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DESIGNING A DRONE DISABLING DEVICE FOR NORTHROP GRUMMAN

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ABSTRACT

Recreational drones are rapidly increasing in popularity during the 21st century. There have been about 10 million drones sold around the world in 2018. Drones equipped with cameras or weapons pose a threat to restricted areas such as prisons. Populated areas and government buildings are also at risk from possible drone attacks. Northrop Grumman is sponsoring our team to develop a product that can detect and disable unauthorized drones and secure an airspace. The target consumer of this device is law enforcement and security teams, so they can disable drones that are flying in restricted areas. The device consists of an automatic detection system, a weighted net launcher and a backpack to house equipment. The detection system automatically detects drones with cameras and alerts users of a potential hazard. These cameras distinguish between drones and other objects using a trained program to prevent false alerts. Cameras were mounted above the pack to provide a 360-degree view of the area around the user. A net is launched using high-pressure air to neutralize and potentially capture hostile drones. This launcher is portable and the size of a rifle. The backpack has air tanks and computer systems stored inside, where air hoses connect the backpack to the launcher. Positioning the air tanks and other components in the pack allows the user to carry necessary components in one place. This design provides comfort to the user. The device has an expected assembly time of five minutes. If a drone comes within thirty feet of the user, the detection system will alert of the approaching danger. The overall system is safe for the user and environment and complies with legal regulations.

INTRODUCTION

The objective of this project is to design a device that is used to protect and secure airspace from unmanned flight vehicles. The major key goals are to detect, neutralize, and secure the unmanned flight vehicle. This project is a continuation of work from a previous team and is tasked with decreasing the form factor, adding a detection system, and improving the functionality. The primary market for this product will be government and military operatives, with the secondary market being contractors, private security, and defense companies.

The device is assumed to be primarily used in defense and security operations. It is not intended for civilian use, but to neutralize civilian unmanned aircraft (specifically drones). These aircraft can pose threats to the safety of attendees at major public events or important private gatherings. The design will be focused on increasing device portability and the addition of a detection system. Portability will allow the user to move more freely and adjust to frantic drone movements. The detection system addition will be automatic. Assembly and integration of the device into security tactics before an event takes place are needed to optimize the device's overall presence.

The type of drones that are going to be targeted are recreational drones that could be carrying Improvised

Explosive Device, IED, or cameras. The original needs of the project were to disable non-military, recreational drones; have a device operable for as long as possible; being able to at least disable the drone (recovering the disabled drone would exceed customer expectations); have a user-operated device; operate the device at the maximum range possible; design the device to be portable and quick to set up (within 4 hours); and to focus on the project development process rather than the product.

The team is tasked with making a device that is small in size (preferably close to the size of a paintball gun) with improved functionality such as: improved drone detection, quicker target acquisition, and quicker assembly and disassembly time, and delivering a product that is sleek in design.

METHODS

Concept generation started with generating several potential ideas. Brainstorming a substantial volume of ideas was important not only for analyzing the feasibility of various combinations of components, but also for creating component combinations that were previously unthinkable. To properly organize the concepts of our project, concepts were separated into several categories of which overall system concepts could be generated. These categories were jamming, capture, projection, net design, net counter-weight, detection, size-reduction, target impact protection.

Neutralization of the target drone is the key function of the drone disabling device. The first stage of successfully neutralizing the drone begins with interfering with the signal between the hostile drone and its controller. After researching how drones react when losing signal with the controller, it was discovered that drones tend to either hover in the air until communication is re-connected or the drone will slowly descend down to Earth. Both of these situations would result in an easy capture of the drone. Most drones currently use Wi-Fi to communicate with the controller. For this reason, we have decided that our jammer will jam either the 2.4 GHz, 5GHz, or both of these frequencies; which are the most common radio-communication frequencies utilized in Wi-Fi communication. Due to federal laws implemented by the FCC, concepts in regard to jamming will not be manufactured or used in this project but may be assumed active in device functions. In addition to the wireless jamming of the drone, one design concept is embedding a Faraday Cage into a net to be launched at the hostile drone. A Faraday Cage has electromagnetic properties that causes radio waves to be substantially attenuated (reduced in power). As a result, the captured drone would be unable to receive a strong enough signal to receive control. In addition, this design would be legal under FCC standards. After analyzing other concepts, it was determined that several of these concepts are either illegal to implement on a non-military scale or would be infeasible to successfully neutralizing common recreational drones. For this reason, our best concepts out of the overall list are jamming 2.4 GHz, 5GHz, or both of these frequencies, and launching a Faraday Cage-embedded net at the hostile drone. Concepts for the neutralization system are listed below in Table 1.

Table 1: Compiled concepts for the neutralization system.

System	Concept
Neutralization	RF - 2.4 GHz
	RF - 5 GHz
	Bluetooth
	Infrared
	Cellular
	GPS
	EMP
	Faraday Cage
	Satellite
	Ultrasonic

Capturing is another essential function of the drone disabling device. These concepts were all generated in order to safely retrieve the drone without destroying it so that it can be examined once it is captured. Our best options for drone capture are using a net to cover the drone's propellers to cause it to fall, counter-drone towing to redirect the flight of the drone to the ground, and a hook to intercept the drone from the ground. The counter-drone would need to be deployed and manually steered close to the target, connected to the target via some sort of rope or hook, then guided by a user safely down to the ground. The hook would need to be connected to a rope, then shot from a rifle to connect to the drone so that it could be pulled down by a user. The final design will most likely implement the net concept because we view it as the most effective, most practical solution for drone capture. In addition to the net weighing the drone down, the spinning propellers for the drone are highly likely to get stuck in the holes of the net, stopping them from spinning, thus causing the drone to fall. Ideas for capturing the drone are listed below in Table 2.

Table 2: Compiled concepts for the capturing of the drone.

System	Concept
Capture	Net
	Hook
	Counter-Drone Towing
	Magnet
	Take Over Controls
	Silly String
	Projectile
	Sticky Substance
	Plunger

Now onto the selected possibilities on how to decrease the overall size and weight of the device in order to make it easier to operate. These size reduction methods will also help to reduce the assembly time of the device so that it can be easily assembled in our ideal target time of 5 minutes. The final design will most likely contain multiple of these concepts in order to maximize the amount of size reduced. Incorporating a disposable compressed air system would improve upon the current design with its large compressor but this has its consequences because the device would not be able to be fired as repeatedly without the compressor, but this trade off would be worth this because of the massive decrease in size and weight as long as the pre-compressed air provides the same launch range.

Table 3: Compiled Concepts for reducing the size of the device.

System	Concept
Size Reduction	Disposable Compressed Air
	Handheld Net Launcher
	Counter-Drone Net Deploying
	Lithium-Ion Battery
	Solar Powered
	Hand-Cranked Pressure Building

To launch a net or hook into the air, a force exerted behind the object is required. This force can be created by a buildup of pressure, a reaction of compounds, or even man powered. Mobility plays a major role in our decision of device propulsion. Any ideas generated that hindered this mobility were easily eliminated, i.e., catapult/hydraulic. Compressed air, combustion, spring launched, and a motor are our best options for device propulsion. Through the use of compressed air/CO2, a buildup of pressure can be created and released in a narrow path and launch a projectile into the air. This is proved in Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho v_1{}^2 = P_2 + \frac{1}{2}\rho v_2{}^2$$

which states that following incompressible continuity, if $A_2>A_1$ then $v_2<v_1$. So, compressed air/CO2 being funneled through a small diameter barrel like path is a feasible option in launching a net or projectile. Looking at the physics behind bullets using gunpowder, a compound with less explosive force may be an operable source of propulsion for this device. Though it is important to keep in mind, it is not intended to damage or destroy the drone. A spring with the proper specifications and compressed state could exert this non-lethal force needed. Nerf guns and spring powered pellet rifles are prime examples of this force. This is a simplistic solution to our problem and is an important concept we hope to work with. Moving the device to be fully electrical with a battery powered mechanical motor is another option that allows us to vary the force and power output through proper gear ratios. Of these four concepts, compressed air/CO2 and spring powered are our best choices. Propulsion ideas for the device to fire into the air are listed below in Table 4.

Table 4: Compiled concepts for propelling the net into the air

System	Concept
Propulsion	Compressed Air/CO2
	Combustion
	Electromagnetic Force
	Throwing
	Spring Launched
	Hydraulic
	Sling Shot
	Catapult
	Motor
	Counter-Drone Deployed

With a net being our best choice of firing to capture the drone, we went further in depth with the concept and looked at possible materials to have the net made out of. Typical net materials include Nylon and Poly Dracon, and both are our top choices. Nylon netting is known to have superior strength and durability, which will withstand breaking from the drone blades. It will also outlast most roping's or nettings due to its UV and rot resistance. Poly Dracon uses plastic fibers to add strength while remaining a lightweight and cost-effective choice. It has a low stretch and high grip that will not allow the drone to escape when coming in contact with a blade. Net materials like metal, ceramic, and wool are not good choices for this project. Metal netting would be heavy and require extra work from the device to launch it into the air. It also would have high drag. Ceramic netting would be too fragile and may fracture or break from a propulsion force. Wool may be too weak and lightweight, meaning it wouldn't be easy to launch and may rip when contact happens with the drone. The best options of net material for our device are Nylon and Poly Dracon. Below in Table 5 is a list of concepts for net materials.

Table 5: Compiled concepts for the net's design

System	Concept
Net Design	Mesh (Plastic)
	Retractable
	Rope
	Poly Dracon
	Spider Web
	Metal
	Ceramic
	Cloth
	Magnetic
	Rubber
	Semi-Conductive
	Nylon

Deciding on which concept of a counter-weighted net should be used is still open for debate. It is undecided on whether any of the concepts listed in Table 6 will be implemented. The net counter-weight will add a weight to the net and allow it to be launched into the air with ease. Ideas of counterweights like the four-small weight "clover" or one large weight center are the best choices of the list. Though the one large weight in the center may prove problematic when launched into the air, it may act as projectile and damage the drone.

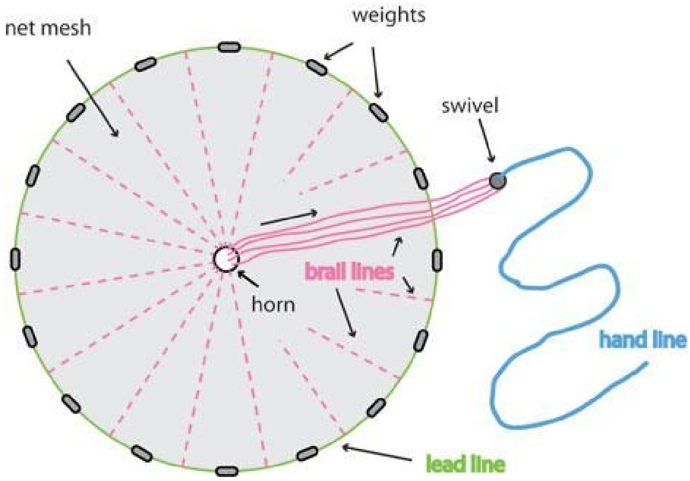


Figure 1: A diagram of a casting net commonly used for retrieving bait fish [1]

With four small weights, or any number of small weights, spread of the net can be improved when airborne with the edging covered in weight. Looking at a casting net for fishing, if loaded properly into the device the net will mimic and spread on launch, greatly increasing the success chance of a capture. Weights may cause hazardous to people below the drone which may call for safety checks before firing. Below in Table 6 is a list of concepts for net counterweights.

Table 6: Compiled concepts for net's counter-weight

System	Concept
Net Counter-Weight	Four Small Weight "Clover" – Projection
	One Larger Weight Center – Projection
	Evenly Weighted Net
	Magnetized Net Edges
	Faraday Cage Embedded Net

Another key subsystem of the project is the detection system. Our sponsors gave us the task of developing a subsystem that could automatically detect a drone in the sky and alert the device operator of the detection. This detection system is to be designed to operate and detect hostile drones passively; in other words, the detection system would function without an operator needing to actively operate the detection system. The most important considerations of generating concepts for this design are how to accurately detect a drone from long range, how to distinguish a drone from another flying object such as a bird, and the means in which the system can detect such an object. Our best option for detecting a mid-air drone is to identify it using image recognition via a neural network. The process would involve capturing thousands of images of drones and backgrounds in order to help distinguish the drone from the background. After the images are loaded into a neural network, an algorithm would be used to analyze live video to recognize whether or not a drone is in the air. The accuracy and speed of drone detection would increase as the amount of training images loaded into the neural network increased. Using the neural network method would allow for fast, accurate, and relatively inexpensive drone detection. Table 7 illustrates several concepts to potentially be used for detecting a drone in the air:

Table 7: Compiled concepts for detection of the drone

System	Concept
Detection	3D Image
	Infrared
	Sound
	Electromagnetic Signature
	Heat Signature
	Radar
	Sonar
	Eye Sight
	Laser
	Velocity Sensing
	Neural Network
	Detect Spinning Blades
	Temperature Gradient Between "Object" and Air

Once the drone gets neutralized, and a weighted net is launched at it, it will fall to the ground. A decision was made for there to be a way to retrieve the drone without damaging it. Depending on what the device will be used for, it might be in the best interest for it not to be destroy. Table 8 below lists the different concepts of impact protection. The best options for this function would either be a net being attached to the net or to hack the drone and safely guide it to the ground. Since the preferred method to secure the drone will be by launching a net, attaching a parachute to the net. This way will allow the drone to be safely brought down to the ground for retrieval.

Table 8: Compiled concepts for impact protection

System	Concept
Impact Protection	Cushioned Net
	Predicted Landing of Drone
	Hack Drone
	Parachute Net
	Cushioned Surface on Ground

Detailed designs were created from the list of concepts above and are described below. These designs are all concepts and help visualize the overall system we expect to build and can give an expectation of how the device will function.

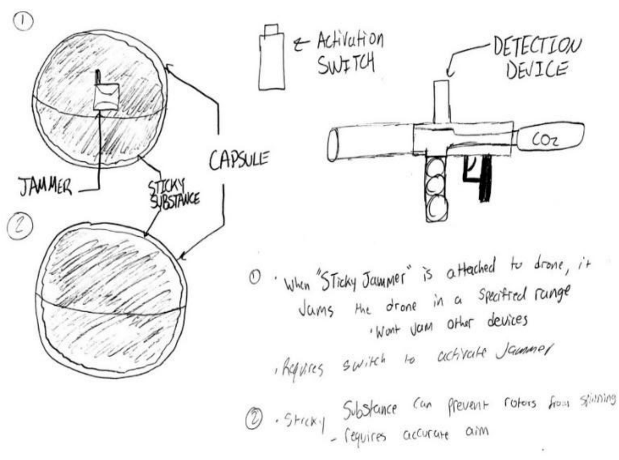


Figure 2: Concept 1 diagram and detailed view of sticky substance

Figure 2 illustrates a full-system concept of the drone disabling device. This device is essentially a paintball-styled gun that shoots capsules. The capsules can either contain a sticky substance with an integrated jammer, or just the sticky substance. The jamming capsule would actively jam the drone in the 2.4 GHz and 5 GHz frequencies, which would disrupt communications between the drone and the controller (after research, this would cause the drone to either hover in the spot where it lost communications, or it would slowly descend to the ground). The jammer would be controlled by an operator-controlled switch, which would be activated when the capsule is attached to the drone. The concept of the capsule not utilizing the jammer would simply release the sticky substance, stick to the drone, and immobilize it either by preventing the rotors of the drone from spinning or by weighing the drone down. The capsule would be propelled by force generated by a disposable CO2 cartridge, similar to how a paintball is propelled from a paintball gun.

Table 9: Concepts used in generation of concept 1

System	Concept
Propulsion	Compressed Air/CO2
Neutralization	RF – 2.4 GHz
	RF - 5 GHz
Capture	Capture
	Sticky Substance
Size Reduction	Disposable Compressed Air
	Handheld
Detection	Eye Sight

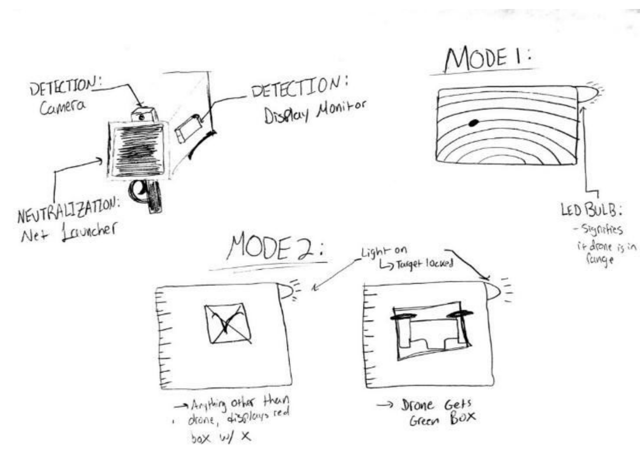


Figure 3: Concept 2 diagram and functions

This design utilizes a weighted net for the purpose of securing the drone once it is neutralized, which would be by means of 2.4 GHz and 5GHz Wi-Fi jamming. The net would be launched using compressed air in a disposable cartridge. In order to detect the target, either a camera would be attached to the launcher, or a radar function will be displayed on the monitor. Either way, an LED bulb would light up, indicating that the target is in range after it was detected. Another function of the detection device would be 3D imagery, infrared, or electromagnetic signature detection, which would tell the user whether the target is desirable or not. This concept is depicted in figure 3.

Table 10: Concepts used in generation of concept 2

System	Concept
Propulsion	Compressed Air/CO2
Neutralization	RF - 2.4 GHz
	RF - 5 GHz
Capture	Net
Net Material	Nylon
	Poly Dracon
Net Counterweight	Four weights "clover"
Size reduction	Disposable Compressed Air
	Handheld Net Launcher
Impact Protection	Parachute net
Detection	3D image
	Infrared
	Radar

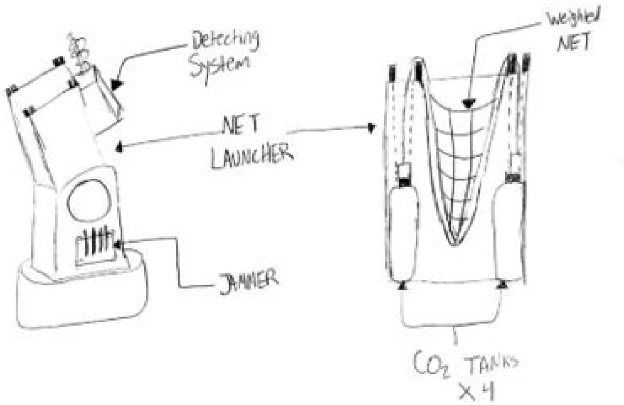


Figure 4: Concept 3 with detailed diagram.

Concept 3 is illustrated below in Figure 4. This design is another net launching device. The weighted net would be in the “clover” projection; four weights in each of the corner of the net. The weights will be guided down a track till it reaches the release of one of the four CO2 tanks. To propels the net, a button will be pressed. The net would be embedded with a faraday cage, which would actively jam any possible radio-frequency signal attempting to communicate with the drone. This concept focuses more on the function of securing the drone than any other function, but this design is open to having any combination of the detection and jamming systems listed in the tables above.

Table 11: Concepts used in generation of concept 3

System	Concept
Propulsion	Compressed Air/CO2
Neutralization	Faraday Cage
Capture	Net
Net Material	Nylon
	Poly Dracon
Net Counterweight	Four Weights “clover”
Size Reduction	Disposable Compressed Air

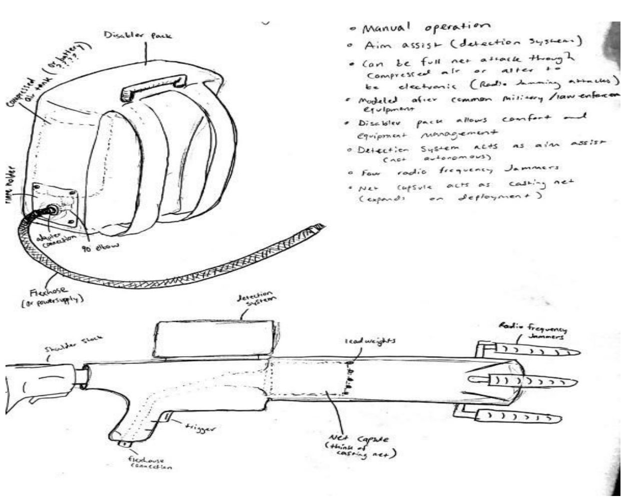


Figure 5: Concept 4 diagram and device description

Concept 4, as shown in Figure 5, is a handheld net launcher powered by a disposable compressed air/CO2 tank. The tank is connected to the rifle through a hose line. For concept and marketing purposes, the tank is placed inside a pack to allow extra storage for the operator. This pack can also hold a battery source to power the detection and jamming systems. The net is in a plastic capsule that breaks upon launch from the rifle. The net is modeled after a casting net with small weights on the lining of the net. This concept allows for high mobility and ease of use, being a device that is similar to military/law enforcement equipment used today. Below in table 13 are the concepts used to generate the conceptual device.

Table 12: Concepts used in generation of concept 4

System	Concept
Propulsion	Compressed Air/CO2
Neutralization	RF - 2.4 GHz
	RF - 5 GHz
Capture	Net
Net Material	Nylon
	Poly Dracon
Net Counterweight	Four weights "clover"
Size reduction	Disposable Compressed Air
	Handheld Net Launcher
Impact Protection	Parachute net

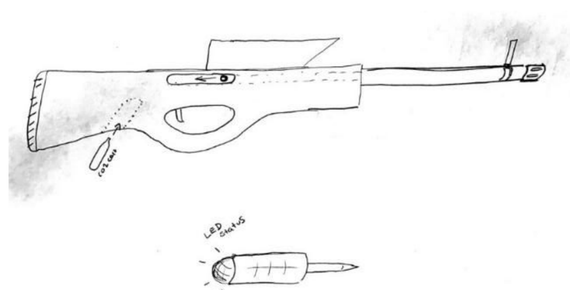


Figure 5: Concept 5, a rifle modeled after pellet rifles that uses either a spring or CO2 cartridge to launch the projectile

Concept 5 is modeled after a classic pellet rifle. It is a single operated device using only a 16oz CO2 cartridge. This device requires the drone to be stationary in order for the operator to accurately hit the drone. When the trigger is pulled the CO2, cartridge is punctured, and the pressure generated fires the projectile used. The projectile used is a dart like projectile that lodges itself into the drone. This dart may be electronically powered and used to disable the drone’s electronics and drop it from the sky. Conceptually, it may also be used as a GPS tracker to allow the operator to track and find the drone user if needed. The electronics on the dart are all remote operated. This device could be also used as a spring powered rifle. Replacing the CO2 cartridge for a high-powered spring, the user would pull the bolt as far back as possible and fully compress the spring. With the bolt open, one dart can be loaded. Once the bolt cover is closed the user can relieve the pressure with the trigger, releasing the compressed spring and propelling the dart forward. This kind of system would be extremely simplistic and require little man power. Table 14 below lists the concepts used in this device.

Table 13: Concepts used in the generation of concept 5

System	Concept
Propulsion	Compressed Air/CO2
	Spring Powered
Neutralization	RF – 2.4 GHz
	RF – 5 GHz
Capture	Projectile
Size Reduction	Disposable Compressed Air
	Handheld Net Launcher

After the concepts have been generated, the best concept must be selected to continue the conceptual design phase. Concept selection is a key element in the design process and the process used ensures the best option is used. The concept chosen as the best option is then expanded into greater details and the process of developing the product can begin.

We incorporated three main strategies to select the best option from the concepts we generated: a house of quality, Pugh matrices, and an analytical hierarchy process. These strategies are used to help rank the importance of the different components of the device, determine the relationship between engineering characteristics and customer requirements, and compare the characteristics of the most viable concepts both amongst each other and with other options.

The House of Quality is used to incorporate the voice of the customer into the design characteristics and targets selected. The House of Quality allows the engineering characteristics that the customer is most concerned about to be selected and used to evaluate the previously selected concepts. In this House of Quality, which is displayed in Figure 6, the importance factors were generated using a pairwise comparison that showed the relative importance of the customer requirements showing that Automatic Detection system is what the customer cares most about. Next, the customer needs relation to the engineering characteristics were decided using a blank space to represent zero relation, a 1 to represent a small relation, a 3 to represent an average relation, and a 9 to represent a large or direct relation. These values were multiplied by the related importance factor and summed show which of the engineering factors are most important when the customer requirements are included. The selected engineering characteristics that were carried on from the House of Quality were target acquisition speed, battery life, disabling range, target max drone wingspan, weight of device, and frequencies jammed.

		Engineering Characteristics									
Improvement Direction		↓	↓	↑	↓	↑	↑	↓	↑	↑	↓
Units		Mins	lbs	Ft	Sec	Hr	Ghz	Sec	in	lbs	$
Customer Requirements	Importance	Assembly/Disassembly Time	Weight of Device	Disabling Range	Target Acquisition Speed	Battery Life	Frequencies Jammed	Device Reload Speed	Target Max Drone Wingspan	Target max drone weight	Project Cost
Automatic Detection System	6		3		9	9			9		9
Device reach	4		3	9		1		3	1		1
Neutralization of Drone (undamaged)	5			9	9	3	9		3	3	
Device Safety	5		3								1
Retrieval of Drone	2			1					3	9	
Device Mobility	3		9								
Length of Operation	2			1		9	9				3
Ease of use	1	9	3					9			
Raw Score		9	75	85	99	91	63	21	79	33	69
Relative Weight %		1%	12%	14%	16%	15%	10%	3%	13%	5%	11%
Rank Order		10	5	3	1	2	7	9	4	8	6

Figure 13: House of Quality

The engineering characteristics previously selected as the most important from the House of Quality were carried over to the Pugh matrix in Table 14. The most important engineering characteristics chosen were the target acquisition speed, the battery life, the disabling range, the target max drone wingspan, the weight of the device, and the frequencies jammed. A datum was then selected to be the basis of the concepts and the Droneshield Drone Gun was selected. The other concepts expected performance was compared to the datum assigning an S meaning the same, a + meaning the concept is better than the datum, or a - meaning the datum is better.

Table 14: Pugh Chart with DroneGun Datum

Selection Criteria	Drone Gun	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Target Acquisition Speed	Datum	S	-	-	S	-
Battery Life		+	+	S	+	+
Disabling Range		-	-	-	-	-
Target Max Drone Wingspan		S	S	S	S	S
Weight of Device		+	-	+	-	+
Frequencies Jammed		S	S	S	S	S
# pluses		2	1	1	1	2
# minuses		1	3	2	2	2

From the Droneshield Drone Gun, it was determined concept 5 was the best choice as a new datum. It had the highest number of pluses along with concept 1 and the second highest number of minuses. From the first Pugh matrix a new

Pugh matrix was drafted from concept 5. The results of the Pugh matrix with concept 5 rated as the datum are listed below.

Table 15: Pugh Chart with concept 5 as datum

Selection Criteria	**Concept 5**	**1**	**2**	**3**	**4**
Target Acquisition Speed		S	+	-	+
Battery Life		-	-	-	+
Disabling Range		-	S	-	+
Target Max Drone Wingspan	Datum	S	S	S	S
Weight of Device		S	-	-	-
Frequencies Jammed		+	+	+	S
# pluses		1	2	1	3
# minuses		2	2	4	1

With concept 5 as the new datum it was determined with the best selected engineering characteristics that concept 2, 4, and 5, were the best choices to continue with in the selection process. Concept 4 has the highest plus score and concept 2 had the safest rating all around.

The Analytical Hierarchy Process, or AHP, is a mathematical approach to separate the best of 3 design concepts. The evaluation criteria used are the disabling range, weight of device, and battery life. This criterion is rated employing pairwise comparisons. The AHP's Rating for Pairwise Comparison is as shown in the following figure:

Rating Factor	Relative Rating of Importance of Two Selection Criteria A and B	Explanation of Rating
1	A and B have equal importance.	A and B both contribute equally to the product's overall success.
3	A is thought to be moderately more important than B.	A is slightly more important to product success than B.
5	A is thought to be strongly more important than B.	A is strongly more important to product success than B.
7	A is thought to be very much more important than B, or is demonstrated to be more important than B.	A's dominance over B has been demonstrated.
9	A is demonstrated to have much more importance than B.	There is the highest possible degree of evidence that proves A is more important to product success than B.

Figure 14: AHP's Rating for Pairwise Comparison

Utilizing the Ranking Factors illustrated in Figure 14, the importance of each criteria can be compared to the others. If both criteria have the same level importance, a 1 is inputted, if A is a little more important than B, a 3 is inputted, and so on. If the Criteria A has precedence over Criteria B, the cell gets the ranking, while the cell on the other side of the cell with a 1 is the reciprocal value of the ranking factor. The reciprocal value allows characteristic values from the house of quality to be measured in order to convey a correlation amongst those values. In order to fill out the Normalized Criteria Comparison Matrix under each criterion you put the Norm Element, which can be calculated utilizing the equation:

$$Norm\ Elementm, n \ = \ elementm, n\ summ, n$$

The Normalized Criteria Comparison Matrix takes the Norm Elements to calculate the Criteria Weight {W} that is calculated by:

$$\{W\} \ = \ 1n * i = 1nxi$$

where n is the number of elements of the criteria and xi is the value of the element. These values can be seen in Normalized Criteria Comparison Matrix.

Table 16: Development of Candidate set of Criteria Weights for Drone Disabling Device

Development of Candidate set of Criteria weights {W} for Drone Disabling Device			
Criteria Comparison Matrix [C]			
	Disabling Range	Weight of Device	Battery Life
Disabling Range	1	0.333	0.200
Weight of Device	3	1.000	0.333
Battery Life	5	3.000	1.000
Sum	9	4.333	1.533

From Table 16, the first matrix of criteria weights, the top three values of the Pugh matrix drafted were used. These values were then normalized to further increase the accuracy and precision of the concepts that had been generated in relation to the engineering characteristics.

Table 17: Normalized Criteria Comparison Matrix

Normalized Criteria Comparison Matrix [NormC]				
	Disabling Range	Weight of Device	Frequencies Jammed	Criteria Weights {W}
Disabling Range	0.111	0.077	0.130	0.106
Weight of Device	0.333	0.231	0.217	0.260
Frequencies Jammed	0.556	0.692	0.652	0.633
Sum	1.000	1.000	1.000	1.000

Table 18: Consistency Check

Consistency Check		
{Ws}=[C]{W} Weighted Sum Vector	{W} Criteria Weights	Cons={Ws}./{W} Consistency Vector
0.320	0.106	3.011
0.790	0.260	3.033
1.946	0.633	3.072
	Average	3.039
	CI	0.036
	CR	0.069

In order to do the consistency check, the Weighted Sum Vector and the Consistency Vector needs to be determined. The Weighted Sum Vector can be equated from:

$$\{Ws\} = [C]\{W\}$$

where [C] is the values in the Normalized Criteria Comparison Matrix and {W} is the Criteria Weights, that was determined in Table 17 for the comparison between the engineering characteristics. The Consistency Vector is calculated using the equation:

$$\{Cons\} = \{Ws\}./\{W\}$$

where {Ws} is the Weighted Sum Vector determined from the equation above and {W} is the Criteria Weights. Theses equations were inputted into MATLAB to find the values for {Ws} and {Cons}. To find the consistency of the comparisons, the Comparison Consistent, CR, value needs to be found and less than 0.10. The equation to calculate CR is:

$$CR = CI * RI$$

CI is the Consistency Index and RI is the Random Index Value. The RI values depends on the number of criteria used, as according to Figure 14. For our concept selection, we use 0.52 for RI because the number of criteria is 3.

RI Values for Consistency Check	
# of Criteria	RI Value
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.4
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57
15	1.58

Figure 14: Values for the Random Index

To find CI, the following equation is used:

$$CI =- nn - 1$$

The variable λ is the Average Consistency, which is just the average of the Consistency Vector and n is the number of criteria. The evaluation was then further detailed into each engineering characteristic used in the AHP to confirm the reading from the normalized criteria comparison. If the CR value is less than 0.1, then it is proven that the comparisons are fairly consistent. This guarantees that there is no overlap between the characteristics and there is little influence from the designers. So once the CR value for the primary comparison matrix is less than 0.1, then the CR values for each engineering characteristic were found. The CR values are 0.069, 0.063, 0.134, and 0.037; the values for the criteria are shown in Appendix A. Three of CR values are less than 0.1, however, the comparison matrix for the Weight of Device criteria has a CR greater than .10, which represents human bias.

Table 19: Final Rating Matrix

Final Rating Matrix				
Selection Criteria	**Disabling Range**	**Weight of Device**	**Battery Life**	**Alternative Value**
Concept 2	0.607	0.751	0.259	0.332
Concept 4	0.090	0.168	0.065	0.347
Concept 5	0.303	0.081	0.675	0.308

The final step of the AHP is to do complete the Final Rating Matrix, which is the {W} values of each criteria for each concept. This produces the best concept to use. In order to accomplish that, the Alternative value for each of the final 3 concepts were found. Once again MATLAB was utilized, taking the transpose of the Final Rating Matrix and multiplying it by {W} from Table 18. The equation used was:

$$Alternative\ Value = [Final\ Rating\ Matrix]T. * \{W\}$$

So, based on the Final Rating Matrix in Table 19, concept 4 has the highest alternative value. This means that concept 4 is the best design to pursue.

Based on the results of the House of Quality, Pugh Matrix, and Analytical Hierarchy Process, it was clear that concept 4 is the best concept to pursue for the Drone Disabling Device. This concept has been quantified to be the most feasible design, proving to meet the standards of customer needs to the greatest extent. Therefore, there is full confidence that this concept will be the best design to create and that the customer needs of the project will be adequately met.

Figure 14 below is the CAD drawing of the final design.

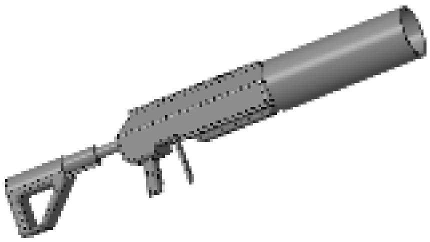


Figure 15: CAD of the final design

The main body is made of Polylactic Acid, PLA. It was decided that it would be easier to 3D print its unique shape and one of the objectives is to be small in size and lightweight.

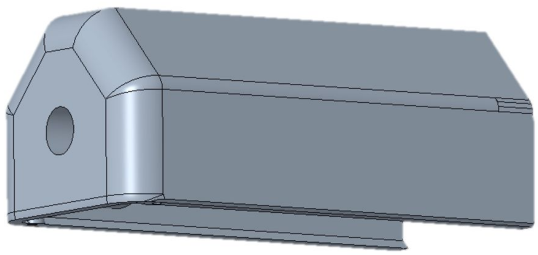


Figure 16: Front part of the body

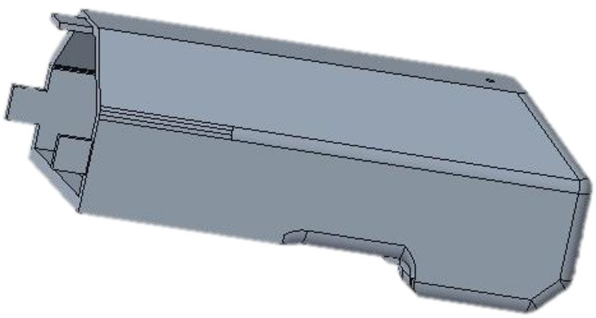


Figure 17: Front part of the body

The body had to be broken up into two halves because the size of the 3D printer is limited in size. The tabs in Figure 17 are slid into slots (not shown) in Figure 16.

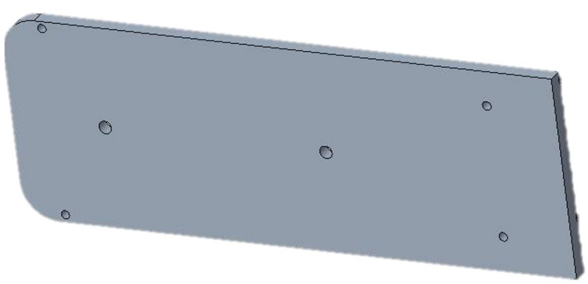


Figure 18: Bottom Plate

Figure 18 depicts the bottom plate that is screwed to the front part of the body. This holds a small MOE polymer rail section where, if allowed to, would hold a jamming system. As mentioned before, the reason a jamming system is not allowed is due to federal laws implemented by the FCC.

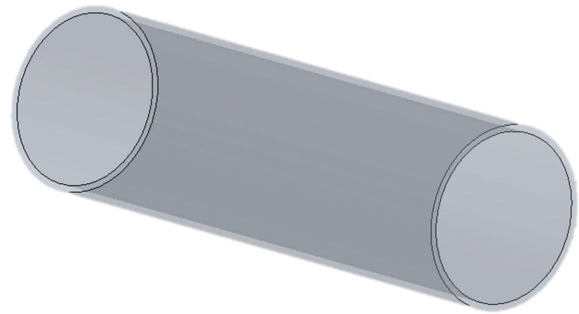


Figure 20: Barrel

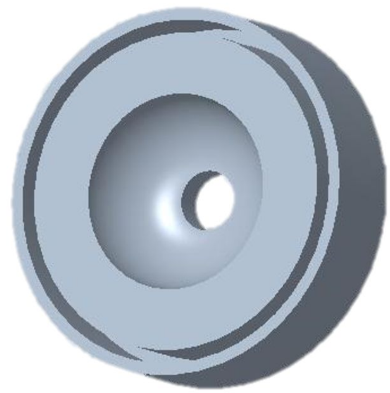


Figure 21: Barrel Cap

Figure 21: Net Horn

Data analysis

For the high-pressure air, HPA, calculations, the Bernoulli's equation as stated in the previous section. It was used twice to determine the velocity of HPA as it leaves the barrel of the device. The first stage is from the tank to the nozzle. The second stage is from the nozzle through the hose to the rifle. For the calculations, it was assumed that the barrel to be modeled as a smooth pipe with turbulent flow, so the friction factor can be calculated using Colebrook-White's Equation:

(8)

Where Re is the Reynold's Number, which was determined to be 151.721. ϵ/D is relative roughness of the pipe based on the material, which the material is PVC. The friction factor was calculated to be 0.0166.

When calculating the velocity from the tank to the nozzle, P_1 in the Bernoulli's equation decreases by about 200 psi each time air is released. The starting pressure is at 3000 psi and the velocity running through the remote coil at this pressure was calculated to be 11246.95 inches per second. As the pressure decreases, velocity decreases. To calculate the velocity of the air flowing from the trigger through the rifle the following equation was utilized:

(9)

This equation relates the velocities flowing through two different size pipes, V_n, to the cross-sectional areas, A_n, of the different stages. When the tank is full, the velocity is 632.26 inches per second.

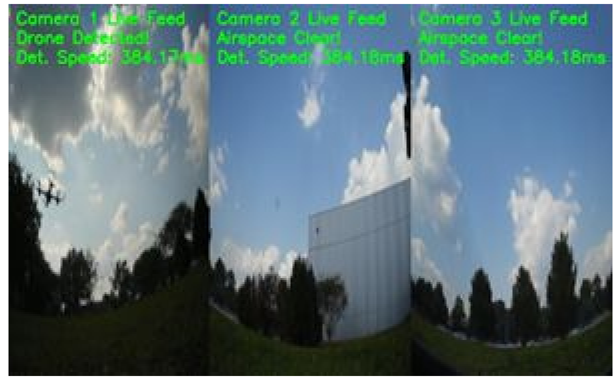
The following equation was used to determine the velocity of the net, assuming no drag forces are acting on the horn:

(10)

Equation 10 relates the velocity of the net to the length of the barrel. m represents the mass of the net, which is 0.078 pounds. P_0 is the pressure hitting the net and V_0 is the volume of the barrel at different lengths. A_c is the cross-sectional area of the barrel, L is the length of the barrel, and f is the friction factor determined from Equation 8. Figure 30 illustrates the affect barrel length has on the net velocity. From the graph, it can be determined that the longer the barrel is, the faster the net exits the barrel.

Figure 30: Graph that shows the relationship between net velocity and barrel length

RESULTS



The results of our detection system exceeded our initial expectations. We were able to achieve a maximum detection distance of 154 feet, exceeding our target distance of 30 feet. The fastest our device was able to detect a drone was 33 milliseconds, exceeding our target detection speed of 5 seconds.

DISCUSSION

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SUMMARY

The detection system consists of three SJ4000 portable cameras that were trained with a machine learning model to be able to distinguish drones in an outdoors environment. In order to run the detection algorithm, a Raspberry Pi Model 3 B runs a Python script while the device is in use. Machine learning and computer vision use a substantially high processing power, which well-surpasses the maximum capability of the Raspberry Pi. As a result, an Intel Neural Compute Stick 2 was purchased and implemented to the system. This USB stick is a dedicated vision processing unit, which drives all of the complex calculations involved with the machine learning functions of the detection algorithm.

The entire detection system is powered by a 30 AH portable battery, which sufficiently powers all of the electrical components of the system for a minimum of 11 hours when running the detection algorithm. By choosing all lightweight and portable components for the detection system, this system can be easily installed to the backpack and give the user maximum comfortability. In addition, no wall-power is needed so that the device can remain fully portable.

While running the detection algorithm, the cameras actively capture video feed at 30 frames per second (FPS) and feed each individual frame through the convolutional neural network that the cameras were trained to detect drones with. When the cameras determine that what they see is indeed a drone, an alert is spoken out the user to let them know which camera saw the drone. Then, an active beeping is outputted until the drone is no longer detected.

In order to account for false-detections, the detection algorithm can be set to read a set number of frames at a time in a packet and only determine that a drone is detected if a set percentage of frames in that packet were classified as drones. In addition, the algorithm can easily be adjusted so that the cameras need to have a higher percentage of certainty per frame before classifying the given frame as a drone.

This level of redundancy increases the overall accuracy of detection (which is 96% accurate if only reading one frame at a time with a 50% certainty). However, increasing the number of frames in the packet that need to be read before a decision of whether a drone is detected or not also decreases the overall detection speed. With the given target of 20 seconds to accurately detect a drone, and a maximum detection speed of 30 FPS, 600 frames could be read at a time in the packet and the detection system would still meet this given target. Therefore, it is negligible to the targets of the project to use a packet of 5 frames at a time, which was the chosen number of frames to demonstrate the detection system with.

FUTURE WORK

For the detection system, the most impactful improvements could be made to the hardware of the system. If the SJ4000 cameras were replaced with higher quality depth-sensing cameras, the detection algorithm could be optimized to give the user an output that shows which direction and how far away the drone is. Currently the system only gives the user a general direction of where the drone is by saying which camera the drone was detected on. If the system could detect which direction and how far the drone is, the overall drone disabling system could potentially be converted from user-controlled to autonomous. The SJ4000 cameras had a max frame rate of 30 FPS, so as a result the detection system was limited to detecting at the quickest possible rate of 30 FPS (about a 33 ms detection time). If higher frame rate cameras were used (for example, 60 FPS cameras), this would allow a quicker potential detection speed by the detection system. As a result, the detection system could potentially detect a drone in as little as 17 ms if 60 FPS cameras were implemented to the system.

In addition, while the Raspberry Pi 3 Model B was powerful enough to meet the project's targets, if a different computer system was used that had a higher graphics processing power, then the detection system could have shown the user a smooth live video feed when in use. For this system, smooth live video feed was achieved if one camera was used, but when using two or three cameras, there was a substantial drop in frame rate due to the graphics processing power of the Raspberry Pi. This drop in frame rate also attributed to a reduced detection speed when outputting live video feed due to stalling the detection script (waiting until the command to output the given frame finished to execute the next line of code). When utilizing live video feed, the detection speed was about 400 ms, but without live video feed, there was a max detection speed of 33 ms! For this reason, the demonstration for this project was performed without the use of live video feed.

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REFERENCES

[1] Adam Marianski, A., n.d., "Casting Net", https://www.meatsandsausages.com/fish/cast-net

[2] N.A., n.c., "Bernoulli's Equation", https://www.princeton.edu/~asmits/Bicycle_web/Bernoulli.html

[3] N.A., n.c., "Colebrook Equation", https://www.engineeringtoolbox.com/colebrook-equation-d_1031.html

Annex A

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