Boston University
Electrical & Computer Engineering
EC463 Senior Design Project

First Semester Report

Pizzair

Submitted to
Spinnaker Analytics
200 Clarendon St, Boston, MA 02116
(617) 303-1938
by
Team 4
Pizzair

Team Members
Compton Bowman comptonb@bu.edu
Ahmet Caliskan aeclskn@bu.edu
Yafei Chen yafeic@bu.edu
Usman Jalil ujalil@bu.edu
Quentin Clark qtcc@bu.edu
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Executive Summary

Current challenges in pizza delivery, including delays, cold pizzas, and operational inefficiencies, prompted the development of an innovative solution. Traditional human driven delivery services face increasing difficulties, exacerbated by factors such as the COVID-19 pandemic. Pizzair aims to transform the pizza delivery industry by introducing an AI-enabled, fully autonomous pizza delivery drone. The final prototype will meet specific criteria including maintaining food temperatures, having a secure harness mechanism, and costing under $3000. The navigation and codebase will support self-navigation, notifications, and prioritization of delivery routes.

Pizzair proposes a technical approach featuring an AI-enabled drone for pizza delivery. The drone ensures timely and safe delivery within a 10-minute radius. Equipped with a specialized harness, Pizzair maintains food temperatures and optimizes routes through autonomous navigation. This system aims to enhance customer experience and operational efficiency for pizza restaurants.

Pizzair employs machine learning algorithms for self-navigation, allowing the drone to adapt to dynamic environments during delivery. The drone features a specialized harness to securely pick up and deliver pizzas while preserving their temperature, ensuring customers receive hot and fresh pizzas. Also, Pizzair's system includes real-time notifications to customers and pizzarias, keeping everyone informed about the delivery process.

1. Introduction

In response to the persistent challenges affecting the pizza delivery industry, we propose an innovative solution aimed to redefine food delivery norms. Many customer quality of service problems lie in the inherent inefficiencies of traditional delivery methods, ranging from delays and compromised food quality to escalating demands on delivery personnel, especially in the context of the recent COVID-19 pandemic.

One potential solution to ameliorate many of these problems is leveraging increasingly powerful autonomous systems to help offload delivery work onto drones. Drones are fast, increasingly reliable, and after the onset cost of purchasing a drone, cheaper both economically and in terms of spent resources (human hours, energy, etc.) than a traditional delivery person in an automobile.

However, current autonomous delivery systems are large, difficult to use, and expensive, being primarily designed for longer-range delivery of larger payloads, like health resources to remote regions. Our project is investigating the viability of a lower-cost alternative, primarily designed for urban and suburban low-range delivery, that would be a viable option for restaurants to individually purchase and use as an alternative delivery mechanism in addition to or in lieu of human delivery.

The purpose of Pizzair is to introduce an AI-enabled, fully autonomous pizza delivery drone. Pizzair aims to alleviate the constraints faced by traditional delivery services, offering cost-effective, efficient, and technologically advanced alternatives that redefines the customer experience. Our team's approach is centered around the development and implementation of an autonomous delivery platform. Pizzair seeks to optimize delivery operations for pizza restaurants, ensuring prompt and high-quality service to customers within a 10-minute radius.

Pizzair addresses the problems with traditional delivery service listed above. The autonomous drone system guarantees swift and reliable deliveries, overcoming issues of delayed arrival and cold pizzas. Through real-time monitoring and secure harness mechanisms, Pizzair ensures the safety, quality, and efficiency of pizza deliveries.

Special features of the project include the following:

- Pizzair will operate autonomously.
- Pizzair will have a specialized harness mechanism to preserve the temperature of the pizza during flight.
- Pizzair will offer a cost-effective alternative to traditional delivery services.
- Pizzair will inform customers and pizzeria with real time notification throughout the delivery process.

2. Concept Development

Here you describe your analysis of the customer's problem and its translation into specific engineering terms. You should address:

- your engineering understanding of the customer's problem,
- the conceptual approach you have chosen to solve the problem, and

You must reduce the customer's needs to a small number of engineering requirements. You must identify those requirements as a ***1-page attachment, Appendix 1***

Elaborate on the conceptual approach for your project. Explain briefly why you chose your proposed concept, and mention one or two of the alternative solutions you considered and abandoned.

(This section should be 2-3 pages)

You MUST include a 1 page Requirements list as Appendix 1.

Our client, Spinnaker Analytics, listed a number of requirements. These include the final product being under $3000, full autonomous navigation, and safe and reliable pizza delivery. One initial area of concern was the budget requirement. Existing holistic delivery drone systems are far more expensive, so our much smaller budget led us to spend a lot of time researching drones that are cheap yet powerful enough to carry 2 medium sized pizzas. For example, most existing industrial use drones are around $10,000 dollars, far beyond our budget. Our search for customizable but powerful drones led us to the Arris EFT X6100 Hexacopter, which is in our budget and suitable to hold and carry a pizza box.

When visualizing the hardware and software architecture we divided the entire system into multiple blocks. There will be a web application that sends address information from the client to the drone. There will be a microcontroller on-board that is responsible for receiving the data from the ground, handling sensor fusion, and giving control commands to the drones' flight controller, which is itself a small computer module. Increased weight puts a greater strain on our battery and cuts into flight time, so reducing weight is an important consideration. Finally, there will be a harness under the drone to carry the pizza, the exact nature of which we are still doing research on.

For our on-board computing, we decided to use the Nvidia Jetson Nano, a microcontroller with a built-in GPU that helps it perform machine learning inference better than other well known microcontrollers like Arduinos or the ESP32. The Jetson Nano will handle all the computation on-board for navigation, and facilitate communications between the drone and the ground. The Nano's tasks include receiving delivery addresses from the web application, sending back the drones' GPS location, destination location processing, our ML algorithms for routing and object avoidance, and feeding data into the flight controller. The flight controller is responsible for controlling the motors of the drone, and research showed the Pixhawk PX4 flight controller is a strong choice for autonomous drone projects.

The Pixhawk PX4 flight controller needs to have drivers installed and calibrated to fly properly, which is done by ground control software such as Mission Planner or QGroundControl. Mission Planner was only supported for Windows, so we decided to go with the QgroundControl program. Aside from driver installation and calibration, these ground control softwares also provide planning missions for autonomous flights. We thought we could use the application to test our drone at initial stages. Because the drone is required to be fully autonomous, we will be replacing the ground control software with a dronekit python API that is capable of mission planning. The flight controller also comes with a GPS module that we will be using to send GPS data to the Nano and the ground web application for monitoring the drone's location.

During test flights, in order to ensure safety, we will set up a manual controller and override to the drone so that we can step in at any time if the drone behaves abnormally.

In order to meet a client requirement that our platform utilize machine learning (ML), and to help solve some of the perception and control problems associated with autonomous robotic navigation, we decided to incorporate a convolutional neural network (CNN) for obstacle avoidance. Inspired by existing literature on autonomous drone flight, this algorithm learns when the drone is close to crashing and learns how to avoid them. This is done via imitation learning (IL) where existing clips of safe and unsafe drone flight are taught to our machine learning model. This will help meet the client requirements about requiring minimal user intervention and greater autonomy.

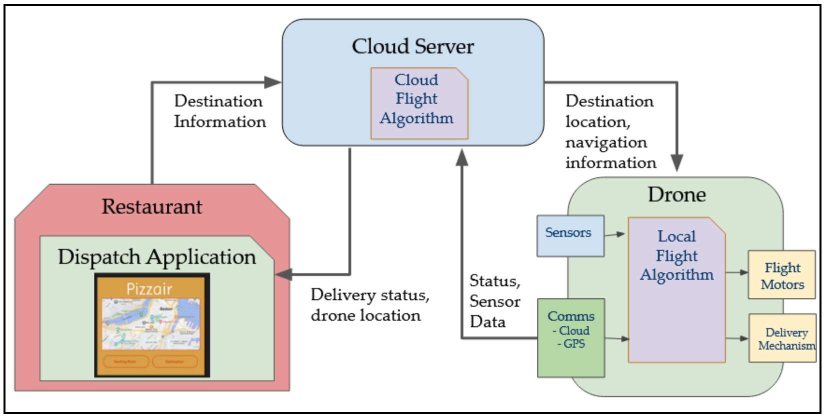
[QUENTIN PARAGRAPH ABOUT APPROACH TO ML ALGORITHMS AND WHY SO, HOW THEY RELATED TO OUR REQUIREMENTS]

[USMAN PARAGRAPH ABOUT WHY FLASK APP ETC.]

[MAYBE A CONCEPTUAL APPROACH ABOUT HARNESS? WHAT OPTIONS THERE ARE ETC]

3. System Description

The Pizzair platform consists of two components: a physical drone for the delivery, and a separate application for the user to interact with the delivery drone. The drone itself combines a large hexacopter drone on the hardware side with a control solution combining GPS, route planning, and imitation learning for obstacle avoidance on the software side. The web application will use Flask, a platform for Python web development, and external hosting.



Figure[X]. Diagram of the Pizzair platform.

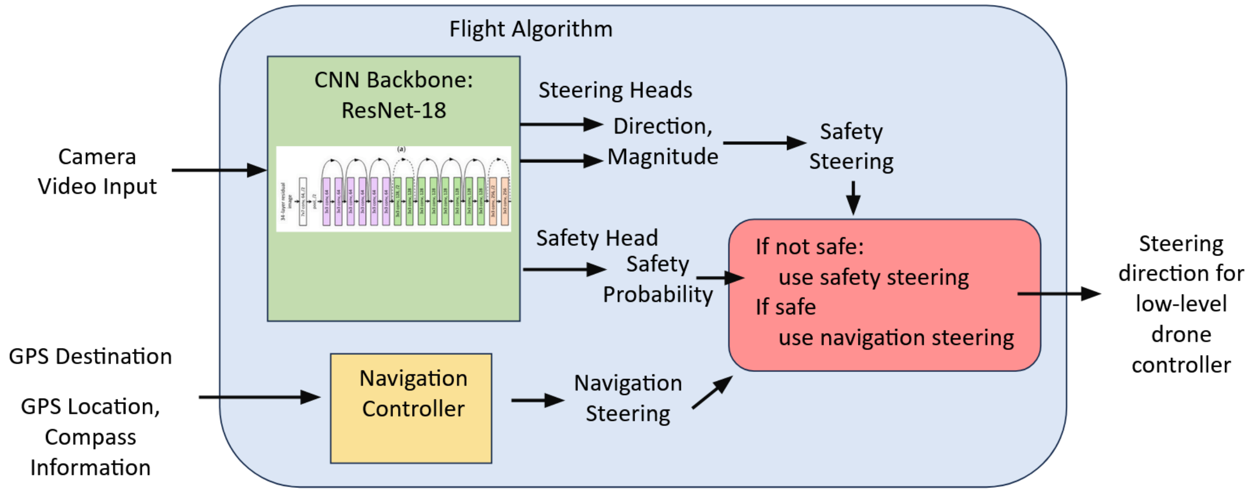
The physical drone is an Arris EFT X6100 Hexacopter, a drone marketed towards industrial uses (like remote maintenance) combined with a Pixhawk flight controller, NVIDIA Jetson Nano for onboard processing for control, and a GPS/Compass and camera for external sensing.

Picture [X]. Arris EFT X6100.

The EFT X6100 can lift an effective payload of around 5 kilograms for approximately half an hour. We estimate our solution for securing the pizza payload and the pizza itself will fit within this weight restriction.

The Pixhawk handles low-level motor controls, and the NVIDIA Jetson synthesizes GPS, compass, and camera information to give high-level navigation controls to the Pixhawk. The NVIDIA Jetson has a built-in graphics processing unit (GPU) that lets it perform real-time inference of a machine learning algorithm to aid the drone in obstacle detection and avoidance. The machine learning algorithm is a deep convolutional neural network (CNN) that takes in grayscale images from the drone's camera, and outputs a safety level, steering direction, and steering magnitude. This network is trained using a combination of data we collected in sim and publicly accessible datasets of drone and pedestrian behavior. To ensure robustness, the dataset includes many samples of both successful drone navigation and unsuccessful drone navigation, which helps recovery behavior.

The flight algorithm itself synthesizes information from the GPS location, accelerometer information, target location fed by the web server, and CNN's outputs to create high-level drone control commands intended to navigate the drone towards its target destination while avoiding obstacles. For our initial experiments, we implemented a simple "decision tree" algorithm: if the safety level is above a manually tuned threshold, the drone will use the network's steering commands to avoid the obstacle. If the level is below, the drone prioritizes moving towards its final destination. However, we are looking into more intelligent ways to synthesize our drones' sensory information and CNN outputs so that flight is smoother and safer.



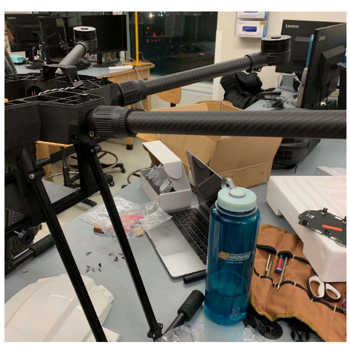
Above - overview of our current, simple flight navigation algorithm.

4. First Semester Progress

We have done the following:

Hardware:

- Finish assembly of the drone including landing gear, battery holder, and motors.
- Wired pixhawk flight controller with motors, GPS module, safety switch, buzzer, radio telemetry and power module.
- Tested functionality and accuracy of all sensors.
- Completed preliminary design of harness and containment mechanism.



Above - Drone under construction

Software:

- Acquired all of the necessary hardware, including the Pixhawk Controller, the NVIDIA Jetson Nano, a GPS/compass device, and a camera. The Jetson has been configured with an operating system and an installation of the needed Python packages, including OpenCV for vision and PyTorch for machine learning inference. Due to the accident in the Senior Design lab, we will need to procure replacements for our camera, NVIDIA Jetson Nano, and re-perform the software setup process.
- Collected and labeled around 30,000 images of training data, including writing a small labeling program.

Above - two samples from our training dataset we collected from Watch Dogs 2.

- Trained an initial CNN architecture on our collected data.
- Set up AirSim, an open-source Unreal Engine based simulator, for testing our algorithm.
- Wrote an initial version of our navigation algorithm and tested our trained CNN in the real world on a Parrot AR drone and in AirSim.

Above - pictures from our real-world testing in a parking lot and park, and a screenshot of a test in AirSim.

We have the following to be completed:

- Experiment with CNN architecture and training regimens for the drone navigation component
- Collect additional training data if we see the need, including potentially real-world data.
- Web stuff?

kjnl

5. Technical Plan

Task 1: Final Drone Assembly check
The drone will be checked for any structural issues, and made ready for energization. This includes ensuring all connectors are secure and at the right torque, leveling the motors, ensuring components are secure in their flight positions, etc. Lead: Compton

Task 2. Battery Power Supply Test
A 16000mAh 15C 6S1P Lipo Battery shall be tested for how long it supports the drone to cruise once fully charged and how long it takes to recharge. The voltage and current ratings of the battery power supply will be compared with the expected values for our motors, propellers, and Pixhawk Controller prior to energizing. Lead: Yafei

Task 3. Drone Connectivity Range Test

We will test the drones connectivity under various conditions include adverse weather. Lead:

Task 4. Automation Tests and Refinements
More tests and improvements of our algorithm, including refining the network architecture, increasing or modifying our training data, et cetera will be performed. We will set up more structured, quantitative tests in simulation (with special obstacle courses defined with quantitative success metrics), and test the resulting algorithms in a greater diversity of real-world environments. Lead: Quentin.

Task 5. Payload Attachment Mechanism Design
An attachment to store the pizza box shall be designed, fabricated, and tested. It shall support the safety and easy access of the pizza box inside while not blocking the vision of the camera and the landing mechanism. The design will be tested for the temperature drop inside before and after the delivery, completeness of the pizza box after being dropped off, toughness, and water resistance. Lead: Compton

6. Budget Estimate

Item	Description	Cost
1	ARRIS X6100 Hexacopter	$999
2	Pixhawk px4 2.4.8 32-bit ARM Flight Controller	$269
3	NVIDIA Jetson Nano Developer Kit	$149
4	Tattu 16000mAh 15C 6S1P Lipo Battery Pack	$319
5	Logitech Hd Webcam C270	$20.5
6	Micro SD Card	$15.0
	Total Cost	$1736

Upon our client's request, we are trying to get the final product under $3000. We already purchased the bulk of the equipment we need. We still haven't fully decided what battery we are going to be using long-term. We have a couple of batteries at our disposal from BU that we are going to use for testing, but, eventually, we are going to stick to a single battery. Aside from the battery unless a replacement is needed, the purchases moving forward are going to be very minor.

7. Attachments

1. Appendix 1 – Engineering Requirements

Team # 4 Team Name: Pizzair
Project Name: Pizza Drone Project

Requirement	Value, range, tolerance, units
Case dimensions	2m x 2m x 1.4m
Power	1GJ photon source, and 3V battery
Transport range	>100 light years

Transport nodes	3 in simplex mode (no return possible); in duplex mode (round trip stored)
Radiation dose	20 REM/trip +1 REM, -3 REM
Transport error rate	$< 10^{-11}$ molecules of normal body mass $< 10^{-15}$ molecules when sending DNA data

These are your requirements specifications that transform the customer's needs and wants into specific engineering requirements. See the course textbook regarding the formation of appropriate specifications. Generally these are at the system integration level. Each unit that you design will have its own internal specifications, but these are usually not listed in a proposal.
Specifications should <u>not</u> include vague environmental constraints.
Specifications should <u>not</u> be statements of technology preferences or early design decisions (e.g. "The unit shall use Li ion batteries" is not a specification.)
Not more than one page.

A preliminary proof of concept indicates the capability of the following:

1. Operating successfully in a controlled test environment, such as an empty field or small neighborhood block
2. Reliable performance in simulation.
3. Smaller delivery load capability of a couple of hundred grams.
4. A working delivery drone final prototype indicates the capability of the following:

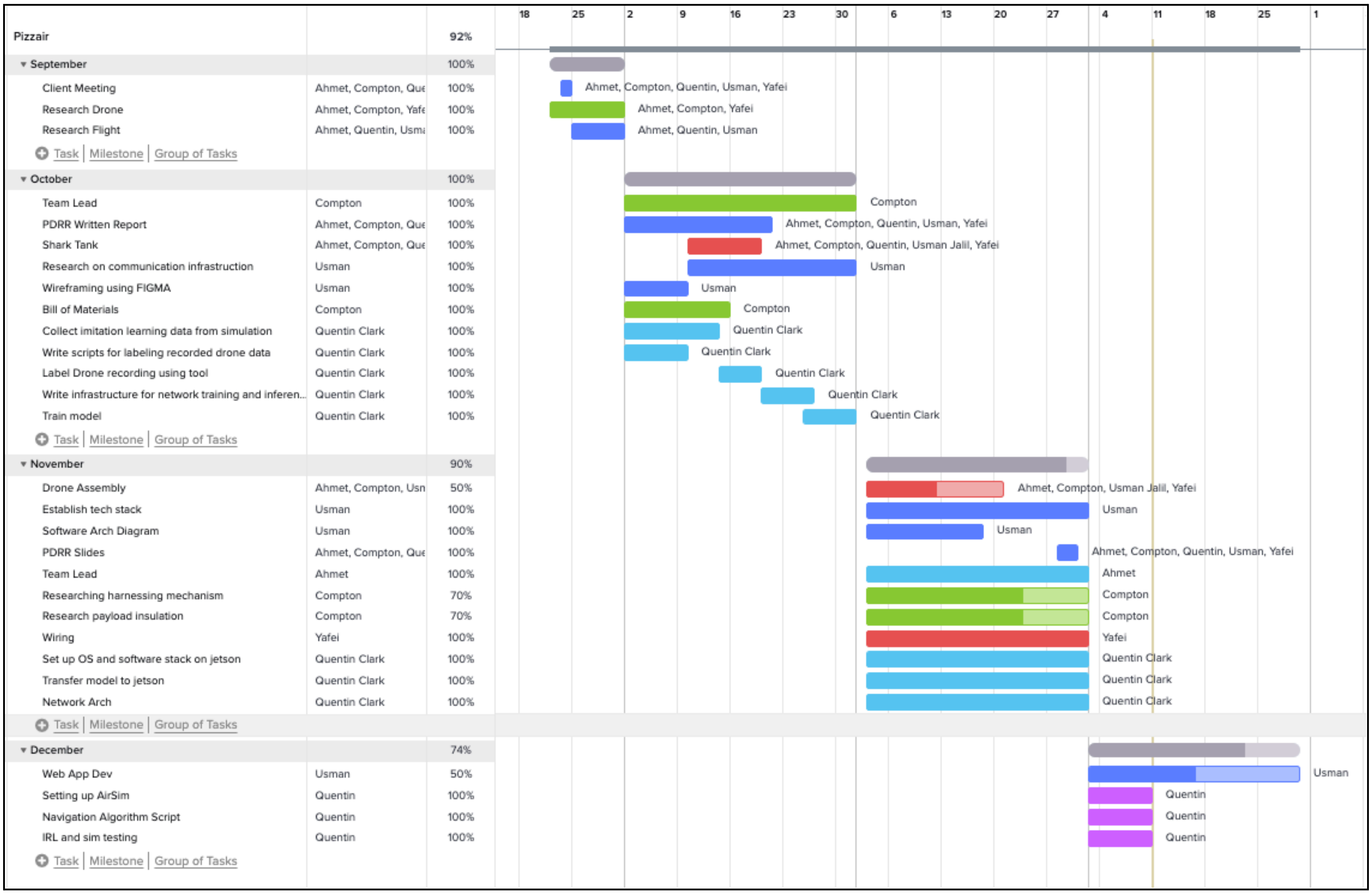
Maintaining the temperature of food product to delivery

1. Harness mechanism allowing easy access to pizza
2. Keeping pizza unharmed under bad weather conditions
3. Costing under $3000 per drone
4. Compliance with Federal Aviation Administration (FAA) regulations for autonomous drone flight, disregarding licensing requirements.

Navigation and associated codebase indicates the capability of the following:

1. Self-navigation
2. Sending notifications to customers and pizzerias regarding delivery
3. Prioritizing delivery routes if multiple orders are to be delivered in short span of time

2. Appendix 2 – Gantt Chart



3. Appendix 3 – Other Appendices

Other typical attachments that are added to bolster the competitiveness of your proposal:

- Technical references (in proper bibliographic form) including key URLs.
- Your drawings and schematics (rather than embedding in text)
- Team information sheet (Biographical paragraph on each member; phone numbers and e-mail, history of team and company)

<u>Do not pad with mundane data sheets and application notes.</u>

Spell Check Everything!!!!

Paginate and edit footers and headers for your team.

Work through <u>at least</u> two drafts before submitting final document.
DO NOT bind, put in fancy covers or otherwise embellish. Simply clip with spring binder in upper left corner.
Use MS Word or PDF format for final document.
Submit one soft copy to course via Blackboard Digital Drop Box, and one copy to customer (include cover letter to customer).

The body of the proposal should not exceed 20 pages.
(This excludes the cover page, table of contents, executive summary, and attachments.)