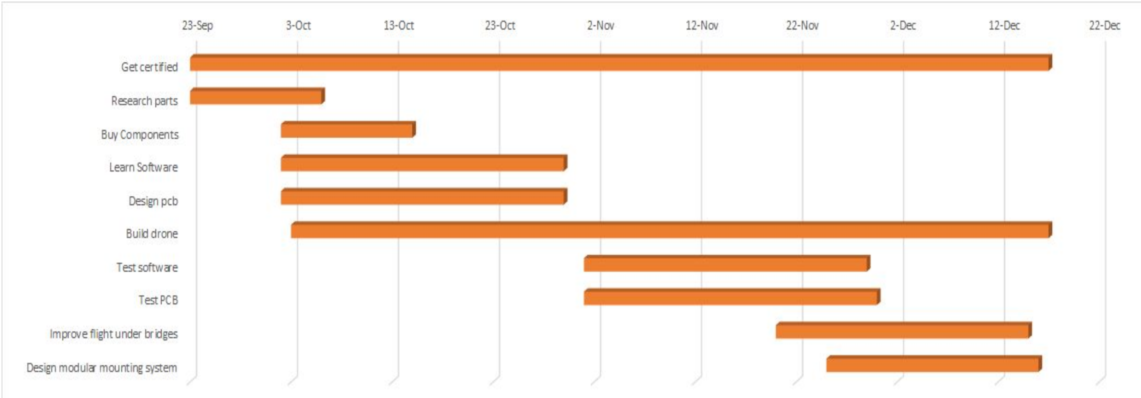
| HD Camera | GoPro Hero 5 | Foxeer Legend 3 UHD Camera | FuriBee F03 AIO Mini FPV Camera |
|---|---|---|---|
| Price | $399.99 | $149.90 | $25.04 |
| Weight | 86g | 67g | 0.092 kg |
| Resolution | 4K, 30fps | 24fps, 4K | 720 x 480 px |
| Camera Angle | Ultra Wide Angle | 155 degrees | 120 degrees |
| Transmission Date | Bluetooth, Wireless LAN | Supported with Bluetooth 4.0 | about 250m |
| Camera Size | 8.8 x 5.8 x 2.6" | 67 X 42.5 X 23mm | 2.00 x 2.00 x 5.00 cm |

These two tables show the research we did for the Lidar and HD camera. The biggest challenges were to find the right parts with a manageable cost. There was a lot of back and forth with our client and finally we were able to come to a decision. The Lidar sensor in particular was pretty challenging because it is an important part of our project but the cost is very high. The cheapest one is $8,000 and for right now we are holding off on buying this one, and making sure we order all our sensors and drone parts so we can start building. As we now start buying each part we will face different challenges, and we have to keep the cost in mind and make sure we build our drone properly so it does not crash.

We have a long way to go and keeping these challenges in mind will help us avoid some of our mistakes and make sure everything is done with great vigor.

# 6 Timeline

## 6.1 First Semester




The group will be split into a hardware team and a software team.

Each member will be assigned certain components to research. This includes sensors, frame, battery, propellers, motors, and many others. The expected time allocated for research is approximately 8 weeks. We are taking our time with the research due to the high cost of parts which results in a small margin for error since we can not afford to repurchase these components. By the end of October, we should have a finalized bill of materials for the parts needed to build a drone. Some of the more expensive components such as sensors will be purchased at a later date. This give the team adequate time for the team to get an idea of hardware limitation of the drone and see if there is any mechanical issues with the compatibility of the more expensive components with physical drone.

After the parts have finalized and ordered, the hardware team will begin researching on assembly guides. This will speed up the process of building the drone and also gives the operator knowledge on the tools required to build it. They will need to fully understand how each part is attached and also how to power each component. Once the parts arrive, the hardware team will begin assembling it. This should take an entire weekend.

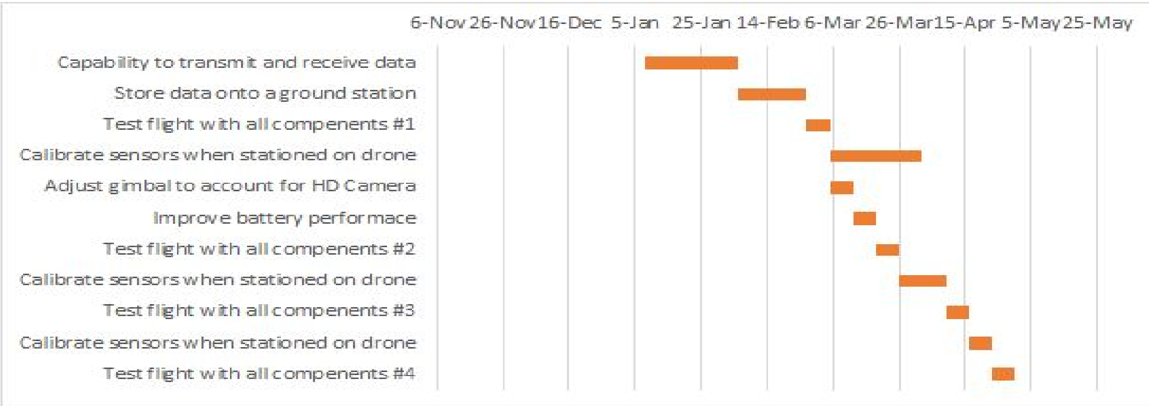
In the meantime, the software team will begin simulating drone flight pattern. This includes getting the drone to hover, fly straight, and all the other basic movements. Other member will be tasked with implementing an automatic flight path utilizing the GPS and the flight controller. Many sensors has their own proprietary software, therefore the remaining software team will spend the next few weeks trying to learn how to operate the sensors and get it to store data.

After the majority of the either the hardware or software aspects are finished, members will begin learning solidworks and work on the design of a gimbal.

During the semester, we will need to get certified to be able to fly a drone. This is essential for flight tests. A full day, when we are all available, will be spent driving to a facility to complete all the necessary paperwork, fees, and test to legally fly a drone.

The end goal for the first semester consist of functional individuals parts. These parts may or may not work together by the end of the semester.

## 6.2 Second Semester




What is needed to get done next semester mainly depends on how much progress we made during the first semester. Assuming we reached our desired end goal for the the first semester, we would need to spend the 2nd half of the school year integrating the various components together and running tests. This would include attaching sensors to the hexacopter in a modular fashion, adjusting the sensor to take accurate data while on the UAV, optimizing battery usage, testing flight under rigorous conditions, and many others. Majority of the time spent will be spent on testing, calibrating, and troubleshooting errors.

The group will be still be split into 2 teams: hardware, and software. The software team will be in charge of overseeing the use of sensors. This includes the calibration of the sensors with the drone, and the data collection tests. They will also try and store the data from the sensors remotely to a ground station such as a tablet.

The hardware group will be improving the controls, optimizing battery, adjusting the gimbal, and verifying modular capabilities.

In the end, we will have a fully functioning hexacopter that has flight time of at least 45 mins, capability to fly undér bridges, and ability to collect data from sensors.

# 7 Conclusions

Our goal with this project is to design and build an unmanned aerial vehicle with the capability to scan infrastructure using a group of sensors, including thermal, lidar, and optical video cameras. The data gathered during these scans will then be used to detect faults and stresses which otherwise may go undetected.

Quite a lot of preparation, planning, and persistence will need to be put towards this project if we want to ensure that all of our goals are met. The largest of these goals are as follows:

- Build a hexacopter with a modular design so parts can be switched easily
- Achieve a flight time of at least 40 minutes so a sufficient amount of data is collected
- Analyze raw data to detect infrastructure faults
- Work as a team to create an efficient and positive group environment

As a team, we have taken the necessary steps (outlined above) to ensure that our project meets all the requirements put forth by our client, instructor, and ourselves.

# 8 References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# 9 Appendices