University of Central Florida

College of Engineering and Computer Science

MediDrone

Divide & Conquer; Version 2.0

Senior Design 1

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Contents

1. Overview

i. *Purpose*

In the past decade drone delivery systems have taken a significant role in reducing delivery time and costs. Companies such as Amazon are working on developing drones to deliver store items to customers. Restaurants are exploring the option of delivery drones for making food deliveries. The purpose of this project is to extend the use of delivery drones for making deliveries of medical items such as vaccines and organs.

The intended use of the medical drone delivery system is to accelerate deliveries between hospitals and to places where land vehicles are slow to reach. Hospitals may sometimes run out of a resource, such as an organ. In the case of an emergency, the time it takes to deliver the organ from another hospital or to deliver the patient to another hospital may be too long. Drones can be used for fast delivery due to the lack of obstacles in their path such as buildings, traffic, or natural obstacles. Our medical drone delivery system will tackle a unique challenge of preserving medical items during the drone delivery process. Medical items such as vaccines and organs often need to be stored at very low temperatures. As a result we will incorporate a cooling system while solving the challenges of designing a lightweight, portable, low cost, easy to use, and accurate drone delivery system.

Figure 1

ii. *Goals*

The main goal of this project is to provide a cheaper and more flexible medical supply delivery system compared to those currently in use. Some systems currently in use include the following. Ground transportation, which is the most dominant form of transportation, is prone to delays due to traffic and does not follow the shortest path. Pneumatic Tube delivery, which allows quick transportation between buildings across a city, addresses the problem of timely delivery, but is expensive to build and maintain. Certain places may only be reachable in a very expensive fashion such as helicopter delivery. Moreover, due to disasters, natural debris and ruins may make delivery through air the only solution.

To solve this problem, we will be designing, building, and programming a drone that is capable of autonomously delivering a medical item from a starting point to a desired location. The drone will contain a box that can be loaded with supplies. This payload box will also implement a cooling mechanism to ensure that the products remain preserved during delivery, keeping the temperature below a set threshold for different items. Upon receiving a signal, the drone will take off and begin moving towards a targeted location. To allow precise delivery, the delivery location location will be designated by a floor mat that is placed by the person requesting the delivery, the drone will use computer vision to detect and maneuver itself to land on or near the floor mat.

iii. *Stretch Goals*

The stretch goals for this project primarily include increasing the range, speed, and cost efficiency of delivery. Another stretch goal is to implement an actual refrigerated system. This is a harder goal to meet as the potential weight for this subsystem would need to be minimized and not interfere with the drone's main functionality of getting from location A to B.

2. Specifications

i. *Requirements*

1. FAA requirements
2. Performance Requirements
    - 2.1. Flight
        - 2.1.1. Be able to carry a payload of 3lb
        - 2.1.2. Range of 1 mile

2.1.3. Maintain distance of at least 5ft from any object
2.1.4. Minimum maximum speed of 20mph
2.1.5. Flight path should be no more than 5% longer than the shortest path accounting for obstacles
2.1.6. Flight controls should be completely autonomous
2.1.7. Initiate safe emergency landing when battery is 20% more than enough for landing from current height.
2.1.8. Maintain communication in case an emergency landing command is needed.
2.2. Loading and Takeoff
2.2.1. System startup should take no more than 30 seconds
2.2.2. Loading box with supplies should be possible in less than 1 minute
2.2.3. Payload can be manually inserted or autonomously
2.3. Landing and Unloading
2.3.1. Land within 5 feet of the target mat
2.3.2. Unloading box with supplies should be possible in less than 1 minute
3. System Requirements
3.1. Frame
3.1.1. Should exhibit elastic behavior
3.2. Propellers
3.2.1. Be able to withstand RPM needed to maintain altitude while flying at the maximum speed at maximum load.
3.3. Motor
3.3.1.
3.4. Battery
3.4.1. Battery must be lightweight and rechargeable.
3.4.1.1. Total battery weight should not exceed 2lbs
3.4.2. Battery should contain roughly 4Ah-6Ah of charge
3.4.3. Battery is maintained and monitored by a battery management system.
3.5. Camera
3.5.1. Produce high enough quality imagery for classification algorithm to work
3.6. Communication
3.6.1. Communication should be possible within the flight range of the drone

3.6.2. Due to a substantially long range from ground control, communication should be done over an RF signal.
3.6.2.1. Drone’s main flight control will be autonomous, but will log flight status data to ground control.
3.6.3. Will require communication for manual overriding flight control.
3.7. Sensors
3.7.1. Sense temperature of deliverable to ensure temperature threshold [3.8] is kept
3.7.1.1. Thermistor will be utilized due to it’s high accuracy
3.7.2. Camera [3.5] will be the main obstacle avoidance driver during forward flight.
3.7.3. Flight landing, and any moving direction not in camera’s range of view, will be handled by a combination of ultrasonic and/or LiDAR sensors
3.7.4. For simplicity, an IMU should be integrated into flight control
3.7.4.1. IMU must include: gyroscope, accelerometer, and inclinometer
3.7.5. All sensors should come digital.
3.7.5.1. Otherwise, all sensors should utilize the same ADC module to keep simplicity.
3.8. Cooling
3.8.1. As it stands to date, drone should keep load within +- 5 degrees fahrenheit of desired temperature.
3.8.1.1. This may vary per sensitivity of medical deliverable
4. Software Requirements
4.1. Determine initial flight direction
4.2. Model should process images taken from the camera in 1 second intervals.
4.3. Model should predict with at least 95% confidence the location of the target mat relative to the drone if it is found in the processed image.
4.4. Model prediction should take no more than 1 second
4.5. Initiate landing protocol if 3 predictions in a row agree on target mat position

ii. *Constraints*

The constraints discussed in this section directly affect many of the specifications and goals noted in the previous two sections.

The main constraint we face when designing the drone is financing. Drone's are notoriously expensive to construct and therefore will require us to optimize cost, quality, and functionality together. Our budgeting constraint can be broken down into a few areas of the drone. Firstly, the drone's range and payload will be impacted. The range for this prototype will be lesser than that of a commercial drone. The total size of the frame and motors will be decreased to support our budget; thus, decreasing the total drone's weight as well as the payload. With the drone's weight being reduced, the battery size must be reduced, and therefore will cut our total range down. Even with our smaller budget, it is still possible to optimize range with payload weight. The drone will be able to carry smaller medical objects longer distances and carry heavier objects shorter distances. Regardless, the payload will be cut down due to our smaller drone size. The range may also be cut down if our stretch goal of developing a refrigeration system isn't completed. The item within the payload-medical box must maintain a temperature as according to the specifications above [3.8]. Without this system, the range may be decreased or the time of flight will need to be decreased to meet this temperature criteria.

Also tapping into our budget, testing will potentially be reduced to ensure damage to the hardware is reduced. On top of that, testing can only be done in certain regulated areas under the condition we have our drone licenses. This all can be time consuming during the development of the prototype. Testing can also lead to safety issues. A flying object carrying lithium batteries (high density of charge) can lead to implications such as fire and/or explosions. Regulating our testing to meet certain safety criteria will be prioritized but also will potentially limit the total testing done on the drone and reduce the total drone's functionality potential.

3. Block Diagrams

i. *Mission Path*

Below, **Figure 2**, is a rough concept of what the mission path will look like. The first if-block's condition is deterministic on whether a cooling system will be developed and integrated in the drone's delivery system. If the subsystem is available, the deliverable will additionally be denoted as cooled or uncooled. The system will need to be aware of this at some point around takeoff. If it is cooled, the carrying box will need to be at the appropriate temperature prior to loading the medical object.

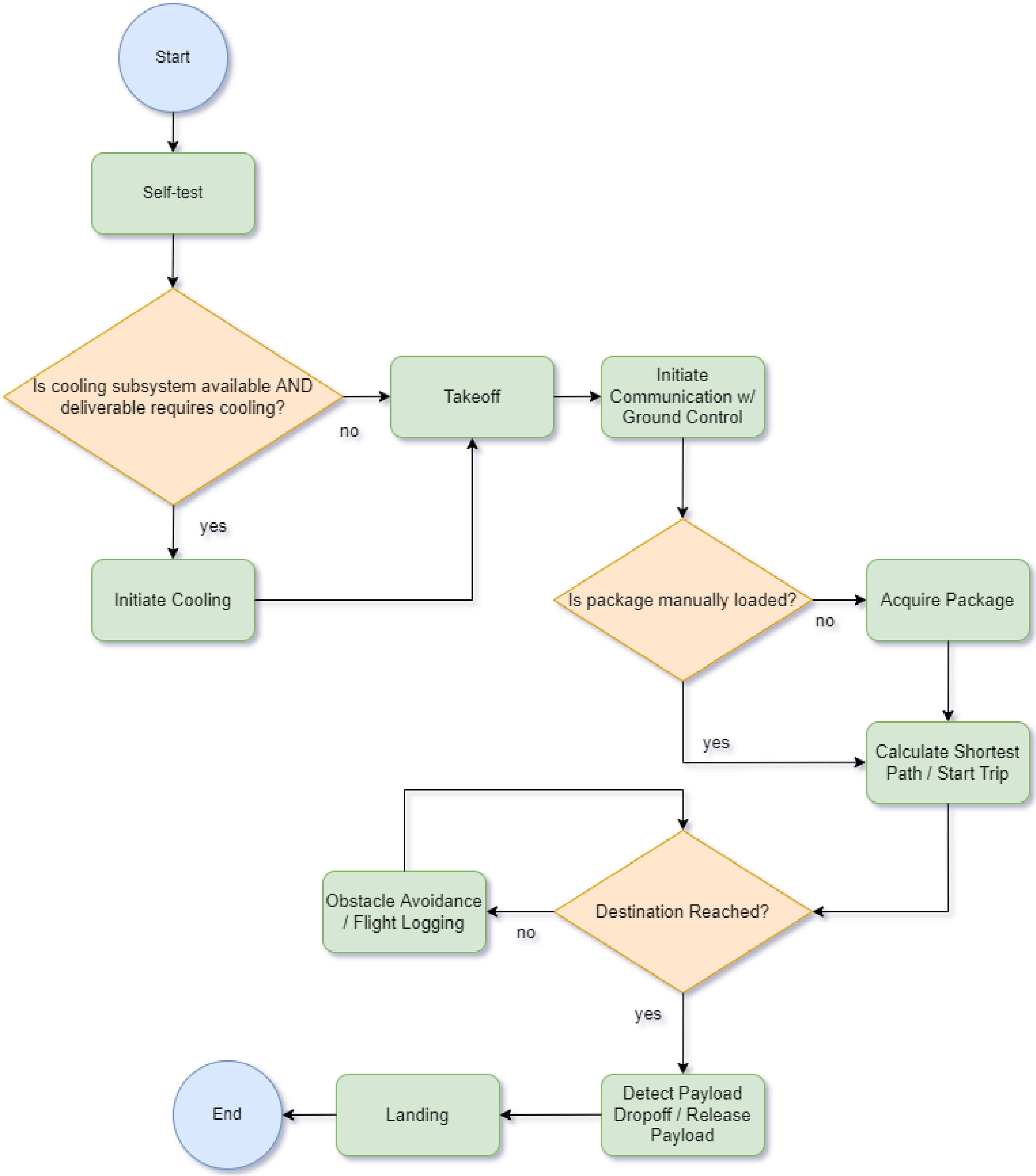

Start
Self-test
Is cooling subsystem available AND deliverable requires cooling?
no
yes
Initiate Cooling
Takeoff
Initiate Communication w/ Ground Control
Is package manually loaded?
no
Acquire Package
yes
Calculate Shortest Path / Start Trip
Destination Reached?
no
Obstacle Avoidance / Flight Logging
yes
Detect Payload Dropoff / Release Payload
Landing
End

Figure 2

ii. *Hardware*

Figure 3 depicts a rough overview of how the drone's hardware will be put together. The types of connections are indicated by the key below. Also, without the addition of the cooling system, the drone should still utilize a temperature sensor to ensure the deliverable is being kept at a temperature within the desired range. This could lead to changes in the drone's plan of action, speeding up the flight time, for example. The diagram below should additionally include a gps module. After a careful review of the budget, we are considering removing the external gpu and utilizing a built-in gpu within our flight controller.

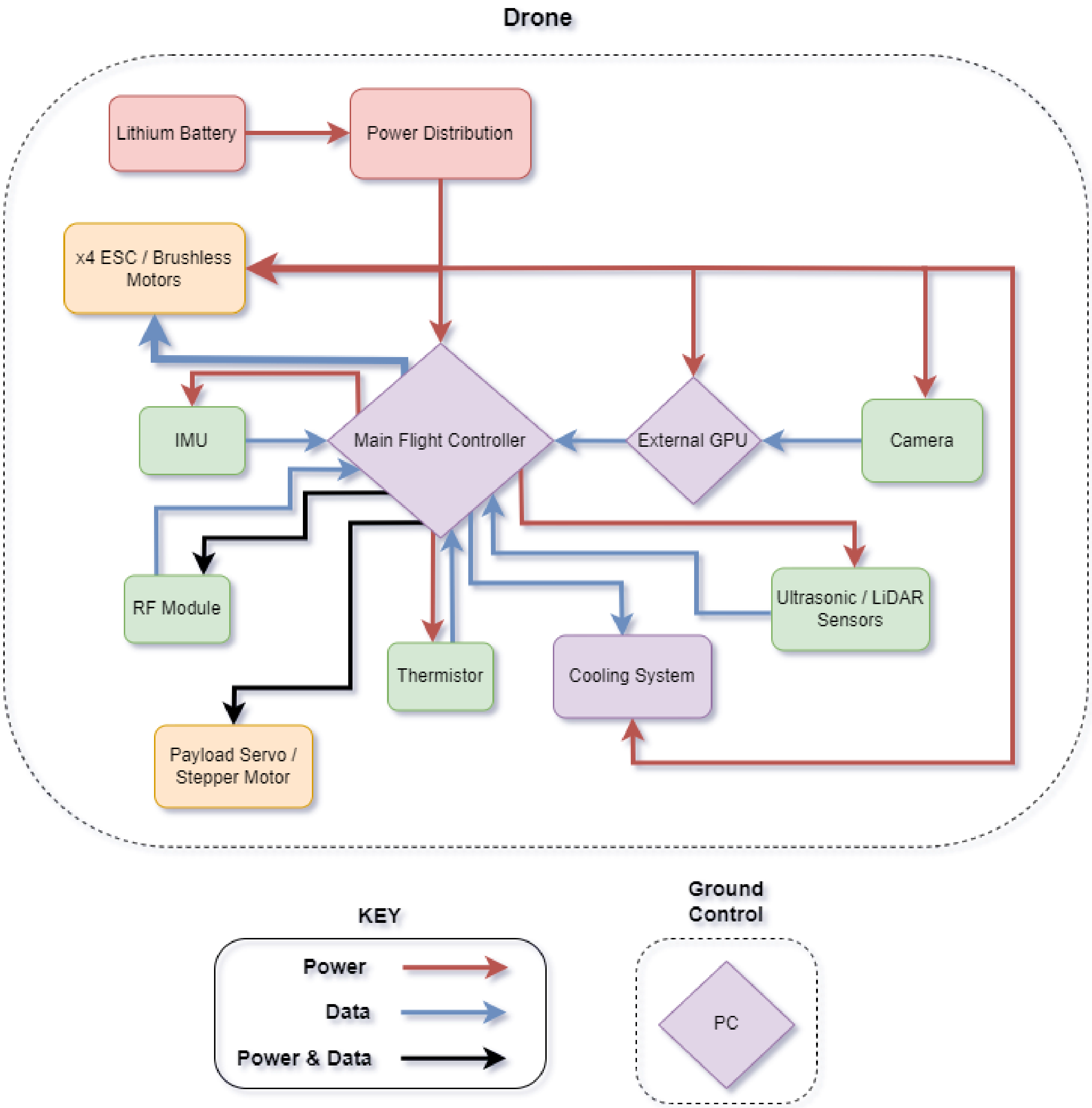


Figure 3

4. Materials & Budget

i. *Hardware / Software*

Starting off with the drone's energy source, we have decided lithium batteries will be our go-to choice due to their higher density of electric charge. This will help with the drone's weight / range constraint noted earlier in the documentation. Currently we're considering either Lithium Polymer or purely Lithium Ion chemical combinations. Building our own battery pack will let us optimize even further, allowing us to create the ideal charge capacity / weight ratio. Doing so would require a battery management system to monitor the charge per cell. The drone will also have a power distribution module, that we must create due to the power's particular distribution, to step-down the voltage differently for each component of the drone and allocate charge accordingly. For these high power applications, we need to consider the types of connectors that will be needed too. For the battery to power management we will use XT60 connectors to handle the high current passing through them. Every other smaller component's connections will simply use standard JST connectors.

The drone will utilize many different sensors and modules. After some more research, we will need to determine whether we want to use ultrasonic or LiDAR for different obstacle avoidance situations. We have discussed using both in the system, one to be a fault save to the other if one were to have issues mid-flight. Having both will also allow us to maximize both of their main benefits that each have over one another. We are carrying a temperature sensitive payload and therefore will require a temperature sensor in our system. We have decided to use a standard thermistor for its higher accuracy applications. As far as our landing goes, and obstacle avoidance, we will utilize computer vision to help with this. We are considering using a camera to gpu system on the hardware side. For manual overriding of the autonomous flight, we need manual communication to the drone. To do so, we plan to use an RF signal around the 2.4Ghz range and will require the drone to have an RF module to transmit and receive data. The land controller will be a pc. The RF module will also allow us to have mid-flight logging available to monitor the status of the drone and all of its peripherals. This communication could also be helpful preflight when giving the drone GPS coordinates and potentially new coordinates mid-flight if the mission were to change. Also, this mid-flight communication will be helpful in keeping track of the payload's temperature. This will allow the drone to potentially pick up flight speed if the projected payload temperature is greater than the desired temperature by arrival to the destination. A GPS module will also be needed for the drone to have a dynamic flight to its destination. Lastly, to ensure stability during flight, an IMU, composed of a few different sensors, will be needed.

Onto the actual flight controller. We have considered different options here from microcontrollers to higher processing controllers like a Pi or BeagleBone. Up to this point we haven't decided whether we want to actually design the controller or not. Designing our own controller will help maximize the total space constraint we face as well. It will allow us to cut out some of the unnecessary space of the development boards' total surface area from our drone. Any pre-designed development board will have some set of unnecessary hardware components to it. Designing our own will allow us to optimize both pricing and future availability during the drone's build phase. If we were to design our own we will be able to quickly build another for a much lighter price than if we were to buy another raspberry pi, for example. For now, the budget below will allocate roughly $75 to fill in the spot of the flight controller.

The motors will more than likely be the most expensive components of the entire drone. We have so far decided on 4 brushless motors over 8. Further research may make us rethink this initial proposal but as of now we agree the 4 will allow the drone to function as needed while minimizing the total price. More research will also be required to determine the torque and RPM specifications needed for our application. Each of the motors will require an electronic speed controller. We have the option to design or purchase these. Building our own would allow us to easily replace one faulty controller if one were to be destroyed or turn non-functional by having spare pcbs. Lastly, we will require one stepper or servo motor for our payload carrier. This will be determined later after further discussion on how we decide to implement the actual carrying box.

The budget below will anticipate us having an actual cooling system within the drone. We still need to decide whether we will be implementing this subsystem or not due to its weight and potentially high-power disadvantages. However, we believe there is a way to design a light-enough weight system to produce a higher quality of our drone overall, obviously giving more potential to the drone's main purpose. We are considering peltier cooling, if the system can draw little power and be lightweight, we will strongly consider it as other UAV systems utilize just this for transporting vaccines and battery heat relief.

As far as software goes, we are not anticipating purchasing any sort of applications or potential frameworks. A few to note, however, are QRGroundControl, an application to monitor the status of the drone mid-flight from our ground control pc. Also, OpenCV for our machine learning application is being considered for its open-source, straight-forward standard libraries. This would allow us to build a simple model. We have discussed utilizing ROS to program the main flight controller. If we do go the microcontroller route rather than an actual CPU, and decide not to use ROS, we have the choice of writing register-level APIs for flight control, preferably in C. Our ML model would then be able to talk directly with these APIs when adjusting motor controls during the mission's flight. A lot more still has to be discussed and researched on how we plan to implement this but regardless of our decisions, we are not expecting any major budget implications on the software side.

ii. *Framework*

After even a little research, a concern for a carbon fiber frame has been found. Carbon fiber has a tendency to disrupt RF communication due to its high conductivity and low resistivity. Instead, we are considering using wood or plastic with a high melting point. Additionally for the frame, we plan on having dampeners fastened for landing and takeoff. The dampeners will help reduce vibration for all of the electronics and hopefully help keep measurements for the different sensors accurate and reduce as much noise as possible. We have to conduct more research on the placement of said dampeners to maximize their potential benefit. Also, not necessarily a part of the drone's frame, but we will be needing to purchase propellers for our brushless motors noted in the section above (*i. Hardware / Software*). The payload's box / container will be estimated here too. Lastly, any fasteners and electronics chassis (which may be 3D printed) will be included here to keep the estimated budget as accurate as it can be.

iii. Estimated Bill of Materials

Table 1, below, provides an estimated total cost for the drone including the components talked about in the previous two sections. We are not considering any spares or duplicates here, but will more likely than not require some during the testing and prototyping phases of the design.

Item #	Item	Price	Quantity	Total
1	Brushless Motors	$40	x4	$160
2	Motor ESCs	$10	x4	$40
3	LiPo Battery [6Ah web estimation]	$40	x1	$40
4	Power Distribution Board	$15	x1	$15
5	Battery Management System	$20	x1	$20
6	XT60 Connectors (male & female)	$8	x1	$8
7	JST Connector Kit	$15	x1	$15
8	Flight Controller (w/ gpu)	$140	x1	$140
9	Wood Frame	$20	x1	$20
10	Vibration Dampeners (pack w/ spares)	$6	x1	$6
11	Motor Propellers	$8	x4	$32
12	Thermistor	$5	x1	$5
13	Payload Stepper Motor	$10	x1	$10
14	IMU (Adafruit 9-DOF)	$30	x1	$30
15	Ultrasonic Sensor	$3	x2	$6
16	LiDAR Sensor Module	$15	x1	$15
17	GPS	$9	x1	$9
18	~~External GPU~~	~~$~~	~~x1~~	~~$~~
19	Camera	$10	x1	$10
20	RF Module (Rx & Tx)	$3	x2	$6
21	Peltier Cooling System	$15	x1	$15
22	Fasteners	$0.5	x20	$10
23	Misc 3D prints	$0.1	x10	$1
Grand Total		-	-	**~$613**

Table 1

5. Milestones

i. *Tentative Timeline*

One of the many important aspects to ensure that our project is completed effectively and on time is to set milestones and deadlines for them. The list below shows the major milestones and their appropriate deadlines as of today. **Table 2** marks both the hard and soft deadlines for Senior Design I, Fall 2022. The adjacent table below, **Table 3**, contains the tentative deadlines for Senior Design II, Spring 2023. **Table 3**'s tasks can be broken up further, but for now, without official deadlines, the table is composed of the main tasks that will be needed.

Deadlines (Hard/Soft)	**Task**	**Completed (y/n/ip)**
September 16, 2022 (Hard)	Divide & Conquer v1.0	y
October 7, 2022 (Hard)	Divide & Conquer v2.0	ip
November 4, 2022 (Hard)	60 Page Design Document Draft	n
November 7, 2022 (Soft)	● Majority of Research ● Final BOM	n
November 18, 2022 (Hard)	100 Page Design Document Draft	n
December 1, 2022 / TBD (Soft)	Proposal For Funding	n
December 6, 2022 (Hard)	Final Design Document	n

Table 2

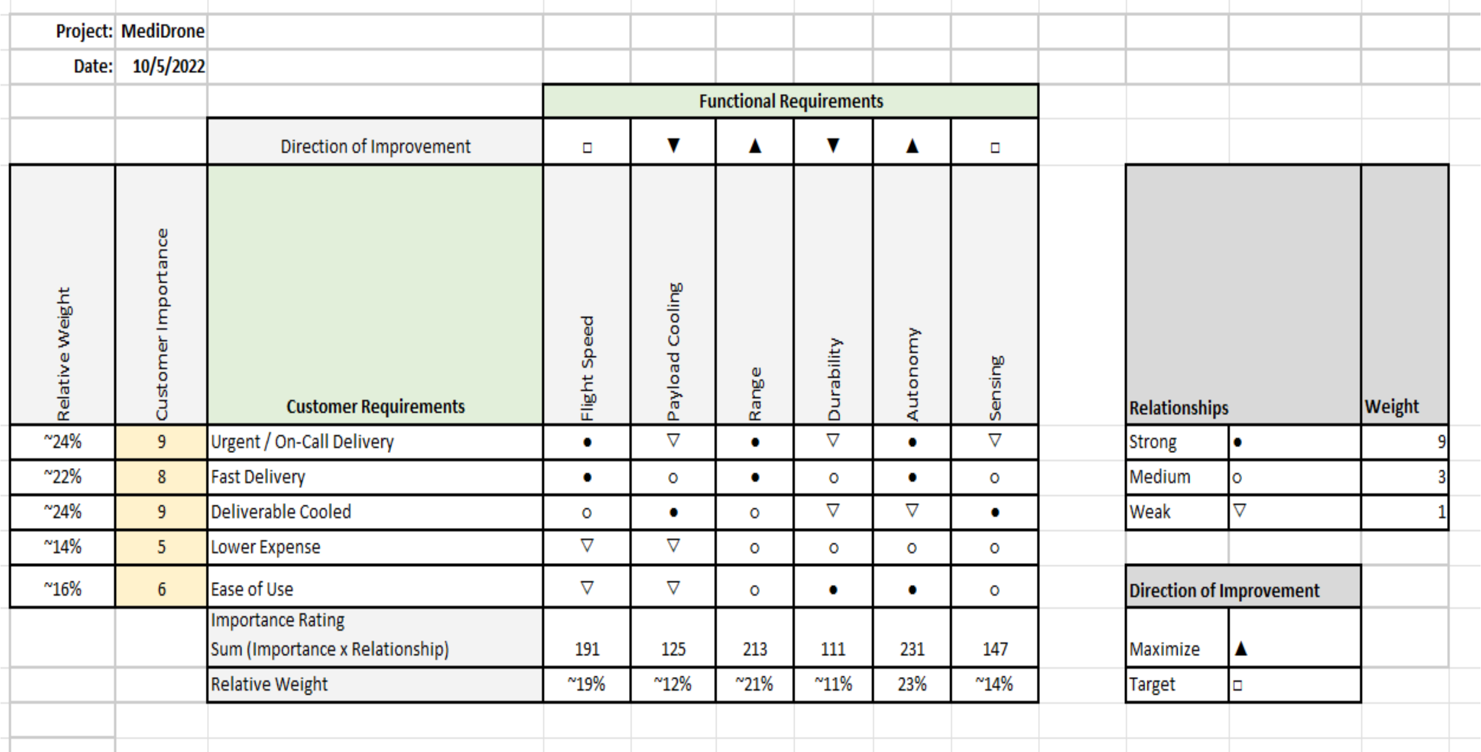
Deadlines (Hard/Soft)	**Task**	**Completed (y/n/ip)**
tbd	Part Ordering	n
tbd	Drone Assembly	n
tbd	Drone (w/o payload) Functional	n
tbd	Testing	n
tbd	Drone (w/ payload) Functional	n
tbd	Extended Tests	n
tbd	Final Demonstration	n

Table 3

6. House of Quality

i. *Market Relationship*

In **Table 4**, below, we are able to make correlations between our functional requirements and the customer requirements. It’s apparent there should be an emphasis in the autonomy and range when it comes to the drone’s design.



Project: MediDrone
Date: 10/5/2022

Relative Weight	Customer Importance	Customer Requirements	Flight Speed	Payload Cooling	Range	Durability	Autonomy	Sensing
		Direction of Improvement	□	▼	▲	▼	▲	□
~24%	9	Urgent / On-Call Delivery	●	▽	●	▽	●	▽
~22%	8	Fast Delivery	●	○	●	○	●	○
~24%	9	Deliverable Cooled	○	●	○	▽	▽	●
~14%	5	Lower Expense	▽	▽	○	○	○	○
~16%	6	Ease of Use	▽	▽	○	●	●	○
		Importance Rating Sum (Importance x Relationship)	191	125	213	111	231	147
		Relative Weight	~19%	~12%	~21%	~11%	23%	~14%

Functional Requirements: Flight Speed, Payload Cooling, Range, Durability, Autonomy, Sensing

Relationships		Weight
Strong	●	9
Medium	○	3
Weak	▽	1

Direction of Improvement	
Maximize	▲
Target	□

Table 4