Counter Drone Technologies

Applied Innovation in Engineering - Group 30

Aarhus University - School of Engineering

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1. Introduction

This report is made as a part of the course Applied Innovation in Engineering taught in the Spring of 2020. It is made by the members of the group 30 (names can be seen on the frontpage) and serves as part of the final exam for the course and should reflect the work and experiences the group has had throughout the course.

The report contains the most significant aspects of the working processes such as formation of the team, a diverging/converging phase in relation to having a case presented by Terma concerning counter drone technologies, innovative and novel ideation processes and all the way to a final concept and business model.

The report is structured the following way, the first section is **Team formation**, describing some basics about going from a group to a team, and the difficulties and dysfunctions within teams**.** Hereafter, follows the sections, **Discover and define, Ideation Development, Intellectual Property Right, Business Model,** and **Brochure** about the innovation project we have conducted in the team. Finally, in the last section **Final thoughts** we give some final thoughts to the project trying to discuss and conclude some of the points made throughout the report.

2. Team formation

One definition of a group could be that of a set of people working collaboratively on a common purpose. A more developed group could be that of a team, a special type of group in which the members have adopted roles and are more aware of each other's strong and weak qualities. The team consists of four engineering students, with the majority in electronic and computer engineering (three of four), which enabled deeper understanding of some of the technical details of the problem/solutions.

An awareness of potential dysfunctions of the team, was formed early on from the “Five Dysfunctions of a Team” by Patric Lencioni. These formed a foundation on which to communicate potential problems, expectations and misunderstanding that happened throughout the project. In addition, to this the team have worked with several models such as the Bruce Tuckman's group model and the model named A Framework for Thinking about System Change.
These models formed a shared foundation for the team to evolve, adapt into roles and settle potential disagreements. Several of these topics will also be elaborated in more detail in the individual part of the report.

We experienced some practical challenges stemming from the Coronavirus, this made meeting and collaborating in person impossible for most of the course. Almost all communication throughout the course and teamwork has therefore been through virtual means, we feel that this, among other things, affected the communication in the group, given that 70% of communication is verbal.

3. Discover and define

The innovation task in this project started with a challenge presented by Terma: ***Counter Drone Technologies***. It is important to discover topics within the problem area, before defining concrete challenges. Knowledge and insight must therefore be created before deciding on a problem statement. This comes from the first diamond in the design process model named Double Diamond (DD) which was used in the design thinking aspect of the project. Thus this first section focuses on

the discover and define phase of the DD[3.1] (see appendix H). Divergent thinking was the main task of the discover phase and hypotheses were created, questions asked and research analysis were conducted to ensure a broad understanding of various aspects of the case. The define phase followed and was used to interpret the gained knowledge into concrete challenges of the case, converging in on a problem statement, note that this was done iteratively going back and forth between the two phases multiple times.

3.1 Collecting knowledge

The rapid progress of the emerging drone technologies field can be hard to track. However, like other autonomous systems it can accomplish great challenges but also potentially cause great harm. A worst case scenario could be that of a low cost, anonymous, drone system. That could target and kill anyone without leaving any trace. This could completely change many aspects of normal daily living. To investigate the past, present and future of the problem, Triz Nine Windows [3.2], created further insight and reduced the problem complexity. For more information see appendix A.

To determine the root cause and the effect of the problem a fishbone diagram (see appendix B) has been used as a tool to analyse the problem . The following main causes to a counter drone system would fail were found; detecting, neutralizing, machine, and environment.

Today it is possible to use radar and electro-optical camera technologies to classify drones. In addition to that solutions for countering drones already exist; e.g. RF-jammers, high-power lasers, hawks to catch the drone and machine guns. However, investigating other systems highlighted a potential issue they had during the neutralizing of drones. If the attacking drone is carrying an object that can still cause harm after having the drone neutralized, e.g. a bomb. Then the whole system is not really neutralized, only the drone. Thus, these other solutions would not work for any padenstrial areas, which consistently is one of the places these drones could do the most harm.

3.2 Creating Insight & Concrete Challenges

To create insight into the challenges related to development of a counter drone system, it was desired to take advantage of the possible benefits of lead users.
Lead users are in the special position to gain from progress made regarding a potential new product. They are therefore especially motivated to get involved with the product innovation.

When strictly identifying lead users by them being able to benefit from this problem solution the danish police comes to mind, as well as any danish firms that have had illegal entry of their airspace, such as Kastrup airport which in the summer of 2017 has an illegal drone enter the airspace [3.3]. Likewise an incident report by the BBC from Gatwick airport in Britain “Flights were suspended for 30 hours after the drone sightings in December, causing chaos for 140,000 passengers”[3.4]. As an potentiel lead user, Kastrup airport was contacted to acquire insight that could be a benefit for the project, but we were not allowed to get the confidential information about drone countering.

The team has been in contact with experts from Terma. The online meeting with Terma´s specialists clearly specified concrete challenges with respect to why drones are a potential threat in public areas and who is allowed by legislation to handle the potential threat. Furthermore, Termas experts pointed out the fact that detection of drones is possible, however the challenge of neutralizing drones in a completely controlled manner is still troublesome.

3.3 Focus the Innovation Task

From the previous sections it stands clear that drones and therefore also the field of robotics that concerns drones is technically very challenging. Therefore, it also makes it very challenging to classify

whether a given drone technology is scientifically plausible and therefore also whether some counter drone systems are desirable. However, when aggregating the knowledge from previous sections it clearly shows the need for a very controlled handling when countering the drones, worded differently, when countering/exterminating the drones the system has to control the potential threats of the situation very carefully e.g. the system cannot blow up a drone and disregard the potentially harmful waste created by the explosion. From this an Innovation question was framed.

How to neutralize/counter an aerial drone in an outdoor environment in a controlled manner?

This was the convergence and end of the first diamond in the DD. Additionally, it also a basis on which a large set of inputs were formed by using a series of creative techniques, this is covered in detail in the next section.

4. Ideation Development

The transition from the first to the second diamond, which this section initiates, in DD was implemented when the process of creating knowledge and insight was converged into a more definite problem that is the starting point for the diverging ideation process.
The next step in the process, following the specified focus of the task, was idea generation. As three of the group's four members had experience with drone technology prior to the project, it was agreed on that the process of ideation should focus on methods which attempt to enhance horizontal thinking and drawing on knowledge outside the classical technologies used for drones.

4.1 Input generation

One might be tempted to think that input generation is trivially easy, however this is arguably not the case. Instead of developing what is needed, desired people often develop what they can, know, or understand perfectly, limiting the overall impact of what is developed. Using various techniques one is able to think beyond known concepts and come up with potentially needed desired and useful ideas. Following handout two, five techniques from three different fields were chosen

- **Brainstorming**
    - Brainstorming (Alex Osborn, Buffalo, USA)
    - Reverse Brainstorming
- **Analogy**
    - Bionic (Jack E. Steele)
- **Random**
    - Random Words/input (Edward de Bono, Oxford, GB)
    - Picture Stimulation (Tom Peters, USA)

The three fields were that of Brainstorming, Randomness, and Analogy. The production of inputs from these techniques were done using different schemes of group formation, meaning that for both techniques of Brainstorming the members of the group worked individually for a set period of time and then the inputs were shared without discarding any inputs and while the (regular) Brainstorming[4.1] worked well, the group found that coming up with potential problems was easy, and therefor Reverse Brainstorming to work particularly well. Then, the technique for Bionic Analogy was applied taking inspiration from mechanisms seen in nature. Finally, the Random techniques, Words/input-, and Picture Stimulation techniques were picked. For these techniques we decided to

use websites as a means of generating/receiving randomized inspiration. We felt that particularly these techniques worked surprisingly well and led both a lot of inputs but also new insight while also offering both *disruptive*- and *problem-solving* ideas, e.g. the word "*wall*" → "*form a wall using drones".*

4.2 Management and development of inputs

Through these techniques more than a 100 inputs were generated, to help with further management and incubation of these inputs we decided to use *Rosetta*. Each input was added to *Rosetta* in addition to a small description and hereafter categorized into originalities in accordance with the C-Box technique. The *green* category represented more regular and easily implemented ideas, *blue* being original but more practically difficult ideas, and finally *red* categorizing the very radical ideas, potentially only implementable with new/future technology.

The inputs were then carefully scrutinized and matured to further develop them into ideas and later concepts, we were able to achieving this through the use of longitudinal and horizontal process' and by consulting domain experts, including but not limited to Erdal Kayacan co-writer of many papers and a book in the domain of drone control [4.2]. Given how the overarching process is that of Double Diamond which is iterative throughout, we also ended up generating new ideas through the development and maturing of the existing ideas.

4.3 Solution

We developed 11 idea-concepts, and from them we chose the three most promising, using the insights of the experts we pursue two of these idea-concepts, conducting both a IPR- and marked novelty search on each. This led us to the final concept which was a development on the "wall"-input from section 4.1, it developed into a group of three drones which are connected by a frame and a net covering the space between them. Using several mechanisms the counter drone system is able to counter an adversarial drone by catching/pushing it away from its target. While having the disadvantage of not immediately exterminating the adversarial drone it does however offer much greater control of the situation than a more brute method of extermination. Control was ultimately of higher value to Terma, given that they wanted the system to be able to counter drones in even suburban areas. This played a major role in the selection of the final idea-concept.

5. Intellectual Property Right

Intellectual Property Rights (IPR) is an essential part of innovation. It can provide some protection in regards to the functionality, design, or unique identifier/name. However, given the many different ways of insuring IPR of a product, one can go about it in many different ways. We started by conducting a IPR novelty search, using google patents. This led us to some of industry standards like the Catch and snare system for an unmanned aerial vehicle [5.1].

5.1 Patent application

The suggested title is Gamma-frame / ɣ-frame. Gamma is the third letter in the greek-alphabet → the frame connects three drones. Additionally the shape of the system also looks like a Gamma.

Suggestions for patent claim:

1. Lock mechanism for drones (the part connecting the three drones): It can easily be released, by pulling a split.
2. Electronic connection/plug for Flight Controller Interface: Special sensor fusion is needed when mechanically connecting the drones, otherwise the flight controllers will counter govern the connected frame, forcing the drone to crash.
3. Net folding (could be something different): When the drones are separated, the net must immediately unfold and catch the drone. The way the net is unfolded, when the three drones pulls away from each other is our patent

6. Business Model

For maturing this product to the final stage, a lot of additional research is required and process can go two ways:

1) We can start our own production but this requires a lot of work that includes company .
2) We can lease our patents to existing companies or manufactures.

6.1 Vertical innovation process

Team used the Vertical Innovation Process to examine different areas in which we need to decide what has to be done for our product to become successful. You can see our VIP table with inputs in [Appendix E]. Team mostly focused on the Product, Political and Social area. This product can be used to ensure privacy laws are not broken or the lives of people are not threatened. Financially our focus group would be government and security companies. But to ensure that individuals can also use a product there would be the possibility to rent a system with staff to control it. Technically looking at the product area, the system should be possible fully implemented with current technology but ideas to make this system even better were discussed, and can be seen as inputs in [Appendix E].

6.2 Business Model and customer gain

Our invention works with privacy and life security. And because drones can be very dangerous when used as weapons. This autonomous anti drone system can find his spot on the global market. To show what value this product can bring to our customer we created a value proposition model see [Appendix H]. System can bring privacy and safety and literally saves humans lives. With help of radars which product can bring better response time to threatening situations than any other manual solution on the market.

To think about it more business like we created Business model canvas which is included in [Appendix F]. This model describes our key elements when it comes to partners, customers, resources and finance.

7. Brochure

For the Brochure see page 9

We would like the brochure to target other businesses that potentially could find a counter drone interesting or investors. The brochure shows the idea is patent pending, this is to state that the idea is serious business.

8. Final thoughts

Throughout the course we found that the double diamond fit perfectly as an innovation design process model for the project we were working on. The different phases in the project followed the discover, define, develop, and deliver phases as seen in Appendix H. While also seeking inspiration from other models such as the Creative Idea Solutions model. Throughout our work we especially experienced the iterative nature of DD and looking back we could have gone through both of the diamonds many more times.

Communicating with experts in the fields both from Terma and also the Aarhus university it is clear that creating a single solution to tackle/neutralize all potential adversarial drones now and in the future is not possible. The focus was therefore narrowed to neutralize/counter an aerial drone in an outdoor environment in a controlled manner. We feel that a serious product that could fulfill this innovation question is presented in this report.

References

[REF]"Fuzzy Neural Networks for Real Time Control Applications, 1st Edition Concepts, Modeling and Algorithms for Fast Learning", Butterworth-Heinemann, Print Book ISBN:9780128026878. (17 Sep 2015)

[3.1]"Module 03 AIE-Triz-slides", Serena, Lecture at Aarhus University(18 Feb 2020)

[3.2]"Module 05 AIE", Henning Sejer Jakobsen, Lecture at Aarhus University (02 Mar 2020)

[3.3]https://www.naviair.dk/nyhed.643/drone-forstyrrede-naviairs-trafikafvikling-p%C3%A5-k%C3%B8benhavns-lufthavn.5275.aspx - accessed March 23

[3.4]https://www.bbc.com/news/uk-england-sussex-49846450 - accessed March 23

[4.1] Osborn, A.F. Applied imagination, Principles and procedures of creative problem solving, 3rd edition, New York 1963

[4.2] Butterworth-Heinemann, Fuzzy Neural Networks for Real Time Control Applications, Modeling and Algorithms for Fast Learning, 1st edition

[5.1]https://patents.google.com/patent/US8375837?oq=patent+counter+drone+system+catch+in+net - accessed April 11

IDEA

Problem statement
We live in a world where it is a fact that everybody can get access to a flying drone. These can be weaponized for bad purposes. How to neutralize/counter a drone in an outdoor environment in a controlled manner?

Patent Pending
We've come up with a new mechanism with a air dynamic folded net. The mechanism holds three drones together and allows for hunting and attacking drones with the speed of a rocket!

Four patent claims

- Lock mechanism for drone
- Electronic connection/plug for Flight Controller Interface
- Net folding (could be something different)
- Build-in-Charge-connector

NEW COUNTER DRONE

Speed-Phase
A drone with a bomb is detected with a radar, the response is an autonomous a counter drone being sent towards the attacking drone.

Catch-Phase
Just before the counter drone is about to hit the attacking drone, the gamma-frame releases the 3x drones and ensnare the drone in a net.

Fly-Away-Phase
After catching the dangerous drone, the counter drones brings the enemy drone to a safe place, where the drone can't do any harm.

VISION

Events
Prisons
Military
Airports
Stadiums
Law Enforcement
Commercial Venues
Executive Protection
Government Agencies
Critical Infra Structures
Mining Facilities
Oil & Gas

Typically, it is urgent when an enemy drone must be countered - before it is too late!

It could be essential for business secrets if it will not get stopped, or even fatal at big events.

If a successful solution to drone attacks exists, it would definitely be used in a world with an increasing number of drones, that constantly are falling in price.

Appendix A - Triz 9

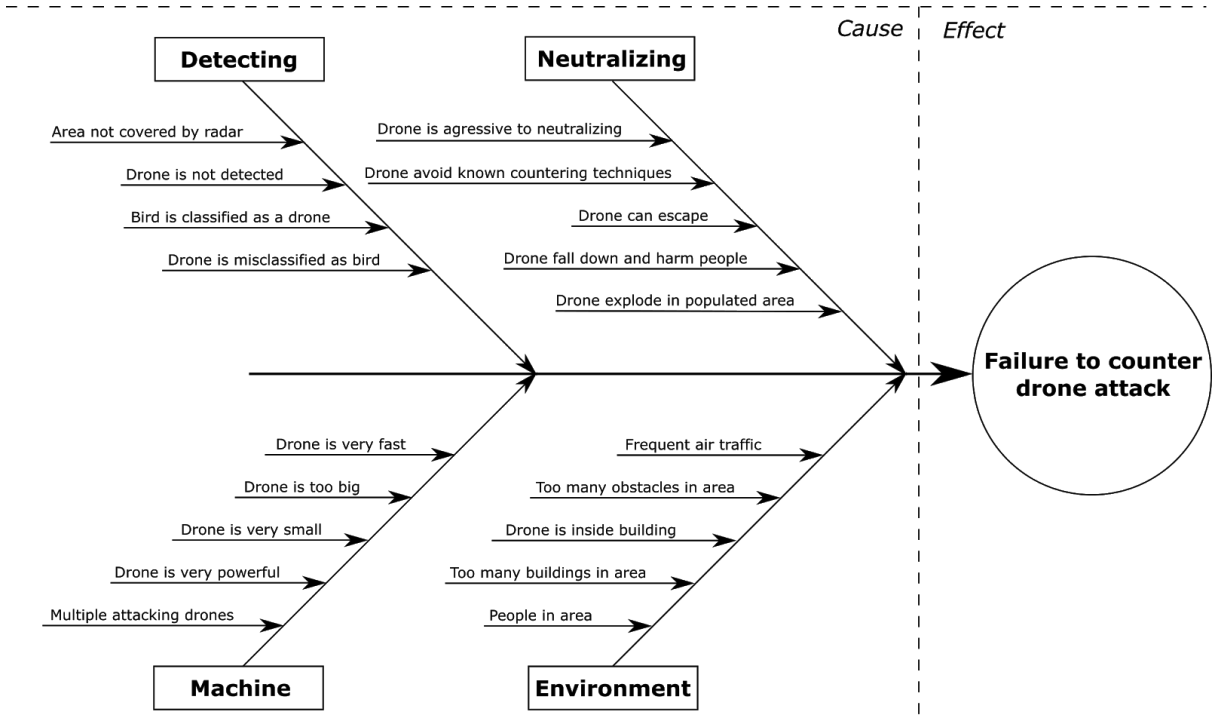
The Triz 9 model focuses on the attacking flying drone. The model gives insight to the problem, in the past, present and future.

The accident that happened at 9/11 at the World trade center is a steady target. Today it is difficult to target a person inside a building with a drone, whereas public areas outside are easily accessible by flying drones. The attacking drone has the advantage of the element of surprise, which makes it easy to strike unprepared targets. In the future the drone AI can follow the target, even though it is performing complex maneuvers or hiding.

	Past (20 years ago)	**Present (now)**	**Future (in 10 years)**
Macro-system supersystem (user)	Battlefield, human, terrorism, steady target	Human, terrorism, steady target	Terrorism, moving target
System (thing)	Manually flown aircrafts	Attacking drones flown by humans	Drones autonomous controlled by AI
Micro-system subsystem (contain)	Aircraft, fuel, seat, control stick and throttle	Remote control, drone, lightweight materials, LiPo-battery, propellers	Algorithms, drone, lightweight materials, high-density battery, propellers

Appendix B - Fishbone

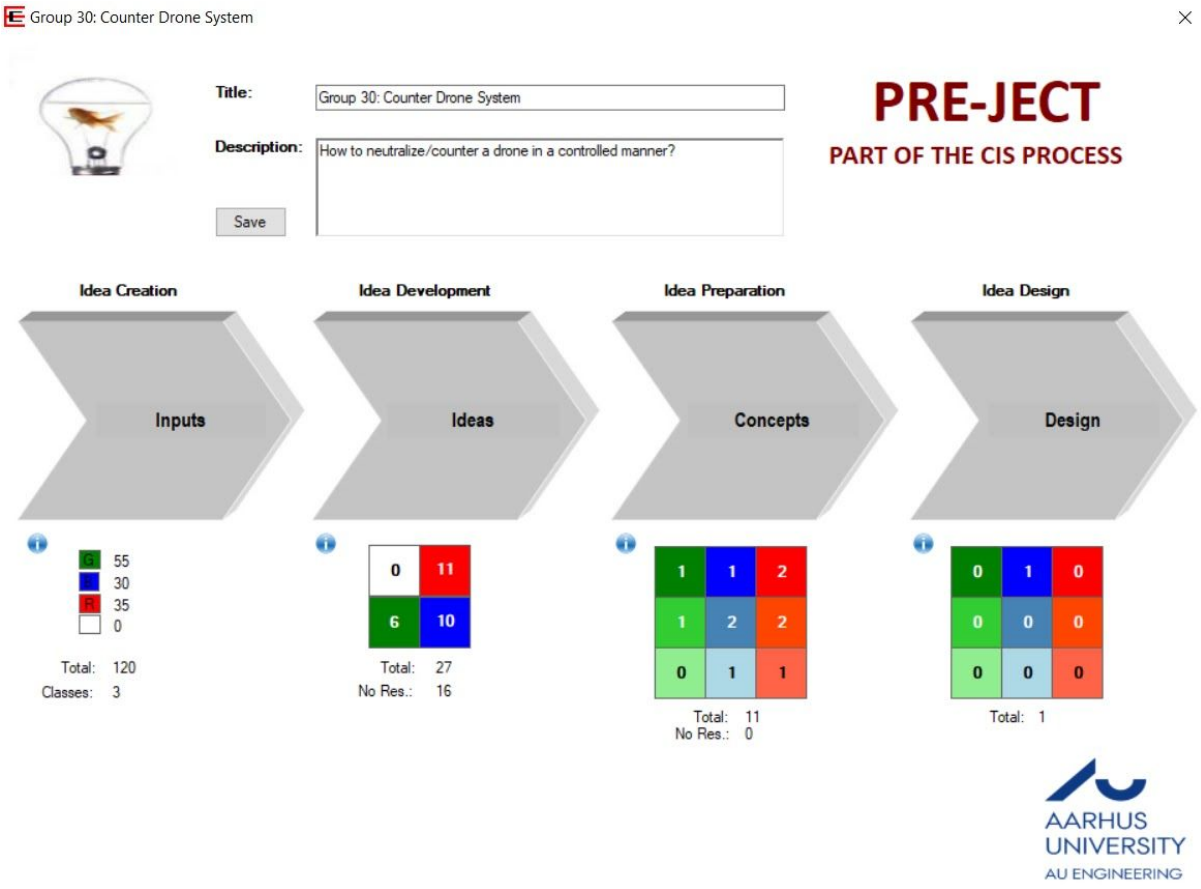
When identifying possible causes for a problem a Fishbone Diagram can be used. This can also help the team's thinking to break free from ruts.

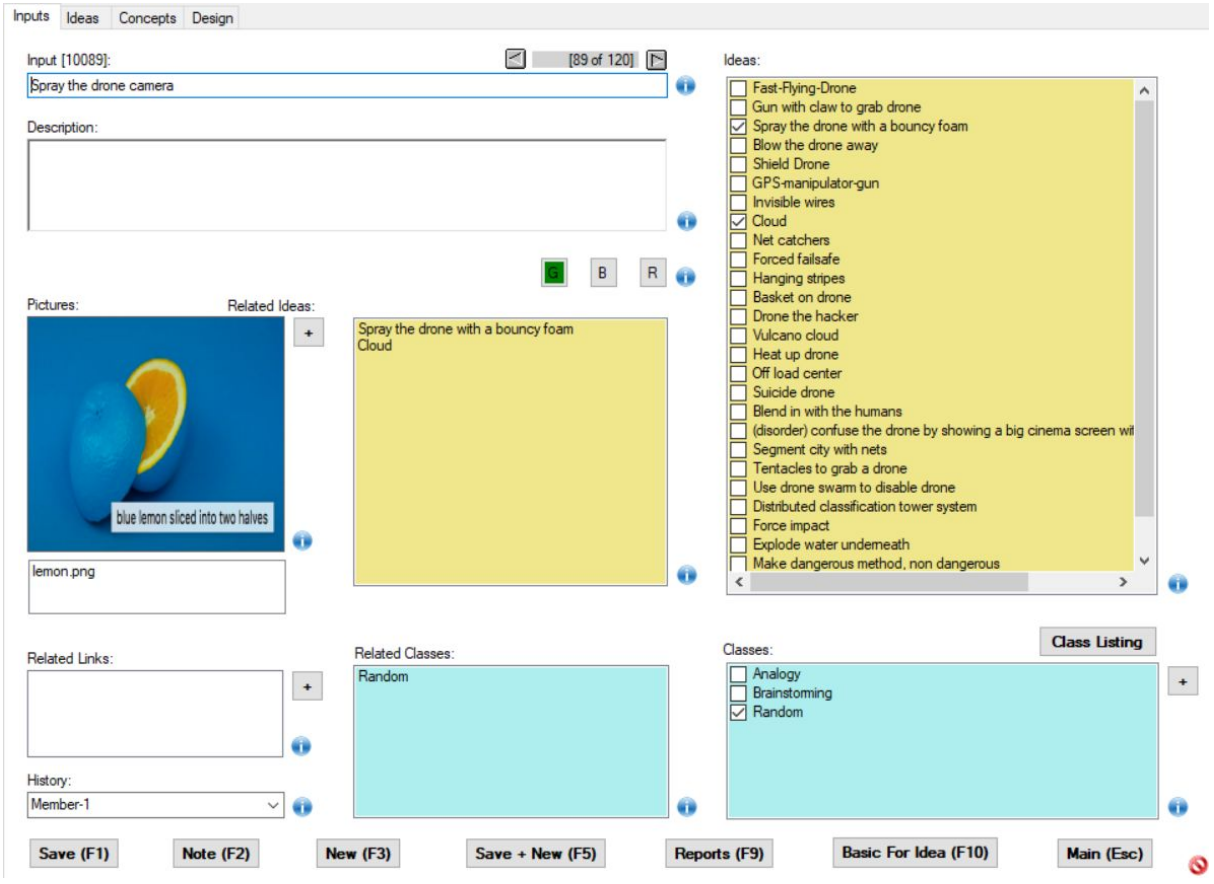


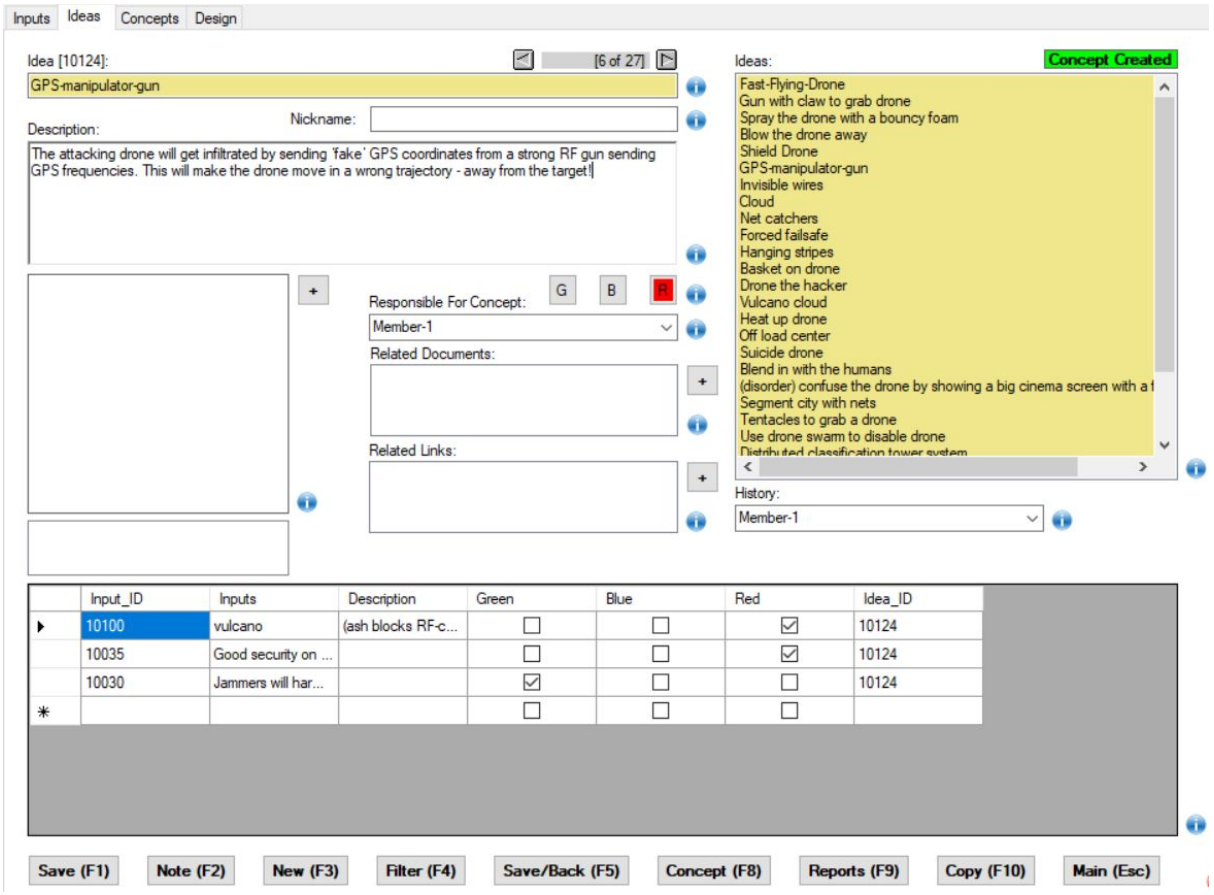
Appendix C - Rosetta

To manage all the inputs, ideas, and concepts Rosetta is used as an idea management tool. This makes it easy to generate new inputs and use them for ideas, which can be further developed upon.

A blue painted lemon was one of the several inputs. Multiple inputs can be used for an idea, this can help to mature the idea in a way so that it becomes a concept. Before a concept is created a responsible person is set for the concept.




Inputs
Ideas
Concepts
Design
Input [10089]:
[89 of 120]
Spray the drone camera
Description:
G
B
R
Pictures:
Related Ideas:
Spray the drone with a bouncy foam
Cloud
blue lemon sliced into two halves
lemon.png
Ideas:
Fast-Flying-Drone
Gun with claw to grab drone
Spray the drone with a bouncy foam
Blow the drone away
Shield Drone
GPS-manipulator-gun
Invisible wires
Cloud
Net catchers
Forced failsafe
Hanging stripes
Basket on drone
Drone the hacker
Vulcano cloud
Heat up drone
Off load center
Suicide drone
Blend in with the humans
(disorder) confuse the drone by showing a big cinema screen wit
Segment city with nets
Tentacles to grab a drone
Use drone swarm to disable drone
Distributed classification tower system
Force impact
Explode water underneath
Make dangerous method, non dangerous
Related Links:
Related Classes:
Random
Class Listing
Classes:
Analogy
Brainstorming
Random
History:
Member-1
Save (F1)
Note (F2)
New (F3)
Save + New (F5)
Reports (F9)
Basic For Idea (F10)
Main (Esc)


Inputs
Ideas
Concepts
Design
Idea [10124]:
[6 of 27]
GPS-manipulator-gun
Nickname:
Description:
The attacking drone will get infiltrated by sending 'fake' GPS coordinates from a strong RF gun sending GPS frequencies. This will make the drone move in a wrong trajectory - away from the target!
Responsible For Concept:
G
B
R
Member-1
Related Documents:
Related Links:
Ideas:
Concept Created
Fast-Flying-Drone
Gun with claw to grab drone
Spray the drone with a bouncy foam
Blow the drone away
Shield Drone
GPS-manipulator-gun
Invisible wires
Cloud
Net catchers
Forced failsafe
Hanging stripes
Basket on drone
Drone the hacker
Vulcano cloud
Heat up drone
Off load center
Suicide drone
Blend in with the humans
(disorder) confuse the drone by showing a big cinema screen with a
Segment city with nets
Tentacles to grab a drone
Use drone swarm to disable drone
History:
Member-1
Input_ID
Inputs
Description
Green
Blue
Red
Idea_ID
10100
vulcano
(ash blocks RF-c...
10124
10035
Good security on ...
10124
10030
Jammers will har...
10124
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Note (F2)
New (F3)
Filter (F4)
Save/Back (F5)
Concept (F8)
Reports (F9)
Copy (F10)
Main (Esc)

Inputs | Ideas | Concepts | Design

Concept [10133]: [1 of 1]

GPS-manipulator-gun

Description: Nickname: The Manipulator

The attacking drone will get infiltrated by sending 'fake' GPS coordinates from a strong RF gun sending GPS frequencies. This will make the drone move in a wrong trajectory - away from the target!

Responsible For Concept: Member-1

Responsible For Design: Member-2

Related Documents:

Related Links:

History: Member-1

Strategical Potiential				
High	D	B	A
Middle	G	E	C
Low	I	H	F
	Green	Blue	Red
	Easy	Intermediate	Difficult
	Short-term	Longer-term	Long-term
	Strategical Implementation		

Powers:

Instead of destroying signals like RF-jammers do, this concept is a little different. GPS-signals will be overwritten by transmitting higher signal intensities towards an attacking drone.

Problems:

It is technical difficult to send and calculate acceptable GPS-coordinates that can mislead the attacking drone. People in public will get affected by the fake GPS-signal. Sending very high power RF-signals requires special permission. The gun is handheld by a person which demands skills.

Simular Areas:

RF-Jammers

Who Knows / Experts:

Jakob
John Rohde

List Of Contacts:

- [ ] Erdal Kayacan
- [x] Jakob
- [ ] Jesper
- [x] John Rohde
- [ ] Martin
- [ ] Member-1
- [ ] Member-2
- [ ] Member-3
- [ ] Member-4
- [ ] Member-5
- [ ] Not specified

Save (F1) | Note (F2) | Filter (F4) | Design (F8) | Reports (F9) | Copy (F10) | Main (Esc) | Expert Listing

Inputs | Ideas | Concepts | Design

Concept [10149]: [3 of 3]

Gamma-Frame

Description: Nickname:

The drone is very aero dynamic, hence it can fly much faster than the attacking drone. It will carry a net to catch the attacking drone.

B

Responsible For Concept: Member-1

gamma_frame.png

Powers:

Connecting drones together and make them able to split into individual drones is a new concept. When the drones are attached together air resistance is reduced, thus increasing speed. Maneuverability is supreme compared to the attacking drone.

Problems:

Technological it is a challenge to combine the control loops of the drones when they are attached together. Unfortunately, three drones are required for each attacking drone.

Pattern:

The concept lies in a place in the strategic portfolio plane, so the we should learn from changes. Since technology can changes this might also result in a change of the scene.

Plan:

Build partnership with Terma, Improve or focus research and development (R&D) to get high quality product that is necessary in an emergency case.

Position:

Ploy:

Ask a advertising agency to make a commercial about how dangeours Drones can be to public or confidential company secrets

Perspektive:

Save (F1) | Note (F2) | Filter (F4) | Reports (F9) | Main (Esc)

Appendix D - Patent

Drones are getting cheaper and more accessible, which make them a potential tool for terrorism. Therefore a solution that can strike fast is necessary, to avoid a catastrophe. This patent allows drones to be combined which makes them very aerodynamic and thus very fast.

The technology consists of a gamma-frame allowing drones to be mechanically connected. Furthermore, it also allows a hardware connection between flight controllers allowing them to communicate during flight.

Patent demands

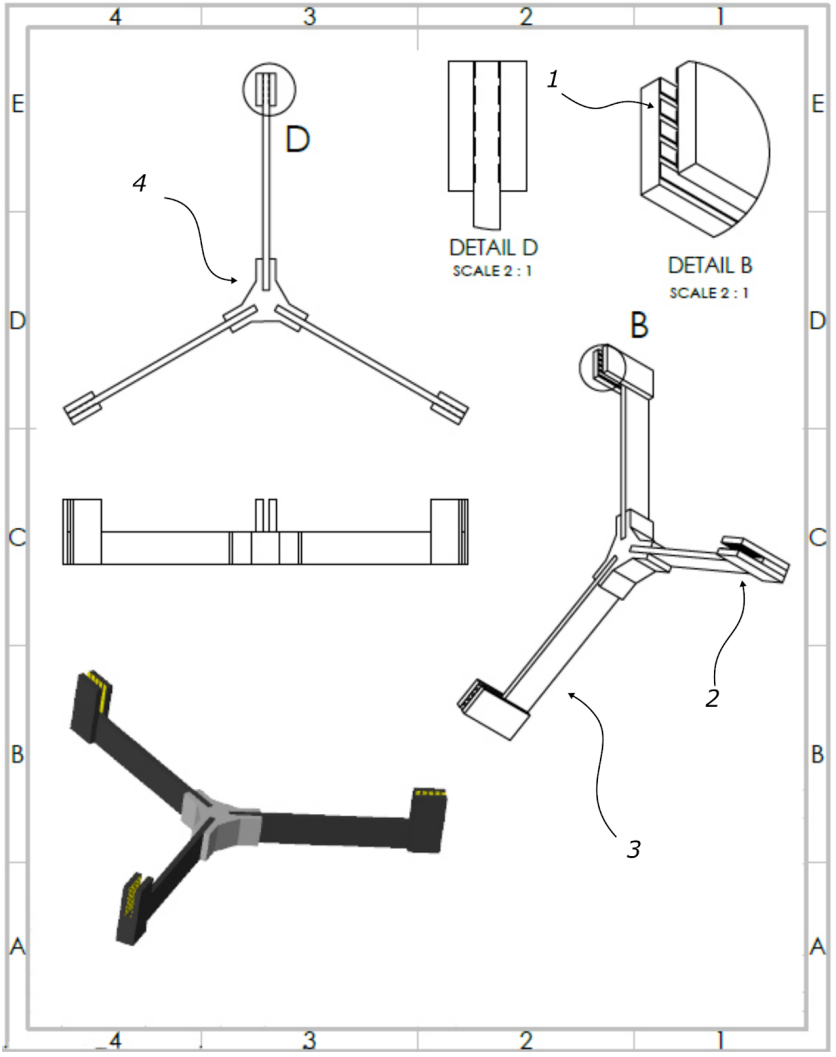
1) Lock mechanism for drones (the part connecting the three drones): It can easily be released, by pulling a split.

2) Electronic connection/plug for Flight Controller Interface: Special sensor fusion is needed when mechanically connecting the drones, otherwise the flight controllers will counter govern the connected frame, forcing the drone to crash.

3) Net folding (could be something different): When the drones are separated, the net must

Patent drawing:

1. Conducting connector for communication.
2. Mechanical lock
3. Frame arm
4. Center piece

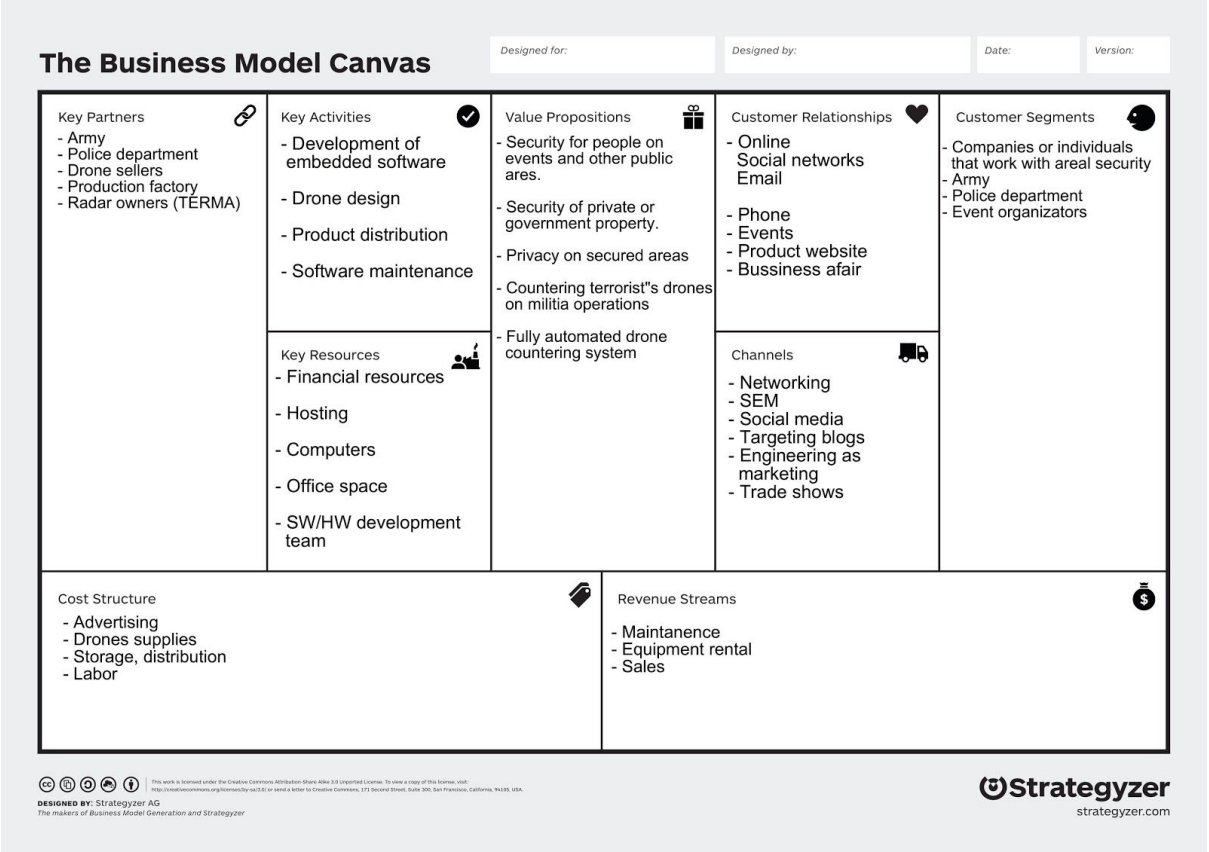


Appendix E - Vertical Innovation Process

		GREEN	BLUE	RED
Product	The technologies, techniques, and design approaches in the product/service	Radar classification Net	Y-frame Folding net	indestructible net material
Process	The way to produce or to provide the product/service	Produce frame, buy and mount drones to frame	Produce both frame and drones from scratch	Reuse countered drones
Business	The interaction with customers and/or users including the brand	Selling to TERMA, government or festivals	Help catching things for people, like cats from a tree	Fly from door to door selling drones
System	The way to work with other products or systems and the other way around	Use TERMA's radar system to detect enemy drones	Radar included in drones	Drone will never need charge Full autonomous
Social	The acceptance of users, partners and employees and their approach towards the case	Ensure privacy Ensure protection Customer service	Demoing the system countering a drone better than any other counter drone system	Fly around with a drone and performing demos on it (like hacking a software system to show that you understand and can protect it)
Financially	The way the money flows in the whole system between all actors	Selling to the customer Repairing, supporting and controlling the system	Rich people will pay for the system	Figure out if someone has had trouble with spying drones and come and help them without them asking
Cultural	The society habits, patterns, and rules among stakeholders	Need of personal privacy	The frame and net indicates security anti-spying	
Political	The way decisions are made, including barriers or opportunities in legislation	Avoid spying with drones Avoid terrorist attacks with		Everybody is allowed to fly with drones everywhere

		drones		

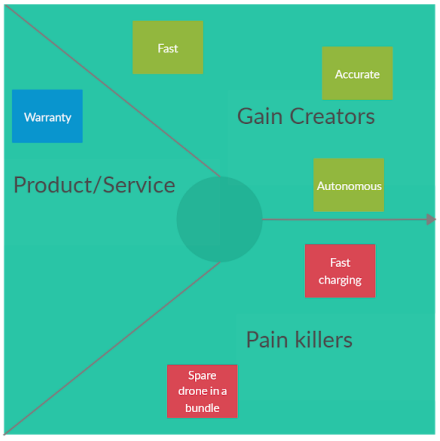
Appendix F - Business Canvas Model



Appendix G - Value proposition design

VALUE PROPOSITION DESIGN

Product



Customer

Appendix H - Double Diamond