Cover Pages

* Title page
* Abstract
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### (Introduction/Background)

#### Chapter 1: Introduction

* + **Project Background and Motivation**
    - USGS Goal
      * Map the earth’s magnetic field
      * Researchers at the United States Geological Institute (USGS) are collecting data on the earth's magnetic field in order to conduct research on geologic faults and anomalies such as underground rivers(citation needed). In order to collect this data they use drones with an attached magnetometer that makes 7 consecutive 15 minute flights in order to conduct just one survey.
    - **Collecting Data with Drones**
      * Pros
        + Mobility
        + Safety
        + Control
        + Autonomous design
      * Cons
        + Battery issues
        + Magnetometer interference
        + General drone operations
  + **Existing Solutions**
    - DJI Matrice Pro
    - H-Aero
  + **The Need for a Better Solution**
    - 4 Lenses
    - Hint at Barone2 design
  + **Project Description**

### (Body)

#### Chapter 2: Design Considerations of a Buoyant Drone

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - In this chapter, we first introduce the flight conditions and payload requirements. Next, we address the necessary physics to consider with a buoyant drone design, as well the problem with drone controllability. Finally, with the high level system understanding developed in this chapter, we introduce the general design of the drone.
  + **Project Goals and Requirements**
    - Team Goals and System Technical Requirements
    - Minimum flight requirements
      * (List Tech Requirements here for flight conditions)
  + **Physics of a Buoyant Drone**
    - Benefits of Buoyancy
      * Reduced Weight
      * Less reliance on motors to lift
        + Less magnetometer interference
        + More battery power = longer flight time
      * Self correcting buoyant moment
    - Issues buoyancy causes
      * Buoyant moment
        + Drone cannot tilt like standard drones
        + Lose controllability with normal quadcopter flight controllers
      * Limited Flight conditions
        + The drones larger size increased drag force on the body of the drone limiting the conditions it can fly in, to lower wind speeds.
      * Makes a more massive frame
        + Motors need more energy to accelerate
  + **General Design Overview**
    - Using rotating rotors to control drone
      * We can rotate our propulsion force axes using servos to change direction of forces so we can fly.
        + Propeller can point up, down, forward, backwards, and anywhere in between
    - Ellipsoidal lift bag to decrease drag
      * Increases controllability and reduces energy needed to fly.
      * Provide wind tech req
    - Motors Mounted far from magnetometer to decrease interference
      * Magnetometer interf req
    - Using Ultrasonic Sensors for terrain tracking
      * Approx 1 m off ground
      * Terrain tracking req

#### Chapter 3: Lift Bag and Drone Frame Design

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 3 covers the mechanical design of the drone, addressing drag and secure physical system mounting.
  + **Lift Bag Design**
    - Technical Requirements that need to be met. 5mph in 15mph wind. Minimize energy expenditure by reducing forces during flight
    - Adopted Ellipsoidal shape to Reduce Drag
    - Drag Analysis
    - 9’ diameter Lift Bag chosen to hold 4m3 of helium
  + **Gondola Design**
    - Technical Requirements
    - Requirements for Gondola
      * What it needs to carry, how its mounted
    - Materials chosen for durability
      * Pugh Chart
    - Keeps center of mass below center of buoyancy
  + **Ultrasonic Mounting**
    - Technical Requirements
    - Design of ultrasonic sensor bracket for best area coverage for terrain tracking
    - Placement in front center of drone
  + **Servo Mounting**
    - Technical Requirements
    - Placed equidistant around center of envelope
    - Discussion of placement to reduce interference. (interference analysis may be done here or maybe in power?)

#### Chapter 4: Propulsion Design and Actuator Interface

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Propulsion design explores in detail the physics of our approach to achieving system controllability. From there, motor, ESC, servo, and propeller selection are analyzed to develop an effective rotating rotor system. Finally, we go over how we interface with the propulsion system.
  + **Physics of a Rotating Rotor Design**
    - Deals with buoyant moment by turning without having to tilt entire drone
    - Describe physics nonlinear model and effects on controllability.
  + **Propulsion System Design**
    - Minimum flight requirements listed. Wind, mass etc
    - Motor, ESC, Propeller, and Servo selections
    - Response times and power output
  + **Interfacing with the Servos**
    - Technical Requirements
    - PWM Interface with microcontroller
    - Duty cycle
    - 360 degree angle
    - Control Software for position
    - PCB
  + **Interfacing with the Motors**
    - Technical Requirements
    - PWM Interface with microcontroller
    - Duty cycle
    - Update rate
    - PCB

#### Chapter 5: Sensor Array, State Estimation, and PCB Interface

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter five goes over the sensor array needed to determine the current state of the drone, error handling, and PCB interface. The process of how the state is estimated, through integration and complementary filters, is analyzed at the end
  + **Microcontroller PCB Design**
    - Technical Requirements
    - Clock rate
    - SPI slave to microprocessor
  + **Interfacing with Ultrasonic Sensors**
    - Technical Requirements
      * Terrain tracking
    - Update rate
    - Name of Sensor.
      * Sensor Specs
    - Trigger pins for distance read requests
    - Echo pins for distance read
  + **Interfacing the IMU Sensor**
    - Technical Requirements
    - Accelerometer detection
    - Fall detection/error detection
    - Name of Sensor.
      * Sensor Specs
    - Update rate
    - I2C communication with microcontroller
  + **Interfacing with the Pressure and Temperature Sensor**
    - Technical Requirements
    - Altitude tracking
    - Name of Sensor.
      * Sensor Specs
    - Update rate
    - I2C communication with microcontroller
  + **Interfacing with the GPS Sensor**
    - Technical Requirements
    - Name of Sensor
      * Sensor Specs
    - Update rate
    - UART communication with microcontroller
  + **Interfacing with the Lift Bag Pressure Sensor**
    - Technical Requirements
    - Detects helium leakage out of the balloon
    - Name of Sensor.
      * Sensor Specs
    - Update rate
    - I2C communication with microcontroller
  + **State Estimation**
    - Technical Requirements
    - State Estimation Design
      * Integration
      * Complementary filters
    - Update Rate

#### Chapter 6: Control Design

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Control design analyzes the drone physics, and develops a control system for the drone. There is open loop control implemented in our Simple Remote Control Design, that allows for basic RC functionality. Next, is autonomous flight control that is necessary for terrain tracking and path following. Next, we confirm functionality through simulation. The state machine and auxiliary autonomous functions, such as auto take off and landing, are developed and tested. Finally, an RC system was developed that uses some autonomous functionality to assist the user.
  + **Simple Remote Control Response Design**
    - System Tech Req
    - Open loop controls
    - Used for early testing
    - No autonomous functions
    - New layout of drone controller
      * Since we don’t fly like normal quadcopters for hexacopters, we have different inputs so we lay them out for the user
  + **Plant Definition in State Space Form**
    - Applying force equations defined in chapter 2 and 4 and solving for the accelerations for the drone
    - Define all states and inputs
    - We applied small angle approximation to the rotation matrix since we don’t change the pitch and roll angles
    - Description of the linearization of the system
      * Describe limits of plant definition. For example, if the pitch angle is 45 degrees, a small angle won't apply.
  + **Applying a PID Controller for Path Following and Terrain Tracking**
    - System Tech Req
    - Applying root locus to pole placement
    - Adding in integral control for robustness
    - System step responses to different inputs
    - Testing model for path following and terrain tracking
  + **Integrating State Estimation with Controller Design**
    - How state estimation is integrated with controller
    - Noise rejection
    - Noisy sensor response to step inputs and autopilot
  + **Testing the Discrete Linearized System Against Nonlinear Model**
    - Discretizing the control system for application on our drone
    - Development of a nonlinear model for system responses
    - Testing the linearized discrete time system with the nonlinear response model
    - Stability analysis
  + **Auxiliary Functions and State Machine Design**
    - System Tech Req
    - State machine design
      * Landing, take off, error handling, switching between control systems (if applicable)
    - Take off and landing procedures
    - Error response
      * Tech req
      * Dead motor
      * Sensor malfunction
      * Crash detection
  + **Remote Control Response with Autonomous Functionality**
    - New input and output definition
    - Applying root locus to pole placement
    - Adding in integral control for robustness
    - System step responses to different inputs
    - Testing system response in simulation

#### Chapter 7: Power Analysis and Flight Time

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - This chapter analyzes the power consumption of the drone during flight, how power is distributed throughout the system, selecting an appropriate battery to meet the minimum flight requirement with minimum wind speed requirement, and dissipating heat on the drone, and the estimated flight time for the drone.
  + **Power Usage During Flight**
    - Technical Requirements
    - Microcontroller and Microprocessor
    - Sensors
    - Motors, Servos
  + **Power Simulation Analysis**
    - Added power consumption estimations into flight simulation tests to confirm power usage estimations
  + **Distributing Onboard Power**
    - Technical Requirements
    - Power Rails
    - Stepping Down Voltage
  + **Heat Dissipation**
    - Technical Requirements
    - List everything analyzed
    - Gondola plate
  + **Battery Selection and Drone Flight Time**
    - Technical Requirements
    - Battery selection
    - Pugh chart of different battery options
    - Estimation of final flight time

#### Chapter 8: Full System Simulation and Validation of Drone Design

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 8 analyses the detailed simulation for drone flight that is developed in a V-Rep environment. The simulation covers physical response to inputs, tests of the state machine, noisy sensor inputs, and control system response to identify flight response before test runs and inform of any necessary design changes.
  + **Force implementation in Design Using GUI**
    - Technical Requirements
    - Buoyant Forces
    - Throttle/Thrust Forces
    - Drag Forces
    - Individual Gravity Forces
  + **RC Control**
    - Technical Requirements
    - Input Layout in GUI
    - Tests run
    - Analysis of data
  + **Sensors Array**
    - Technical Requirements
    - Noisy sensors and the accuracy of state estimation onboard the drone.
  + **Autonomous Controls**
    - Technical Requirements

#### Chapter 9: Testing in a Controlled Environment

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 9 is where we test the drone in a lab setting in order to ensure safety during test flights. We also test certain functions only in this setting, such as crash detection, since it is not feasible or safe to test these functions in an actual flight for our team.
  + **Designing tests to test drone capabilities**
    - Description of each test and setup
  + **Analysis of Test Data**
    - Flight Time
    - Crashes
    - Helium Loss
    - Control Systems
    - Autonomous/Remote Control

#### Chapter 10: Testing in a Variable Environment

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 10 goes over test flights outside on campus
  + **Designing Tests to Test Drone Capabilities**
    - Description of tests and setup
  + **Analysis of Test Flight Data**
    - Flight Time
    - Helium Loss
    - Control Systems
    - Autonomous/Remote Control

#### Chapter 11: Legal and Safety Requirements

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Flying drones requires XYZ and we go over the processes we went through in order to meet minimum FAA and campus requirements.
  + **FAA Registration**
  + **Drone Insurance**
    - “Insurance for school projects is provided through the school when you submit your documentation. “
  + **Flight Requests**

### uas safety to processes paperwork

* + **Covid Restrictions**
    - Limits on people in lab

### (Lessons Learned)

#### Chapter 12: Successes and Failures

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
    - Chapter 12 analysis the ability of the drone to meet the system technical requirements and determines that the project is (successful/unsuccessful)
  + **Meeting Technical Requirements**
    - List all requirements and whether they were met or not
  + **Client Response**

#### Chapter 13: Next Steps

* + Introduction to the Chapter. Brief summary of chapter contents and what to expect, 1~2 paragraphs, directly under chapter title, no section header.
  + Areas that need improvement, or changes to consider in future iterations
    - Improvements to client response
  + What to watch out for in further iterations
  + Research these other areas
  + Future/developing technology

### (References)

#### Chapter 14: Appendix

* + **Github**
  + **Other links**
  + **CAD Drawings**
  + **Bibliography**