Autonomous Health Monitoring of Transportation Infrastructure Using Unmanned Aerial Vehicle

DESIGN DOCUMENT

Team 25
Client: Program for Sustainable Pavement and Research (PROSPER)
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1 Introduction

1.1 Acknowledgement

Our client, Dr. Halil Ceylan, has informed us that he would be willing to assist our project with both financial aid and a significant amount of technical knowledge. The cost of parts for our drone along with the thermal and hd camera will be fully covered by Dr. Ceylan. However, this funding has a soft limit around five to eight thousand dollars. Dr. Ceylan will be reviewing our desired part list for the drone to review the costs of said parts. Our parts lists includes possible alternatives at differing price points so that the client may adjust the budget to his desires.

Our client is also providing us with access to technical knowledge pertaining to civil engineering. Since none of our team members are civil engineers, our client has arranged for a couple of civil engineering grad students to help fill this knowledge gap. These grad students will provide information critical to creating an effective data analysis system. This information will include road crack names and definitions, crack severity level classifications, and thermal imaging relevance to infrastructure health.

1.2 Problem and 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.

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 operational Environment

The UAV we provide to our client will need to be useable in a wide range of environments. It is required for the drone to be flyable outdoors year round. In order to obtain this, the drone will be flying in temperatures ranging from -20 to 45 degrees celsius able to fly in light rain with winds up to 40 mph. Furthermore, the drone will be expected to fly up to 400 ft above ground level and to maneuver underneath bridges and around other infrastructures safely.

1.4 Intended Users and uses

Our drone is intended for data collection about infrastructure health. Civil engineers or drone operators will fly the drone over roads, under bridges, and around other infrastructure to record video and collect LiDAR and thermal data. They will be able to draw conclusions by analyzing crack severity, weak areas, and other faults in the structures. This information will help them determine the health of the structures and highlight areas in need of maintenance.

1.5 Assumptions and Limitations

- Assumptions
    - 4k HD video from regular camera
    - Thermal camera has adequate resolution
    - LiDAR will be added eventually
    - Range of motion on gimbal is adequate for needs
    - User will have basic knowledge of flying drones
    - Parts can be replaced relatively easily if necessary (client requirement)
- Limitations
    - Budget limited by client funding, exact amount to be determined
    - Flight time must be at least 40 minutes (client requirement)
    - Drone must conform to all FAA specifications under Special Rule for Model Aircraft
    - Drone must be able to function fully in light rain (client requirement)

1.6 Expected End Product and Deliverables

The end product we expect to produce is a UAS (drone) equipped with an HD camera, a thermal camera, and a LiDAR sensor. In addition to the drone and its control system, we will compile a set of open-source programs to use in analyzing the data.

To meet our end goal of a complete data collecting and analyzing system we must complete the following major deliverables:

- Build a drone (minus sensors and cameras)
- Configure control system
- Design and build mounts for sensors and cameras
- Assemble full drone including sensors and cameras
- Organize suite of open-source software for data analysis

Build a Drone - 11/7

To properly build our drone we need to choose the correct drone option, like hexacopter, choose the correct parts to build the drone, and be able to tune all the hardware components to different situations. We must build the drone in accordance with FAA regulations for flying under the Special Rule for Model Aircraft. At this stage we will not attach the sensors and cameras, but we will get the drone to a stage where it can fly. We will keep in mind that we still have to attach more items when assembling the drone so as to stay within the weight requirement.

Configure Control System - 12/15

In order to fly the drone we must be able to communicate with it. The hardware and software teams will collaborate on this deliverable to establish a reliable connection. 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. Once the control system is functional we will test it with the drone and perform test flights. The drone is still not complete but at a stage where it can be flown.

Design and Build Mounts - 12/15

Even though we will purchase a gimbal for the HD camera, we must design and build other mounts for the other cameras and sensors. This will likely include modifying the existing gimbal to support more than just the HD camera and possibly even ordering an additional gimbal or mounting system for the other components. This will require the efforts of all team members as we must ensure the safety of the cameras and sensors, the most expensive parts of the drone.

Assemble Full Drone - 1/19

Once we have all of the mounts designed, it is time to assemble the full drone with all sensors and cameras. This should be fairly straightforward. Once the drone is assembled, we will run various tests to ensure everything is connected correctly and securely before attempting to fly. This testing is crucial because the most expensive parts of the drone will now be attached and we cannot risk breaking them. When we feel confident in the connections, we will start flying the assembled drone.

Organize Software Suite - 1/26

The software team will work on finding data analytics software to process the data we have collected with the drone. This will be mostly, if not entirely, open-source software. Our focus is to be able to render topographic mappings of the structures from our camera and sensor data for further analysis.

2. Specifications and Analysis

To fill most of the requirements listed in section 1.6, the drone will need to be versatile in what sensors it can use, be able to fly in many conditions, and be easy to fly. There are multiple different ways that this can be achieved. There are three main design choices that make up the UAV system. The three choices are the drone flying configuration, the hardware on the drone, and the data communication layout.

The flying configuration is the type of drone that we will use. The main types are fixed wing, quadcopter, and hexacopter. A fixed wing drone is a drone that looks and flys like a traditional airplane. Figure 2.0.1 is an example of this type of drone. A fixed wing uses it wings to provide lift, and horizontal propellers to provide force to pull or push the drone in the air. 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.

Figure 2.0.1: Fixed Wing Drone

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 2.0.2 shows this concept.

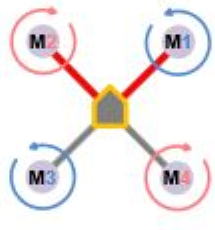

Figure 2.0.2: Quadcopter

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 2.0.3. Generally, Hexacopters have the same capabilities as quadcopters, and operate in much the same way.

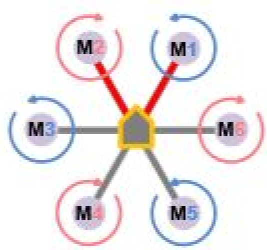

Figure 2.0.3: Hexacopter

The frames for the flight configurations can be made out of various types of materials. 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.

The onboard hardware is the hardware that will be on the drone. This hardware consists of a flight controller, secondary computing devices, electronic speed controllers (ESC), video camera, thermal camera, lidar, and transmitters. All of the hardware is interconnected, allowing for any computing device to talk to any sensor.

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. These advanced software libraries have the ability for preflight planning, autonomous flying, and data transmission to a ground station.

Most of the flight controllers are not designed to be interfaced with thermal or lidar sensors. Instead, a secondary computing device running custom software is needed to handle the data from these sensors. This can be in the form of an Arduino, Raspberry Pi, or other computing device. Through UART, you can connect these computing devices to a flight controller, to allow for system wide communication.

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. Many CAN enabled ESCs are not in the form factor that would work for drones. Most ESCs in the form factor that is needed for this project are PWM based. As long as the ESC is produced by a reputable brand, and the amperage is rated high enough for motor it is connected to, there is very little difference between ESC manufactures.

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.

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.

The communication method is the hardware for communicating data between the drone and the control station. The control station is the hardware on the ground, which generally consists of communication hardware, a laptop for data storage, and a RC controller to control the drone. The required communication hardware is dependent on the computing devices on the drone. Figure 2.0.4 outlines how data would be transmitted through a single transmitter and receiver. This design is not feasible, because the amount of data that could be sent is not sufficient to provide reliable and responsive communications. Most communication hardware is optimized for one method of communication. So to use a single transmitter, we would need to encode the data, build a queue based communication order, and then transmit the data. This would overload the flight controller. If we offloaded this to a secondary computing device, this would increase the response time, which would confuse a human pilot. All flight controlling protocols are designed for their own transmitter. A multi-transmitter setup is shown in figure 2.0.5. This method would be used if video feed is sent to the controller, then passed on to the transmitter.

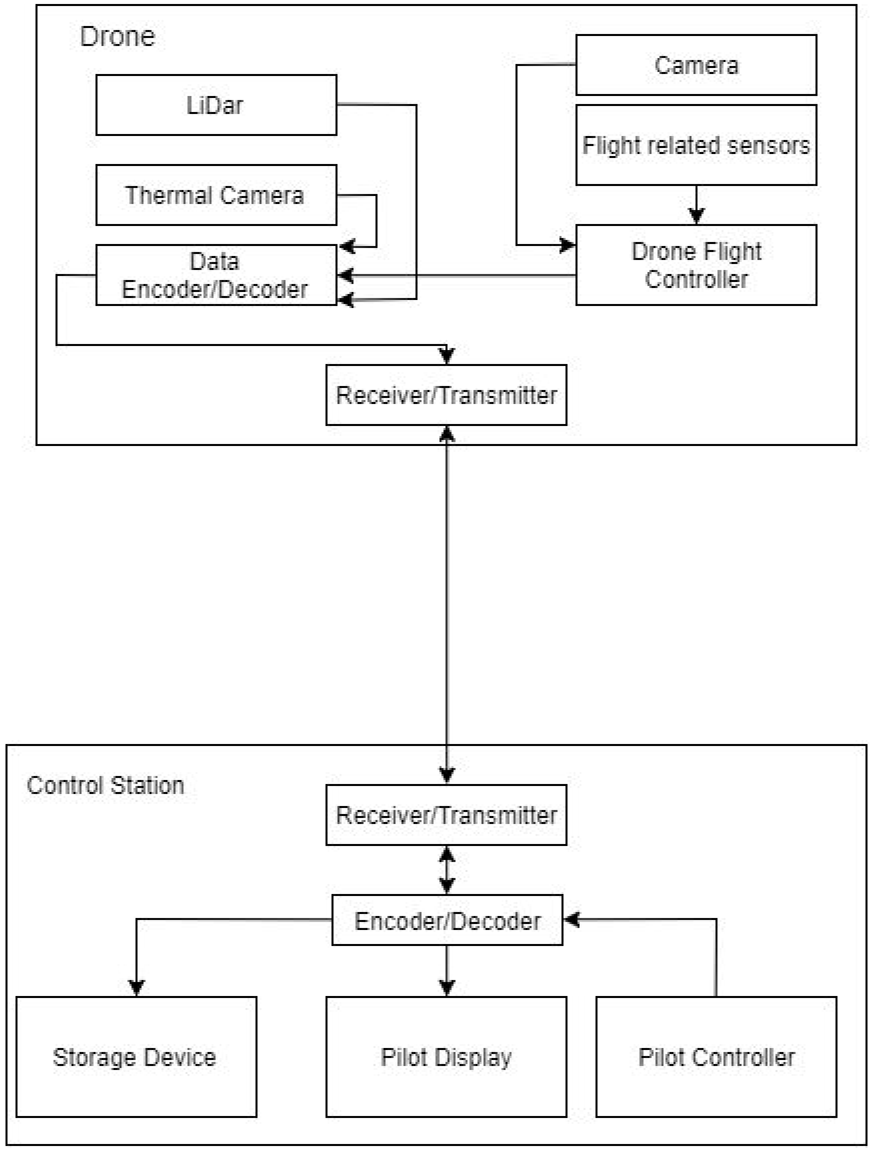

Figure 2.0.4: Single Transmitter

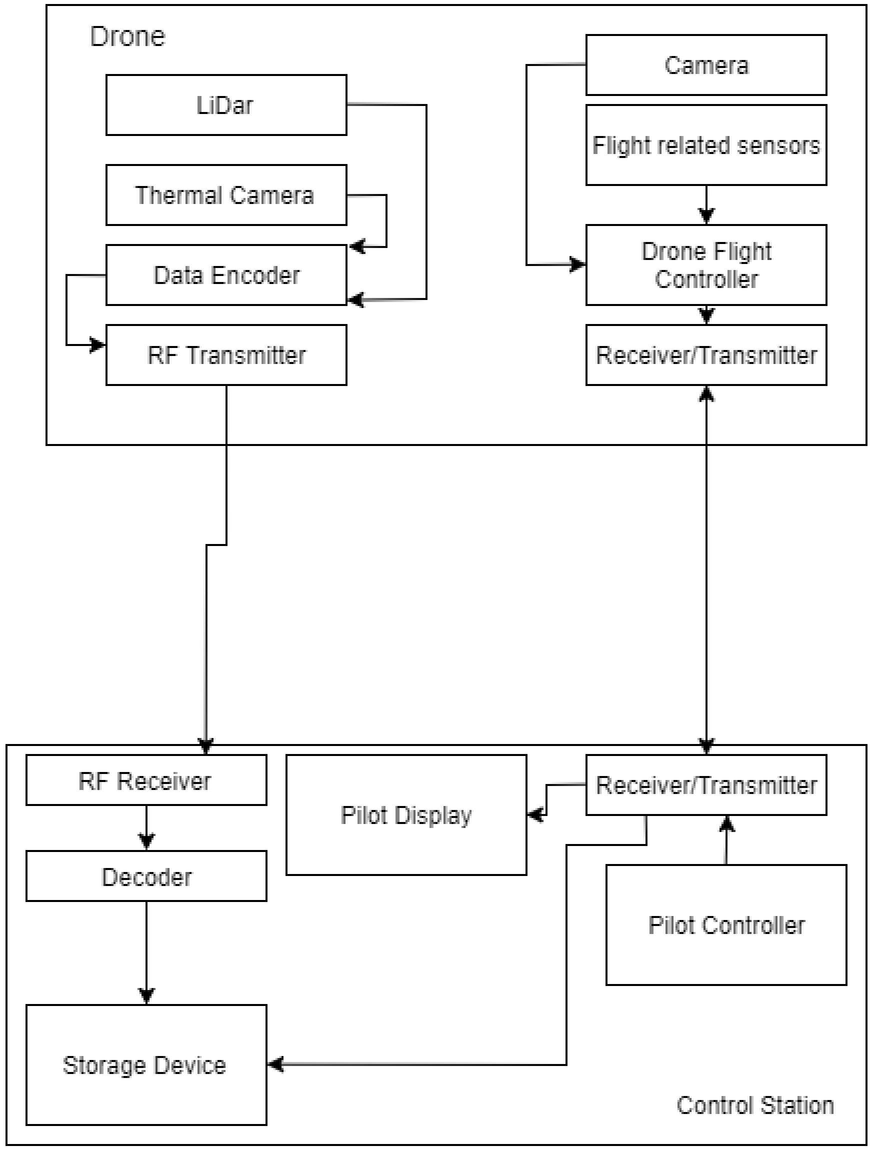

Figure 2.0.6

2.1 Proposed Design

Our proposed design has taken all the research we have done into consideration, as well as feasibility studies we have conducted. For a flying configuration, we are using a hexacopter design. The hexacopter is the most versatile design, allowing for multiple sensor configurations, future sensor upgrading, and multiple hardware mounting options. A hexacopter is also the easiest to fly with its vertical takeoff and landing, as well as its hovering ability. However, this design has the worst battery life. This will require us to use a bigger and heavier battery to keep it in the air for longer. For a hexacopter, carbon fiber is the cheapest and strongest material frame. With this in mind, we are using the Tarot T960 frame. Figure 2.1.1 is an image of this frame. Its larger frame allows us to be more stable in 20-30 mph wind, as well as space for a large battery for longer flight time.

Figure 2.1.1: Tarot T960

Figure 2.1.2 shows the drone's onboard hardware layout, and communication protocols where appropriate.

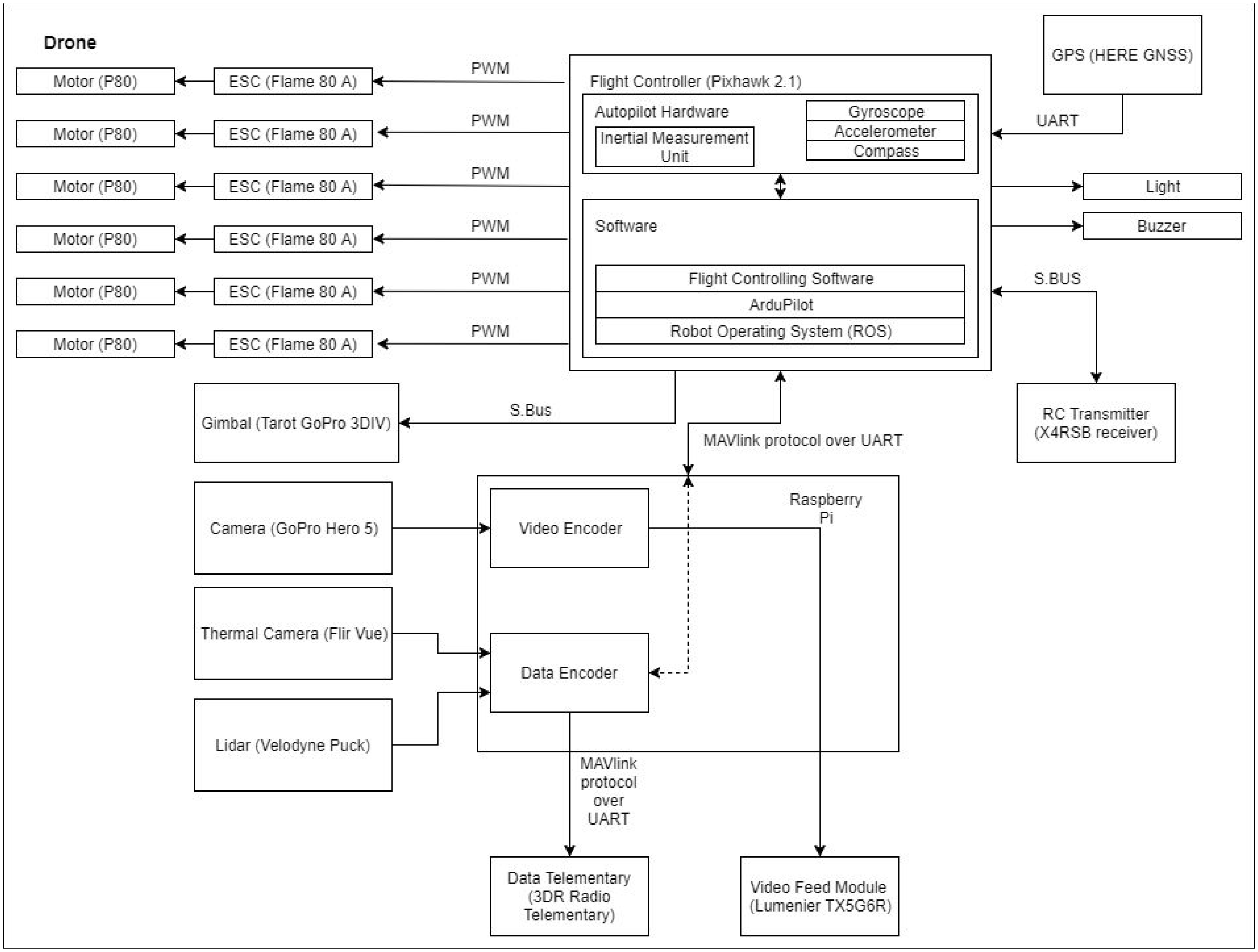

Figure 2.1.2: Onboard Hardware Layout

For a flight controller, we are using the Pixhawk 2.1. We chose this flight controller because of its diverse I/O, open source software and hardware, and reliability. The Pixhawk 2.1 has an ADC port, Spektrum RX port, I2C port, 8 dedicated PWM (output), 2 CAN ports, 2 Telemetry ports 2 Power ports, RC in, S.Bus out, and 8 general purpose I/O ports (each with power, ground, and signal). The pixhawk 2.1 runs on ArduPilot, which is an open source drone software. ArduPilot has many software drivers written, as well as a functional autopilot. Written in C++, it also allows for expansion for custom software. Ardupilot uses MAVlink, a protocol to transfer data to a MAVlink to a ground station. Each release is also thoroughly tested. The Pixhawk 2.1 is designed for industrial usage, and has industrial grade sensors, and onboard sensor redundancy. The Pixhawk 2.1 does not have onboard GPS, so the HERE GPS/GNSS sensor will need to be purchased.

For an ESC, we are using a Tiger Motor Flame 80 A . This ESC supports PWM, has voltage regulation, and is IP 55 rated, which will allow it to be dust and water resistant in normal outdoor usage. We went with the 80 amp variant, as it is compatible with the motor we selected, The Tiger Motor P80.

The Gimbal we are using is the Tarot GoPro 3DIV. This 3 axis gimbal supports a Gopro Hero 5, can interface with our flight controller, and uses the Tarot mounting system.

We are using the Tiger Motor P80 because of its price per performance. The P80 outputs the most thrust at that price point. It also powerful enough to have enough thrust to have one motor fail, and still be able to fly.

Because of the flight controller we are using, we will need a secondary computation device. We are electing to use a Raspberry Pi 3 for this because of its plethora I/O, its GPIO pins, and its processing power. The lidar will be gathering multiple gigabytes of data each flight, which may have to be written to an onboard storage. Our team also has a lot of experience with Raspberry Pi, which will allow for easier development.

The thermal camera we decided to go with is the Flir Vue. The Vue is a thermal camera that is drone friendly, has a higher resolution, and is reliable. Because the drone is higher in the air when scanning roads, we will need the higher resolution to accurately measure the size of the heat pockets on the road.

For a camera, we needed a small form factor, high resolution, and long battery life. For this, we elected to use the GoPro Hero 5 camera. The GoPro camera has the ability to be connected to a Raspberry Pi through third party means, is water and dust resistant, has high resolution. The high resolution is needed for later image analysis.

The lidar we choose to use is the Velodyne Puck. The Puck is a small form factor lidar sensor that is light, and designed for usage with drones. The Puck is also used with other sensor solutions that make custom software to use with the lidar unit. From the lidar sensors we could find with the desired accuracy, the Puck was the cheapest option by at least $10,000.

For radio transmitters, we went with the 3DR Telemetry kit for lidar and thermal data, the Lumenier for TX5G6R, and the FrSky X4RSB receiver paired with FrSky Taranis X9D controller and transmitter. These transmitters and receivers work on 3 very different spectrums. which should minimize interference. Each transmitter is tied to a different functionality.

The ground station will consist of a single laptop running with the receivers for the 3DR and Luminier transmitter, and the X9D controller. On the laptop, the video feed and the lidar data will be captured on a specified path, which can be a local hard drive or an external USB hard drive. The lidar data will be hard to process, so offline data analysis will need to be done at a later time when connected to a power source. With the ground station, the user can configure which sensors to record, what sensors are connected, and the ability to re-scan for sensor changes if a sensor is removed from the drone. The multiple receivers allow for one receiver to fail, and still have graceful degradation.

2.2 Design Analysis

Through the Ardupilot, we are able to do full software simulation of the drone, and is a big help in the development process. With sample code from Ardupilot, we have been able to simulate a drone in this environment. There is a 3D simulation environment that can be added for better understanding of drone sensors, and visual representation of what is happening in this simulated environment. Through this, we have seen that a hexacopter is a good selection in the event of motor failure, as the drone could still theoretically fly.

The Pixhawk 2.1 was selected because of its use of the open source ArduPilot. As stated earlier, Ardupilot has a simulation environment that will help with the development process. It also is thoroughly tested by the community before a stable release is pushed. It also supports many major interfaces and protocols. It also has the framework set up for autonomous flying and preflight planning. This feature was pushed hard by our client, which is why it is important to us. It also has the framework for a ground station, which would allow the user to view the health of the drone, and get real time information on data collection.

We designed this UAV system with the idea that expensive equipment could be attached to the drone. Thus, flight related hardware redundancy and graceful degradation capabilities were important. This can be seen in the choice of a hexacopter, which allows for motor failure without crashing, a flight controller with triple hardware redundancy sensors, health status system, and the ability for somes communication failure, while still being able perform graceful degradation.

The use of a laptop for the UAV system can help the system, but can also be an issue. The drone will most likely be used in a location without power. The amount of data that can be recorded cannot be stored on a single SD card. Thus, the use of a laptop with USB hard drives allows for limitless storage. However, then the entire storage mechanism is tied to a laptop, which can have its own failures, as well as limited battery life. This issue can be solved by having multiple laptops with the software configured to act as the ground station. Because the ground station is modular component part of the system, and the use of open source software, a lightweight control station can be designed with expanded drone storage.

One major concern we have is the battery life. With the size of motor that we choose, battery life is a big concern. With a standard 1,000 mAh battery, we would not be able to get any use out of the battery. Because of this, we are using a 13,000 mAh battery, which is heavier, and will require extra modification to the drone frame for mounting. With the 13,000 mAh battery, we will achieve the 40 minute flight time requirement. Another issue with battery life is the need for a secondary computing device. With more computation power comes more battery consumption. We feel with the raspberry Pi underclocked should see power consumption improvements, and still have the computing power we need. It is also noted that the Raspberry Pi power usage is minimal when compared to the power usage of the motors.

Another concern is all the transmitters we are using, and the interference they may cause. In theory, all 3 work on different frequencies, and should not interfere with each other. Future quality testing will need to be done to verify no interference is found.

Including the raspberry Pi would allow for future sensors to be attached to the drone. With its ample I/O, many various sensors or other peripherals could be connected. Possibilities for future projects include image processing on the Raspberry Pi, onboard storage of all sensor data which would allow one to eliminate the need for a laptop.

3 Testing and Implementation

3.1 Interface Specifications

- Flight Control PC Simulation
    - Ability to simulate drone's flight without the risk of crashing and damaging parts
- Drone Performance
    - Transmitters and Receivers
        - Ensuring these devices are sending signals from the sensor data to a ground station for data storage and live video streaming
    - Sensors
        - Needed to capture video and other imaging for data analysis
    - Onboard Storage
        - Data from the Lidar sensor will be stored on the drone due to insignificant wireless data transfer reliability
- ArduPilot
    - Capability to make the drone autonomous for repetitive tasks
    - Provides interface between hardware and software with included hardware and protocol drivers. Each driver has its own simulation profile.

3.2 Hardware and software

- Flight Simulation Software
    - Testing the performance and flight capabilities of the drone in a virtual environment will allow us to see problems before putting the physical equipment at risk of damage.
- Data Acquisition/Analysis
    - Checking to make sure the sensors are collecting accurate data and reliably sending it to be analyzed is of utmost importance, and the cornerstone of this project
- Hardware Performance
    - The two main hardware performance characteristics we will be monitoring are data reliability and power management. Maintaining accurate data transmission is critical to being able to detect faults correctly and consistently. Quality power management is necessary so every component has the power it needs to perform efficiently, and no component(s) draw too much power away from any other component(s).

3.3 Process

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

3.4 Results

We have not yet begun the testing phase, and do not have any results to share at this time. Our team is optimistic that with careful testing of each component and the system as a whole, the UAS will meet or exceed the goals we set out for it.

4 Closing Material

4.1 Conclusion

Our end goal is to be able to use an Unmanned Aircraft System to evaluate the safety and effectiveness of bridges, roads, and any other infrastructure that needs inspecting. We started this semester by understanding all the aspects of our project, like what hardware and software requirements are needed and how each member can contribute to solve these problems. After talking to the client, and reading more about the project requirements, every team member had a thorough understanding of what needed to be accomplished.

The next step in our process was to make a goal sheet, where we planned out how we can accomplish this task in the two semesters we have. So, we created gantt charts, tables, and lists to map out what we want to accomplish, and have thoroughly done so for at least this semester. Once we have accomplished some of the goals this semester, then we can start to map out what needs to be done for 2nd semester. Our major goals this semester include:

- Be able to modify a drone, to meet our project specifications
- Research about the specific parts, sensors needed for our drone, ex. Lidar, gimbal, etc.
- Buy these parts
- Build the drone with our ordered parts
- Test out the sensors and parts, and make sure everything can run smoothly

As of right now, we as a group have finished up researching our specific parts, and now are in the phase of trying to purchase these equipments. We have sent our parts list, with a specific recommendation that we think is the best for our project, to our client. Once we discuss this in detail with him, we can start purchasing the parts and as they arrive we can start building and testing to make sure we are on the right path.

If all goes to plan, then we should be able to build and start testing our first prototype of our drone. We can try to test with a flying drone, but as of now what we plan to do is a great end to the semester, and an amazing start to the next semester, where we will focus on flight and testing in the air.

4.2 References

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4.3 Appendices

Appendices will be added in the future as needed.