Faculty of Technology, Natural Sciences and Maritime Sciences
Department of Science and Industry Systems

Subject code: IB2010
Subject: Systems Design and Engineering

Shahin Mobile System

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April 28, 2023

Abstract

This report documents our groups approach to the System Design and Engineering case on eliminating threats from unmanned aerial systems by mitigating using a system of our design.

Topics will include the case, concept of operations, our approach to system thinking, system black-boxing, and concept selection. Additionally students from the three different courses has gone down in the system and partially designed some of the subsystems using domain knowledge.

Using the combined work we have established an entire system or a «system as a whole» and used this to describe the life cycle and business proposition for our system.

Contents

1 Introduction

Our group is excited to present our Systems Design and Engineering project addressing the increasing challenges with unmanned aircraft systems, commonly known as drones. Drones has become increasingly popular in recent years in part to increasing availability and growing market [1]. The popularity has also resulted in new challenges faced by several sectors of society and industries [2, p. 34], mainly regarding safety. In this project we aim to identify and address these challenges by scoping the problem in the context of events.

The concept of operation we have focused on is deployments at festivals and other short-term events. Festivals provide a fun and enjoyable experience to the attendees, but it is also one of the type of events that are vulnerable for drone attacks, posing safety risks and privacy concerns. We have analyzed the issues and needs to provide a technical and business solution to this case.

Our group acts as a start-up company consisting of a group of multidisciplinary engineers *(mechanical, software and electronics)*, along the report we will provide you our technical approach on managing drone threats at festival settings. We will showcase our physical «mobile defence system», technical analysis of the festival environment, drone detection, tracking and intercept system and an overview over how the whole system is tied together. We will also provide you a business plan and defend our approach to an modular, mobile and leasing based system.

Overall, we hope our presentation provide you an valuable insight into the problem domain of managing drone threats in festival settings, and a potential solution that can be implemented in the future.

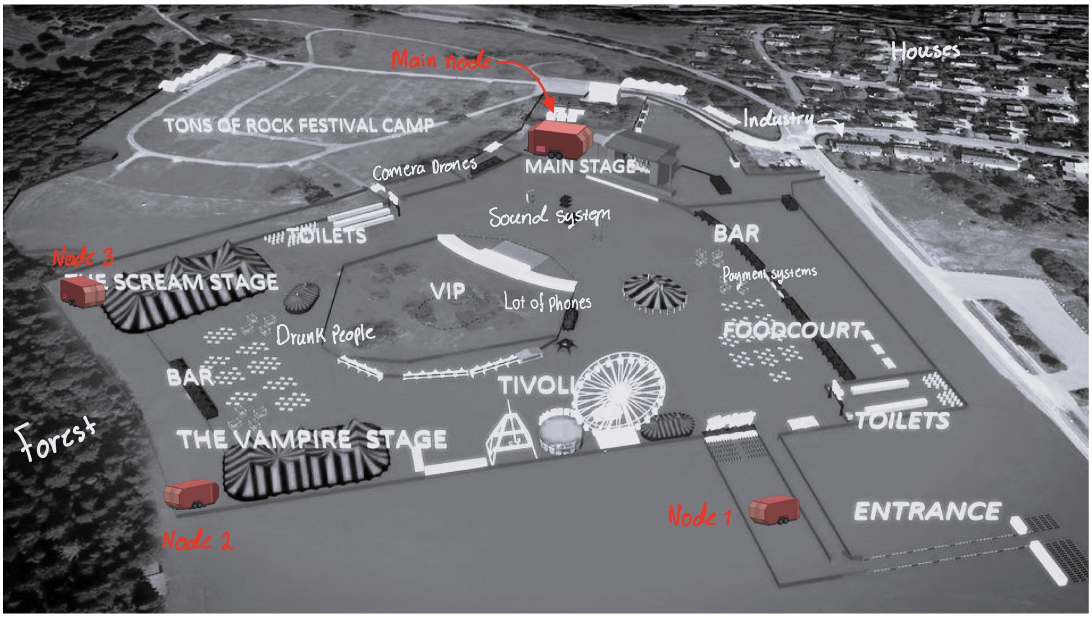


Figure 1: Our system in a festival context

2 Group organisation

Our group is organized as a flat organization structure where the responsibilities are divided into the disciplines we have at our disposal. However, we always start our work with a group meeting to exchanges ideas, knowledge, challenges and hand out work for the coming week. After some weeks of work we decided to split the group into smaller working groups of 2-3 within software, mechanical and electronics, the purpose was to take advantage of our corresponding discipline knowledge and experience.

Early on we spend some time to get to know each other, and it was important for the project leader to analyze the group dynamics and knowledge to find an optimal way to organize the group work. It turns out that our vision soon went to be an tunnel vision as we sat together for four hours each time and productivity went down. Our measure to avoid that was:

- Divide the group to smaller groups
- Use time boxes for a particular problem
- Some times we just voted for an idea/solution to save some time and sleep on it

However, the report shows more or less a static and linear flow of the project work. In reality we have worked through the T-shape model, and done several iterations to find critical points of the system and consider different solutions. Our diagrams is also a result of several iterations, you can see some of our early sketches in appendix. We have also collected valuable knowledge on various project management models that can be applied to future projects. In Figure 2 bellow you can see how our project group is organized.

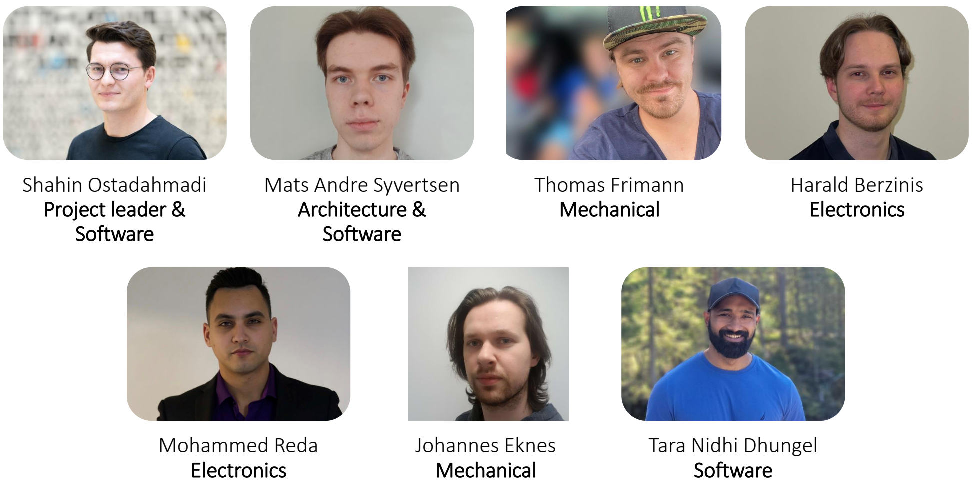


Figure 2: Our group members

3 Concept of Operations

3.1 Case

The case handed to us is a widespread case with follow «The goal is to eliminate threats posed by An unmanned aerial system (UAS)»

In this section we will develop the framework of the entire system by defining the concept of operations (ConOps), which will set the technical roadmap for the project. We started to gather information about what such system needs to achieve its goal to stop the unwanted drones. After while of discussion and analyzing the problem and brainstorming over some days, we created a long list of things which we thought it was necessary for the system to have. We then had some iterations of going through the list starting from sorting the list into categories in Figure 3 and prioritize such that the system under development(SUD) to meet the drone problem.

Since the drone problem was new for the group, we started to gather information about different drone problems and drone industry to really understand the problem and find critical points of the system that we should take into consideration later in the development. In Figure 3 you can see the the the needs, goal, objectives and constrains of the system which is translated into technical requirements later.

Figure 3: Concept of operations

3.2 Scope

Unmanned aerial vehicles (UAV), or drones, have revolutionized how we capture videos and images. However, these flying machines have also become a growing concern for businesses, event organizers, and government officials. Drones can fly over restricted areas and capture sensitive information or images, leading to privacy invasions and security breaches. As a result, it is essential to have a solution to prevent unauthorized drones from entering restricted areas.

Since it is widespread problem, we had to find a smaller scope that was within a manageable scope, time and resources we are given. After some research we found events to be interesting and evaluated drone challenges in events given it‘s attributes such as highly crowded area, the short duration of events requires mobile and effective setup and locations that making it easier for drones to fly in undetected.

Once our scope was set, we chose to focus on outdoor festivals as our use case for the project.

3.3 Risk analysis

To address the consequences for unwanted drones in restricted area there was necessary to describe and gather the incidents/threats which could occur and their impact to be able to understand the importance of functionalities and capabilities of the system under development. We have gatherd the information in table 1 bellow with legends bellow it.

Id nr.	Incident	Degree of Danger	Impact	Assessment of Impact				Degree of Risk after Measures			Risk Reducing Measures
	What?			P	E	C	SUM				
1	Recording	S5	Potential incident within the festival	-	-	K1					#1, #2
1.1	Amature Rec (with and without drone)	S1	If inside the area, the drone can fall down and harm the public	K5	-	K1					#1, #2
1.2	Drone recording (Profesional)	S3	Potential unauthorised sharing of recordings live and uploaded	K3	-	K2-K5					#1, #2
2	Recreational Flying	S5	Potentially unwanted drone over the festival area, leading to unwanted incidents	K5	K2	K5					#1, #2
2.1	Accident involving personal injury and affecting the festival	S3	Drone(s) crash over the festival	K5	-	K4					#1, #2
2.2	Within the Area	S4	Potential collision and/or fall within the area	K3	-	K2					#1, #2, #3
3	Sabotage (potential act of terrorism)	S2	Intentional event within the area (e.g. collision)	K5	-	K5					#1, #2
3.1	Sabotage (destruction/disrupting)	S3	Interfere with and/or destroy production equipment	-	-	K3					#1, #2
4	Transport of drugs and other undesirable substances	S3	Transport and release of drugs within the festival area, after the security point of the	K5	K3	K5					#1, #2, #4

ID	Risk reducing measures
#1	Main node w/radar/antenna and drone-modules
#2	Warning message is sent to drone-operators
#3	Mini intercepting module
#4	360° camera w/ view to module on both sides

ID	Probability
S1	Highly Unlikely
S2	Unlikely
S3	Possible
S4	Likely
S5	Almost Certain

P	People
E	Environment
C	Economy

Table 1: Rapid risk ranking - RRR

3.4 Stakeholders

To ensure that stakeholders are kept informed, involved in decision-making, and that their concerns and interests are taken into consideration, effective stakeholder management is essential during the development and implementation of a system. This can promote trust and guarantee that the system is efficient and in line with the requirements of all stakeholders.

Maintenance team, operators and engineers will be working closely with the system hence customers, investors, law, public and other are important stakeholders for the system and will be working around the system.

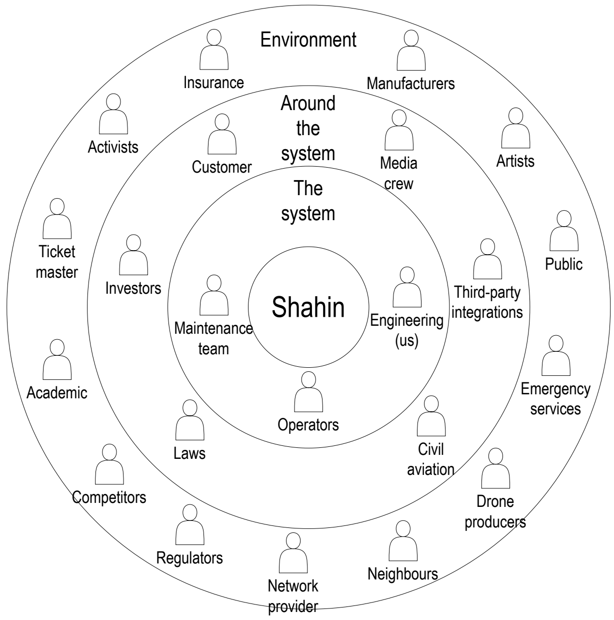


Figure 4: Stakeholder diagram

3.5 Customer key drivers

Customer key drivers are essential considerations for any business or start-up looking to develop and deploy a new system. In our case, it is crucial that the drone detection and prevention system is safe and reliable and does not cause harm to festival participants or any living beings.

Safety: Safety is a top priority for festival organizers, and they need to ensure that the system they use does not pose any risks to the participants. Therefore, the system should prevent potential hazards or accidents from using drones, such as collisions or other malfunctions.

Reliability: The system should be able to detect and prevent any unauthorized drones and provide real-time feedback to the operators. It should also be able to function effectively in different weather conditions and resist interference from other sources.

Integration: System should be able to interface with external systems, such as security cameras, alarms, or other sensors etc., to provide a comprehensive and integrated solution.

Non disturbing: The system must not disrupt the festival atmosphere or cause any inconvenience to the participants. Hence, the system should operate silently and unobtrusively without drawing attention to itself or creating unnecessary distractions.

Easy setup: Since our system is mobile, it must be fast to set up. All nodes are interconnected with mesh topology, which makes it easier to connect and deploy.

4 System thinking

4.1 Approach

Our group adopted a collaborative approach for working with the project, this involved meeting weekly and holding discussions with all group members. This often led to a longer duration for the first iteration cycle for the various parts of the system. But it also ensured everyone got to provide their own input on the part of the system being worked on.

To be able to take advantage of the different skill-sets most of the system has been split into multiple subsystems where responsibility is assigned to the student(s) with the most relevant course and experience.

Early on we spent time sketching the concept of the system, we have continuously iterated on this based on external feedback and knowledge gained during the course.

4.2 System as a whole (Blackbox)

To be able to understand the inputs and outputs of our system we have analyzed the festival environment and the elements who interact with the system to get an overview over interfaces. You can see how the system interacts with the environment in the context diagram in Figure 5. The diagram provides an understanding of the system to follow up the interfaces and design the system to overcome the requirements.

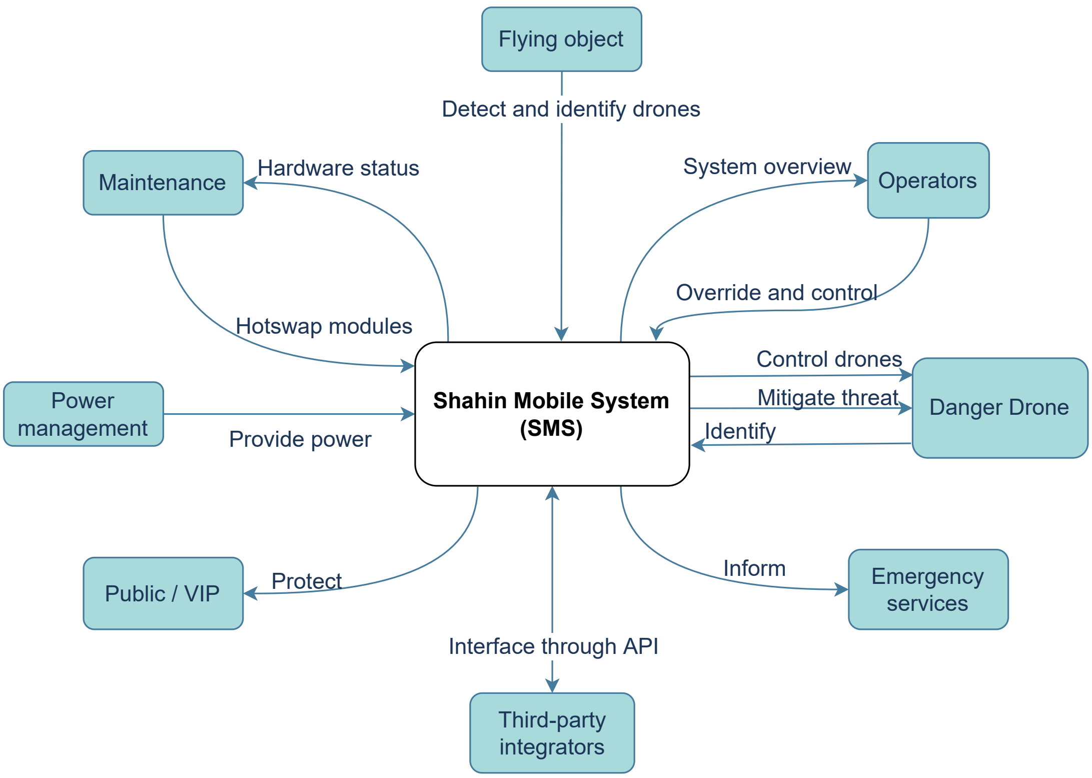


Figure 5: System context

From a use-case perspective the system can be divided into the actors it has to protect and the threat actor. The various actors under protection includes operators and maintenance with will directly monitor and manage the system.

There is also security and other staff which will get the ability to receive alerts, this can be helpful for the actors involved with crowd control and securing other actors and assets.

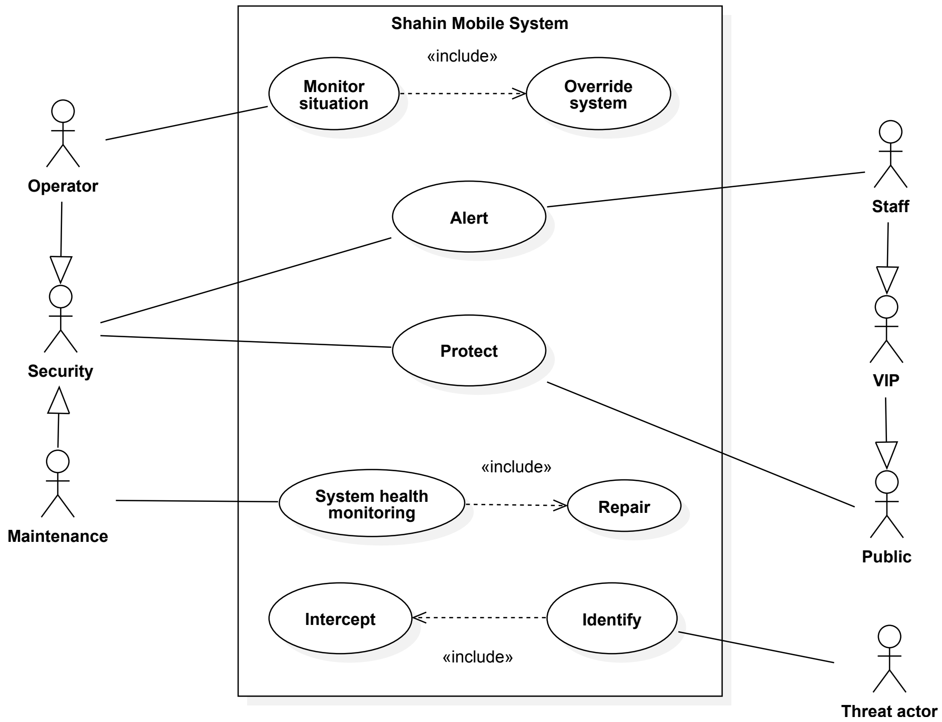


Figure 6: Use-case diagram

Note that while the threat actor is listed as an actor, the use-cases for it are driven by the system itself to identity the threat and mitigate it by intercepting it.

4.3 System requirements

From our work of developing concept of operations and analysis of the needs for the system, we have developed the technical requirements. We have done several iterations to ensure that the requirements actually answer the need to achieve the goals for the system. We have divided the requirements into —— different categories as follow:

Functional:

- **Detection:**
  - Drone size: larger than 10 cm
  - Range: Within 1 km
- **Elimination:**
  - Intercept the drone
- **Weather condition:** The system should operate in -20° to 40°

Interfaces

- Radar signal receiver
- Human Machine Interface
- Provide location, size, shape and speed of detected object

4.4 Concept selection

To fulfill the system requirements we have done brainstorming to come up with concepts on what solutions and technologies to base the system on.

The first concept selection we did was on what kind of system we would want, and what kind of mobility it should have. We landed on three separate concepts, to have it mounted in a car, to have the entire system as a trailer and just package it in boxes as a module based system. To weight these different concepts we did a round of concept selection using a Pugh matrix, see Table 3. Here we ended up choosing the trailer-based mobile system as it struck a good balance with easy setup, sustainability and reliability as it does not have the mechanical subsystem of a car present.

Being able to detect threats within the requirements lead us to the second concept selection, this time for detection methods. The relevant technologies we found was Radar, Radio Frequency based tracking (RF), Lidar using laser and a combination of Radar and RF as they can be deployed alongside each other easily. Using a Pugh matrix, see Table 4, we landed on using a combination of Radar and Radio Frequency as it made it possible to detect remotely controlled droned over RF and track foreign objects within the airspace.

Another critical part of the system is the ability to intercept foreign unmanned aircraft systems within the area. We came up with various concepts with focus on existing and proven technology to minimize risk. The concepts we came up with was intercepting with a another drone, meaning it would try to intercept its path and have a small net it can disable the others exposed propeller blades with. Another concept was directional jammer where we would point a directional jammer and try to block any relevant RF signals. Another one was shooting a net automatically, but reloading and maintenance and reliability scored low in this one. The last one is the intercept drone with the directional jammer attached instead on the ground. All of this got weighted based on criteria using a Pugh matrix, see Table 5. We ended up finding the intercept drone and direction jammer combo as the best choice for our system.

4.5 System architecture

As already mentioned in the Approach section of this chapter we decided to split the system as a whole into smaller subsystems. Using model-based systems engineering (MBSE) we could create models relevant for both software, electronics and machine engineers.

To visualize all of this we adopted a version of the SysML Block Definition Diagram to model the relationship between the various system blocks [3].

For the main system overview diagram, see Figure 15. The diagram is compromised of the all the subsystems that we have defined within our system boundary, see Table 2 for a list of all the subsystems and accompanying SysML Block Definition Diagram.

Subsystem	System ownership	SysML Block Definition Diagram
Mobile System	Machine	Figure 16
Communication network	Electro	Figure 17
Communication node	Electro & Software	Figure 18
Power Subsystem	Electro	Figure 19
Phased Array Radar	Electro	Figure 20
Radio Frequency tracking	Electro	Figure 21
Drone Interceptor	Electro & Machine	Figure 22
Interceptor Drone	Electro & Machine	Figure 23
Compute	Software	Figure 24
Operating console	Software	Figure 25

Table 2: Overview of the various subsystems

Figure 7 shows overview of the system as a whole. We can follow the diagram from top-left where our physical trailer is located and follow the arrows to see the information flow and actions the system performs. In this diagram you can see where the elements in the context diagram 5 is connected to the system. In our context diagram we saw that the operators shall be able to get an system overview and override and control the system manually; They are able to do that through the **HMI**(*Human-machine interface)* interface, where the operators get access to the system through a user interface.

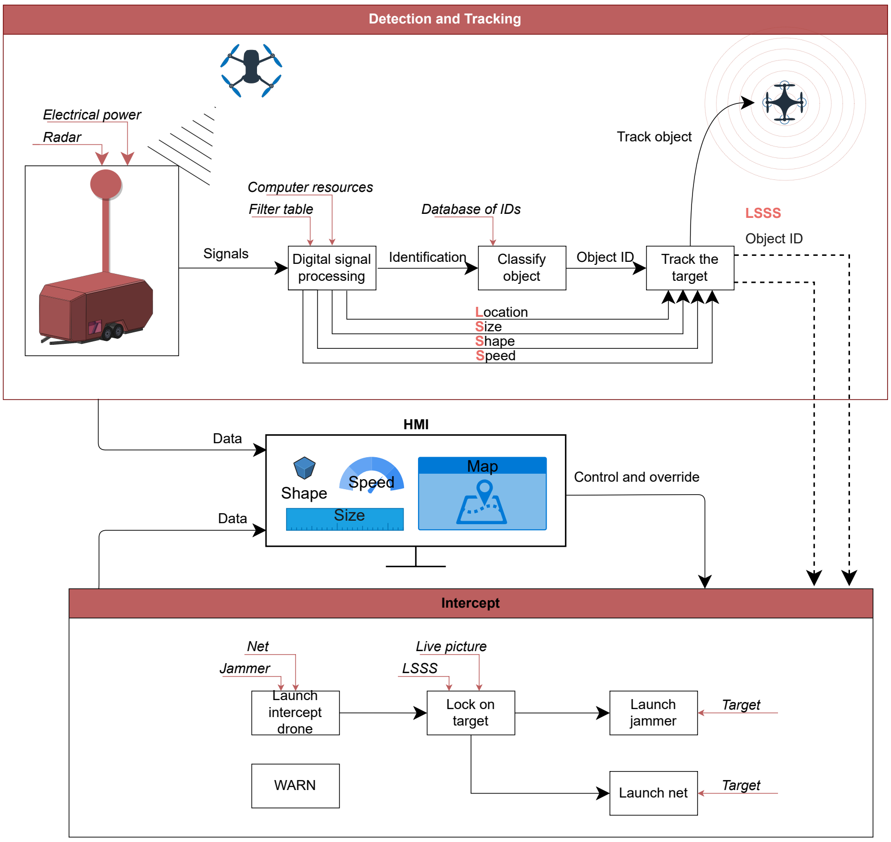


Figure 7: Technical overview diagram - Showing overview over the system as a hole

5 Electrical System

One of the key components of our Shahin Mobile System is the electrical system. This section is important for powering all the different components and subsystems. This includes the power distribution system, hemispherical phased array radar for detection of incoming targets, communication between the different modules, and drones with net-catching and jamming components. We will also be explaining the different design choices we made, and why the different components that we have chosen are appropriate to our context.

5.1 Quantization of Hemispherical Phased Array Radar

We have chosen to quantize the Hemispherical Phased Array Radar to show the importance of the electrical component in our system. The quantization can be found in the appendix, and it will consist of radar specifications and parameters, signal processing, simulations and simulated performance.

5.2 Power Distribution

The power distribution system is a key component for our mobile platform. The system will be able to to connect to 3-phase and 2-phase main power connections for operation and charging. These connections will be then rectified and converted to the DC-current from main power AC-current to the desired voltages. The results of this conversion will be charging the main battery and supplying different electrical systems.

5.3 Direct-Sequence Spread Spectrum Communication

Communication for our mobile platform is a key factor for a functional system. The different modules will be using Direct-Sequence Spread Spectrum [DSSS] modulation for communication. This type of communication modulation is important to have for our festival context, where interference from mobile phones can be an issue. Another side note is that this modulation type is resistant to jamming due to its fluctuating frequency of transmission.

DSSS communication works by using a wide range of transmitted Pseudo-generated frequencies. These different frequencies are generated by a feed-back shiftregister to generate the wanted the pseudo generated sequence. This means that the receiver and the transmitter need to be synchronised with each other, which makes it possible to spread the sequence in different frequencies [4].

5.3.1 Modulation of DSSS

The transmitted signal $d(t)$ consists of the binary sequence $b(t)$ which is the information binary sequence multiplied with the pseudo-random sequence $p(n)$, this is shown in Eq.1. A simple modulation of DSSS can be found in Fig.8. When multiplying the information signal and the Pseudo-generated sequence the transmitted signal becomes wider in bandwidth, thus spreading the signal over a broader frequency range.

$$d(t) = b(t) \cdot p(t) \tag{1}$$

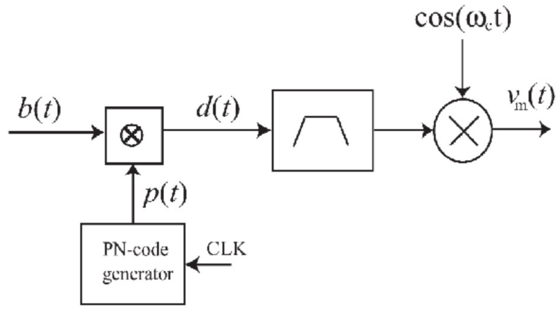


Figure 8: Example of DSSS modulation [4]

5.3.2 Demodulation of DSSS

The demodulation of DSSS works by first receiving the transmitted signal, and then synchronizing the clock. The receiver then finds the correct replica of the generated code and matches it. The receiver then tracks the phase and timing variations in order to maintain synchronization, the general term for this is Code tracking. Later the signal is multiplied with the same Pseudo-generated code found in the transmitter, in order to de-spread the signal. The last part of the demodulation is about the receiver deciding if the data bit is a "0" or a "1" in binary. This then gets compared to a threshold value. A simple example of the demodulation process can be found in Fig.9

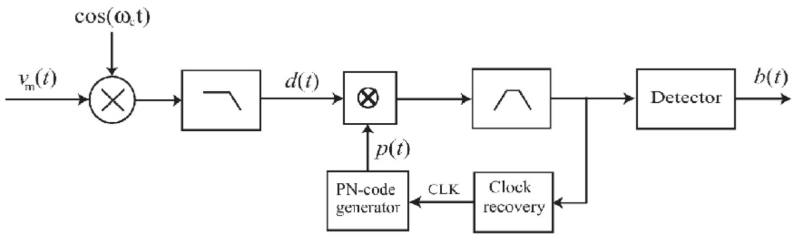


Figure 9: Example of DSSS demodulation [4]

6 Software

6.1 Software architecture

From a software perspective the goal is to create a modular and flexible system with focus on being upgradable and maintained throughout the product life cycle. To achieve this we put a lot of thought into this during the early architectural decisions. The software project is split into different smaller projects based on what node/subsystem it belongs to e.g. detection, intercept and compute.

The compute subsystem can be referred to as the «brain» in the system and does all the logical decision making based on data generated from other nodes, and will use this to control the Intercept subsystem. The data generated from the Detection and Intercept subsystems are combined into a single situational overview of the area through a process called «data fusion».

6.2 Software stack

From a software perspective we can segment all the software components into layers (See Figure 10), this is commonly referred to as the software stack. In the bottom there is the hardware abstraction often through drivers in the operating system, direct I/O and/or other firmware. Then there is the operating system which provides high level abstractions for managing processes. On top of this we reach the scheduling layer and after that the main software components which are spread out between the different nodes in the system.

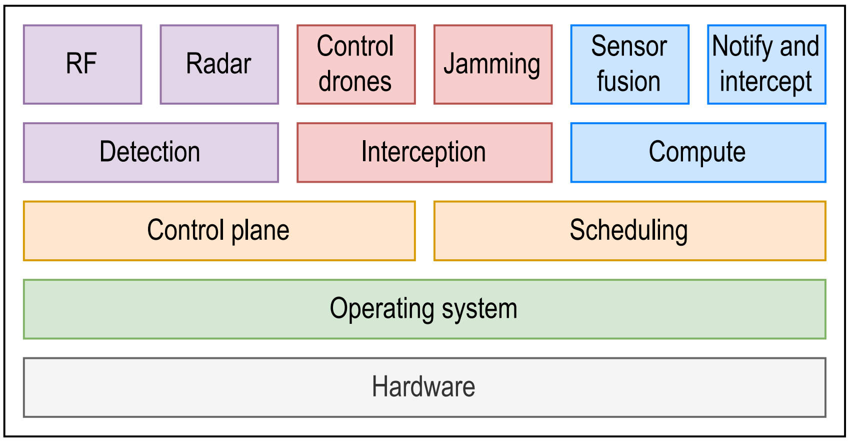


Figure 10: Software stack

6.3 Distributed operations

All these projects share common code used to create a distributed network through wireless and interconnect based networking. The nodes will pick a leader that will assign responsibility within lead the control plane which manages scheduling across the cluster to provide scalability. If it fails a new leader will be elected and the cluster will restore itself to working order if possible, this introduces redundancy to the system. It can be extended by adding more nodes, which can also increase coverage and reliability. Partitioning may be introduced too in case a single cluster has bottlenecks hindering further scaling.

7 Introduction to the Mechanical Engineer work process

From the mechanical engineers' side, the SIMILAR model has been closely followed throughout the project as well as the 7 Ws, both the German (Was, Wie, Wo, Wer, Wann, Warum & Womit) and the 7 Step Routine (Structured Way of Thinking), (Why?, Who?, What?, How?, By Whom?, When & Where?, How it Went).

7.1 The initial design phase

(Ref. Appendix for Mechanical, Section 9.5.3)

After concept screening is selected the main unit shall be a trolley with an operations center/workplace inside, as well as modules with a drone equipped with a jammer type and a net thrower. The main unit will be equipped with a Radar that must be able to be hoisted to an operational height while remaining stable and stationary. The final concept chosen has taken inspiration from how a caravan is constructed, and the drone docking module with a drone inside will be placed in a docking/charging rack in the back of the caravan.

There is a strong desire to reach a target of a maximum tare weight of 3500kg, where the main target is 2800kg - 3000kg, so that the system can be transported by a B-registered vehicle, and at the same time have the possibility to adapt the total system as needed.

7.1.1 Wagon Model

The trolley unit is inspired by a minimalist and timeless design, but also robust and practical design. To satisfy the requirements of sustainable, smart solutions, economic aspects and customizable. The wagon unit is inspired by a minimalistic and timeless design, but also robust and practical design.

7.1.2 Drone dock & Drone Unit

We chose the design of the DJI Matrice 30T drone because of its very simple design. With this design, this will allow us more room for improvement during the development phase and its folding function of the rotor arms. For the drone to be able to lift itself and a captured drone, the arms need to be longer and the same with the rotor blades. The drone unit will be equipment with the counter-measure systems.

For the drone dock, it's design is inspired by the DJI Matrice Drones [5].

7.2 How, Why, When & Where - Process

7.2.1 Central of Operations & Slave Unit

A main unit and a certain number of slaves, if necessary, will be placed beyond the area to be protected.

Main Unit

A main unit shall have the ability to override other slave units. Any unit should also be able to be incorporated into another system so that it will act as a slave unit but can still be controlled.

The main unit is equipped with a powerful machine that receives signals from the radar and sends information back to the central station for live monitoring.

Slave Unit

The slave unit does not necessarily have to be equipped with a monitor, but it can be. The number of slave units needed may vary depending on the size of the mission area.

7.2.2 Drone Module

In a Drone Module there is an intercept drone that should be able to intercept a potentially dangerous drone in the workplace. The drone will have a docking system that it will go to when it goes into standby mode.

Intercept Drone: The main task of the Intercept drone is to capture unidentified drones in the workplace, whether it is a private drone or a hostile drone. Our drone is equipped with several tools to reduce the damage that could possibly be caused by the unidentified drone.

Drone: The drone will receive information on the location of the potential threat in the airspace and will use non-harmful means.

Jammer: The drone is equipped with a jammer that should override the signals of unidentified drones so that it will be easier to intercept them.

Net Gun: Once the plan to jam the unidentified drone is successful, the intercept drone will use a net caster to capture it.

7.2.3 RRR of Drone Unit

Id nr.	Incident	Degree of Danger	Impact	Assessment of Impact	Degree of Risk after Measures	Risk Reducing Measures
	What			People		
1	Drone malfunction over crowd	S1-5	Accidents, injuries or death may occur	K5		#1, #2
2	Drone Crash leading to injury or death	S1-5	Accidents, injuries or death may occur	K5		#1, #2
3						

Figure 11: RRR of Drone Unit

7.2.4 Safety solution

In case of a malfunction of the intercept drone system above operating altitude (20m), the drone is equipped with a parachute that is deployed by means of compressed air and the propellers will be stopped. In case of a short circuit or uncontrolled descent, the parachute function will be activated.

If the drone must fly below 20m altitude, the system will have a sensor mounted below that detects if there are people below the drone in a radius equal to the current altitude of the drone and require human observation. The drone is further equipped with a kill switch that will activate the parachute function; this function will also be activated if the RC unit loses contact with the drone.

7.2.5 Drone module docking system

The drone has a docking system where the battery or batteries will be charged and/or replaced. Here the drone will remain in a standby mode until possible threats are detected in the air. The docking system has two hatches that open automatically when the drone is tasked to capture other hostile threats.

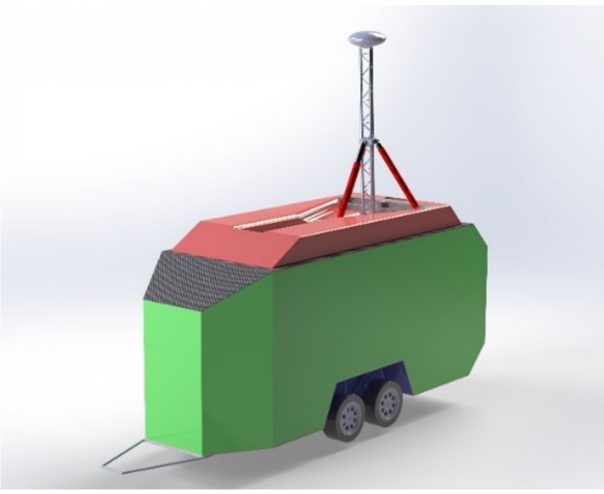
7.2.6 Technical weight budget and target

This diagram is actively used during CAD modeling and development of solutions to reduce weight while maintaining the objectives and requirements. See Figure 37 for technical budget.

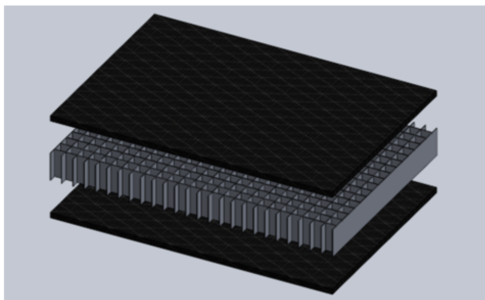
7.3 How to reach sustainability and lifetime requirements

To satisfy the requirements of sustainability, smart solutions, economic aspects, and adaptability, it has been decided to go for a solution where the body is built up with two layers. The outer shell is a thin fiberglass plate that is foiled with a self-healing foil. The inner plate is made up of two thin plates with a thin honeycomb patterned aluminum core filled with foam, this will provide a strong self-supporting construction that can easily be changed without a major job.

This means that a plate can be easily be dismantled and then changed to a door, window, or storage, this will be possible to changed afterwards without great cost or a time-consuming job. This will satisfy sustainability requirements as we are both able to change a unit instead of replacing a fully functioning system, at the same time our options to reuse or fix the material are present to minimize the use and throw away philosophy. Together with a minimalistic design, it will ensure that the lifespan of the product is not about the design, changed needs and/or new area of use, but the lifespan of the material.



(a) Our mobile Wagon



(b) Docking open with intercept drone

Figure 12: Wagon and body material

8 Business proposition

8.1 Business model

As we decided to narrow the case down to a festival environment and other short-term events, that does not need a permanent installation, it made sense to focus on a leasing based business model. This makes us lease the size needed for event and; maintain and upgrade the system when it is not at a customer.

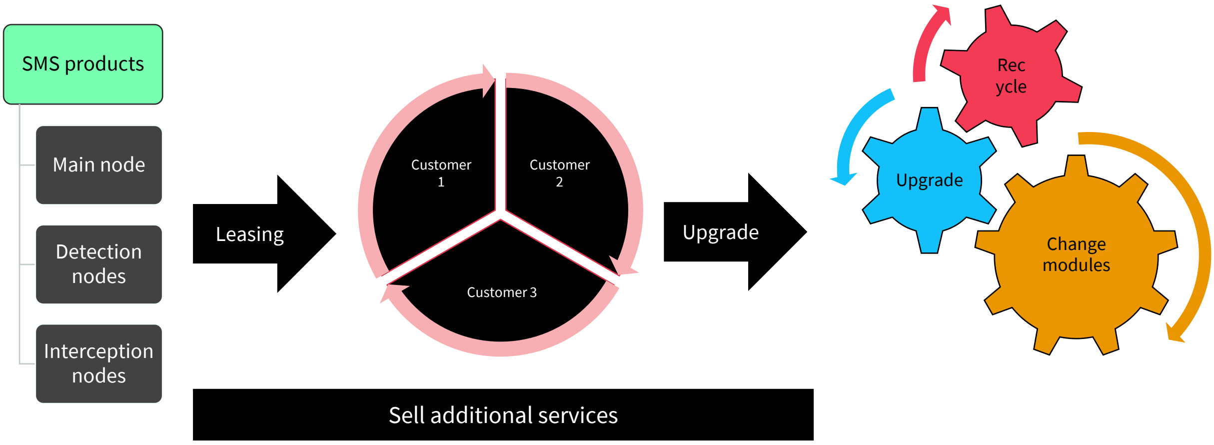


Figure 13: Business model for SMS

8.2 System Life Cycle

As a part of our focus on sustainability we have decided to continuously utilize the modular structure of the system to incrementally upgrade and maintain the system based on need.

While this needs more engineering upfront, it gives long-term benefits when it comes to upgradability and extending the lifetime of the system.

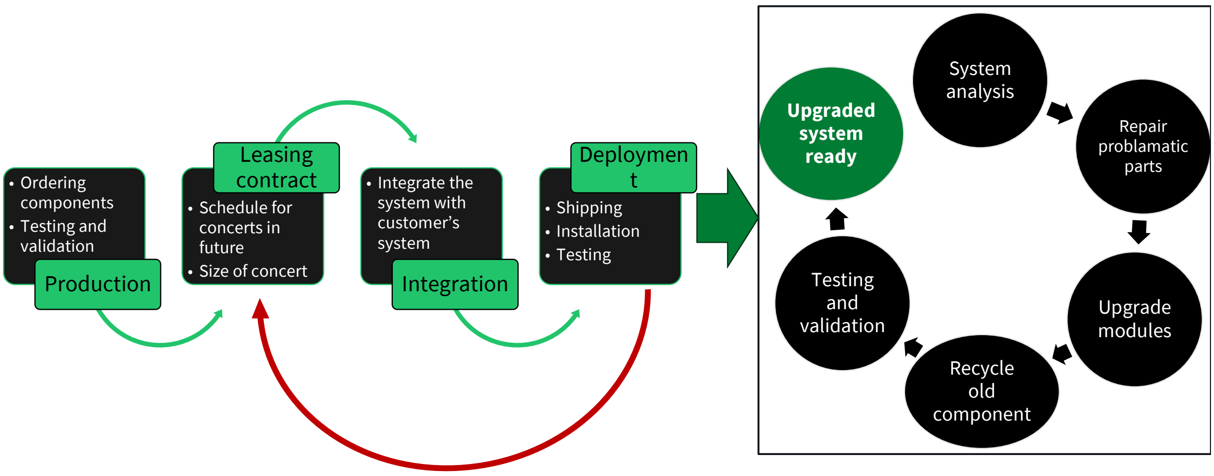


Figure 14: System life cycle for SMS

9 Appendix

9.1 Concept selection

Criteria	Weight	Car	Trailer	Box
Easy setup	5	5	5	3
Manufacturing cost	2	2	4	5
Maintenance cost	2	1	4	5
Sustainability	4	3	4	3
Appearance	1	3	3	4
Reliability	5	3	4	4
Handling	2	5	4	3
Non-obtrusive	3	3	3	5
Safety	5	5	5	3
Totals		105	122	107

Table 3: Concept selection for mobility

Critea	Weight	Radar	RF	Radar + RF
Easy setup	5	4	4	4
Development cost	2	3	5	2
Manufacturing cost	2	3	5	3
Maintenance cost	4	4	5	4
Risk	4	3	3	4
Sustainability	5	3	3	5
Appearance	1	3	4	3
Reliability	5	4	4	5
Handling	2	5	3	3
Non-obtrusive	3	3	4	3
Safety	5	5	5	5
Range	4	5	4	5
Detection accuracy	5	3	4	4
Prone to obstructions	4	2	4	4
Totals		185	206	211

Table 4: Concept selection for detection method(s)

Criteria	Weight	Intercept with drone	Directional jammer	Net	Intercept + Directional Jammer
Development cost	5	3	4	2	3
Manufacturing cost	2	3	4	2	2
Maintenance cost	2	3	5	1	3
Risk	4	2	4	2	5
Sustainability	4	3	2	2	4
Appearance	5	4	3	3	3
Reliability	1	2	3	1	4
Handling	5	5	4	4	5
Safety	2	3	3	1	4
Range	5	3	5	1	4
Accuracy	4	3	4	1	5
Totals		127	147	79	153

Table 5: Concept selection for intercept method(s)

9.2 System architecture (SysML)

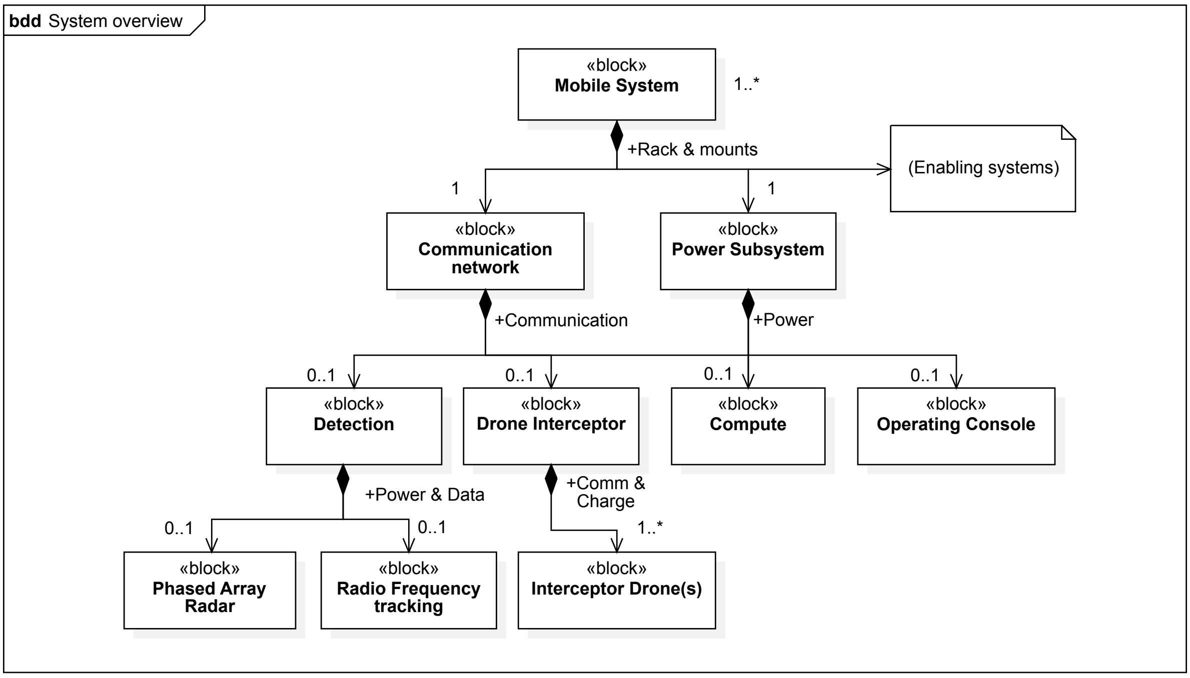


Figure 15: System overview

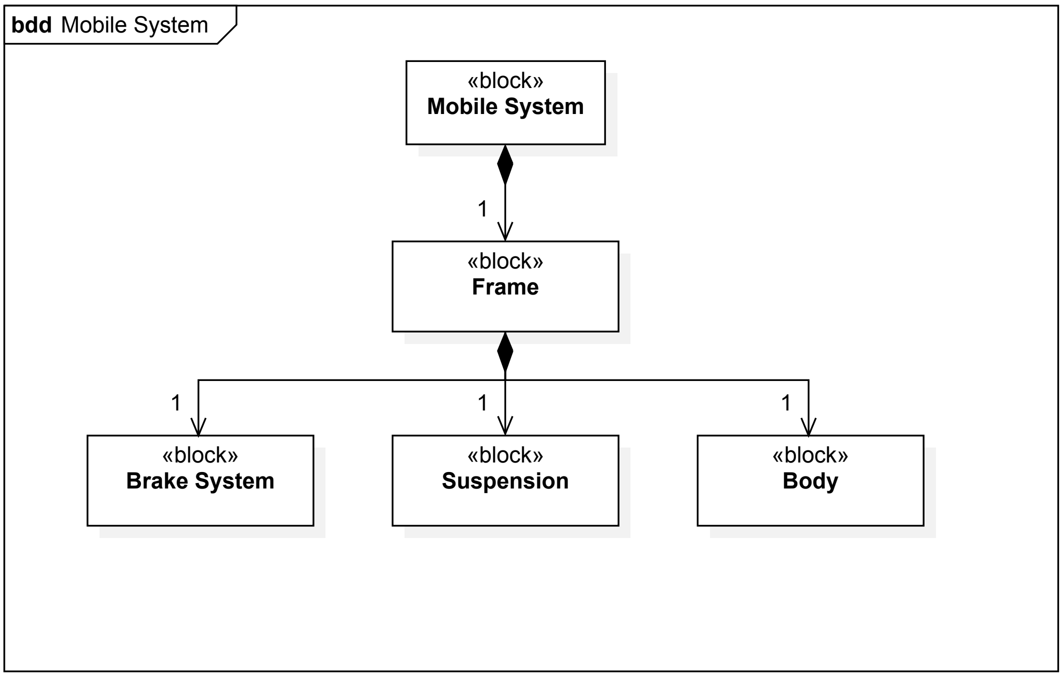


Figure 16: Mobile system

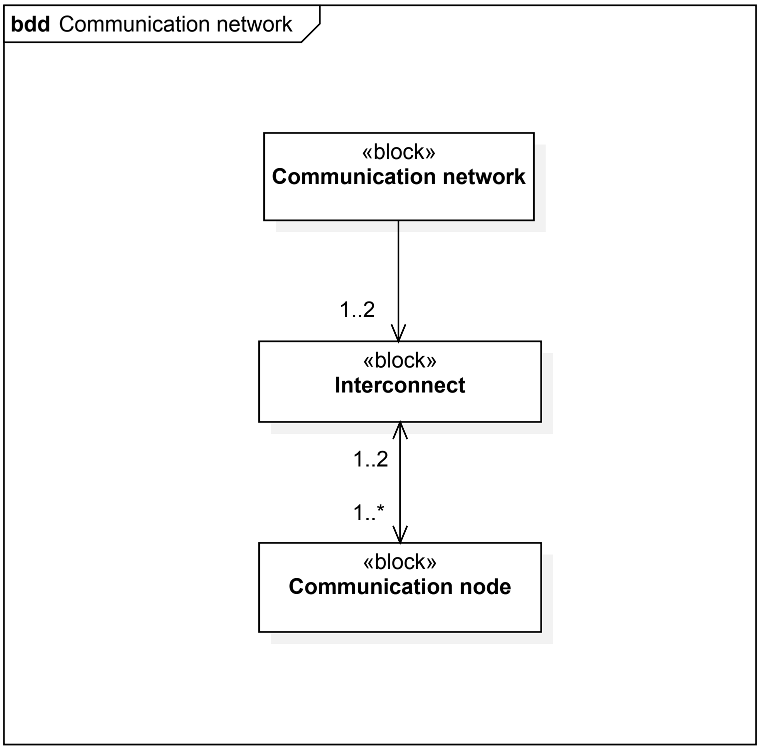


Figure 17: Communication network

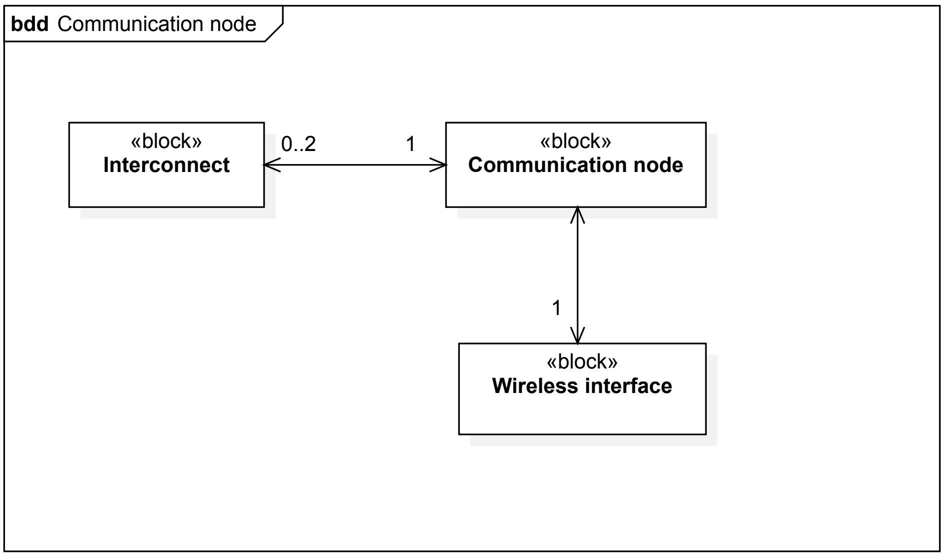


Figure 18: Communication node

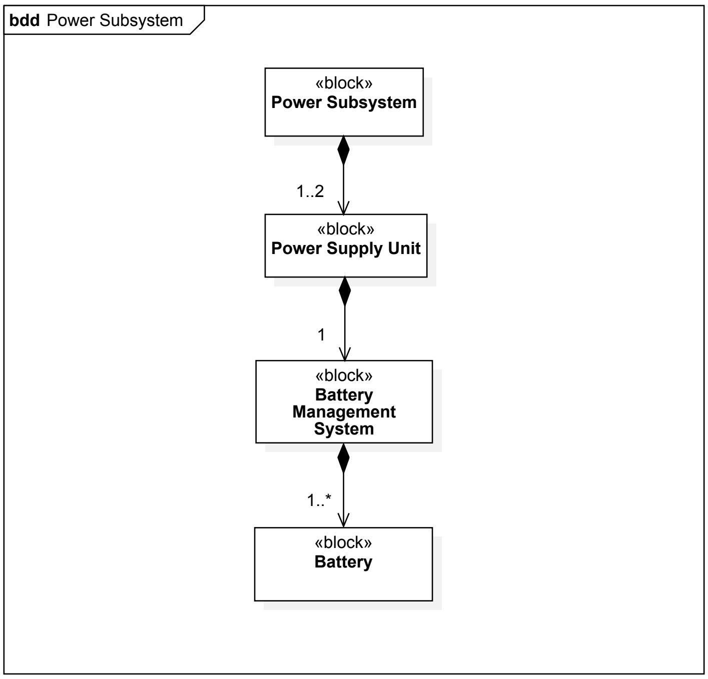


Figure 19: Power subsystem

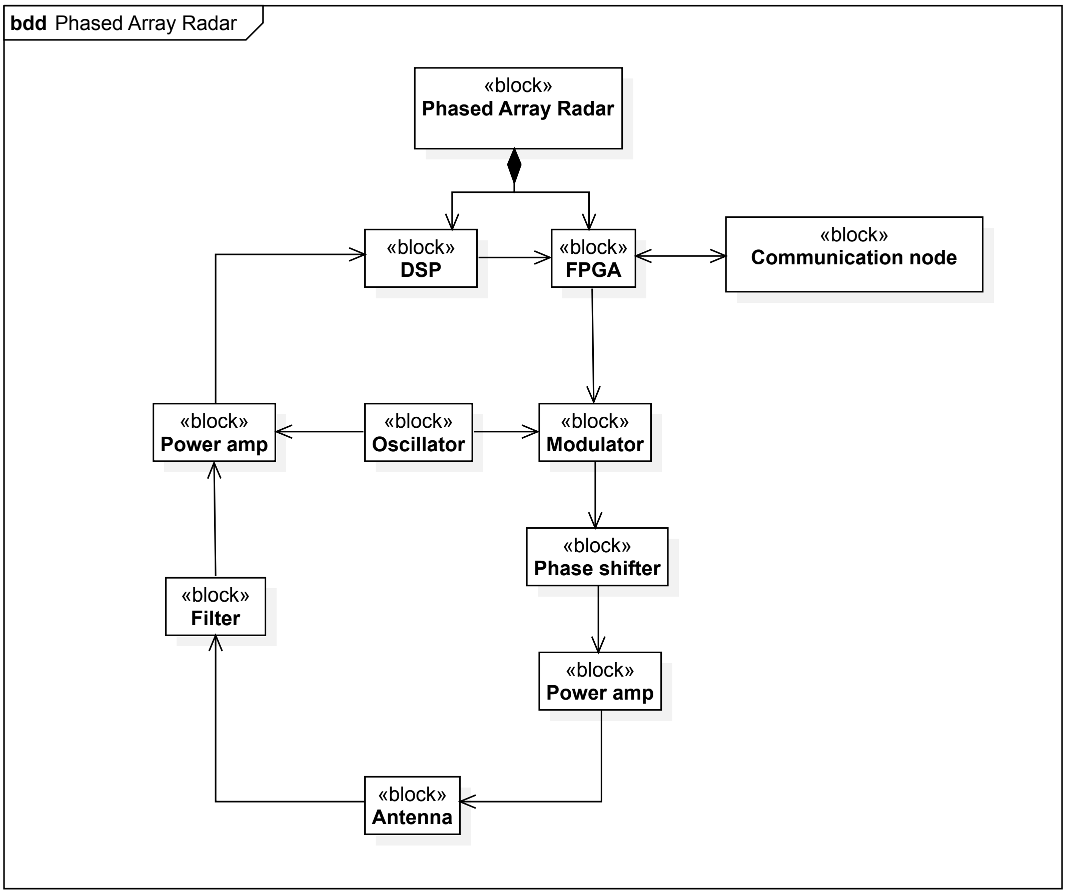


Figure 20: Phased Array Radar

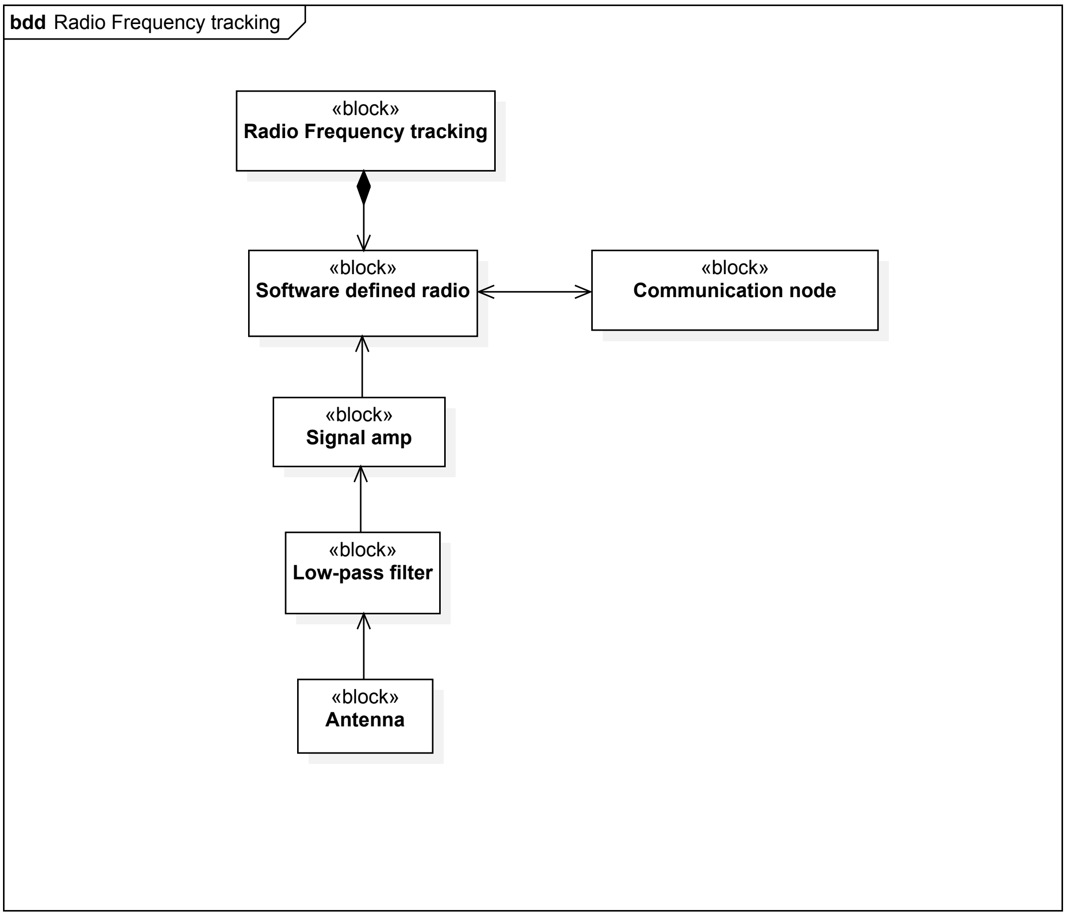


Figure 21: Radio Frequency tracking

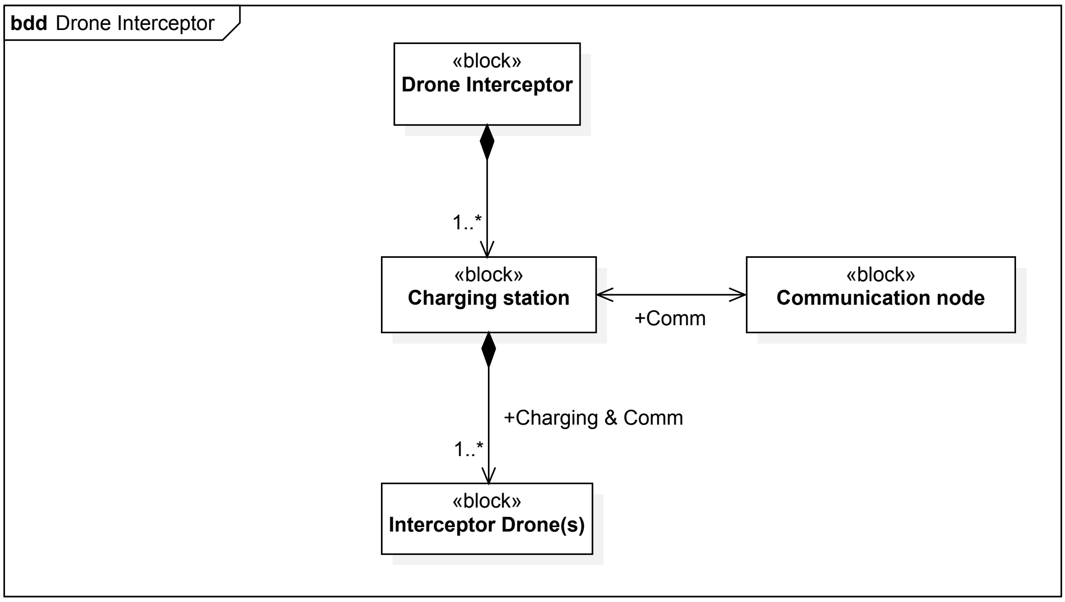


Figure 22: Drone interceptor

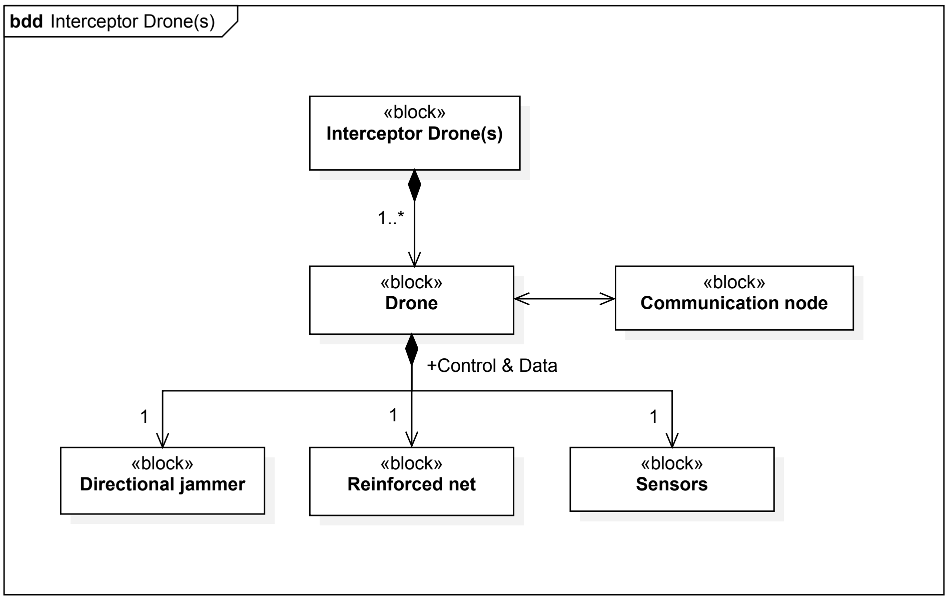


Figure 23: Interceptor drone

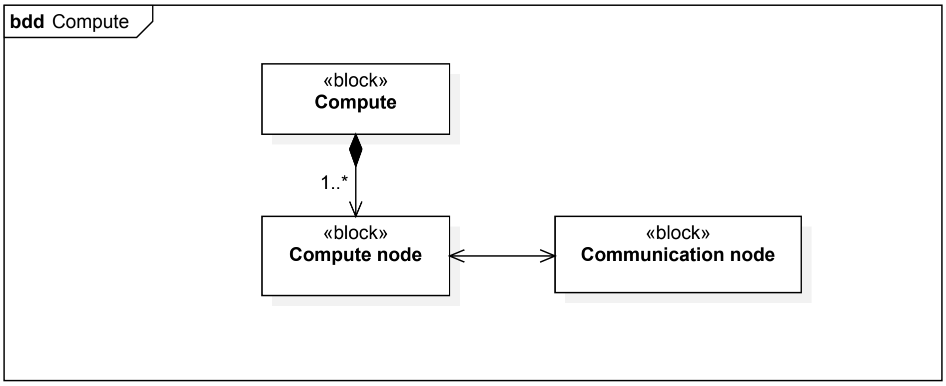


Figure 24: Compute

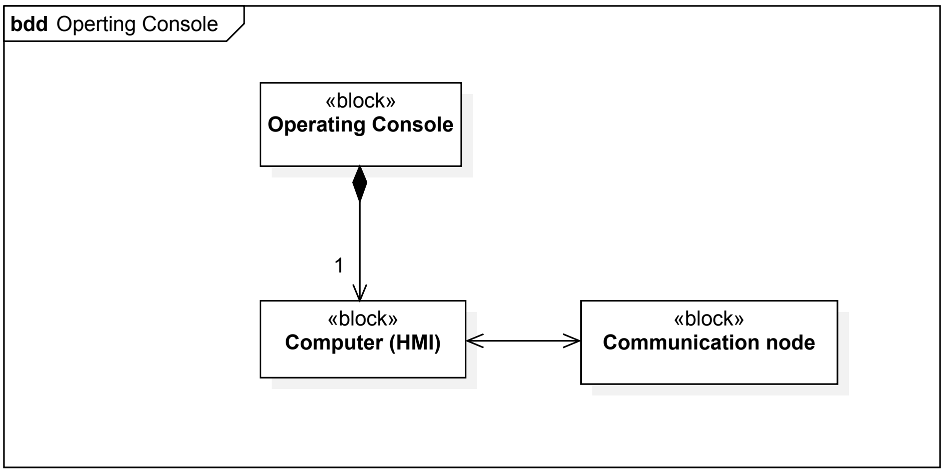


Figure 25: Operating console

9.3 State machine diagram

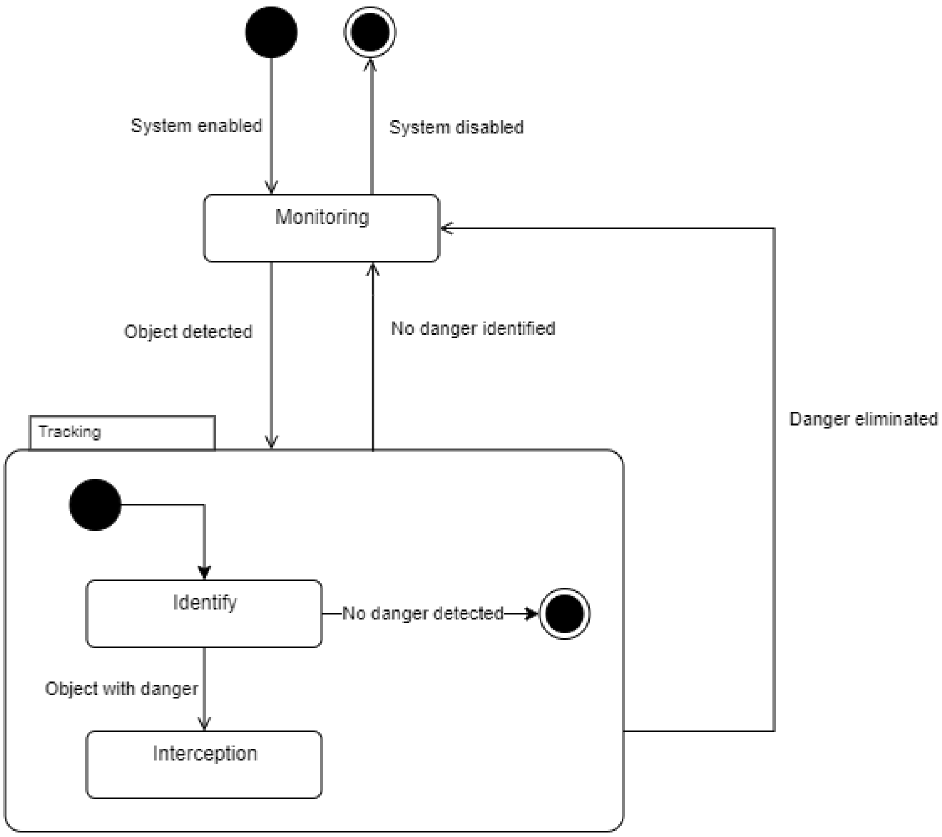


Figure 26: State machine diagram

9.4 Hemispherical Phased Array Radar

9.4.1 Introduction

In this section, we will be looking at an in-depth analysis of a Hemispherical Phased Array Radar. This radar will be specifically designed to detect and track drones to sizes down to 10 cm with a range of 1500 m. By using a Hemispherical Phased Array Radar we can detect targets 360°, and control the electromagnetic waves to desired locations and thus remove unwanted interference while providing high-resolution tracking. In the following subsections, we will be looking at the technical side of specifications and parameters, and the simulated performance of the radar system in our context.

9.4.2 Design Considerations

In order to design a well-working antenna, there are several technical requirements that must be taken into consideration, such as frequency range, gain, element spacing, and a number of elements. To be able to detect commercial drones that are operated at frequencies 2.8 GHz and 5.8 GHz, the antenna must guarantee to cover frequencies of interest. Therefore, the X-Band at 9 GHz is used. Another important factor is high gain to help detect weak signals as well which is the case in most situations in the real world. To achieve a high gain an appropriate number of elements and element spacing is crucial to avoid grating lobes and decrease in gain.

To achieve the desired parameters in the antenna design, the following calculations are necessary. We start with wavelength: We choose the lowest frequency (2.8 GHz) to provide a good approach to designing the antenna system. The wavelength is inversely proportional to the frequency (2). It is very important to choose the lowest frequency to ensure that the antenna will operate effectively throughout the entire frequency range.

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8 \text{ m/s}}{2 \cdot 10^9 \text{ Hz}} \approx 10 \text{ cm} \tag{2}$$

In order to avoid grating lobes and increase the gain, the element spacing should be equal to or less than half of the wavelength which means, it must be less or equal to 5 cm.

The last thing is to calculate the total surface area for 182 elements that are used and then determine the radius of the antenna. To do that, the following equation (3) is used:

$$AreaTotal = NumberOfElement \cdot AreaElement \tag{3}$$

where: AreaTotal is the total area of the antenna. NumberOfElement is the number of elements used to design the geometry of the antenna and is set to 182. AreaElement is the area of one single element in the antenna.

A single element is square-shaped with a length equal to the maximum element spacing and is calculated by following the formula (4):

$$AreaElement = (5 \text{ cm})^2 = 25 \text{ cm}^2 \tag{4}$$

Equation (3) will become:

$$AreaTotal = 182 \cdot 25 \text{ cm}^2 = 0.445 \text{ m}^2$$

Now, it is easy to calculate the radius of the antenna and the equation (5) is used:

$$Radius = \sqrt{\frac{AreaTotal}{2 \cdot \pi}} = \sqrt{\frac{0.445 \text{ m}^2}{2 \cdot \pi}} \approx 26.9 \text{ cm} \tag{5}$$

Half-Wave Dipole Antenna

The frequency that the antenna will be transmitting is 9 GHz. This results in a wavelength of 3.33 cm (Eq.2). In order for this antenna to be a proper Half-Wave dipole antenna, the frequency of the generated waves needs to be resonant with the length of the antenna. This is to ensure that the current oscillates through the antenna with the same frequency as the electromagnetic wave. Furthermore, this results that the length of the antenna is half of the wavelength, which corresponds to approximately 5 cm (Eq.2). These precautions make the antenna efficient at the desired 9 GHz frequency.

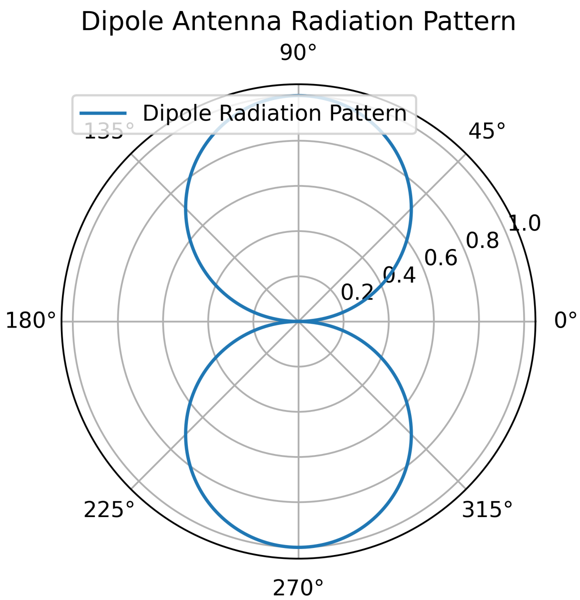


Figure 27: Dipole Antenna Radiation Pattern simulated in Python

The dipole antenna radiation pattern is shown in Fig.27. This figure shows how the electromagnetic waves radiate away from the antenna. The distance from the center shows the intensity of the given radiation, while the angle shows the direction.

From this simple simulation, we can see the main lobes of the antenna. These main lobes of the antenna are where the majority of the radiated electromagnetic wave energy is distributed. The ratio between Front-to-Back is identical so that the transmitted energy has the same intensity as the main lobe.

9.4.3 Filters

Notch Filters

In a festival, thousands of visitors will bring a cellular mobile for filming the event. A huge number of mobiles will generate a significant number of signals which may interfere with the antenna system and decrease the overall performance. Therefore, the Notch filters ([6, p. 793]) are used for attenuating interfering cellular signals. To design a Notch filter, there are three important components to consider. The center frequency, bandwidth, and sampling frequency. Cellular mobiles typically use a frequency range between 800 MHz and 900 MHz. Therefore, the center of frequency is set to 850 MHz and the bandwidth of the Notch filter is 100 MHz. Because the X-Band at 9 GHz is used, and according to the Nyquist criterion which says that the sampling frequency must be twice the frequency of the sending signal, which is in this case set to 9 GHz. The sampling frequency must be then 18 GHz.

We will simulate the function of the Notch filter to see how it will help our system enhance its performance. Figure (28) shows how the Notch filter attenuates only frequencies from cellular mobile and lets other ranges of frequencies pass. An example of how the notch filter will function is illustrated in figure (29) where the first curve shows the original signal without using the filter. We can clearly see that there is too much noise regarding the shape of the signals. However, the second curve in the same figure shows an output of the signal after it passed the filter. We get a cleaner signal, with almost no noise affected by the cellular mobiles.

Overall, despite in the real world situation, the notch filter does not attenuate the whole frequency range of cellular mobile, but it removes enough range to considerably enhance the performance of the antenna.

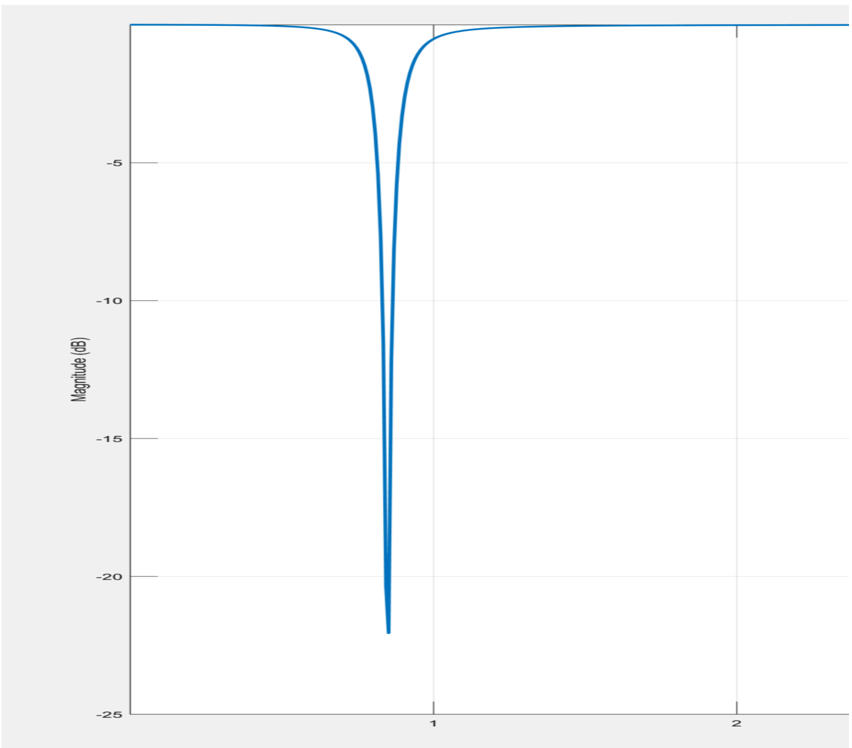


Figure 28: Design the Frequency Response of the Notch Filter.

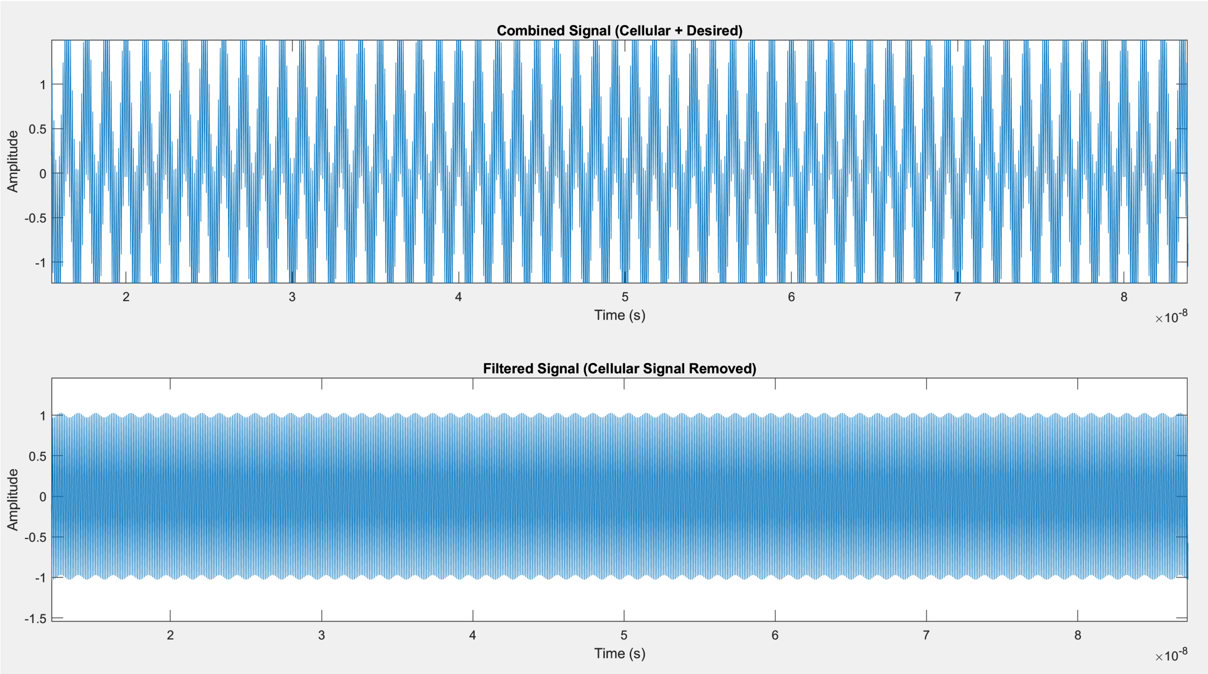


Figure 29: Signals without and with Notch Filter.

9.4.4 Bandpass Filters

In our system, the bandpass filters will be employed as well. Those filters will be centered at 2.4 GHz and 5.8 GHz in order to isolate the frequency band used by most of drones in the world. The implementation of these filters will significantly enhance the radar's system performance by only focusing on the frequency of interest and reducing the impact of noise and other interfering signals in the event. We will demonstrate an example to show how bandpass filters function. Figure (30) shows clearly the isolated 2.4 GHz and 5.8 GHz components, separating them from other frequency components present in the original signal. After filtering, the radar system will now only concentrate on the drone signals without being disturbed by other frequencies. The result will be an enhancement in performance in both detection and tracking capabilities ([7, pp. 576–577]).

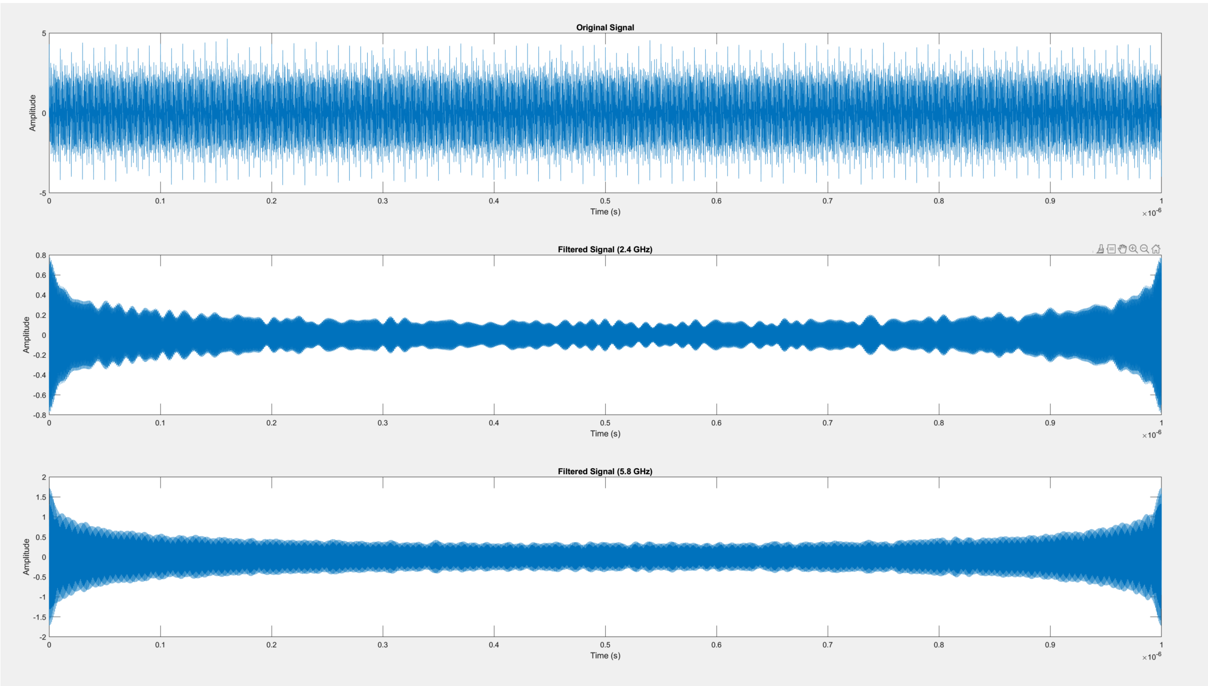


Figure 30: Filtering Original Signal with Bandpass Filters.

9.4.5 Radiation pattern of the Hemispherical Phased Array

After determining the necessary parameters for the antenna, we shall now see how it will perform in the simulation by using MATLAB ([8]). After determining the required parameters as wavelength and a number of elements as mentioned before, it is time to simulate the physical arrangement and positioning of the antenna elements in x, y, and z dimensions which is illustrated in figure (31).

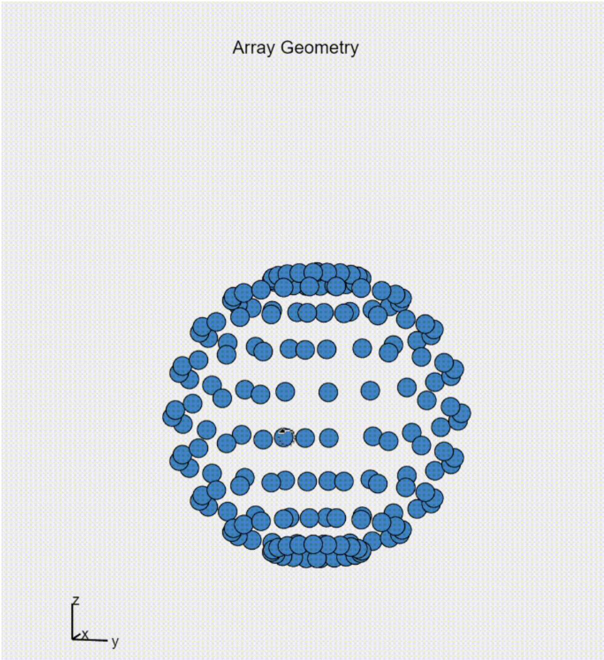


Figure 31: Geometry and Arrangements of Antenna's Elements

Moreover, Figure (32) illustrates a 3D pattern of the antenna. We can see that the main lobes are pointing in all directions which is important for the 360° coverage of the radar. In addition to that, we see that the directivity measurement in all main lobes is greater than 0 dB which guarantees that the antenna will perform as desired in the real world.

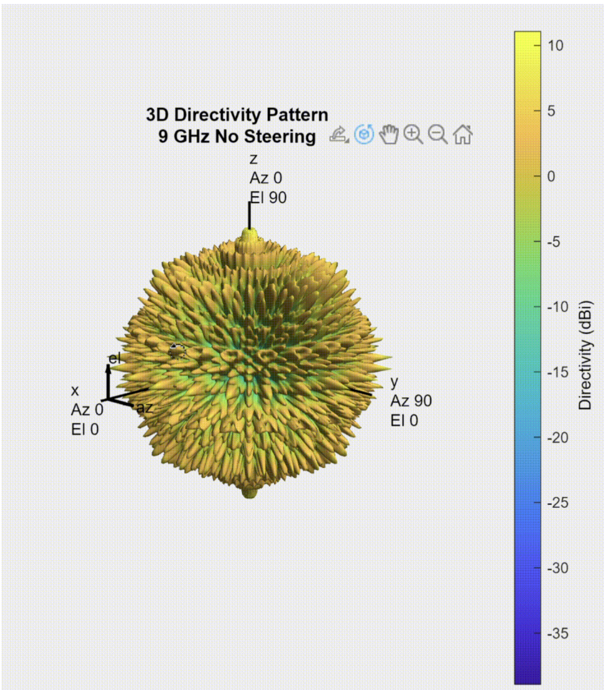


Figure 32: 3D Pattern of Hemispherical Phased Array Antenna

Parameters	Values
Number of Elements	182
Radius	20 cm
Signal Frequencies	$9{\cdot}10^9$

Table 6: Summarising some of the antenna parameters

9.4.6 Pulse Repetition Frequency

Pulse Repetition Frequency or PRF as an acronym. This parameter determines the number of pulses sent by the radar in a time period. This is crucial to a radar system due to that it is used for how frequently the radar can update its targets measurements. In this case, our radar needs high PRF values in order to track and detect fast-moving targets.

We need to first look at how long it takes for the signal to travel to the maximum range and back, which is 1500m. We can then find the pulse repetition interval (PRI). This is done in Eq.6.

$$PRI = \frac{2R_{max}}{c} = \frac{2 \cdot 1500m}{3 \cdot 10^8 m/s} = 1 \cdot 10^{-5} s \tag{6}$$

From Eq.6 we can see that the signal takes 10 μs. For our purposes, the range resolution needs to be 1 m. In this case, the range resolution is an important factor in the radar's pulse width [τ].

$$\Delta R = \frac{c\tau}{2}$$

By using simple algebra we can isolate [τ] and put in the correct values:

$$\tau = \frac{2\Delta R}{c} = \frac{2 \cdot 1m}{3 \cdot 10^8 m/s} = \frac{1}{150} \cdot 10^{-7} s$$

We then need to convert the pulse repetition interval to pulse repetition frequency. This is done in Eq.7.

$$PRF = \frac{1}{PRI} = \frac{1}{1 \cdot 10^{-5} s} = 100\ 000 Hz \text{ or } 100 kHz \tag{7}$$

The pulse repetition frequency for this radar is 100 kHz. In addition, with these parameters for this phased array, the pulse width will be 6.67 ns shown in Eq.8

$$\tau = \frac{1}{150} \cdot 10^{-7} s \cdot \frac{10^9 ns}{s} = 6.67 ns \tag{8}$$

This radar system will be categorized as a High PRF class due to the pulse repetition frequency being over 30 kHz. The side effect of having a high PRF value is that there is a high risk of interference and a lower maximum range for detection.

9.4.7 Radar Cross Section (RCS) Simulation

In this subsection, we will be discussing the Radar Cross Section or RCS. This value is a measurement of how detectable a target is by our phased array. The way this is determined is how the radar pulse reflects back on the surface of the target. Furthermore, this is highly inflicted by the target's size, material, and shape. In our case, we will be detecting drones with a size down to 10 cm which makes the target have a low RCS value, this increases the difficulty of detection.

9.4.8 Stopping and Catching the drones with a Jammer and Net

Our system is developed for catching unauthorized drones using drones equipped with both jammers, nets, and IR camera sensors. The process begins by determining the relative position and velocity between the unwanted drone and the chaser drones in the system. Those pieces of information will be used to determine some parameters such as the time required for our drones to reach the target drones. Our company takes safety seriously and we are updated to ensure following the law. For this reason, our system will follow the proportional navigation guidance law [9] to steer the chaser drones toward the target drones, considering the actual position and its changing rate. We developed PID (Proportional Integral Derivative) [10, pp. 224 – 238] to maintain the desired speed and altitude of our drones while following the guidance law and avoiding any chance of collision. When the distance between the chaser and unwanted drones is small enough to avoid any kind of unpredictability, our drones will take an action. Firstly, a jammer will be used to block the signal between those drones with their pilots. Signals from the jammer will travel in very short distance to avoid any chance to disturb or block any other connection in the environment. In a short time after the jammer, a net will be used to catch those drones to avoid the possibility that drones can fall and cause any human or material damage.

9.5 Mechanical

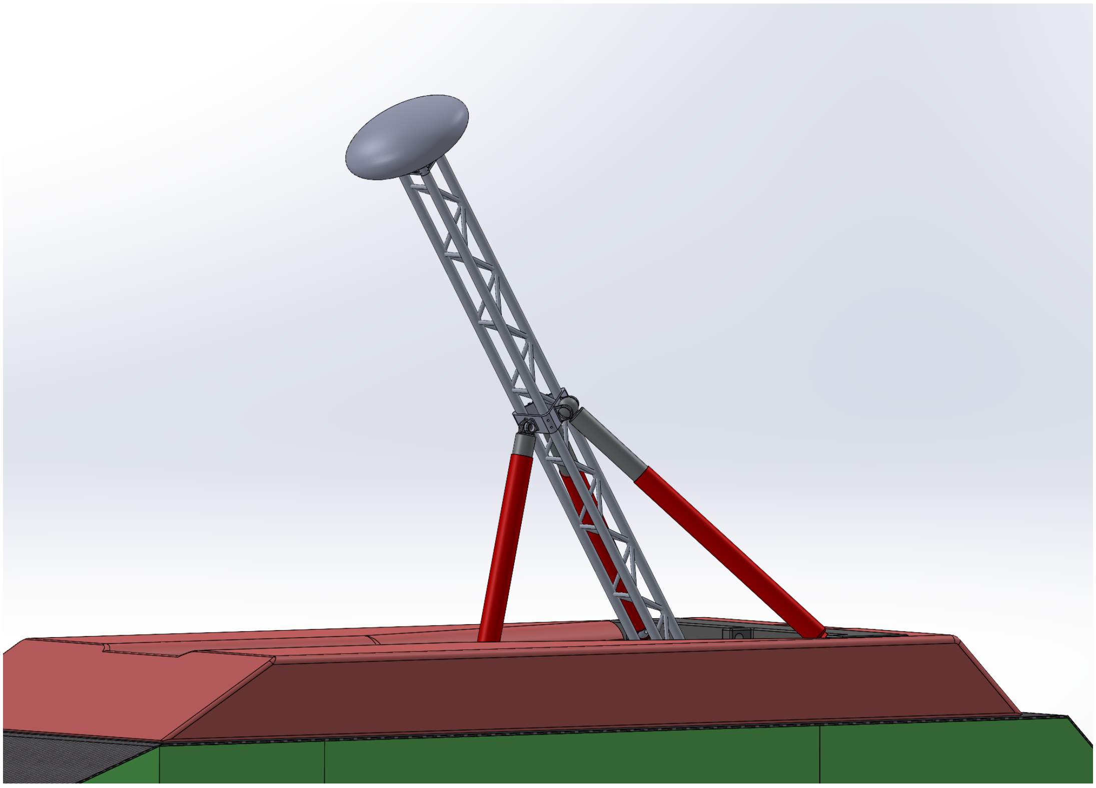


Figure 33: Construction of mast

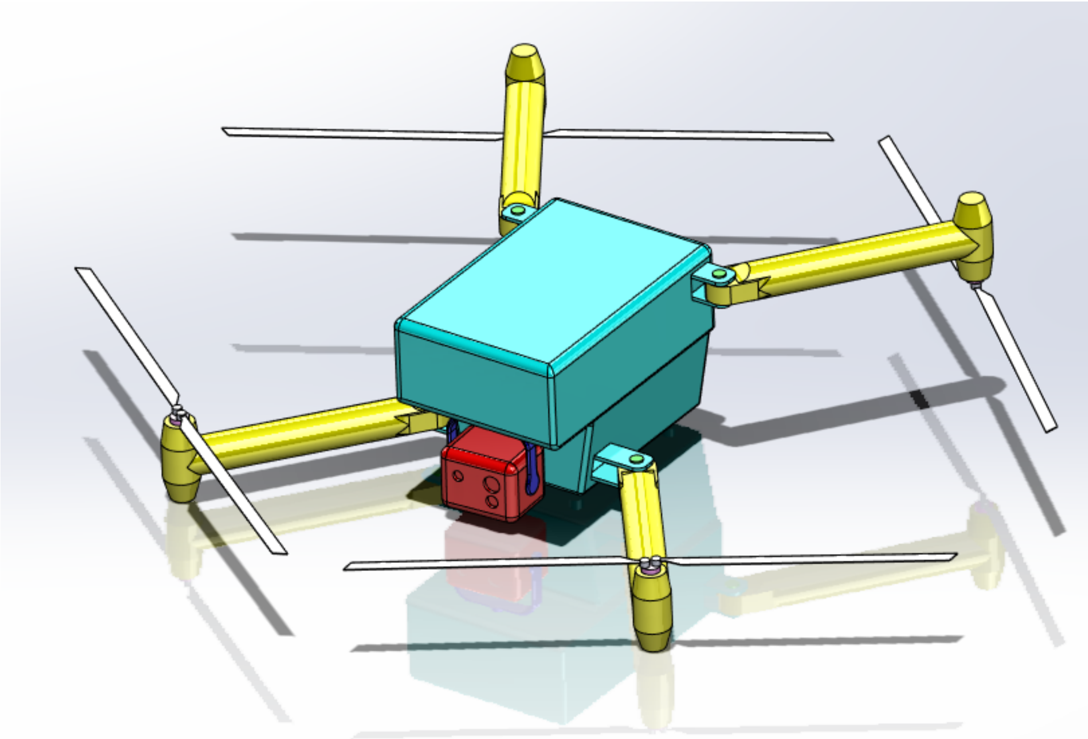


Figure 34: Main node construction

9.5.1 Introduction

This appendix focuses on the process from the mechanical engineers' point of view and is actively used in, for and during work on the project. The purpose is to gather thoughts, processes, and ways of proceeding around the physical and imagined physical aspects in and around systems design & Engineering.

From the mechanical engineers' side, SIMILAR (with a classic V-shape model at the bottom) has been closely followed throughout the project as well as The 7 Ws, both the German (Was, Wie, Wo, Wer, Wann, Warum & Womit) and 7 Step Routine (Structured Way Of Thinking), (Why?, Who?, What?, How?, By Whom?, When & Where?, How it Went). CAFCAR and chaos model/philosophy have also been looked at along the way, but SIMILAR is what has been most natural, and especially after concept screening where the design phase for the machine started.

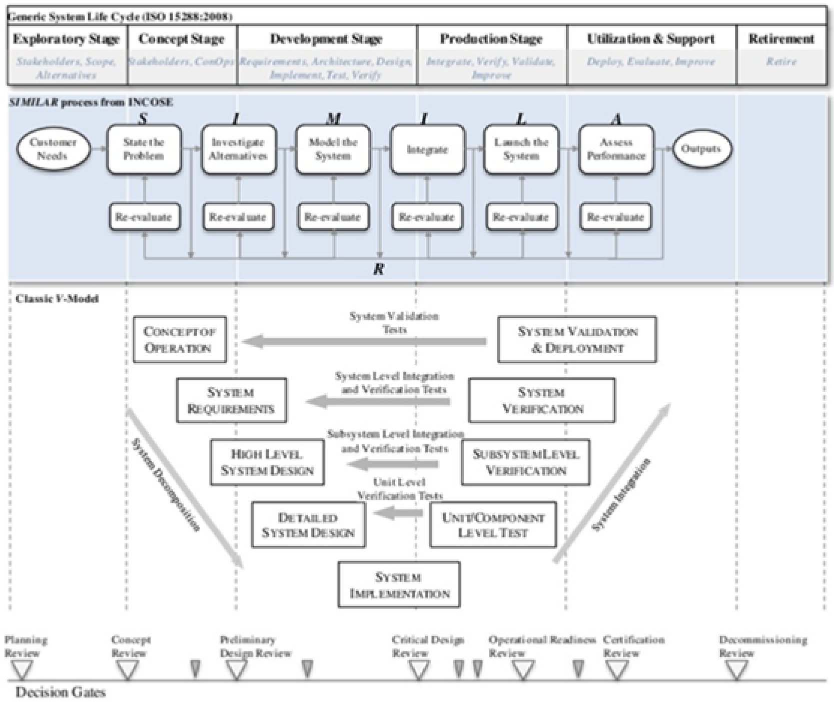


Figure 35: SIMILAR Model

The 7 Ws By following the 7 Ws: Was (What), Wie (How), Wo (Where), Wer (Who), Wann (When), Warum (Why) and Womit (With what), and the SIMILAR Systems model, a foundation and some initial requirements are formed that should be the basis for further system design.

Why Specify, Architect and design of Counter-Drones system Initially, we look at what needs to be done and how it can be solved, what methods exist and are consistent with our goals, thoughts, and values. We have concluded that we want a non-violent and as ethical as possible solution.

What, With What & How How to solve the different challenges posed by the case. What choices and possibilities exist that cover the needs and implicit requirements according to the case given.

- Detection & Tracking:
  - Radar
  - RF
  - LiDAR
  - Visual detection, (Camera, IR, Heat signature, eyes)
  - Sound
- Identify
  - Via id signals from drone if drone sends this (e.g., C-tagged drones)
  - Visually
  - Direct contact or control on drone pilot
- Action (neutralize): As we have opted for non-violent progress, we see that options for safe and appropriate methods are severely limited.
  - Direct Jamming (drone only, this would probably be within the law)
  - Capture
  - Hacking

As we have a desire for an ethical and pacifist solution, we see several challenges around both jamming and hacking. The biggest issue is around hacking where this raises several red flags around both ethics and morality, but we also question the legality of this. When it comes to jamming, we see this more as feasible, but it brings with it several ethical and moral dilemmas that need to be resolved and investigated more thoroughly if this is something that will be relevant to the system further. It is important to check and investigate whether the system is within the Electronic Communications Act and/or whether it can be approved here.

Capturing a drone is a solution we see few problems with, except for how it should be solved to return the drone to the owner if applicable. Otherwise, we see that the only credible solution for fangs is via own drone with a form of net launcher / capture net, as other solutions entail risk and danger of damaging others / other objects.

Both points above need to be further assessed after a concept screening if they are still relevant.

Where & When, Who Initially, there is an agreement on a system as mission based, i.e., a system that is temporarily deployed as needed. Areas that are/have been discussed are:

- Events
  - Our scope (Festival)
- Critical infrastructure
- Oil & Gas installations
- V.I.P (e.g., presidential visits, celebrities, etc.)

- Industry with temporary needs
- Other within similar categories

Based on the above criteria, the following questions, requirements, and problems are posed. What will such a system need, what needs will be fundamental for a system to be able to be moved around to different locations.

To answer this, we have worked with possible stakeholders, associated requirements and further to key performance parameters. From this list, the need for a system that is mobile, easy to set up, customizable, smart solutions, upgradable and at the same time at least follows the UN Sustainable Development Goals. These are key points that are fundamental to the system's further process. Other thoughts and points that follow are what the economic picture will look like, how the product fits the chosen business model, what opportunities around production are there and are there more opportunities around possible production methods / chosen system.

9.5.2 Concept Thoughts & Ideas

In order to know what the product should look like and why the design was chosen, a deep investigation was made where a design was thought out, and then investigated whether this would satisfy the goals, wishes and requirements of stakeholders and the UN's sustainability goals. In the initial phase, several different solutions were investigated that could possibly satisfy the sustainability goals and requirements drawn up by stakeholders, and then move on to a concept screening phase. From a larger selection of several types of concepts of a system that is mobile, a rough selection of three main categories has been made for concept screening where two of these have several possible options with their respective PROs & CONs. The system is decided to be split into three sub-systems:

- Main unit (with hardware) (Main responsibility of the mechanical engineer) <- Focus field here in the appendix
- Detection unit/module (Electrical engineer's main responsibility -> design by mechanical)
- Neutralization/Action unit/module.

Different concepts

A Compact and Foldable System

A system that is packaged in separate boxes where the product is intended to be small hardware stations that can be connected to the workplace system and/or as a separate independent system. Such a system has some conflicts with the idea and requirement that the system should be independent, and it will also present greater logistical challenges for the user of the system.

System on a Trailer Platform

The concept is conceived around a system constructed with a trailer platform at the bottom which will be able to be towed by a B-registered vehicle. The system will be integrated in the same way as the previous concept system. This system will be automated and will be able to localize and send information to its own drone and an operator, furthermore, the system and or the operator will then decide whether there is a threat or not.

Challenges with such a system are limitations in terms of space, operator workspace and protection of sensitive information. The desire for a system that can be easily modified and adapted to a customer's needs is particularly limited in terms of the space available for such a design. For such a construction to satisfy given requirements, it will have to design the system according to worst-case thinking about size and needs, thus the possibility of customization is not as great as desired.

Wagon with Integrated Operation/Workplace
The last concept presented is based/inspired by the caravan design. This will be a stand-alone system where the detection sub-system can/will be integrated. The neutralization system is decided that this sub-system will be a separate module so that the system can be scaled up and down according to the size and needs of the mission. The vehicle can be customized with a rack for charging x-number of modules, where the possibility of storing additional units is possible, but without connection to the charging rack. To satisfy both sustainability and adaptability, it is desirable that the system can easily be equipped with both own solutions with also 3rd party equipment as needed.

The advantages of such a design will be increased possibilities, easily customized and scaled according to a customer's wishes. The system also has several possible areas of use as the requirement for customization is at the bottom, and the desire for 3-party equipment to be integrated, this will provide opportunities for use beyond the purpose. For example: camping, work truck, operation center within several security fields etc.

Vehicles with Integrated System
The last concept platform is very similar to the Wagon with an integrated system, but based around a vehicle, the design and size of the vehicle has not been decided at this stage due to challenges around what options are available and how much space such a system would require, along with the desire for similarities with the above-mentioned wagon concept.

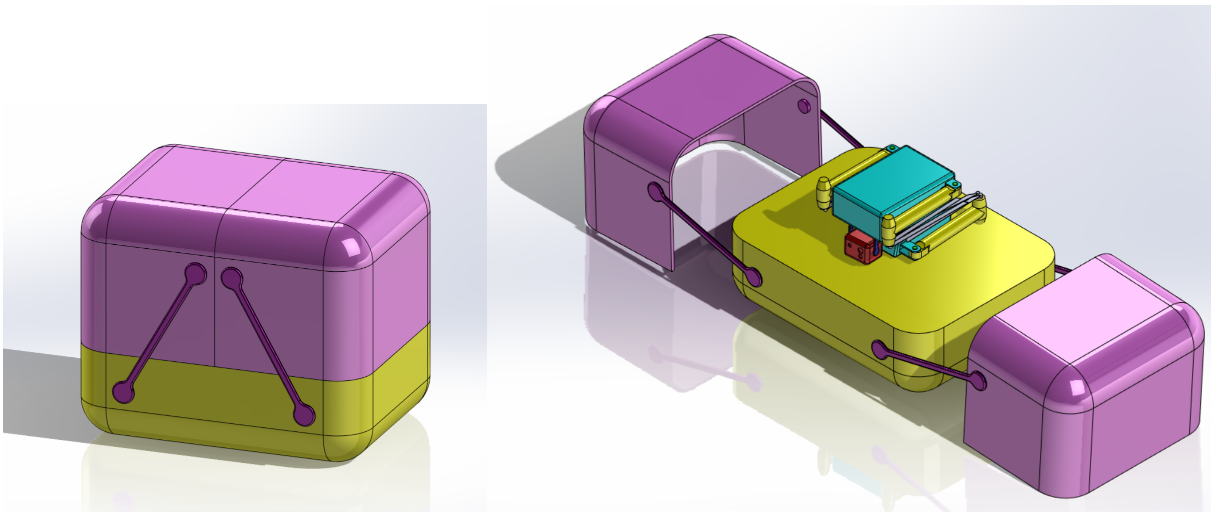
9.5.3 Choice of Concept

Based on concept screening, the choices landed on a trailer type where we have an operations center / workplace inside, as well as modules with a drone equipped with a jammer type and net thrower. The detection method fell on a combined solution between RF and Radar. After some work from the electrical engineers where the focus has been mostly on an in-house developed radar, RF has been put on hold. The final concept that has been focused on during modeling and further development is then a caravan inspired construction, with a radar mounted on a lift / liftable mast and a drone docking module with a drone inside. Initially, a rough analysis has been made of weight and what weight targets will apply to the system. There is a strong desire to get the system below an own weight of 3500kg so that the cart can be pulled by a B-registered vehicle, where the goal is an own weight of between 2800-3000kg so that the system reaches the requirement of being adaptable.

Wagon Model

The trolley unit is inspired by the idea of a minimalist, robust and practical design. To meet the requirements of sustainability, smart solutions, economic aspects, and adaptability, we have chosen to go for a solution where the trolley is built with a 2-layer plate construction that can be easily changed without a major job. This means that a plate can easily be dismantled and then changed, whether it is a door, window, or storage, this can be changed afterwards without major costs or a time-consuming job. This will satisfy sustainability requirements as we are both able to change a unit instead of replacing a fully functioning system, at the same time our options to reuse or fix the material are present to minimize the use and throw away philosophy. With this and the goal of a minimalist design, we ensure that the lifespan of the product is not about the design or changing needs, but rather the lifespan of the material. For further work, a technical budget on weight is set up, where this is followed to reach the goal of 2800-3000kg.

Drone dock & Drone Unit We chose the design of the DJI Matrice 30T drone because of its very simple design. With this design, this will give us more room for improvement during the development phase and its folding function of the rotor arms. For the drone to be able to lift itself and a captured drone, the arms need to be longer and the same with the rotor blades. But if the arms had a telescopic function, we would need to change the blades and the drone would become even more compact. The equipment should also be easily mountable. In each rotor there should be a collective pitch, a feature that allows it to adjust the angle. This gives the drone the ability to maintain a stable position while the pitch controls the direction of the drone. For the drone dock, it's design is inspired by the DJI Matrice Drones, also a very simple design. The dock's design should be very strong. The drone module will be placed beyond the workspace, but it depends on how much space is needed to cover the area.



(a) Docking locked (b) Docking open with intercept drone

Figure 36: Docking system

9.5.4 System Design & Solutions

Operation Central & Slave Unit A main unit and a certain number of slaves, if necessary, will be placed beyond the area to be protected.

Main unit A master unit shall have the ability to override other slave units. Any unit should also be able to be incorporated into another system so that it will act as a slave unit but can still be controlled. The master unit is equipped with a powerful machine that receives signals from the radar and sends information back to the central station as live monitoring.

Slave unit The slave unit does not necessarily have to be equipped with a monitor, but it can be. The number of slave units needed may vary depending on the size of the mission area.

Drone Module In a Drone Module there is an intercept drone that should be able to intercept a potentially dangerous drone in the workplace. The drone will have a docking system that it will go to when it goes into standby mode.

Intercept Drone

The main task of the Intercept drone is to capture unidentified drones in the workplace, whether it is a private drone or a hostile drone. Our drone is equipped with a number of tools to reduce the damage that could possibly be caused by the unidentified drone.

Drone

The drone will receive information on the location of the potential threat in the airspace and will use non-harmful means.

Jammer

The drone is equipped with a jammer that should override the signals of unidentified drones so that it will be easier to intercept them.

Net Gun

Once the plan to jam the unidentified drone is successful, the intercept drone will use a net caster to capture it. By using a net-thrower, critical parts are not destroyed so that we have the ability to identify the drone, find film/photos of the workplace, or similar malicious information about the drone that may seem like a threat.

Security Solution

In case of a malfunction of the intercept drone system above operating altitude (20m), the drone is equipped with the SAFE-DECENDIG program where a parachute is deployed by means of compressed air and the ECU will be disconnected so that the props will stop. In case of a short circuit or uncontrolled descent, the SAFE function will be activated. If the drone must fly below 20m altitude, the system will have a sensor mounted below that detects if there are people below the drone in a radius equal to the current altitude of the drone and require human observation. The drone is further equipped with a kill switch that will activate the SAFE function; this function will also be activated if the RC unit loses contact with the drone. (Take off & Landing time is set to max 17.5 sec between altitude 2.5-20m, each module should have a safety zone of 5meter in diameter)

Technical weight budget and target This diagram is actively used during CAD modeling and development of solutions to reduce weight while maintaining the objectives and requirements.

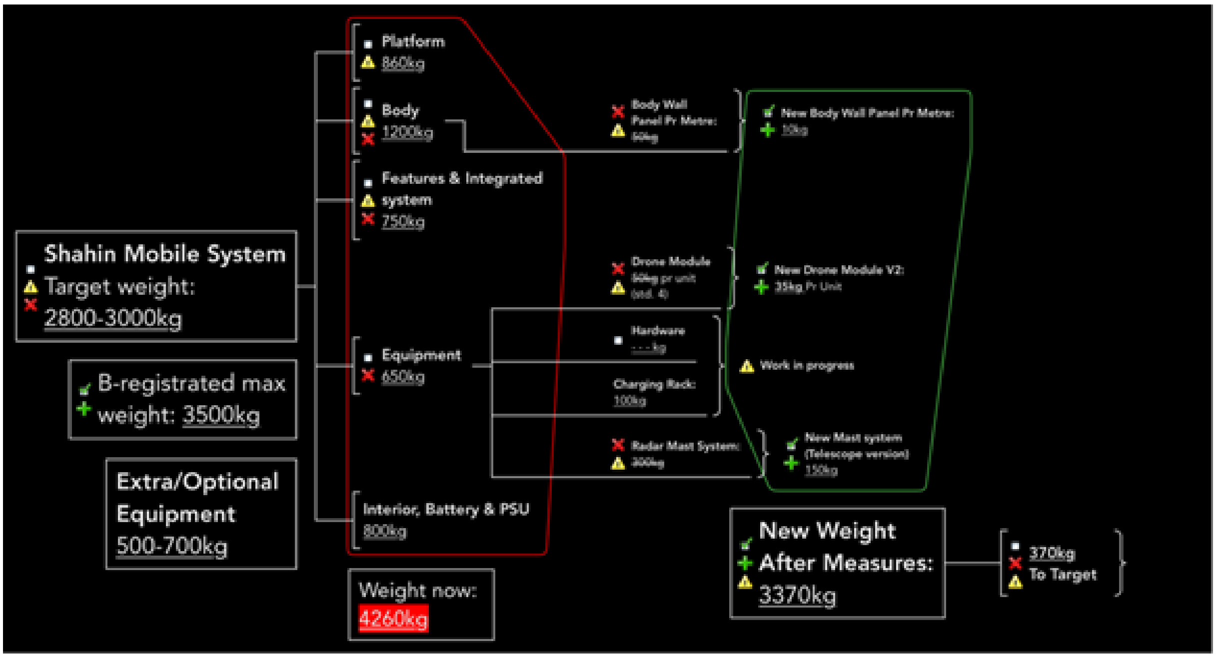


Figure 37: Technical budget

9.5.5 RRR of the Solution

Id nr.	Incident What	Degree of Danger	Impact	Assessment of Impact People	Degree of Risk after Measures	Risk Reducing Measures
1	Drone malfunction over crowd	S1-5	Accidents, injuries or death may occur	K5		#1, #2
2	Drone Crash leading to injury or death	S1-5	Accidents, injuries or death may occur	K5		#1, #2
3						

Figure 38: RRR of Drone Unit

9.5.6 Safety systems and solutions

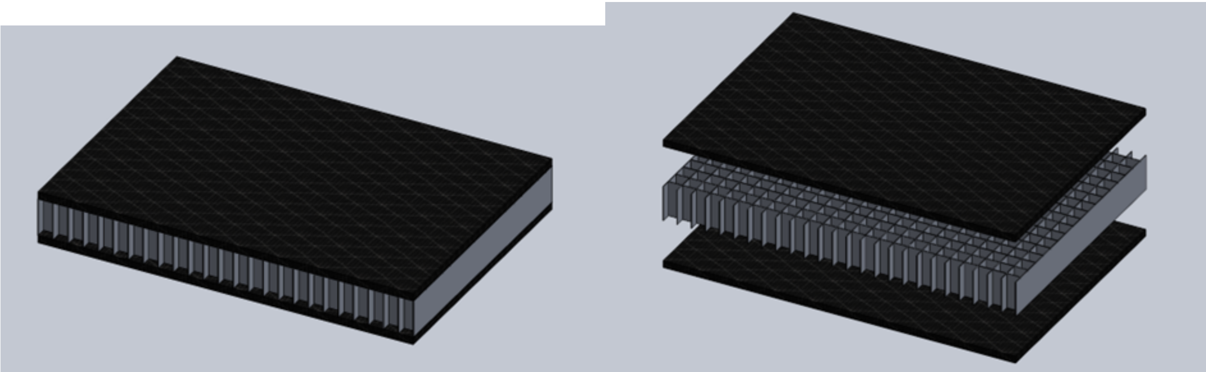
9.5.7 Design, Construction and Maintenance

Choice of Design & Layout The design is based on a minimalist look and where accessibility is a major focus for the trailer. The trailer/carriage should handle both demanding and uneven terrain and be powerful and durable. With a timeless and minimalist design, the lifespan of the system will be based on the durability of the materials and maintenance and repair possibilities, this will provide a sustainable and timely construction and attitude towards resource use and future-oriented thinking.

Design & Construction Method The design and construction method are based on a modular structure using several easily interchangeable parts, both for repair and modification/customization according to customer needs and/or wishes.

Wagon The trolley is constructed so that the body is composed of several plates with a fiberglass plate that is lacquered and finally foiled with self-healing foil. With such a structure, it will be possible to customize the trolleys and make changes during the lifetime of the unit. In case of damage, each part can be replaced in its entirety and the damaged parts can be repaired for future use/repair of other wagons.

Modularity All devices are composed of parts that can be easily replaced and/or modified. Parts used are parts that are and can be easily recycled.



(a) Body material (b) Exploded 3d model

Figure 39: Material

Maintenance, Changes & maintenance The design has been optimized for an efficient and easy maintenance model. Parts are intended to be easily adaptable/modifiable and repairable so that the reuse, lifetime, and economic aspects are well taken care of to satisfy both the customer and the manufacturer's (fence owner) goals and wishes with/for the system.

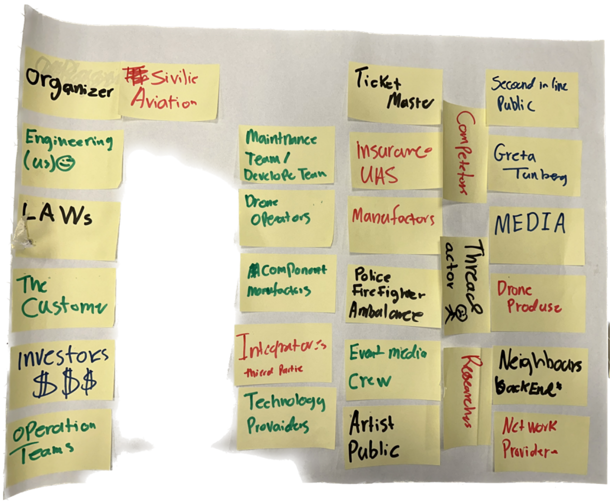
9.5.8 About SMS

To design a system, we first need to understand the threat landscape and what the system should do. Once the threat picture is mapped, we will see which threats we need to focus on to design a solution that meets the needs of the customer. Initially, an RRR is performed to see and get to know what is important to focus on and find a suitable solution. From the RRR we have come to a conclusion that the biggest threat will be alien and unwanted drones over the festival area is the most important threat to avert and unwanted drones in the surrounding area that is controlled by the festival.

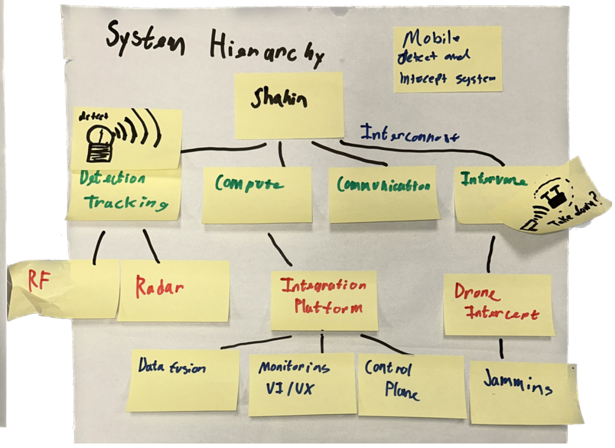
The solution we have come up with and designed is a mobile platform that is modular and adaptable to different situations and challenges. The mobile platform has several modules with a drone whose purpose is to ward off any threatening drone within the festival's area of action and is equipped with both a directionally controlled jammer and a net thrower which is the last solution if the threat cannot be averted by denying access with the jammer.

9.6 Early work on paper

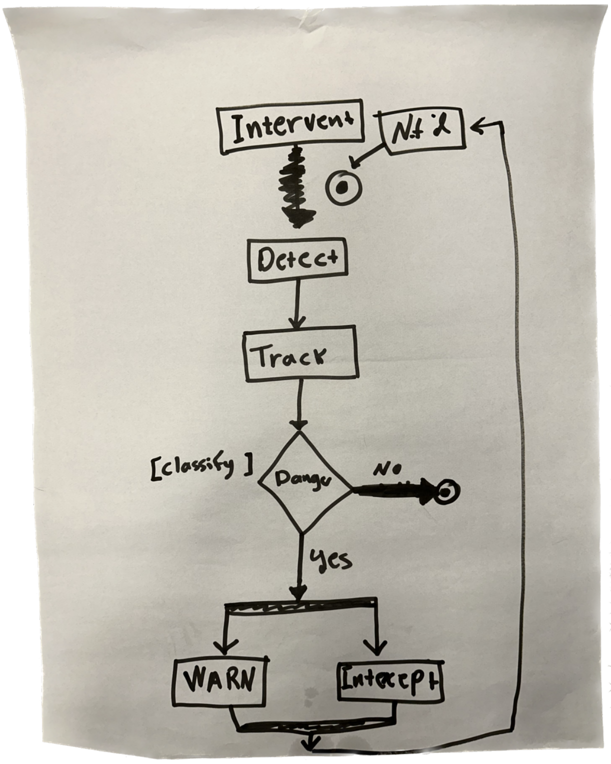
Some of out early work on paper.



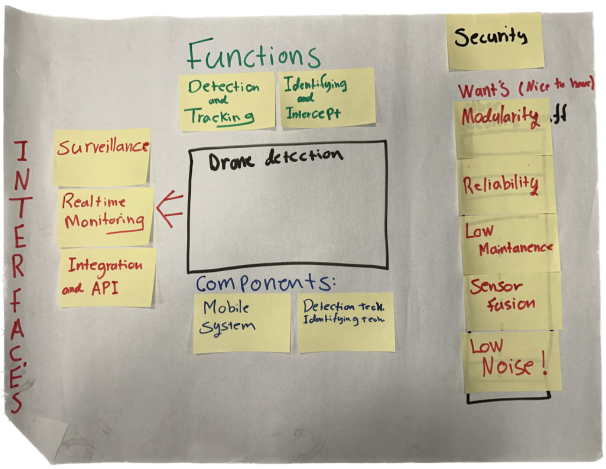
(a) Collecting stakeholders



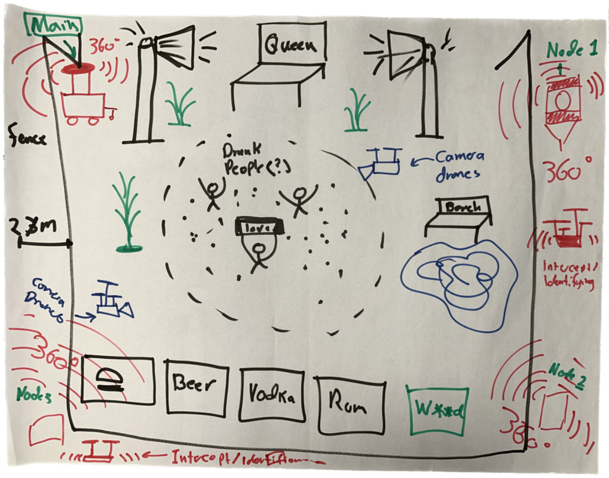
(b) System hierarchy



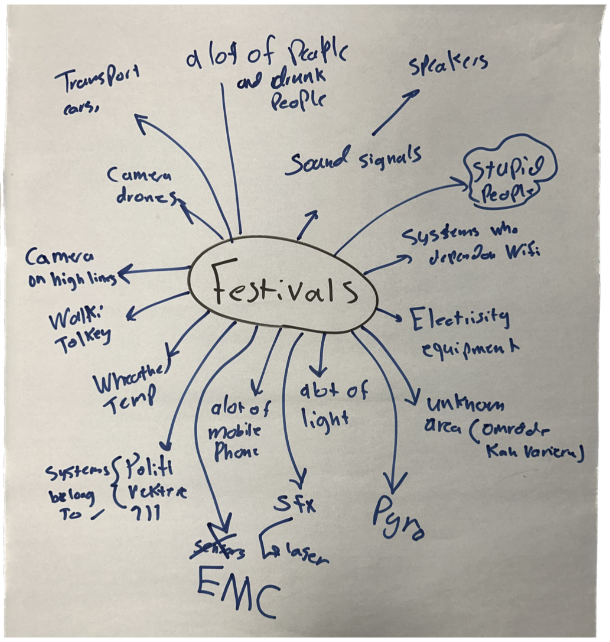
(c) Activity diagram for intervent



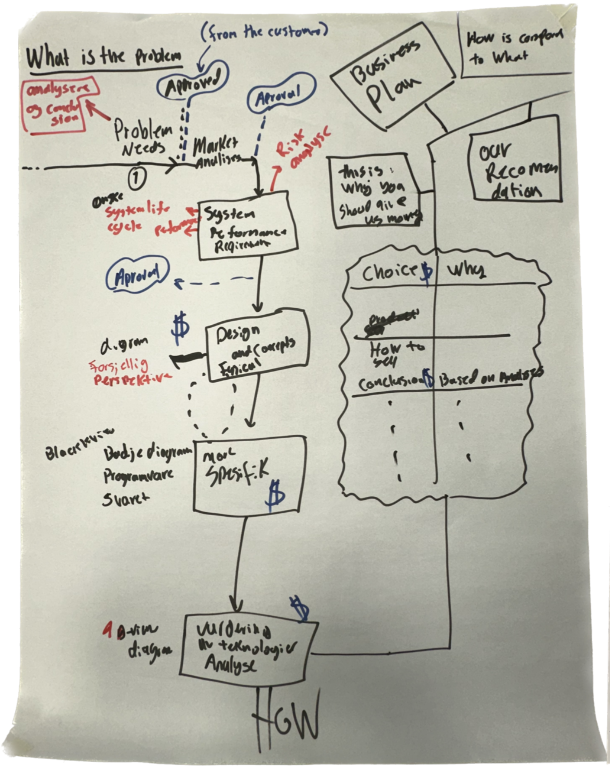
(d) Functions



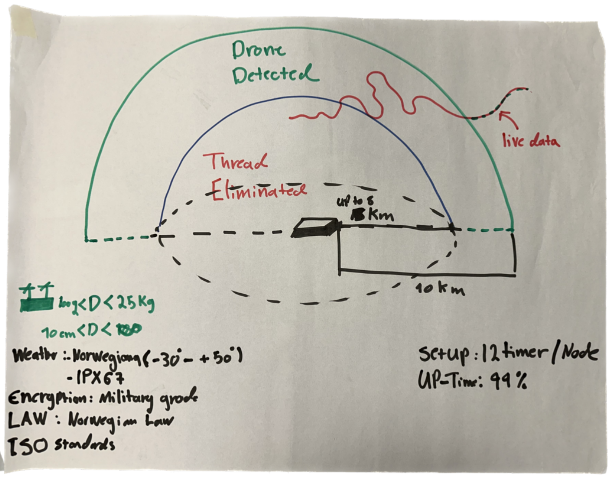
(e) System environment



(f) System environment in different way



(g) Planing how to use T-shape model



(h) Going through requirements

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