Symposium bundle 10 papers about 10 innovations

Exoskeleton project

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Abstract

On a worldwide scale, construction occupies 14.7% of global gross domestic product. The industry is growing with a rapid pace but the amount of accidents that take place in construction is shocking. 1 in 10 construction workers is injured annually. A big contribution to this striking number is the fact that construction workers lift objects that are either too heavy or inconvenient to work with over a prolonged period of time. This paper reports on a project aimed at realizing an innovative solution to aid with heavy lifting and handling of tools on construction sites. This will be done by means of adapting an exoskeletal suit and actuating it, as well as designing a tool attachment and developing software for such a system.

The project was performed as the central component of the 7th semester of engineering at Fontys University of Applied Sciences, in the Netherlands. It was completed in collaboration with fellow engineering students from the Technical University of Denmark (DTU).

The report outlines the design choices made on the mechanical aspect of adapting a filming crew camera support suit, including developing a modular tool head for various commonly used construction tools, as well as building prototypes, optimizing the design and selecting materials. It follows up with a mechatronics perspective on how to select motors and gears to actuate the arm, combining it with a software feature of having a tool database and tool tags so the spring can be actuated correctly for the tool in hand.

The end product presented is an exoskeleton which is actuated and makes use of the 'zero gravity' principle to make sure that the tools placed onto the exoskeleton can be operated safely for a long period of time. Furthermore, the concept includes beneficial logistical aspects such as inventory updates and work hours log.

For future developments, it is highly recommended to study the implementation of a force sensor in the tool head to determine the right spring tension. This way the tools do not have to be placed into a database and the suit can balance anything placed on it independently. Server wise, the front-end functionality of web application could be developed further including registration form for tools and employees, navigation and monitor view of current arm status and its operator. Back-end functionality of the web application could include functionalities to monitor timekeeping and vibrations for a given tool and its operator. Integration with a wireless module could be considered as well. Mechanically speaking, material selections can be reconsidered given the limitations on time constraints and availability when the proof of concept was developed. The tool head attachment was designed to prove the zero-gravity effect on tools and their support, and thus naturally dampens its vibration. For further benefits, a dampening system can be implemented.

1. Introduction

Exoskeletons have been developed over the last decade to help people perform heavy load carrying. In several situations, craftsmen must lift relatively heavy loads or need to perform intensive work with heavy tools in extremely difficult positions. This results in craftsmen increasingly getting injuries over time. These injuries can last for some time since this mostly focuses on the shoulder and arm region. Craftsmen rely on their physique because they need their bodies to perform their duty. These injuries may result in leaving craftsmen unable to work for a prolonged time and, in more extreme cases, rendered medically unfit for the job.

Based on the project constraints that lays emphasis on innovation, the adaptive design of exoskeleton to aid in heavy lifting, and tool management during construction activities seemed ideal.

The main requirements of the prototype are that it must balance and support tools of up to 10kg, battery life should last at least 8 hours and ensure the communication between hardware and software is reliable. More requirements were in place for mechanical, mechatronics and software components individually.

2. Theoretical background and Approach

The theoretical framework for the project may be discussed under 3 categories based on respective general disciplines involved; that is mechanical, mechatronics, and software engineering.

2.1 Mechanical

Mechanical engineering theory was used to generate design concepts and to ensure strength and integrity of the system when under external loading and torque.

Since an exoskeleton suit intended for filmmaking is to be purchased, it must be adapted for a construction prototype capable of holding tools. this adaptation process provides an additional challenge since there is a system in place already, and some changes cannot be made. However, it still provides the convenience of a ready to use suit and therefore justifies its use. This requires the design of a modular head which can accommodate several of the common tools found in a construction site. Such head must be easy to operate, provide a strong tool grip while still allowing the workers to comfortably operate the machinery. For this, designs must be made and compared, proceeded by calculations to ensure its integrity, a material choice is to be made for the proof of concept, and lastly a production plan and the manufacturing process.

The first part to be designed is the modular tool head. It is important to consider that most construction tools are heavy and therefore robustness is required. The attachment must grip the tool and restrict both translation and rotation in all directions, meaning that any movement of the tool which may be desired is provided by the movement of the arm itself.

The main principle is therefore a clamp which prevents translation and makes sure that the plate's height and tool surrounding will prevent rotation. As a basis, in order to ensure a good grip, at least four contact points in each clamping area are required.

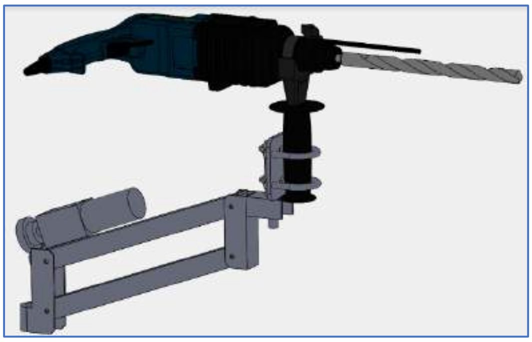

Figure 1: Proof of concept clamping design.

With the design in hand, calculations can be performed. The first step after deriving a free body diagram is to determine what values are known and what assumptions can be made in order to calculate the desired values. In the calculations for the tool attachment, given the number of unknowns in the modular head, assumptions of distribution of load were made to simplify the calculations. Lastly, since the reaction forces are due to the weight force and torque of the tools, solving the reaction forces as functions of these variables is possible. These can be solved using the summation of forces and moments around support points. After that, in order to obtain realistic answers, a construction drill was selected, and its information was used to derive a numerical answer for the calculations. This allowed for further calculations and material selection.

After the head design, the total force on the connection pin between the suit and arm can be supported to ensure its integrity. The weight of both the arm and the attachment are known, and all dimensions can be measured and calculated and are therefore given as well, combined with the weight of the designed head.

The main task focused on ensuring that the system could withstand the stresses provided by heavy tools and their reaction forces, as well as designing a modular head attachment for a variety of tools, ensure vibration dampening by the spring is sufficient, and lastly limit degrees of freedom of the arm to ensure the operators are safe in any case of accident with the tools. When dealing with power tools, they provide vibrations from their use, as well as high torque if such tools happen to get stuck or malfunction during operation. This means that the worst-case scenario for tools does not only rely on their own weight, but in their use conditions. Calculations must be performed in order to identify exactly what such scenarios are and counteract their impact on the system. These external conditions are added to the standard use in the calculations.

Since the support pin which attaches the arm to the suit, it is a crucial point to be calculated. Once again, bearing in mind the worst-case scenario, this was calculated with the heaviest possible tool weighing 10kg, assuming all moment is applied in a single pin. The formula used for this is the sum of moments, by calculating force (weight of each component) multiplied by distance (from the centre of gravity of component to pin). This results in 124.5 Nm. This is below the allowed stress on the material, approximately half the value, and therefore is safe by a large margin.

Such tasks accompany a 3D design of the exoskeleton arm, which allows for prompt design changes and preliminary simulations, as well as calculations of relevant aspects.

2.2 Mechatronics

In the mechatronics part the, focus remains on the sensors and actuation for the self-balancing arm. For the data collection, several sensors will be integrated into the suit. To detect which tool is attached to the head, an RFID (Radio-Frequency Identification) reader will be used. This reader can identify an RFID tag that is attached to the tool and gather its data using the supporting software. The data can include the type of tool, it's weight, vibrations, how stressful it is on the body and its lifespan. The weight of the tool is used to determine the spring tightness required to balance it, and this in its turn actuates the springs to the correct tightness to support it. Vibrations and stress to user are monitored to ensure a safer exoskeleton operation, thus preventing overworked personnel. The same RFID reader can be used to identify the user with a personal tag or card. With the personal data the health and work time can be monitored so that the worker can be warned when he/she is working too intensely or is putting too much stress on their body and suggest taking a break or do lighter work.

To make sure the arm self-balances the tool, the spring needs to be tensioned to the correct amount. This is done by mounting one side of the spring to a spindle and driving it with a geared down DC motor. To position the spindle, it has two limit switches at both ends that are used to zero itself and an encoder that measures the rotations of the spindle. For the tools that are in the tool database the weights are known, so that the suit can determine the amount of spring tension required. In a future version a system could be made that would self-adjust the spring without knowing the tool's weight.

The adjustment of the tension and the sensor data is controlled with a microcontroller which is connected to a wireless module. The microcontroller controls the motor using a simple PWM (Pulse Width Modulation) motor driver circuit and connects to Wi-Fi using an ESP module. With the Wi-Fi connection the suit has access to the database where all the user and tool data is stored. The picture below illustrates the stated above.

The motor used in the prototype is a 12V DC motor coupled to a 1:50 reduction gearbox and two gears that couple the gearbox to the spindle with a 2:1 ratio. The total reduction from motor to spindle is 1:25 and with a spindle pitch of 1.2 mm the maximum spindle speed is: 13000 rpm / 25 * 1.2 mm = 624 mm/min = 10.4 mm/s.

The total travel length of the nut on the spindle is 90 mm, so at the maximum speed the nut can travel from fully loose to tight in 90 mm / 10,4 mm/s = 8,6 s. This time is a theoretical number and, in practice, will be slower due to friction and the spring force that is acting on the spindle.

With a motor torque of 0.4 Nm the output torque is 0.4 * 25 = 10 Nm at the spindle.

The electrical components are mounted in a separate housing that is attached to the vest itself, in this housing the OLED screen, RFID scanner and two buttons are accessible to the user to interface with. The housing has a power connector to attach to the battery and connector to plug in the arm (motor and two limit switches).

To attach all the electronics to each other a custom PCB (printed circuit board) was made. The PCB includes screw holes to attach it to the housing.

Figure 2: Actuated arm.

2.3 Software

Monitoring data such as time of operation, identification of tools and their respective vibration output propose a solution to help construction managers comply with regulations. Thus, the components making up the electronics exoskeleton are categorized into the following:

Arm interface: an interface residing on the vest used to interact with the arm and transmit data to the server.

Server: a central storage and processing unit of sensor data and inputted data.

In the following flow chart, the basic layout of the software design is displayed.

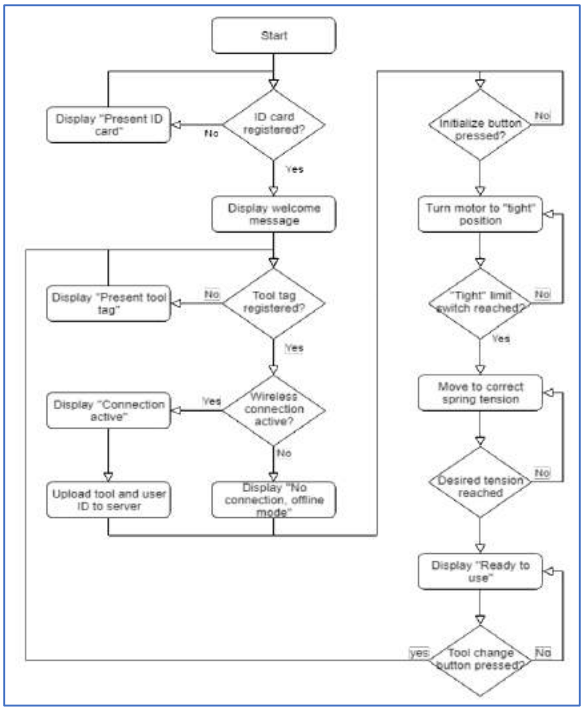

Figure 3: Software flow chart

3. Results and Discussion

Present summarized results in relation to objective, design question, more to discussions. Explain how results show POC, technical specs achieved, changed or not met.

3.1 Interface

The interface will measure data from the zero-gravity arm and send data to the server through the wireless communication. Furthermore, a user-friendly display is needed for great end-user experience. Battery circuit for charging and discharging are needed because the zero-gravity arm must be portable.

3.2 Server

A low fidelity prototype web server and web application is implemented with Swift and currently running on localhost. Web Server contains a database with fields for storing employee identifications. Web application currently has no interaction options but will only display database content in the browser with JSON formatting. Updates to the database is done through a local shell.

3.3 Wireless communication

The wireless communication technology has been chosen for this project. The device used on the zero-gravity arm are the device ESP8266. The ESP8266 can connect to the internet over Wi-Fi and can connect to an MQTT server where its able to ask for the latest database containing all the necessary information such as id, name, weight and arm position. The ESP8266 stores this new information onto an SD-Card such that if it loses connection to the MQTT server or the WI-FI is out of range the tool can still perform as intended. As extra security this information is also stored on the RFID card such that if the data aren't stored on the SD-Card the exoskeleton can operate without any interrupt. If newer information on the other hand is stored on the SD-card the RFID card will then get its information updated. This implementation is to secure that the worker always has an automated exoskeleton that works when its online and offline and attempts to update old information with new one. The cool thing about having a server on the internet makes it easy for the company to work at multiple working sites at once where the only requirement is some WI-FI where the exoskeleton can update its internal database. The information about the tools such as their weight can be edited through a program that can connect to the MQTT server. In the future this should get accessible through a website with more graphical content and user profiles.

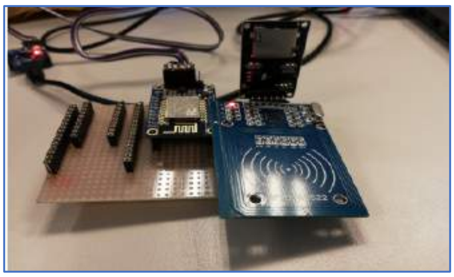

Figure 4: ESP8266, SD card, RFID comprising a circuit for the wireless communication between the server and interface.

3.4 Mechanical Design Results

For choosing a material, the choices easily available at Fontys were steel, aluminium, wood and PLA (from the 3D printer). Given the delivery time of materials, as well as the project budget limitation, using these would be the most convenient. Factors such as weight, machinability and others, the following table was created and allowed aluminium to be selected for this proof of concept.

	Weight	Hygiene	Durability	Water resistance	Production costs	Total average
Aluminium	4	4	5	4	4	4.2
Wood	5	2	2	2	4	3
Metal	1	4	4	3	3	3
PLA	4	4	4	3	2	3.4

Figure 5: Material matrix.

The critical element of preventing translation and making sure that the plate's height and tool surrounding will prevent rotation needs to be met. As a basis, in order to ensure a good grip, at least four contact points in each clamping area are required and achieved. The resulting solution includes two 'U-clamps' that make sure that there are always 4 points of contact because of their round shape. The 'U-clamps' can distribute the forces that are applied by the tools and are therefore a feasible solution, since they don't limit the degree of freedom for rotating the attached tools.

Conclusion

In conclusion, the adapted exoskeletal suit contributes to a safer working environment and reduces the risk of injuries on operators. Its actuation system makes it a unique product in the worksite and it's monitoring features add value to safety and efficiency. The modularity of the system allows it to be used with easy and comfort. This leads to significant improvement in working conditions. As written in the next chapter recommendations, there is still a great potential to develop the concept to a further extent.

The added value of the exoskeleton is its potential to reduce or even eliminate workplace hazards and repetitive strain injuries. This means that, in the long run, employees are healthier and happier, while companies save money on medical treatment for their workers and having to replace them and train new staff as often. It also contributes to other aspects beyond safety, such as monitoring work hours and overtime, logistics and tool management.

Currently, the exoskeleton is limited by its load capability, as it was modified and is not guaranteed to handle heavier tools and larger vibrations than its calculated limits. Since the suit was commercially purchased, further research on optimal orthopaedics and comfort aspects can be researched, but this goes beyond the scope of the project.

Recommendations

For future developments, it is highly recommended to investigate the possibility of implementing a force sensor in the tool head to determine the right spring tension. This way the tools do not have to be placed into a database and can work independently. Other variables that can have an impact on the working time, but the end-product does not include are vibrations, body position, temperature and humidity. These parameters are not measured now but can be developed to a further extent in the future.

Also, the data could be measured on the zero-gravity arm itself, a user-friendly display for the user could be implemented and a battery circuit for charging and discharging of the suit can be included in a future model.

Furthermore, server wise the front-end functionality of web application could be developed to further extent. This includes registration form for tools and employees, navigation and monitor view of current arm status and its operator. Back-end functionality of the web application could include functionalities to monitor timekeeping and vibrations for a given tool and its operator. Integration with a wireless module could be considered as well.

Overall there is great potential to develop the concept to a further extent. The recommendations at hand add further value to this innovation, making the system more efficient and further increasing its user's safety.

Use of a quadcopter for a celebratory lightshow

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Abstract

Today advancements in the development of aerial robotics has generated countless applications by utilizing autonomous Unmanned Aerial Vehicles (UAV). Unmanned Aerial Vehicles like drones and quadcopters have revolutionized flight as they helped man take the air in new, profound ways. As the technological development of drones and related software continue to develop, the associated benefits and commercial applications continue to grow. Motivated by the idea of entertainment UAV's this paper is written with the main objective of showing how the programming, selection, designing of a lightshow quadcopter was done in addition to showcasing how formation flying was achieved. The main goal associated with this project paper is to have a conceptual design that can serve as an alternative to fireworks that are used in New Year celebrations in the city of Eindhoven. In order to accomplish this goal, the Kesselring method was used to determine the most compatible and efficient parts needed for the design and construction of the quadcopter, all of which were sourced from online and partner suppliers except for the frame which was designed on Siemens NX12 and 3D printed in the Fontys lab. The quadcopter was then assembled, wired, and flashed in preparation for flight using BetaFlight a and INav mission planner firmware's. This was demonstrated in a limited way using a simulation and successful prototype drone system and control design.

Keywords: UAV, alternative, quadcopter, lightshow, fireworks, sustainable

1. Introduction

This year's new year's firework celebrations caused more than 15 million euros in damages and resulted in more than 1300 people making their way to the hospital in the Netherlands. The Dutch government has been trying to regulate the use of fireworks, banning certain types and forbidding the use of fireworks before 18:00 on New Year's Eve. In 2017, the importation of illegal fireworks was also banned, leading to the police confiscating tones of them each year [1]. However, this did not stop the tragedy that befell a father and his four-year-old son from dying as a result of a fire in their apartment building caused by fireworks during this year's celebrations in Arnhem [2]. In Rotterdam, doctors announced that they treated eighteen people with firework-related eye injures between 11:30 p.m. on December 31st and 7:00 a.m. on January 1st, 2020, which were more than double compared to the year before [3]

As a result of this the government's debate over whether fireworks for public use should be banned or not came to a conclusion as city councils and citizens are in favor of this ban. In Eindhoven, more than fifty-five percent of the residents want a ban on fireworks during the New Year period. This is according to a survey involving 4200 residents, commissioned by the city council of Eindhoven. The survey group cited several reasons for supporting the ban. Most respondents cited public nuisance. The emissions that fireworks create, and their dangerousness was also mentioned. A slightly larger group – sixty-two percent of residents – expressed their preference for a large central show in the city on New Year's Eve which can be a professional show organized by the city council, and that takes place in a central venue in Eindhoven [4]. With that, fourth year innovation specialization students from Fontys University of Applied Sciences in Eindhoven and software engineering students from the Technical University of Denmark came together to work on an alternative to fireworks. This alternative came in the form of a quadcopter that is able to fly in formation and perform a central lightshow to the citizens of Eindhoven. This quadcopter serves as the main topic of this paper where the methodology used to construct it is explained. In addition to that the structure of the quadcopter, software design, frame, construction and testing are thoroughly described. Furthermore, this paper elaborates on their project work and highlights it.

2. Background

As mentioned before the main objective of this paper is to give information on the programming, selection, designing and testing of a lightshow quadcopter that could perform a lightshow and fly information. The reason the team went for a quadcopter is because they are easy to manufacture at a relatively low price. This was attractive to the team as there was a time and budget constraint of 6 months and 200 euros respectively. The quadcopter designed by the team consists of four rotors/propellers positioned at the four ends of the cross intersection. Each rotor/propeller is driven by a brushless motor attached to electronic motor controllers in order to communicate with the microcontroller, with which control of the speed of each individual motor is achieved. The speed of each motor determines the upward and downward acceleration. Using a four-motor quadcopter design allows for change in directions, elevation, and tilt which are all features needed when preforming a lightshow. The latter is achieved by manipulating how much voltage goes into the motors while it is in the air. Quadcopters comprises of four motors in total, with two pairs rotating in the counter-direction. Furthermore, fixed-pitch blades located at the four corners.

3. Methodology

The design process of the quadcopter was heavily dependent on the requirements set at the beginning of the project and the functions the quadcopter must be able to perform. Applying a methodical design approach to the project contributes towards making a certain decision for designing or ordering of a component based on its performance of the function assigned, while considering its effects on other components involved in the designing process. The decision support tools that were used during the design phase of this project as methodical design approaches are the Kesselring method and Morphological chart.

3.1 Kesselring

Decision support tools are meant to help engineers specifically in making decisions. Conducting the Kesselring method before choosing a design or a component allows an evaluation of different alternatives based on common features between these options. These features fall into two main evaluation standards, functionality and productivity. Each component or design is given a rating based on its positive contribution towards the feature. For example, when choosing a software as one of the three sub-systems to program the drone between BetaFlight, ArduPilot and INAV, the following features from the two main criteria's where chosen

1. Functionality: Speed, Autonomous, Performance and Durability.

2. Productivity: Reliability, adaptability and assembly.

Then proceeding into rating, them from one to five, five being the highest score and one being the lowest

Table 1. (Example of Kesselring method application)

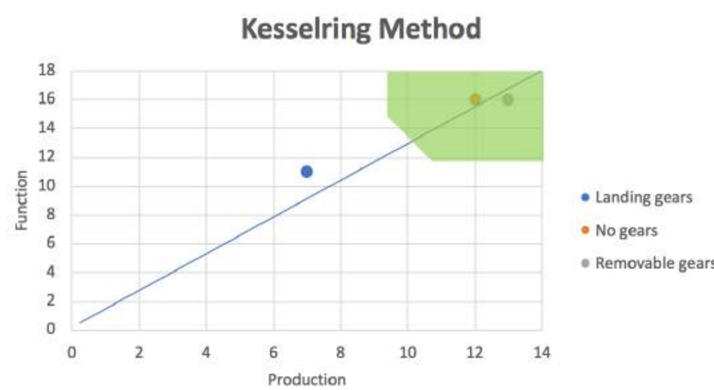
FUNCTIONS AND PRODUCTION	*ArduPilot*	*BetaFlight*	*INAV*
SPEED	4	4	4
AUTONOMOUS	3	4	5
PERFORMANCE	1	5	4
DURABILITY	3	3	3
RELIABILITY	1	4	4
ADAPTIBILITY	4	4	4
ASSEMBLY	2	5	4

Furthermore, the ratings of each software are summed into the main criteria's, as shown in the table below.

Table 2 (Example of Kesselring method application)

	ARDU PILOT	**BETAF LIGHT**	**INAV**
FUNCTIONA LITY	11	16	16
PRODUCTIVI TY	7	13	12

Finally, a scatterplot can be conducted from the ratings summed, with a green area showcasing the wished ratings scored by the component. If one of the compared components falls withing the green area, that means it has a high probability of being most efficent component moving forward to the construction phase



3.2 Morphological chart

The morphological chart is a visual way to capture the necessary product functionality and explore alternative means and combinations of achieving that functionality. For each element of product function, there may be a number of possible solutions. The chart enables these solutions to be expressed and provides a structure for considering alternative combinations. This can enable the early consideration of the product through the generation and consideration of different combinations of 'sub-solutions' that have not previously been identified. Used appropriately, it can help to encourage a user driven approach to the generation of potential solution. The chart down below shows the components that were conucted through the kesselring method and combined together to generate different concepts for each sub-system sub-system.

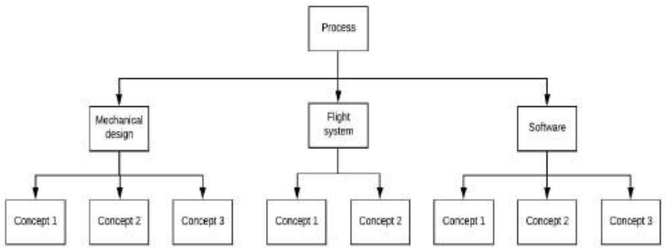


Figure 1 (Morphological diagram)

For example, the two concepts that were generated for the flight system of the quadcopter consist of the following components

Flight system	Concept 1	Concept 2
ESC	BlHeli 32 4 in 1 ESC	BlHeli 32 4 in 1 ESC
Microcontroller	Omnibus F4 V6	Self-programmed Arduino
Lights	LED lighting ws2812	Light bulb
Propellers	Reely propellers	Tello propellers

Figure 2 (concept generated from kesselring)

4. Requirements

Table 3. Software Requirements

1	The drone should fly a path set in advance autonomously
2	The drone should be able to withstand wind up to 30Km/h in any direction while hovering in one location and autocorrect to the preset position within a tolerance of 0.5 meter.
3	The drone should have at least 15 minutes of flight time. Flight time is considered from the moment the drone takes off till it performs the act and ending by the drone landing.
4	The drone should be able to fly in formation enabling the drones to perform a light show, for example forming the number 2020 or a countdown from 10 to 1 celebrating New Year's Eve.
5	The drone should be able to hover for 5 minutes in the same position, if a show doesn't require change in formation or if number of drones waits for other drones to get into position.
6	The drone must operate on INAV, BetaFlight and ArduPilot, since multiple functions can be executed through one or two of the programs listed above

Table 4. User Requirements

User requirements	
1	The drone must be lightweight compared to other drones used in lightshows, the lightest being 300 grams. (Draolux drone should not exceed 200 grams)
2	The drone has to be able to fly higher than 25 m above sea level, which the height required to avoid interference with surroundings.
3	The drone must ascend swiftly without malfunctioning due to lack of power supplied to it and have a battery life of 15 minutes minimum.
4	The frame must be removable for maintenance and tests.
5	The drone must be able to fly in bad weather conditions, such as rain, snow and wind. (Till a certain level of the conditions)
6	The drone must have multi colored LEDs on its exterior that must be visible to spectators whom are seeing it from below.
7	A power button must be present on the exterior of the drone to activate it, so it can launch on the indicated time and won't fly away in a room unexpectedly.
8	Since the New Year's Eve celebration is held in winter, the exterior of the drone must be water resistant at 3 atmospheres pressure rating, which means being water resistant to rain and water splashes.
9	The frame must be small. It should fit in the palm of your hand. 100 mm in length, 100 mm in width and 70 mm in height
10	The overall look of the drones must be attractive.

5. Structure of quadcopter

A typical quadcopter consists of the following essential components:

1. A main frame, typically in light metal, with a motor to perform functions such as takeoff, hovering and landing
2. Electronic Speed Controllers (ESC), which is an electronic circuit that is responsible to control the motor's speed and direction.
3. A flight controller to detect the orientation changes of the quadcopter. It is essential to the quadcopter as it receives user commands, and controls the motors in order to keep the quadcopter in the air
4. Sensors to measure signals which include the following:

Accelerometer: This sensor is designed to measure linear acceleration. It is an electromechanical device that will measure acceleration forces. These forces may be static, like the constant force of gravity pulling at your feet, or they could be dynamic - caused by moving or vibrating the accelerometer

Barometer: This sensor is designed to let the quadcopter know how high above the ground it is. It does this by measuring pressure. Since air pressure changes with altitude, the drone can determine its own height with the help of a barometer.

Gyroscope: A gyroscope is designed to measure angular acceleration on an x, y, or z axis. Basically, it's responsible for allowing the drone to fly in a stable manner.

GPS: Also known as a "Global Positioning System", a GPS sensor allows satellites to pick up on the location of the quadcopter so that the person flying it can do things like set specific coordinates for their quadcopter to fly to or even bring the drone back to its original starting location despite it not being in their field of sight.

Inertia Measurement Unit (IMU): Small board that contains the gyroscope and accelerometer.

Compass: This reads/gives off information regarding the quadcopter's direction.

The main part of the quadcopter is frame which has four arms. The frame had to be light and rigid to host a LIPO battery, four brushless DC motors (BLDC), controller board, four propellers, a microcontroller and different types of sensors along with a light frame. The speed of BLDC motors is varied by Electronic Speed Controller (ESC). For higher stability i.e. to have lower C.G. the batteries are placed at lower half. The motors are placed equidistant from the center on opposite sides. To avoid any aerodynamic interaction between propeller blades the distance between motors is roughly adjusted. All these parts were mounted by the team on the main frame of the quadcopter as shown in Figure 1

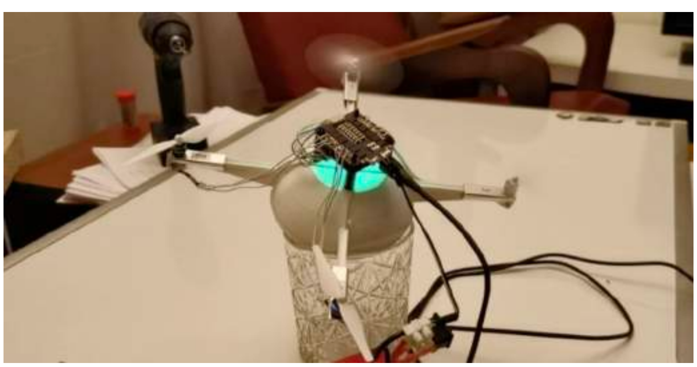


Figure 3 (Quadcopter)

6. Quadcopter components

6.1 Microcontroller

The microcontroller gathers information from the sensors, interpret the data and send the appropriate control signals to the actuators a microcontroller. The decision for the microcontroller was one of the most important component choices the team had to make. In order to choose the right microcontroller different aspects needed to be taken in account. At first there was the possibility of using a basic microcontroller like an Arduino. However, that meant that in order to program the quadcopter everything would have to be programmed including keeping the quadcopter stable and this was a whole project by itself. As a result, decision was made to go for a flight controller which is a controller that is focused on flying drones or aircrafts. This decision meant that no extra software had to be programmed in order to achieve stable flight for the quadcopter.

After some research a decision was made to use ArduPilot for controlling the Quadcopter. The Ardupilot website gave multiple options for microcontrollers that could be flashed with the program. This project needed a lightweight microcontroller cause the quadcopter was going to be really small, so the big controllers were ruled out. Another important part of choosing a controller was the availability. Not all microcontrollers were available in the Netherlands with a fast delivery. In the end the Omnibus F4 V6 was chosen. This microcontroller is similar to the Omnibus F4 Pro. This was fairly useful due to the large amount of information available on the Omnibus F4 Pro on ArduPilot website. This also included how to flash a controller.

Figure 4 (Omnibus F4 version 6)

6.2 Brushless DC Motors (BLDC Motor)

Brushless DC motors are exclusively used in Quadcopter because they superior thrust-to-weight ratios compare to brushed DC motors and its commutators are integrated into the speed controller while a brushed DC motor's commutator are located directly inside the motor. They are electronically commutated having better speed vs torque characteristics, high efficiency with noiseless operation and very high-speed range with longer life. BLDC motors do not use brushes for communication. They are typically given two ratings: Kv ratings and current ratings. Kv rating is the relationship between the RPM and the voltage. Kv rating indicates how fast the motor will spin (RPM) for 1 V of applied voltage. The current rating indicates the max current that the motor may safely draw. Generally, BLDC motors are referred in Kvs like 850 KV to1800 KV depending upon application. If 1 volt is applied on 1000 KV BLDC motor, it will spin at 1000 RPM while 12 volts applied on motor, it will spin at 12000 rpm. The motor we chose had a voltage range of 3.4 -7.4V which means that is will spin at an RPM between 3400 to 7400 rpm

6.3 Propellers

Propellers come in many sizes and materials. They are measured by their diameter and their pitch, in the format (diameter x pitch). Pitch is a measurement of how far a propeller will travel in one revolution. Propeller selection is important to yield appropriate thrust for the hover or lift while not overheating the motors. Each BLDC motor had a propeller. The four propellers are not oriented in the same way. The front and back propellers are tilted to the right, while the left and right propellers are tilted to the left as shown in figure 2. Propellers transduce the rotary motion to aerodynamic lift force. The two pair of counter rotating propellers make the aerodynamic torque is zero. The propellers used in for the quadcopter were *Reely multicopter propellers.* These propellers are 78mm in width, 8mm in height and have a minimal diameter of 8mm

Figure 5 (Reely Propellers)

6.4 Electronic Speed Controller (ESC)

Electronic Speed Controller (ESC) is an electronic circuit to vary the speed and direction of a brushless Motor. It controls it by converting the supplied DC from the battery into three phased AC. For the quadcopter, 4 ESCs were needed, one connected to each motor. The ESCs were then connected directly to the battery through a power distribution board. Every ESC has a current rating, which indicated the maximum current provide to motor without overheating.The ESC the team selected was the BlHeli 32Bit ESC's. The reason being is that on the ArduPilot website it states that the Microcontrollers are compatible with BlHeli 32Bit ESC's.

Figure 6 (32Bit ESC)

6.5 Battery

Lithium Polymer (LIPO) rechargeable batteries are used for quadcopters because they have high specific energy and light in weight. Electric power is provided to motor and all electronic components of quadcopter by the batteries. The capacity rating, in milliamp-hours (mAh) indicates how much current the battery may output for one hour. Discharge rating indicated by the letter "C", show how fast the battery may be safely discharged. LIPO batteries can be found in packs of everything from a single cell (3.7V) to over 10 cells (37V). The cells are usually connected in series, making the voltage higher but giving the same amount of Amp in hours. The battery package used for the project was the Conrad energy LiPo accupack 7.4 V

6.6 LED

A light-emitting diode (LED) is a semiconductor light source that emits light when current flows through it. Since the main object of this paper revolves around the quadcopter being able to perform a lightshow, lights were a crucial component to have for this quadcopter. The initial approach to achieve this was by means of adding a small lightbulb to the bottom of the quadcopter. The problem with this was that a lightbulb was too heavy to use. The team then chose to go for LED's as a lighting source. The reason being is that it would help the drone save
energy as they do not draw in a lot of power like lightbulbs do. In addition, they are also lightweight. The team chose to go the WS2812 LED's because they that they are easily implemented and supported on BetaFlight.

6.7 Servo leads

Servo leads are the connection cables between the receiver - control board and ESC board. These have three leads which connect the signal, power (+) and earth (-) connection.

7. Software design

The software design consisted of a microcontroller Omnibus F4 V6. This microcontroller was chosen because of the LED output it has, which is easily accessible via the programming software Betaflight. To perform the desired lightshow performance. The combination of the components is from great value cause the data transmission from microcontroller to electronic speed controller to the motors, is crucial to have a stable and safe flight.

This microcontroller has access to its location by component number two GPS module: the beitain 880 the newest and best reviewed module which obtains accurate precision of 0.1 meter by use of GPS tracking and an electrical compass. This together with the information in the microcontroller about pitch, roll and jaw will control the drone while hovering and guide the drone along the preset markers along the horizon.

Component number three is the electronic speed controller named the BL_heli_32 4 in 1 ESC used to control the brushless dc motors. To upload the program in the electronic speed controller, the software program BL_heli_Suite is used to flash the electronic speed controller. The variety of settings makes the electronic speed controller very useful for this application. Also, current sensing allows the user to have access to current data and power consumption of turning motors. Also, a telemetry connection is available to communicate precisely with GPS module. The output if the ESC is a sin wave modulated DSHOT signal that allows smooth transition in motor speeds and control each motor separate.

Component number four are the motors from Racerstar. Four brushless DC motors which are capable of delivering 19000KV each. Extra lightweight 1.7 gram and with a shaft of only 0.8mm. Capable of lifting the drone to heights where it can perform the light show.

Component number five are the four Led's from the brand Lighting ws2812, controlled by Betaflight via libraries and commands given in the command prompt. The programming language C++ offers many possibilities to control the led illumination in 16 million colors. All these components are connected to component number 6 the battery. 11.1 volt 3 cells, 800mA which can supply the power needed to present a light shows up to 15 minutes.

8. Frame design and construction

The full frame of the quadcopter was printed in four parts making up the main frame, bottom part and two arms in which the propellers are mounted. The main frame hosts the microcontroller, ESC and the GPS inside of it. The placement orientation of the GPS is on top to garner the most accurate measurements. The components are screwed and held in place with spacers, connected to the top of the main frame.

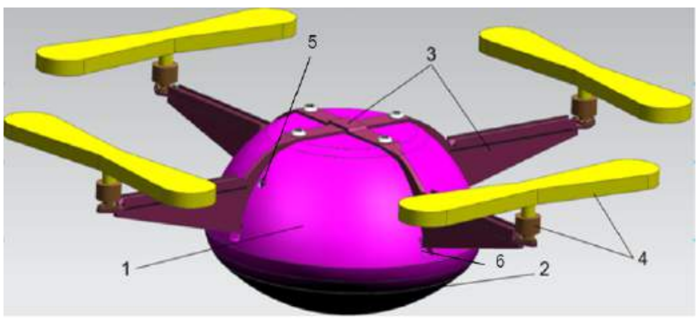


Figure 7 (Quadcopter. 1 Main frame; 2 Bottom Part; 3 Arms; 4 Motors and Propellers; 5 Wire holes; 6 Claw grip)

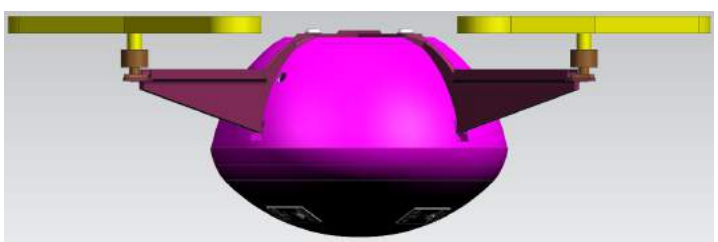


Figure 8 (Bottom view of quadcopter)

The GPS is placed on top for the most accurate measuring. The components are screwed and held in place with spacers, connected to the top of the main frame. The arm parts, that hold the motors, are placed on the sides of the main frame. They are clammed between two screws that hold the components. At the bottom of the arms are claws are held on the lower part of the main frame. The length of the arms depends on the length of the propellers. They cannot be placed above the main frame or the thrust will be influenced. The arms have a cable gutter to guide the wires between the motors and the inner components. The components in **Error! Reference source not found.** are

1. GPS,
2. Spacer,
3. ESC,
4. Microcontroller,
5. Battery
6. LEDs

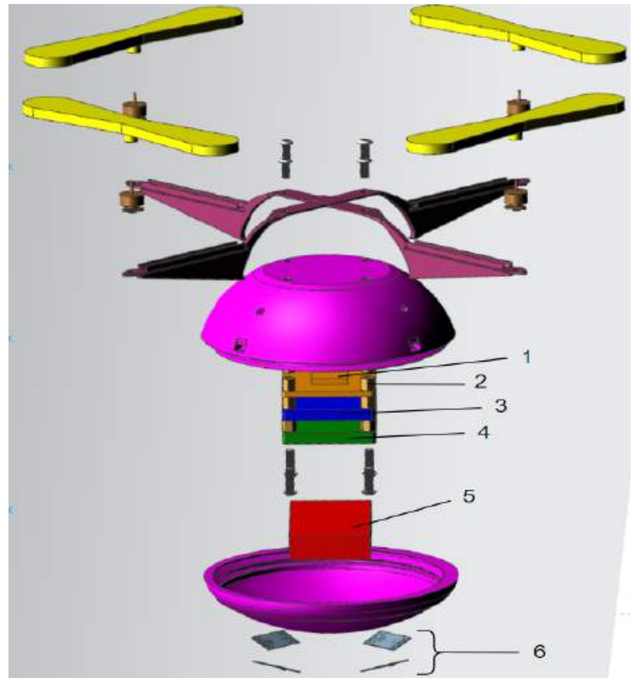


Figure 9 (Exploded view of quadcopter)

Due to the battery is the heaviest component, it was placed in the bottom part to get a low center of gravity to allow for the most stabilization. A hole was drilled in the bottom half of the drone to facilitate a cable to connect to the four LED's placed on the exterior to it. The drilled holes at the sides and bottom of the quadcopter were then sealed with a filler to ensure that no environmental factors affect the performance of the quadcopter such as water or dust. This also makes the drone water proof. The overall shape of the frame was round to give the drone an aerodynamic shape. By doing this the effects and impacts of turbulent air are reduced. Furthermore by. As previously mentioned, the frame was 3D printed using the Ultimaker 3. This prointer supports the use of PLA, Nylon, ABS, CPE, CPE+, PVA, PC, TPU 95A, PP, and Breakaway. Other materials are not officially supported but can be used on the Ultimaker 3 due to the open filament system. The main frame of the quadcopter was printed in PLA (Polylactic acid) and the arms were printed in ABS (Acrylonitrile Butadiene Styrene). The reason behind this is due to the low melting temperature of PLA (between 60-65 °C). This low material temperature caused the arms to melt when the motors were operating at full speed and so an alternative material with a higher melting point had to be used to print the arms.

9. Testing

In order to check and verify components, software, choices and mechanical design a test plan is created to keep track of what has been done and executed. The test document is set up in six test phases. Which are given as components below. Trough out the process the result we obtained was a detailed explanation of each component tested individually:

1. Frame

Dimension meet the with the proof of concept. Holes pitches mounting holes and the 3d printed frame fit all components and parts explained in the design phase. Propellers have the right size. FEM analyses is done to check strength and durability. The frame design suites the requirements.

2. Battery pack

The wiring is done in a safe way and all components are soldered correctly. Battery fits in the frame and is easily accessible and replaceable.

3. Microcontroller

The microcontroller is easy to use and can be operated on demands of the operator. With the right software and drivers, the mission planner Betaflight is best to use for the purpose we need it for. Missions are set up by setting a desired location and altitudand the drone will fly the path programmed starting from a independent location. GPS module makes sure an accurate coordinate system is tracked and live update at all times to unsure safety. To perform the show the LED lights can be preprogrammed in 16 million colors.

4. Motors

The brushless dc motor turn by a signal that is transmitted form the electrical speed controller. DSHOT 150 protocol is most suitable for our application and allows enough torque and little power consumption. The motor turn in the right direction two clockwise and two counterclockwise.

5. Final stage testing

We got all the motors of the drone to turn. We were able to work with the new microcontroller and additional software. To get a stable flight we are testing to hover in a stationary position. The next step is the test to fly to a given location and fly back from it's initial position

10. Conclusion and recommendations

The main goal of this project was to have a conceptual design that can serve as an alternative to fireworks that are used in New Year celebrations in the city of Eindhoven. This was achieved and elaborated throughout this paper. The project team was able to successfully achieve a unique quadcopter that is able to fly in formation and is capable of performing a lightshow. Furthermore, the team was able to achieve that with the aid of the faculty advisors from Fontys University of Applied Sciences and the Technical University of Denmark, and the resources and technical knowledge they supplied to successfully complete this project. At this point the project could go in a variety of directions since the platform seems to be flexible. This flexibility allows changing the functions it performs and also allows integration of any technology that would prove to be useful.

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FOOD PACKAGING

"SusPack"; Sustainable Packaging

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ABSTRACT —
Nowadays, food is packed in single use plastics in supermarkets. Food is packed, because it improves the quality, preservation and protection of the food. However, this creates a heavy toll on the environment. In the Netherlands, the biggest amount of plastic is derived from the food shopping industry. Therefore, it is from great importance to find an innovative solution to the problem of single use plastics.

This paper is initiated from the Innovation Engineering project of Mechanical Engineering. In this research the main question was stated as follows: "How can a sustainable development reduce the amount of single use plastics in the food shopping industry?"

The goal of this project is to investigate the possibilities to start a company named SusPack. research from the project concluded that there are possibilities to start a company in the food shopping industry due to potential market size and competitiveness. The company's solution to the problem has been found in the development of a sustainable packaging that can be used circularly within a cost-covering deposit system.

KEYWORDS —
Innovation, Food packaging, Sustainable, Business, SusPack

1. Introduction

This paper is based on the project report of Food Packaging [1]. During this project, a new way of food packaging for supermarkets has been researched. Plastics where invented in the 1830s, however, plastic food packaging was not adopted till the 1970s. The reason behind food packaging was to improve the quality, preservation and protection of the packaged food. Because of these good properties other materials such as glass and metal became gradually redundant. Nowadays, food in supermarkets, is packed in single use plastics. However, this creates a heavy toll on the environment because single use plastics are manufactured and used at a high rate depleting resources, while the valuable resources are burned after single use [2]. Another disadvantage is that most of the plastics are not biodegradable and when not processed, these plastics enter the environment. Their it breaks down into smaller pieces ending up as microplastics in the food chain, where it is already found [3]. In the Netherlands, the biggest amount of plastic is derived from the food shopping centres, currently about forty percent [4].

Therefore, it is from great importance to find an innovative solution to the problem of single use plastics. Already, there are developments in the sustainability of plastic packages [5]. The development of the Food Packaging project will be discussed in this paper in which the following research question will be answered: How can a sustainable development reduce the amount of single use plastics in the food shopping industry?

One of the goals of the project behind this paper is to investigate possibilities to start a company named SusPack. SusPack develops an inventive and sustainable product which makes use of a cost-covering deposit system. In this way, SusPack hopes to reduce the amount of single use plastics in the food shopping industry.

This project was in collaboration with Escola Universitària Salesiana de Sarrià – EUSS from Barcelona. Two students collaborated in this project focused on the Life Cycle Assessment (LCA) of the product researching the feasibility during the products life cycle. Two students who collaborated from Business Management investigated the market and business possibilities and assisted in setting up the business plan.

2. Research questions

With the research question in mind, five sub research questions have been prepared to investigate whether SusPack can develop a sustainable solution. The sub research questions are stated below:

1. What are the possibilities of development in the food shopping industry?
2. What are the company's business plans and goals?
3. What is the company's solution?
4. What are the company's operations?
5. How is the company going to finance this innovation?
6. How can SusPack be as environmentally friendly as possible?

3. Business Plan

To start a company the possibilities of development are researched. One of the possibilities lies in the potential market size. The consumer usage of food packaging shows that every year 1500 packages are used. Every Dutch person uses approximately four packages per day. Trends from the ING Economic Bureau show that usage will increase to 5770 packages per year, approximately sixteen packages per person per year in 2023 [4]. Since there are currently 6338 supermarkets in the Netherlands and 17.4 million residents the target market size is large enough. Secondly, to enter an industry is to research the competitiveness. Competitiveness could interfere with the business opportunities. The five forces model of competition by Porter pictured in figure 1 is used to identify the competitiveness. There it can be seen that the threat of new entrants is mainly determined by key partnerships.

SusPack is a company with the vision of "A circular economy for plastic food packaging.". As a company SusPack has the mission to create a solution to food packaging to drastically reduce the amount of single used plastics for the food shopping industry in the Netherlands. The goal is the implement SusPack together with a cost-covering deposit system and reduce this amount by twenty five percent within five years.

The opportunity for SusPack is in product and market development, as there is no current deposit system for food packaging in the Netherlands. This is an advantage over the competition in ways of substitute products and markets.

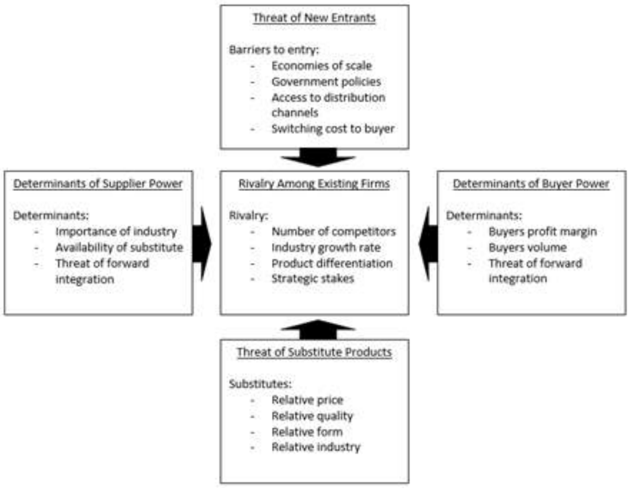

Figure 1: Porter's Five Forces Model of Competition

The strategy of SusPack is to segment, target and position itself in the market. Differentiation is the leading factor for positioning. SusPack seeks to be unique in its industry along some dimensions that are widely valued by buyers such as environmental friendly [7].

4. Company's Solution

To come to a solution first was thought about customers experience and how a standard food packaging should be shaped. These so called demands are important for the ease of use in experience of the packaging. Important keys for customer demands are: knowing your brand, materials, construction, distribution, shelf life & other design considerations [8]. The solution came from applying the Kroonenberg Method [9]. With the use of the Kroonenberg method multiple functions are acquired. The functions are formulated by a morphological chart [1] and are: closure, stack-ability, dimension, airtight, manufacturing and hinge.

The functions are translated into features for the food packaging. In *table 1* the inner dimensions are visible. These dimensions are based on standard food packages, as these are currently in use. The dimensions are important for SusPack's functions, that the SusPack's will be stackable onto each other for easy transport. For SusPack's prototypes, standard dimensions are used, these dimensions can easily be replaced for dimensions seen in *table 1*.

Size	Length [mm]	Width [mm]	Height [mm]	Thickness [mm]
Salami	180	120	25	0.25
Milk	70	70	200	0.25
Butter	130	80	85	0.25
Shoarma	230	145	50	0.25
Meat	180	180	60	0.25
Yoghurt	r=65	r=65	125	0.25

Table 1 Inner dimensions food packaging [1]

The prototypes are designed for additive manufacturing but the final SusPack will be manufactured trough injection molding for cost efficiency. Because of the food that are inside the packages, the material is important for the chemical composition, that need to stand being save and must be able to withstand 4 cycles per year in 6 years [6]. For the use of material multiple materials can be used for a SusPack prototype, this to give the prototype a shape. The first prototypes are made with the use of a Ultimaker 3D-printer. The used materials are: Poly Lactic Acid - for rapid prototyping (shape), TPU - flexible material for the hinge and the package closure and polypropylene- for good chemical resistance. For the end concept multiple colours are used to indicate what kind of food is inside: Red colour- for meats, sliced or whole piece, Blue colour – for milk products, Green colour- for vegetables and fruits. An example can be seen in the *figure 2*. With the realisation of the SusPack packaging system the products will be produced by plastic injection moulding so the price will reduce with high quantities.

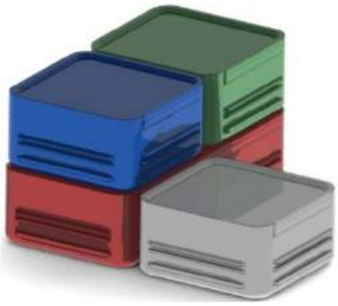

Figure 2 SusPack concept prototypes

The first prototypes were focussed on specific features like dimensions. After a few designs Prototype 6 was made (*figure 3*), this design is a solution to all the features and demands. In earlier prototypes the closure was designed for a 'force bound' closure, this means that the top lid will close the packaging trough a constant applied force on the edges of the packages. This 'force bound' closure will result in a package that will wear out faster and therefore cannot be used for as long. In prototype 6 a 'form bound' closure is designed, in *figure 4* can be seen how the lid is fitting in the bottom part. When the lid is mounted on the top the materials will not be under an applied force. So the package will not wear as fast.

For the feature of airtight the closure will also solve this problem because of the notch all around, this will seal of the SusPack when closed.

Figure 3 Prototype 6

Figure 4 Prototype 6 section view

The hinge of prototype 6 is a thin design plane that is bendable. With this bendable hinge no separate parts are needed, the customer will therefore not miss any parts when the customer returns the SusPack for his/hers deposit. For the distribution and stacking system side notches on every side are applied so the packages could slide in each other horizontally, this will help stacking the SusPacks for easier carrying and ease of use. This connection between SusPacks can be seen in *Figure 4* or even more SusPacks like in *Figure 2.*
SusPack is better in use then conventional packaging because of the reusability in this deposit system. The package is easily stackable so also no plastic bags will be needed when carrying your groceries to home.

5. Life Cycle Assessment

The Life Cycle Assessment (LCA) is performed by the EUSS Students to analyse the advantages of the new method compared with the conventional supermarket. The Life Cycle Assessment is an analysis that looks at all the factors of a product, from producing to consuming and discarding. The LCA is with a bias towards the Spanish market. The Spanish supermarket chain Mercadona is used as a benchmark for the current situation.

The environmental management standard of ISO 14047 is applicable to the LCA. The value's following from this standards are: Climate change, stratospheric ozone depletion, photo-oxidant formation, acidification, nitrification, human toxicity, ecotoxicity, depletion of abiotic resources and depletion of biotic resources. These aspects are further divided into three sub-categories: Human health, ecosystems and resources. The results can be found in figure 6.

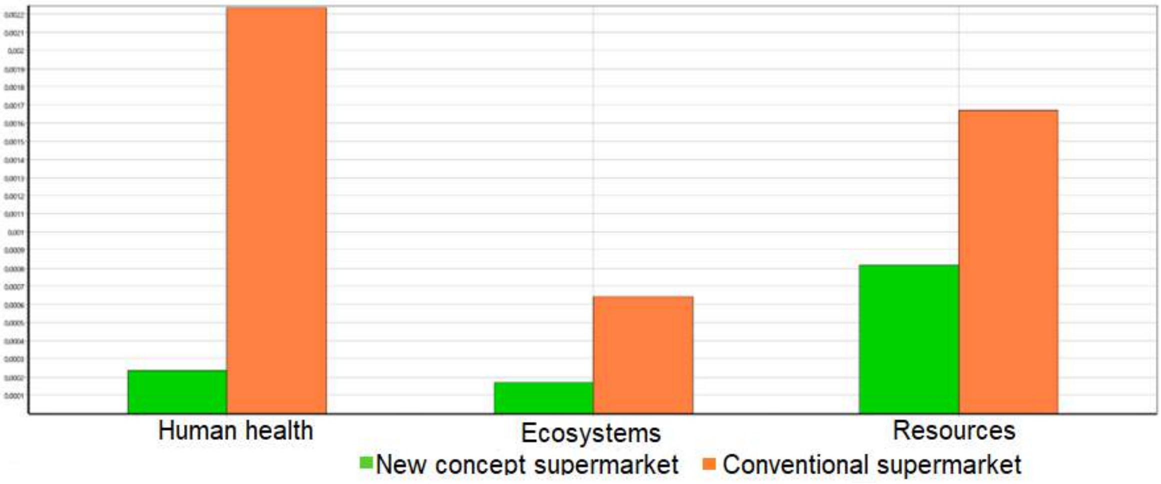

Figure 1: Impact on the environment

With the implementation of the new concept supermarket only four values are affected which are: depletion of resources, climate change ecosystems, climate change health and particulate matter formulation. The resource depletion is justified because of the proportion of plastic used due to the reusability and long-life span of the package.

From the LCA Report of EUSS can be concluded that the biggest impact that the conventional supermarket causes is in human health due to the pollution of plastic to the environment. Whereas, with the new concept resource depletion is impacted the most. This impact can be reduced by recycling, which is the case with the usage of SusPack [9].

6. Business Operations

The business operations of SusPack add value to the customer segments and is divided in production and cleaning operations. The customer segments from start to restart are: SusPack – Food processors – Distribution centres – Supermarkets – Consumers , back to supermarkets and distributors which bring the collected packages to SusPack. The operations begin at the production of SusPack where key partners supply resources [10].The production process is dependent on the rate of return by the deposit system. This rate of return is expected to be between seventy and ninety percent [11]. According to this percentage the sales approach is adjusted. Sales of production to food processors are defined as:

$$production\ sales = amount\ of\ \frac{packages/residents}{year} \cdot marketshare \cdot (1 - rate\ of\ return)$$

The added value for food processing companies are brand awareness. As mentioned in [7] the environmental impact of a company is valued by customers. The partnered distributor then transports the packed products to supermarkets where consumers buy the product with an added 25 cents for deposit. The added value for supermarkets are preserve able packed products. As the shelf-life time prolongs, less valuable food is wasted saving up to 145 euro per person per year [12]. After consumption the consumer returns the packages receiving there deposit. This promotes the use of the deposit system [13]. The rate of return provides a profit which is spread across the segments. This cost covering system is executed by an governmental organization. After collection the packages return to SusPack and cleaned. The cleaning operations starts with removing all packages that still contain food remains. The divided packages then go through a device called a 'Sniffer'. This is a device that smells if there have been harmful substances in the packaging, which are then also removed. Finally, the packages are cleaned in a washing plant. All labels are removed, and new labels are made of this. The average re-use is 25 till 50 times over its life cycle. Annually the cycle between the segments take three months so about 4 times a year. Reducing the amount of single used plastics in the first year by 25 percent in the first year from 1500 packages to 375 per year. And 20 percent in 2023 from 5770 to 1162 because the packages have a life cycle of 6 years [1]

Then the expected cleaning sales, can be defined as:

$$cleaning\ sales = amount\ of\ \frac{packages/residents}{year} \cdot marketshare \cdot (rate\ of\ return)$$

Part of the cleaning sales are added to the system to cover costs from the customer segments. The profit per net return package is 17 cents where the production costs are 8 cents per packaging. The business operations are financed the sales approach. Research points out that in the first two years of sales the revenue grows exponentially from 1.3 million euros to 9.85 million euros [1]. As the market share continues to grow, sales will also grow. The start-up of the company is mainly financed by governmental subsidies due to an public-private cooperation and environmental angel investors.

7. Conclusions

Nowadays, food in supermarkets, is packed in single use plastics. The reason behind food packaging is to improve the quality, preservation and protection of the packaged food. However, this creates a heavy toll on the environment. In the Netherlands, the biggest amount of plastic is derived from the food shopping industry. Therefore, it is from great importance to find an innovative solution to the problem of single use plastics. The research question discussed in this paper was stated as follows: "How can a sustainable development reduce the amount of single use plastics in the food shopping industry?" to answer this question, the first step is to look at the five research questions.

the possibilities of development in the food shopping industry are mainly due to potential market size and competitiveness as described in chapter 4. The business plan and goals are to drastically reduce the amount of single use plastics by implementing, SusPack together with a cost-covering deposit system and reduce this amount by twenty five percent within five years. It can be concluded that within 5 years a reduction of 20% is realistic.

From the LCA Report of EUSS can be concluded that the biggest impact that the conventional supermarket causes is in human health due to the pollution of plastic to the environment. Whereas, with the new concept resource depletion is impacted the most. This impact can be reduced by recycling, which is the case with the usage of SusPack.

The company's solution to the problem has been found in the development of a sustainable packaging that can be used circularly within a cost-covering deposit system. The circularly use is maintained by an governmental executive organization which maintains all customer segments. The operations of SusPack are production and cleaning of the packages. The division between the two is determined by the rate of return. Overall the company is going to finance the project through sales, subsidies and investors.

It can be concluded that SUSPACK can reduce the amount of single-used plastic in the food shopping industry with the development of a sustainable packaging. The reduction is achieved through a cost-covering deposit system.

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Modular e-scooter sheltering

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Abstract

The assignment which led to this paper was to design a modular shelter for E-scooters which can be locked and is sustainable. This shelter will be placed in Barcelona, since there is a high amount of fines of placing the E-scooters in the wrong spots. This led to the main research question: *'In what way can a shelter be designed in such a way that there will be less fines while being modular and sustainable?'.* The design of the E-scooter shelter is set according design requirements and designed with the help of the V-model. It should be stiff, though, resistance and well-priced. The design is limited through aesthetics, space, costs and the weather. Before designing the assumption was made that the project is a pilot. Because the lack of time would restrict the ability of designing multiple products. The pilot would be placed at the main station of Barcelona, one of the most busy places. In the end a shelter is designed in the form of lockers with a pull-mechanism which makes it easy to place the E-scooters in the shelter. There are charging possibilities within the lockers and this energy will be generated from solar panels placed on the roof of the shelter. Spare energy will be stored in a battery.

Keywords: Sustainable, Modular, E-scooter, Parking, Locking

1. Introduction

Since 2016, Barcelona is witnessing an incline growth in the usage of E-scooters with a share of around 30% of E-scooters and bikes. E-scooters have become a personal vehicle for many people in Barcelona due to its flexibility, comfortability and ease of use. Barcelona is a popular city with over 32 million tourists a year. The E-scooter is a good way to sight-see the city. The e-scooters are gaining popularity not only in Barcelona but in many big cities across the globe. The increasing use of the e-scooters has not led to only positive events. If the e-scooter is not used properly it can cause unwanted incidents like fines or accidents.

Barcelona is troubled by lots of E-scooters parked in unauthorised spots. This resulted in confiscating 400 E-scooters last September (lavanguardia, 2019). Besides that, there have been given between 1700 and 2500 fines this year due to placing the E-scooters in the middle of the sidewalk or leaving them chained against trees or bicycle racks (Mercader, 2019). The regulation says that the scooters can only be parked in authorised places, but there are none so far. This results in the many fines but also in the theft of E-scooters. This all combined leads to the biggest problem: there are a lack of sheltering for E-scooters in Barcelona.

In order to solve the problem, together with the rapid increase of tourism and the usage of E-scooters, it is important to look into the need of having a shelter for E-scooters in Barcelona. The aim of this project is to deliver a proof of concept which could be a prototype or simulation of a shelter. This shelter has to be more than just a parking spot. It has to be innovative, sustainable and modular as well. The main objectives of the modular E-scooter shelter are the locking and charging of the E-scooters in a sustainable matter. By locking the E-scooters in a safe and structured way, it will prevent theft, vandalism and fines. The energy supply needs to be sustainable, for the environment as well as the image of the product. In order to succeed, there is a collaboration with EUSS Barcelona engineering students and Fontys marketing and engineering students. With all knowledge combined, there will be a shelter design especially for E-scooters. To do this, the following question should be answered at the end of this report: *'In what way can a shelter be designed in such a way that there will be less fines while being modular and sustainable?'.*

2. Scope and limitations

For different reasons it is important that the scope and limitations of the project are clear. Because the students that are connected to this project are interdisciplinary and intercultural, every group of students has its own objectives and activities. The students can be divided into three groups: The innovation differentiation students, the Barcelona students and the marketing students. The Barcelona students do not get the same amount of study credits as the innovation students do. That is why the only task assigned for them will be the material selection. The marketing students are responsible for the business canvas model, marketing plan and the possibility of gaining a sponsorship. The rest of the workload will be distributed between the innovation differentiation students. The work has to be finished in half a year, which is the duration of this project. On the 5th of February the project has to be presented at the Symposium held by Fontys University of Applied Science.

The budget for this project on the moment of writing is €250, -. This is the budget that is available from Fontys. Any more necessary money has to come from external investors that have to be found. The design, modelling and simulation will be done during the design phase. If a physical proof of concept has to be made, this would be outsourced and paid by the budget available. This limits the capability of delivering a fully working prototype.

The scope of the project will focus on the sheltering of e-scooters only. So, any peripheral matters according E-scooters will not be taken into account. The focus will be on the design of the shelter, not on the politics or legislation of the E-scooters in general

3. Approach

The overall methodology used for the project is the V-model as seen in Figure 1. Not all the steps of the V-model have been done because of lack of time and money. This means that the verification phases have been done till coding. The validation phase has not been done. The methodologies used in this project defer per chapter or paragraph. In the literature survey, sources on the internet have been researched and analysed. For the design process, different methods have been used. The material selection has been made with the help of CES EduPack 2019. CES EduPack is a unique set of teaching resources that support

Materials Education across engineering, design, science and sustainable development. The Kesselring method and comparison spider diagram are used for choices that needed to be made for different parts.

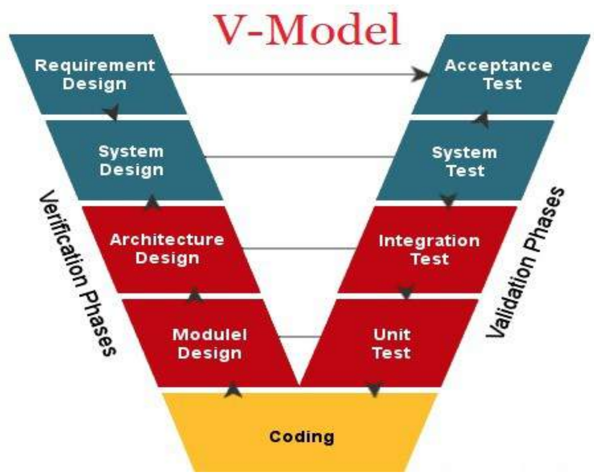

Figure 1 V-model (V-model, n.d.)

4. Literature study

This section presents an overview of the literature study found will be written. The part includes sheltering for small vehicles, the stakeholders, the implications and a market research. If all that is done, the design phase can be started.

Sheltering for small vehicles

Electric transportation is becoming bigger and bigger. More and more people are opting for an electric car, scooter or bicycle. This is not a surprise because the environmental and financial benefits are huge. The number of electric charging stations around the world is increasing and this particular development will intensify in the future. A couple of inventive shelters and charging stations which implement as sheltering for small vehicles are the following: ECOTAP, SWIFTMILE, Y-LECTRY, MAGMENTS MAGDOCK. The Ecotap is a pole where you can charge your vehicle (Kuneverda, 2019), the swiftmile is a rack where you can charge your E-scooter (Dickey, M.R., 2019, Oct 24), Y-lectry used an application which leads you to a usable E-scooter (Ajuntamen-Barcelona. (n.d.)) and magments magdock is a wireless charging and docking station for E-scooters (Bliss, L., 2019, March 13).

Most of the companies listed above are trying hard to find solutions for E-scooters around the world. Charging stations are available but not safe enough. In Barcelona specifically, there are no charging stations nor shelters for E-scooters. Hence, a shelter has to be made to solve the problems raised because of the increased demand for E-scooters in the city of Barcelona.

Stakeholder Analysis

For this project there will be multiple stakeholders which might be interested in the end product that will be designed. There are the following stakeholders: government, rental companies, E-scooter users, material suppliers, manufacturers. Without any of these stakeholders, this project and product will not make any sense. These stakeholders can invest in this product, they can buy the shelter and they can make money out of it.

<u>Operational Implications</u>

Research implications refer to the impact that the research conducted might have on future research, policy decision or on the relevant field of interest of the innovation. The implications have to be substantiated by evidence that the E-scooters within the cities would be a greener option. The limitations considered must be pointed out to avoid over generalization of results.

To properly assess these claims, it is important to consider all relevant environmental factors. This is including the materials and energy required to manufacture scooters and its shelter, the impacts of collecting them in case it was turned off in the street to charge them, and the electricity needed that would charge their batteries and how would they be charged. In addition to the environmental aspects, societal aspects have to be taken into consideration as well.

<u>Benefits for society</u>

<u>Reduction of CO2 emissions:</u> Due to more E-scooter's usage, there would be a decline in the use of the vehicles which would lead to less pollution from the cars. In addition to that, less kilometres would be travelled since the routes for the E-scooter are way more convenient, especially in the centre of the city. This might lead to decline in the need of manufacturing cars in the future (Johnson, 2019).

<u>Reduction of congestion on roads and streets</u>: Less privately-owned cars on the roads and shorter distances travelled on shared cars means less congestion in and out of the cities, and more on-street parking available. That can also have a positive impact on the congestion caused by people looking for parking. A study conducted in Barcelona by Avancar, a round-trip car-sharing operator, reported an even bigger impact on car ownership: every shared car on the streets of Barcelona replaces from 15 to 20 private cars so imagine what kind of impact E-scooters could have if sharing cars have made this impact. E-scooters is more convenient than cars as it also does not require a license.

5. The design process

Since all research and literature was given, the start of the design was made. In the design of the E-scooter shelter to lock and charge E-scooters in the city of Barcelona there were specific things required to run the model. The body of the shelter require some specifications that must be fulfilled by the materials. These are, stiffness, to ensure the rigidity of the structure and that it will be able to sustain hits from cars without deforming. Toughness, in order to assure that the structure will deform and avoid fracture if the impact is too high. Resistance and price, since the project needs to be as affordable as possible. Those are the main mechanical requirements, there are also the electrical components which must be fulfilled. The main aspects which be looking at are the quality, the high quantity and sustainability. E-scooter charging batteries needs 3840W per day for charging the battery full once. Hence, it is important to make sure to have sufficient power supply to supply all the batteries with enough charge.

All research of the items has been done which will be used for the E-scooter shelter. A morphological chart has been made to help connecting all these items. It is divided into four sub-charts, which are the most important components of the E-scooter shelter. The four sub-charts are:

- External material for the shelter
- Power generation

- Charging means
- Locking means

In Figure 2 the morphological chart can be found with the four sub-charts and all options.

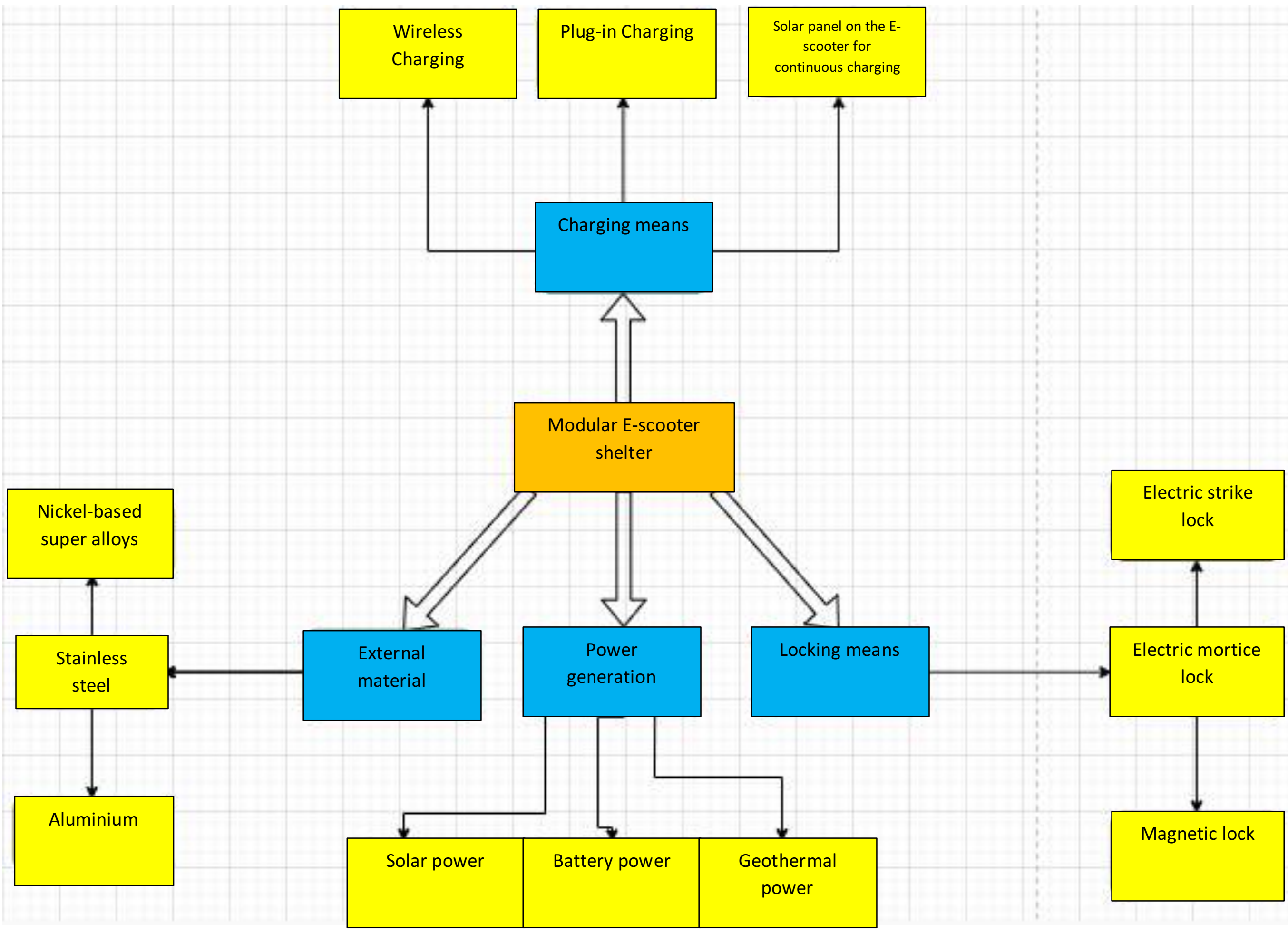

Figure 2 Morphological chart

6. Final Design

Now after all the research is done, it is time to put everything together. In this chapter, all the decisions that has been taken will be discussed. Decision has come to the following picture as seen in Figure 3. The shelter will exist of two lockers on top of each other, where the bottom lockers are for the unfolded E-scooters and the top lockers are for the folded E-scooters. Besides that, there is the possibility to park the E-scooters on both sides of the shelter as well.

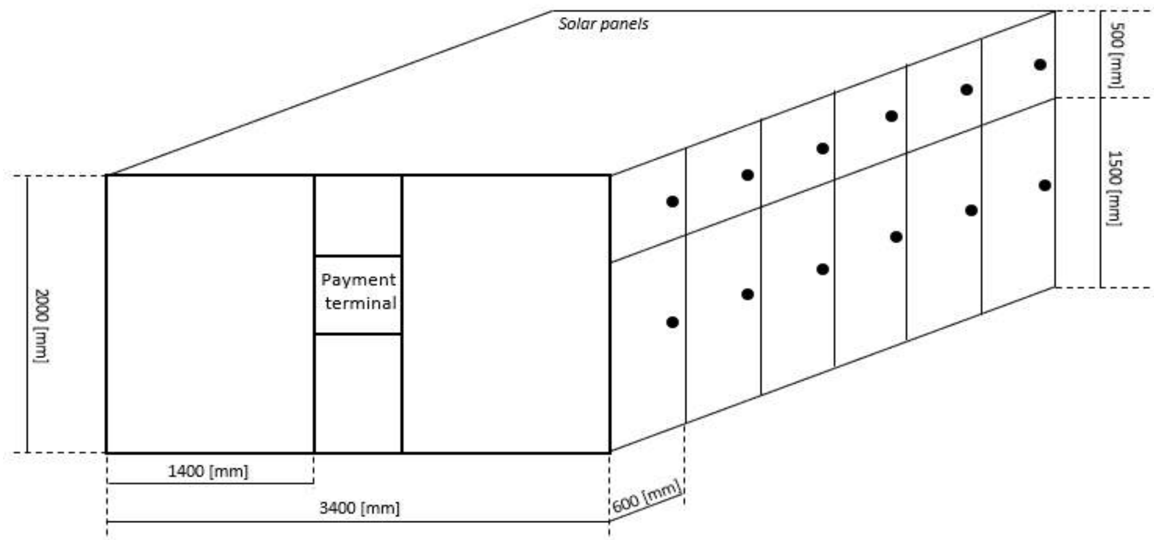

Figure 3 Shelter design

For the wiring in the shelter, it is important to consider the complexity behind it and make it less complex as possible so that the maintenance is easy to do. Hence, a decision has been made to design an extra space between the mirrored lockers with a width of 600 mm. Using that space, the mechanic can easily do maintenance and apply the wires. As you can see in figure 3, the front side has a terminal for payment and opening the lockers, besides that, all the wires are distributed to the separate lockers and the red lines represent the wiring.

For the solar panel selection, a decision has been made to choose monocrystalline solar panel. Monocrystalline is the most efficient solar panel compared to the other types. Their efficiency is within the range of 12-25 and with a typical value of 18.5%.

The shelter will consist of different units where the client can choose how many units he needs. Each unit has four lockers on each side which means eight lockers in total. As you can see in the figure above, this is a design of three units next to each other and this is where the modularity comes from. In figure 4 you can see a description of the process of how energy would be supplied to the shelter. The energy will come from the sun onto the solar panels. Then with cables, convertors etc. it will be put into storage (the battery) or into the chargers for the users. All this has an energy loss which are described in the figure as well.

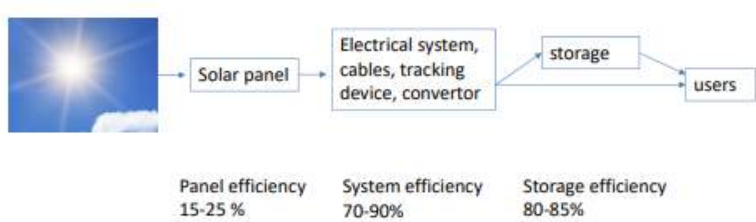

Figure 4 Energy process supply to the shelter

7. Conclusion

As discussed earlier, the city of Barcelona facing a problem of parking the E-scooters. The main problems are the increasing of fines, confiscation, and no security provided. ESSE came with the right solution and main goal of this project by designing a modular shelter which is provided with a locking system, charging, and security. This is important in order to decrease the amount of fines and provide a safe way of parking and charging the E-scooters. Furthermore, this will lead the people to rely more on the E-scooters than car vehicles which is safer and greener for the environment.

Going back to the main research question, *'In what way can a shelter be designed in such a way that there will be less fines while being modular and sustainable?'*. This is the question that was stated in the introduction of this report. To answer this question, it is important to look at everything combined. Literature survey has given that there are not any competitors in the market with a shelter that provides security, locking and charging. Swiftmile is the product that comes the closest to it but does not provide sheltering. Because it is a new market it brings a lot of opportunities with it. The benefits of such a shelter are founded in environmental factors, time and efficiency benefits and benefits for the society. Speaking from environmental factors, it will be sustainable by using renewable energy and less cars will be used by the people in the streets which all results in a better environment. Speaking from society factors, it will be way more convenience and efficient for the people to transport easily around the city.

What will the shelter bring to society? The modular shelter must have locking systems and be able to charge the E-scooters, designing such a shelter will meet the objectives of this project which is having a sustainable and modular solution to minimize, or even eliminate, the fines and all the problems around parking the E-scooters anywhere.

To review, the shelter has to be made into a prototype and tested through the pilot stated above (see figure 3), before making more of them. The payment system, software, and solar panel installation should be outsourced to a specialist company before rolling out the product. Clearly, there is need for a greater focus on the electrical system. Hence, more research should be done to help learn to effectively cover all the electrical and software parts missing to run such a product.

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SMART MOBILITY

E-steps as an Alternative to Public Transport in around Eindhoven and Ulm

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SUMMARY

The smart mobility project 2019-2020 consists of 10 engineering students in the sectors of mechanical and mechatronic engineering. The focus is the electronic steps which can be found in multiple countries across Europe. The goal is to improve the public transport systems within the cities Eindhoven and Ulm. The steps are already an existing technology, so this project will be focussed on the implementation of the technology within the city, including improving the charging stations, ease of use and anti-theft techniques. Whilst doing this project, it was first important to research the situation of the e-steps technology and how they currently stood in the market. It became clear that enough development was already underway for the e-steps themselves, meaning that focus more had been given on the charging and storage stations. After choosing this focus, considerations were given the current alternative for public transport within Eindhoven and Ulm. It was clear to see that the buses are fairly inefficient when considering cost, time and flexibility. As well as this, the bicycle parking spaces at the station are incredibly large and obstructive, so the smaller parking spaces for the e-steps will allow for a huge improvement in the city's infrastructure. The Go-sharing scooters are much more flexible, however they have a higher cost. Bicycles is the other common option for people travelling in and around Eindhoven. These have a much lower cost, but are considerably slower, meaning that this option is not so attractive for customers. This leads way to a gap in the market for a new public transport which is faster, flexible and affordable for everyday use. The e-steps were a suitable solution for this. The next question was: *"is this a financially feasible thing for Eindhoven and Ulm to invest in?"* Our business canvas model and profit calculations have proven that this is the case. The final thing to consider was how the charging stations will look. A number of different design concepts and ideas have been considered, but the group has come to the final proof of concept model which shows the mechanism, shape and sizing of the storage and charging system for the e-steps which we would suggest to the cities of Eindhoven and Ulm to implement.

Keywords:

Business model- An overview of how the start up company would work including: finances, start up fees, promotion, etc.

Public transport- A mode of transportation which is publicly available to use, usually for a fee.

Affordable- Costs to the user are minimal

Flexible- How often the user is able to access the product

Profit- The difference between how much money is being made, and how much is being given out. A profit is a positive figure.

CONTENT

1. THE PROBLEM

Eindhoven is planning on becoming car-free in the year 2025 in the city centre[2]. This means that an alternative public transport needs to be introduces for people who are travelling to work. Some people commute in from

other cities, so don't have a bicycle at their disposal within Eindhoven. They rely deeply on buses and other public transport, however if this is a daily occurrence, then it becomes a personal financial burden very quickly.
Unfortunately, however, the step scooters as they exist right now are not permitted to be used within the city[4].
In order to determine which requirements are set for the vehicles, first the category in which our vehicle falls - according to the national road traffic service (RDW)- must be determined.
The vehicle in question will be an alternative to the bicycle. For this reason, the step will fall under the category of mopeds. The category includes two-wheeled motorized vehicles with a limited speed (45 km/h or 25 km/h depending on the sub-category). Within this category, a distinction is also made between normal and special mopeds.

A requirement of a normal moped is that it has a saddle. A step does not meet this criterion, so a step falls under the category of special mopeds. A special moped does not qualify for a European type approval because it falls outside the scope of Regulation (EU) 168/2013 [3]and:

- Does not drive faster than 25 km/h;
- Has a combustion engine with a cylinder capacity of up to 50 cm3 from an electric motor with a maximum power of up to 4 kW;
- Is not a disabled vehicle, electric bicycle with pedal assistance from moped.

In order to be able to use the public road in the Netherlands, permission is required, which is issued by the Minister of Infrastructure and Water Management. To obtain this permission, the special moped must meet the legal requirements. The requirements can be found in the Policy Rule for Designating Special Mopeds.

2. Current public transport

The company 'Go Sharing' have recently launched a new transportation solution within Eindhoven in the form of e-scooters. These scooters are allowed to travel on the cycle lanes [5], meaning that they -like bicycles- can bypass lots of the traffic in the city.
This is, however, not suitable for everyone to use. You have to be in possession of an AM driving licence because of the speed and control of the scooters. This means that the target market for this company is much smaller than that of the e-steps. Not everyone has a driver's license and people under the age of 16 can't use this. This is because the scooters fall under the "requirements for the driver of a special moped" rules as specified in the previous section.
One solution to this is that on the go-scooters, it is a possibility to take passengers. This mean that more people are able to make use of the transportation systems if they are accompanied by someone with a suitable driving license.
Other means of transport within the city are the buses, or a bicycle. How efficient are these means of transport? Let's consider the following example of route:

Bicycle:

Bus:

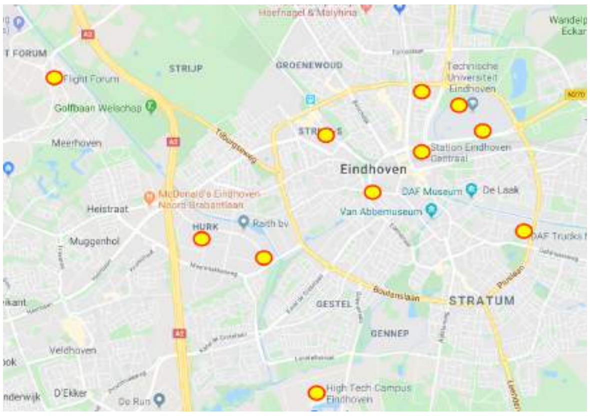
Travelling by bike takes around 20 minutes to go from one side of Eindhoven to the other, whilst travelling by bus takes around 30 minutes and can only leave at a certain time (highly dependant on the bus schedule).
None of these current options of public transport are ideal because they are either too slow, too expensive, or the person travelling is dependant on too many external factors, for example if the bus is running late).

Fortunately, the e-steps are faster, cheaper and more flexible. When travelling the route in the above example, the e-steps will take 12.7minutes based on an average speed of 25km/hour. The e-steps are controlled by the user, so the route is to be decided by the user themselves, and the cost of hire is less than the costs of getting on the bus.

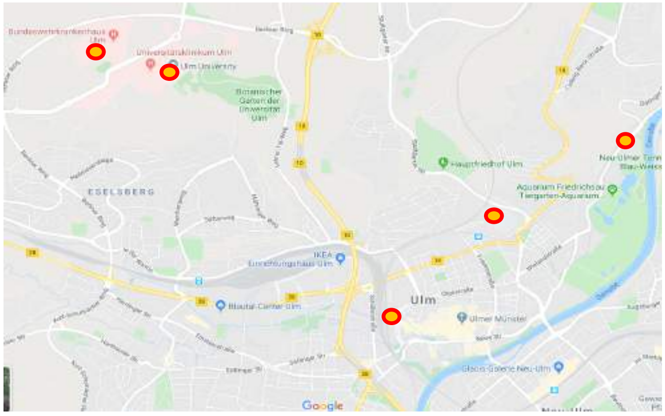
3. Eindhoven and Ulm

The next thing to consider is where will the e-step charging stations be positioned?
Considering the target market of commuters, we have chosen the most popular locations. This includes the central station, the university, and areas with a high density of companies. These can be seen below in the 2 maps of Eindhoven and Ulm.

Eindhoven:



Ulm:



This means that in Eindhoven, 11 charging stations are suggested to be implemented, and 5 in Ulm because there are 11 suggested locations in Eindhoven and 5 in Ulm(as indicated on the map).

4. Financial feasibility

The next to be considered is whether or not this business plan of hiring out e-steps is something which will make or lose money. The following calculations have been done to discover this.

Scooter hires and sale/maintenance of docking system to local governments:
General model: Scooter docks are at train stations and other high-volume locations such as universities and large workplaces (pending approval). Commuters can hire a scooter for the day to get from the station to work and back. Scooter hires – personal scooter costs ~€400, we hire out for €2,50 per day, buying scooters at volume is ~€200 per scooter

$$€250 * €2,50 = 100 \text{ Days to return cost}$$

If we say the scooter lifetime is one year of service and assuming that they are on hire for 60% of days in the year.

$$365 * 0.6 * €2,50 = €547,50 \text{ per scooter per year}$$

This does not yet allow for maintenance and other costs, so we estimate this to be €200 per scooter per year. This brings the total income per scooter per year to:

$$€547,50 - €200 = €347,50$$

Which, minus the initial cost of the scooter gives a profit of:

$$€547,50 - €200 - €200 = €147,50$$

If we have 1000 scooters for a trial in Eindhoven:

$$€476 * 1000 = €147.500 \text{ per year}$$

This does not include staffing costs as when starting this initial trial, we will not be paying ourselves out of the company. As the number of scooters grows, we can begin to pay ourselves salaries. Initial investment for 1000 scooters: €200.000, with an income of €347.500 per year it takes ~210 days to return the initial scooter investment.

$$\text{ROI} = 200.000/347.500 * 100\% = 57,5\%$$

5. Final concept

After considering a number of different options for the proof of concept, the group have landed on this final concept which includes a sliding mechanism using two rollers and a seam, meaning that the e-steps will be stored in a compact manner. This proof of concept is also something which can be stacked on top of each other, meaning that the space is optimised. Considering that Eindhoven is a design oriented city, multiple options for the shape of the charging station can be offered in the future, however the basic proof of concept can be seen below.

This proof of concept shows the sliding system of the board upon which the e-step will be placed. This system slides into the larger storage unit which is horizontal.

Once the e-step is attached, the sliding board moves from the vertical position, to horizontal (which must be done by the user).

After this, the board is slid into the main storage unit, where it will be protected from weather and theft. The sliding board has a stopper at the back, which stops it from going too far.

CONCLUSIONS

From this project, we can conclude that the e-step rental business could be a successful replacement for public transport within the city of Eindhoven. The profit margins are positive, so implementing these as public transports will benefit the city in an environmental and financial way. The e-steps are also cheaper to rent per day than the existing public transport available in Eindhoven, so this implementation will also benefit the users, in this case: commuters. As this will be a start-up process and company, there will need to be an investment of funds from an external source. This could be governmental funding, which would need to be applied for. This could be a plausible source, considering that this company is coming up with a solution to public transport in the city, so is helpful for the local council. Other than the governmental funding, there is also a big opportunity for angel investors, considering that this is an up and coming technology, so people are willing to support it. As shown by the proof of concept, the mechanism in the storage system is successful, so the e-steps can be parked and charged in these stations which can be stacked, meaning that they won't take up too much space within the city. They take up less room that the bicycle parking spaces, because the e-steps can be folded. The initial implementation of the charging stations will be expensive, however the maintenance is minimal, so overall costs will be low. As well as this, because it is a rental service, the payback period is very short. More research needs to be done on the efficiency of the batteries within the e-steps, and up to which percentage the batteries need to be charged, to ensure the longest life. Further development of the charging station can be continued, aiming for a more efficient, smaller, safer product. However, this project has proven that the concept of e-steps as an alternative public transport solution is a feasible and achievable goal.

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(https://www.rdw.nl/over-rdw/actueel/dossiers/bijzondere-bromfietsen)
[5] Wanneer mag ik op een bijzondere bromfiets zoals een Segway rijden?:
(https://www.rijksoverheid.nl/onderwerpen/brommer/vraag-en-antwoord/welke-regels-gelden-er-voor-een-segway)

A Conceptual Design of a Portable Mechanical Ventilators for Small Animals

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Abstract

This paper describes a conceptual design for a portable mechanical ventilator for small animals. The mechanical ventilator will be used by veterinarians and animal ambulances. This paper will only cover a proof of concept, which mainly consists of a Matlab/Simulink model. For a fully functional mechanical ventilator more research and designing will have to be done. Within the Matlab/Simulink model a few respiratory values can be adjusted to make sure the mechanical ventilator can be tuned for different animals. The respiratory values that can be adjusted are: tidal volume, inspiratory to expiratory (I:E) ratio, respiratory rate, and the Positive end-expiratory pressure (PEEP). During this project there was a collaboration with the electrical engineering department of Fontys University for Applied Sciences and the mechanical engineering department of the Technische Hochschule in Ulm, Germany. The electrical engineers focused on sending patient data to the cloud so a doctor can monitor the patient by accessing said patient data. The mechanical engineers in Ulm designed a mouth piece for dogs to be used on the mechanical ventilator. The mechanical ventilator is powered by a fan that was supplied by DEMCON Macawi Respiratory Systems, who also helped with research & design, which was greatly appreciated. This design has to be innovative, which means it has to be inventive as well as profitable. Because of this the paper will also describe a business plan.

Introduction

Assignment Description:

During this project it will be investigated if it is possible to build an innovative portable mechanical ventilator for animals. Innovative means that it has to be new and inventive but it also means that you should be able to build a business with it. A new and inventive product is only also innovative when a company can make money off of it. Since veterinarians have a tight budget it is vital that the mechanical ventilator will be cheap and affordable. The affordable ventilators that veterinarians now use often are second-hand and use outdated technologies. The innovative mechanical ventilator will use a fan provided by DEMCON Macawi Respiratory Systems to automatically ventilate the patient instead of manually ventilation. This mechanical ventilator will be supported by Matlab/Simulink models, which will also be built during this project. The design for the mechanical ventilator will have to be conceptual since there is not enough time to completely design and manufacture a mechanical ventilator.

Project deliverables, scope of project:

The conceptual design includes the required ventilation modes, functional hardware, sensors and control of the mechanical ventilator. However, before designing the mechanical ventilator there still is a considerable amount of research to be done. There will be research on respiratory systems, what kind of diseases there are, already existing mechanical ventilators and how they work and market possibilities. After this research it will be clear what kind of technical and user requirements the mechanical ventilator will have to comply with. The conceptual design will have to be fully tested with the use of various Matlab/Simulink models. To do so, a Matlab/Simulink model of a respiratory system will have to be built to test the model of the mechanical ventilator. It is also important to build a third model; one of a respiratory system that includes respiratory diseases. Since this is a conceptual design, some aspects of the mechanical ventilator do not fit within the scope of the project. For instance, designing a manufacturing process or manufacturing a complete working prototype is out of scope for this project.

Product research

Respiratory system:

To understand how a mechanical ventilator works it is first important to know how respiratory systems work. Respiratory systems work with pressure differences between the inside of the lung (alveolar pressure) and the air outside the body (atmospheric pressure)[1]. During inspiration muscles in the chest (the diaphragm and the intercostal muscles[1]) contract, making the volume within the lungs increase. An increase in volume means a decrease in pressure. A decrease in pressure within the lungs means that the air outside the body (with a higher pressure) will want to flow to the low-pressure area (the lungs). Once the pressure outside the body and within the lungs are the same, no more air will be flowing and (during normal breathing) expiration will start. Expiration works a little different than inspiration. Where inspiration uses muscles to create low pressure within the lungs, during expiration no muscles are used. This is because the lungs and chest are elastic which means that air within the lungs will be forced out when the muscles used for inspiration relax. There are a lot of different ways the lungs can be impaired. The lungs and chest may not be as elastic as they need to be which means there is not enough air leaving the lungs, which on turn means that there is not a lot of room in the lungs for fresh air.

MV systems:

There are many different types of mechanical ventilators for different scenarios, a mechanical ventilator on an intensive care unit in a hospital for instance is a different mechanical ventilator as one that is used in ambulances. However, most of the mechanical ventilators on the market work about the same, some may be more complicated than others but the basics stay the same. Mechanical ventilators consist usually of a turbine or a compressible air reservoir (to pump the oxygen to the patient's lungs), air and oxygen supply, valves, tubes, sensors and electrical components to control the ventilation. There are two types of mechanical ventilation; invasive and non-invasive. Non-invasive ventilation means that the patient can breathe on their own but needs assistance. This could be during sleep, rest or when they're operated on. Invasive ventilation is used when the patient cannot breathe on their own at all. Intubation (placing a plastic tube into the

[1] (Marieb & Hoehn, 2015)

windpipe) is required during invasive ventilation as the slightest leakage of air can have major effects on the patient's health. During non-invasive ventilation usually a nasal mask or face mask is used because this is easier and more comfortable for the patient.

Market Research

Methodology:

To make sure the mechanical ventilator would be innovative it was vital to do market research to verify that there is actually a market for a portable mechanical ventilator. During market research a method called Design for Excellence (DfX) was used. During DfX the group picked four aspects the mechanical ventilator would be 'designed for', these four were chosen because they are important to a profitable (and innovative) design. The group also decided on four 'scenarios' that would be investigated regarding the four aspects. The four aspects are:

- Legal Restriction: Any law or regulation that applies to the scenario will have an effect on the design process and will need further investigation.
- Market Saturation: If a market is saturated it means that there is no more room for more products, there is no more demand.
- Resource Availability: Access to the right resources for the given scenarios is vital for a successful product.
- Patent Application Trend: Looking at long term growth regarding the scenarios patent trend can be a good indicator of what the market looks like.

The four scenarios that were picked to be investigated are:

- Veterinary Ventilators: Portable mechanical ventilators for animals could be very innovative.
- High-Particle Ventilators: Locations such as deserts or mines can contain a very high particle concentration in the air. Filtering air would be a major role in designing a mechanical ventilator for this scenario.
- Air Ambulance Ventilators: An innovative robust device that can be used on emergency air ambulances. Compact and lightweight are important key words for this scenario.
- Arctic Region Ventilators: Extreme remote and cold locations could be a good scenario for an innovative mechanical ventilator. Weather resilience and longevity are vital for this scenario.

Results – Final decision:

After investigating the four scenarios regarding the aspects it was clear that the best chances lay within the veterinary ventilator. This is because there are less legal restrictions for veterinary devices than there are for devices for human health care. There are also a lot of mechanical ventilators on the market for human beings which means that the market saturation is higher than for animal mechanical ventilators. The patent application trend for animal mechanical ventilators is lower than for human mechanical ventilators, this means that less companies are developing these kinds of devices, which in turn means that there will be less competitors. However, this could also work against the animal mechanical ventilator because it could mean that there is not a high demand for these devices. Resource availability could pose a problem for this project as there is a lot of information about human mechanical ventilators to be found, however there is considerably less information to be found about animal mechanical ventilators. After doing some interviews with for instance Geert van Dijk from DEMCON and a local veterinarian, who both told us they think this is a good, innovative idea, it was decided to change the project slightly and design a portable animal mechanical ventilator.

Conceptual design

New problem definition:

Mammals have very similar respiratory systems as human beings do, which means that they also suffer from similar diseases and ailments that can affect the patient's ability to breath in a negative way. These diseases and ailments often are the cause of weaker respiratory muscles, which causes an inadequate flow of oxygen to the patients' lungs. Weakening of these muscles can also occur due to anaesthesia during surgical operations. When these diseases or ailments occur with human beings a common solution is the use of mechanical ventilators. There are a lot of mechanical ventilators on the market for human beings, as well as a lot of portable mechanical ventilators. However, the supply of animal mechanical ventilators is very low compared to human mechanical ventilators. The animal mechanical ventilators that are on the market right now are not portable and are extremely outdated, these are ventilators that have to be hand operated and/or constantly monitored by a veterinarian.

Product requirements:

The portable animal mechanical ventilator will have many requirements, however since this paper is limited in its number of pages not all requirements can be listed. These are the main requirements for this project:

- The ventilator should be compact, portable and easy to operate.
- The ventilator needs to be robust so it will not break during an accidental fall or other ways of rough handling.
- The purchase and service of the ventilator should be economical.
- Tidal volume, inspiratory time, inspiratory pressure, respiratory rate and I:E ratio have to be controlled by the ventilator.
- The ventilator can be used for invasive as well as non-invasive ventilation. - Continuous monitoring of airway pressure and expired volume.
- Alarms for low pressure, circuit disconnection, high pressure and pressure overload.
- The displacement of the air will be done by a fan that is provided by DEMCON.
- Battery life should be at least 4 hours.

Component selection:

Selecting the different components for the mechanical ventilator will be done using morphological charts. The components that need to be selected are, among others, valves, sensors, tubing, electrical components. These components will be selected by investigating their properties regarding different functions. Some of these functions are: intubation method, connection between ventilator and patient, respiratory control variable, pressure control, volume control, oxygen supply, alarms, etc.

Modelling

System modelling:

One of the key project deliverables was to make a working Simulink model of the controller and response of the respiratory system. Fortunately, the blower provided by Demcon already contained a control chip and with these characteristics known, we were able to build a model easily as long as we were able to model the lungs.

The entire digital model can be divided into multiple subsystems, see *Figure 1.* This includes the blower, hose-filter system and patient. We divide these sections because it makes it easier to simulate each part individually and determine its validity. The system will be operated by a blower that is provided by the company Demcon and will compress ambient air in order to transport it to the patient. The flow of air will travel through the hose system into the patient when inhaling until the patient exhales and the air will travel back into the hose exciting through a leave valve near the patients mouth cap. The remaining low-oxygen exhaled air inside the hose may cause difficulties for the patient and therefore a leak in the hose must be applied in order to ventilate this low-oxygen air. The entire system contains resistances that we will have to determine in order to calculate the flow and pressure in the patient. These resistances include the resistance of the hose, leak and lungs.

The full derivation of the equation for can be found in the long report, but the final result for flow of air supplied to the patient can be found with the equation:

$$Qpat\ (t) = -Rleak + Rlin/\bar{R} * plung\ (t) + Rleak/\bar{R} ** \ Pout\ (t)$$

$$\bar{R} = Rleak * Rlin + Rleak * Rlung + Rlin * Rlung$$

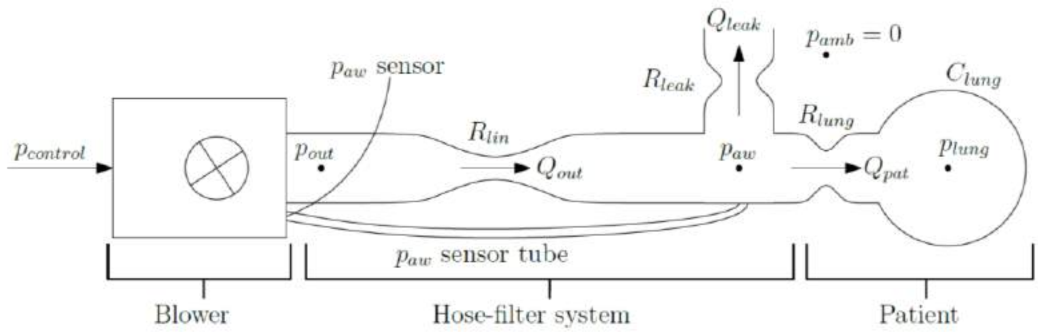

Figure 1 (Demcon, n.d.)

Using this equation, we were able to successfully build a working PID controller for the system.

Interface:

As well as building a working model, we also wanted to design a user-friendly working interface that would allow for the fine tuning of settings and parameters with minimum required data and knowledge. In order to do this, we needed to first identify the key defining parameters that affected the system response – in order to do this, we used the system requirements that we made following our interviews with the vets and made dials for the following parameters:

- I:E ratio (Inspiration to Expiration ratio)
- Respiratory rate (Breaths per minute)
- Tidal volume (Volume of breath)
- Inspiratory time (Time taken during inspiration phase)
- Inspiratory pressure (Lung pressure during inspiration phase)

Results:

The response of the control loop gives us the ability to control the volume flow. For example, *Figure 2* shows the volume flow of air when the model is set to 0.5 Litres tidal volume, a 1:2 I:E ratio and a respiratory rate of 20 breaths per minute. As expected, the controller allows the fan to provide airflow during the inspiration period up to a maximum level of 0.5 Litres per second. The fan then allows for negative flow during expiration as the patient breathes out. Unfortunately, the fan here is under dampened, meaning that we see a momentary spike at the start of every cycle.

Figure 3 shows the total volume of flow achieved per cycle is 0.5 Litres, as required.

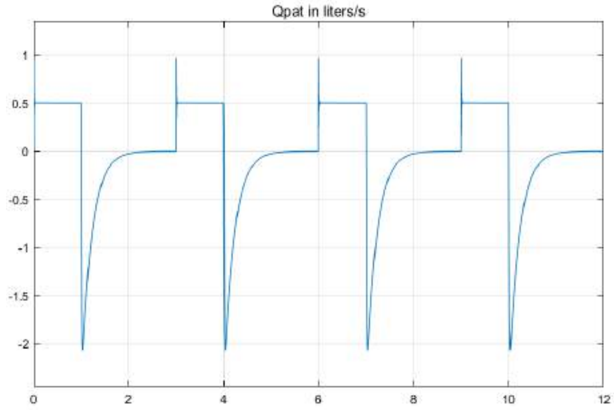

Figure 2

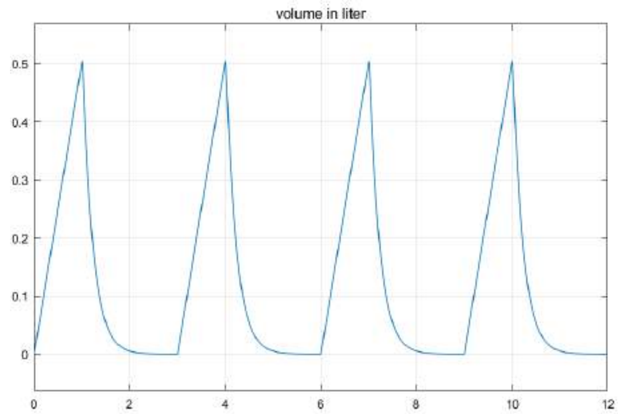

Figure 3

Data research

Important values and relationships:

They key parameters that define the response of the lungs to volume flow are as follows:

Rlung – Resistance value for airflow over lung tissue.

Rlin – Resistance value for airflow over tubing

Rleak – Equivalent value of resistance caused by valve and facemask leakage.

Clung – Compliance value of lung – change in volume per unit pressure.

The original plan was to find the relationship of these values to the mass of the animal in question. This, however, is not really possible to do in a way that retains the accuracy required for effective ventilation. This is because these relationships are not linear and therefore data can only be acquired through experimentation and comprehensive research over multiple breeds simply has not been done yet.

Problems with data collection:

It is therefore important that the veterinarians are aware of the parameters that need to be set on the interface in order to achieve safe and stable ventilation. One possible way to do this that could be possible in the future is to employ a 'questionnaire' about the patient before the ventilation is able to start, ensuring that all the correct parameters are in place. This requirement highlights one of the fundamental problems with our system, however, which is that despite the fact it is designed to save time and manpower, it requires time and knowledge to input the correct parameters to operate effectively. In an emergency situation this may not be possible. Future solutions to this problem are discussed in the next chapter.

Business Plan

Added value:

The added value that purchase of our product could have for veterinaries and animal rescuers is as follows:

Ability to provide ventilation outside of clinics: There are currently no portable mechanical ventilators for small mammals, our innovation allows for the ability for animals to be cared for out in the wild and emergency operations can occur with less risk of death from anaesthetics.

Hands free ventilation for clinics: As previously stated, the majority of veterinary clinics rely on hand-operated ventilators. Our product would allow for less staff to be present during surgeries. As well as this, our product is more accurate and not prone to human errors such as lack of concentration and distractions.

Revenue streams:

Sales: The majority of our revenue would be generated by sales of our product to veterinary clinics and professionals.

Service and subscriptions: As well as this, additional revenue could be generated through service of parts and subscription to software updates, possibly including portfolios of animal respiratory data.

Leasing: A leasing service could also be possible for clinics who can't justify the purchase costs if the product but need to use it for a specific operation or situation.

Cost structure:

Fixed costs for the business would include the standard fixed costs for any business. Mainly; rent payments, electricity gas and water payments and employee wages.

Variable costs would include purchases of components, assembly costs and distribution expenses. Overall the business would have a traditional cost structure, using market pricing to determine the number of products needed to be sold on a yearly basis to cover costs.

Overall price /viability:

Our interviews with veterinarians suggested that they would not be willing to pay over 1000 euros for such a product upfront. Therefore, with no similar products on the market to determine the price of the product, we anticipate that it would be sold at roughly 800 euros. With our initial cost predictions, this suggests that 548 units would need to be sold in order to break even. This is probably an unrealistically high number considering this is an unestablished product attempting to create its own market.

Future potential:

We believe that if the variable costs of production can be reduced, either from finding a cheaper fan and control system or by achieving a discount with the supplier through bulk purchases, it would be fully possible to turn this into a professional business. This is because, having interviewed the vets ourselves, we know that they appreciate the added value of our product. The only thing holding them back is their limited budget for new equipment, meaning that in order to produce maximum sales and build a marketplace for this product, the focus must be on cost reduction which can be passed on to the customers.

Conclusions and recommendations:

Results vs deliverables:

The purchase and service of the ventilator should be economical – This has only been half achieved, with the expected prototype costs exceeding the desired value, but future potential for cost reduction is there.

-Tidal volume, inspiratory time, inspiratory pressure, respiratory rate and I:E ratio have to be controlled by the ventilator – This has been achieved, the interface and inputs of the control system allow for adjustment of these points.

-The ventilator can be used for invasive as well as non-invasive ventilation – this is indeed possible with this ventilator.

-Continuous monitoring of airway pressure and expired volume – these can be monitored using the Simulink model.

-Alarms for low pressure, circuit disconnection, high pressure and pressure overload – this is not yet achieved, but it would be possible to implement in the future.

-The displacement of the air will be done by a fan that is provided by DEMCON – Yes, completed

Short term recommendations:

Our main recommendation for the next project group relates mainly to the user interface and data input. Firstly, it is recommended to simplify the amount of data required for input by the operator as much as possible. Try to find as many parameters as possible and relate these to mass and species. Then it should be possible to simplify the user interface so only the species of the dog and its mass are required. Also focus on ways to reduce cost of system.

Long term recommendations for project's future:

Implementation of cloud data to record the lung values of different animals. This could be used to build a database of information which could help save time when programming the controller for a specific animal. As well as this, it could be used to recognise ailments and diseases through pattern recognition. A cloud function could allow vets across the globe to share data very quickly and easily to enhance treatment practises.

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Topology optimization of a rescue drone

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***Abstract*— A rescue drone can be an important device during search and rescue operations with bad weather conditions. The rescue drone can help a rescue team to locate and find a victim. In addition to locating and finding, the rescue drone can also provide aid to the victim. For this reason there is a rescue drone developed which can perform under bad weather conditions to support a rescue team. With the use of topology optimization the body of the rescue drone has been optimized so that the body is lightweight and with a rigid construction. The rescue drone has been developed and designed in the way that it could fly with a payload of 3 kg and fly for at least 60 minutes during bad weather conditions.**

Keywords—Search and rescue operations; Drone; Topology Optimization; Bad weather conditions

INTRODUCTION

An innovation within the rescue drone market is being developed which will support rescue workers during search and rescue operations. The innovation is that the rescue drone will be able to operate during bad weather conditions while being able to carry a high payload. After research it was found out that rescue drones aren't widely used during these operations but mainly helicopters. These helicopters are staffed with rescue specialists and are specially equipped to help and find those victims. When there is a notification of an accident the helicopter will go with the resources to the location of the victim. Also, for missing persons a helicopter could be used to search, especially in hard-to-reach areas like mountains. Most of these search and rescue operations are successful. More often it happens that the operations couldn't take place due to bad weather conditions. Due to the change in weather conditions by means of global warming, extreme weather conditions are becoming increasingly common. During these extreme weather conditions it is too dangerous to perform the search and rescue operations with a helicopter. The risk of getting into the air with a fully equipped and manned rescue helicopter is in that moment too big, as a result of which the rescue action is postponed. When it's not possible to deploy a helicopter during the search and rescue operations, the lives of the victims are in danger. The proposed alternative is that the search and rescue operations can continue during bad weather conditions without endangering the lives of the rescue workers. Because, a drone is developed which can be used during bad weather conditions to find and help the victims. The drone has been developed by means of Topology Optimization (TO), a method for automatically generating design concepts using optimization techniques.

Topology optimiztion

Topology optimization (TO) is a mathematical method that optimizes the material distribution within a predetermined design space. The purpose of TO is to maximize the performance of the system to be designed, given a number of mechanical loads and/ or other limitations [1]. The best-known example is lightweight and rigid construction for applications where the mass must be minimized so that material costs are reduced to improve acceleration while a certain rigidity requirement must be met. TO varies the topology by changing the material distribution within a predefined design volume. For each new material distribution, the quantity to be optimized is calculated and it is determined whether and to what extent the specified limitations are met.

METHODS AND DESIGN

Method

The method that is used due the development and design of the drone is the Kroonenberg method [2]. In the first phase of the design process, several steps are taken that have led to an objective. The goal of the development is to design a drone that can support rescue teams during search and rescue operations despite extreme weather conditions. The main reason behind the goal is that the rescue workers won't be in any danger during the operations. To achieve the stated goal, requirements have been set that the drone must be able to meet. The requirements are divided between customer requirements and functional requirements. The most important functional requirements are shown in Table 1. These requirements have been given priority, so these requirements must always be met, if a design does not meet this requirement it is dropped.

Table 1 The most important requirements that must be considered during the development of the drone.

ID	Version	Requirement	Source	Rationale	Priority
S2	1	The drone must be able to operate within 8 Bft. Windspeed (62-74 [km/h]).	Students	Weather Conditions	Must
S3	1	The drone must fly in heavy rainfall (10 [mm/h]).	Students	Weather Conditions	Must
S7	1	The drone must be able to fly within a temperature range of -20 °C up till 40 °C.	Students	Weather Conditions	Must
S9	1	The drone must be able to have an operation time (flight time/ battery duration) of at least 60 minutes.	Students	Specifications	Must
S16	1	The weight of the drone must not extend 20 [kg].	Students	Specifications	Should
S17	1	The drone must have a flight speed of at least 25 [m/s] in midair.	Students	Specifications	Should
S20	1	The drone must carry a payload 3 [kg].	Students	Payload	Must

In order to achieve the stated goal, a certain set of functions must be performed. These functions can be deduced from the difference between input and output status. Subsequently, it was checked which functions can be classified into sub-functions and which functions can be combined. These functions are described in a function block diagram [3]. The functions can often be performed in several ways. The different methods are presented in a morphological overview [3]. The morphological overview shows the functions on the vertical axis and the methods on the horizontal axis. The methods are combined to logical combinations to make eight different concepts. The eight concepts are indicated by a line in the morphological overview. The eight concepts are assessed using various requirements. These requirements are given a weight factor, the weight factor indicates how important the requirement is. For the different concepts, it is determined to what extent they meet the variable requirements. The concepts are assessed with scores between 1 and 4. The scores are shown graphically in the Kesselring diagram (figure 1). On the horizontal axis is the weighted score of the functional requirements given and on the vertical axis the weighted score of the manufacturing requirements is stated. The blue line represents the optimum score, the closer the points to the blue line the better. The points must be within the striped limitation line, if this is not the case, the concept is dropped. This is to generate an optimal product.

The three concepts with the best scores are combined with the best functional scores and the best manufacturing scores. These three concepts are combined to the final concept, the black dot in figure 1. The most important features of the final concept are: twelve coaxial DC brushless motors, 2 blades, a fuel cell and gas tank and a 3D carbon fiber printed body.

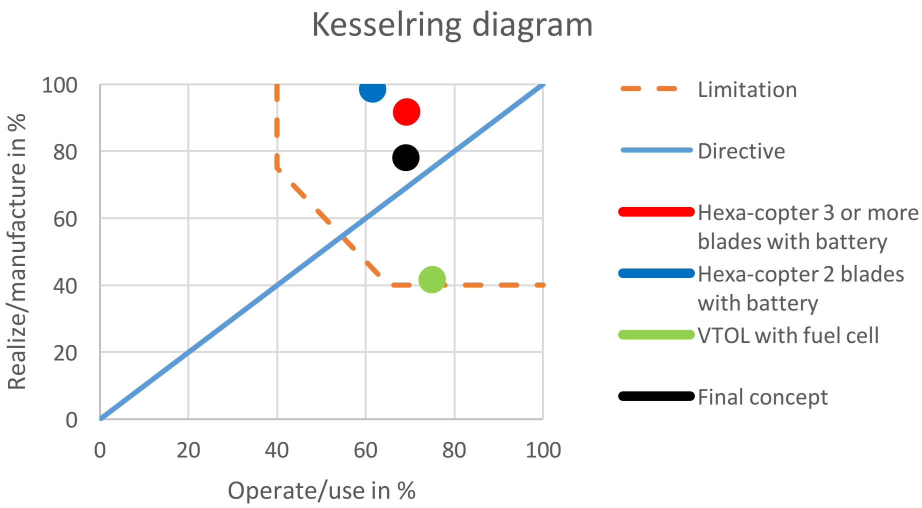

Figure 1 Kesselring diagram for 3 concepts

Final concept

Now that the final concept is selected a final design can be made and components can be selected. Within the requirements it was stated that the drone shouldn't exceed more than 25 [kg] this included all the components and payload. So, with that in mind the drone should be able to deliver a thrust of 250 [N] with a throttle of 50% this means that the drone will be able to fly with a throttle of 50%. But in order to ascend and move around in the air the motors in combination with the propellers should be able to provide double the thrust so 500 [N].

$$T = c_t * \rho * n^2 * D^4 \quad (1)$$

Equation (1) [4] shows how the thrust/propulsion force can be calculated this depends on certain factors ρ represents the airtightness [kg/m^3] determined at a temperature of 15 ° C, n represents the rotational speed of the propellers [rev/s], D represents the diameter of the propellers [m] and c_t represents the thrust coefficient which is a function of the propeller and can be read from the graph in figure 2.

$$J = \frac{v}{nD} \quad (2)$$

Equation (2) [4] gives the function of the propeller with n and D representing the same factors as in equation 1 and v represents the speed which the drone should be able to achieve [m/s]. Using an excel calculation sheet [5], there is calculated these unknown values that are related to each other, which results in the thrust of 500 [N].

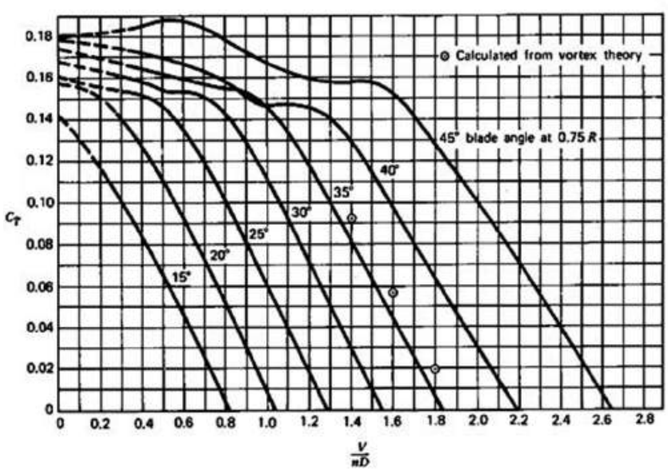

Figure 2 Typical propeller thrust curves as a function of advance ratio (J=v/nD) and blade angle [4]

When the diameter of the propeller is known (D = 22 [inch]) and the thrust of (500 [N]) that the motors should be able to deliver all the important information is known. With this information a motor is searched which will meet the required specifications. A motor in combination with a propeller is found namely, type MN6007-160KV motor with a 22" diameter * 6.6 " pitch propeller [6]. This motor can deliver with 50% - 55% throttle 21 [N] thrust. So, 12 motors can deliver more than 250 [N] thrust, the power that is needed to achieve this thrust is 191 [W] per motor. So, 12 motors have a power consumption of 2292 [W]. To deliver the required power to the motors there is chosen for a fuel cell as energy source. A fuel cell is a device that generates electricity through an electrochemical reaction, no combustion is involved. In the fuel cells a chemical reaction of oxygen and hydrogen to produce electricity is used. A fuel cell is composed of an anode, a cathode and an electrolyte membrane. The reaction takes place when hydrogen passes through the anode and splits between an electron and proton. The electrons are forced through a circuit which generates electricity. Fuel cells are way more efficient compared to LiPo batteries, compressed hydrogen contains more usable energy than a LiPo battery. The fuel cell system contains a fuel cell, a battery and a cylinder. The fuel cell generates the power (W) for the system, and the battery is used for the system to deliver a peak power when needed. The cylinder contains the hydrogen for the fuel cell, which generates the energy (Wh) for the system. For the drone a fuel cell with 2400 W power is used to deliver the needed amount of energy for the motors. To achieve a flight time of at least 60 minutes, the amount of hydrogen, which the fuel cell will need, is calculated. This has been done with equation (3) where power is the average power consumed by the drone in (W), the energy content of hydrogen is 33,3 [Wh/g], and the efficiency is 0,55 for a 2400 [W] fuel cell.

$$The\ fuel\ consumption\ \left(\frac{g}{h}\right) = \frac{Power\ (W)}{Energy\ content\ of\ hydrogen\ \left(\frac{Wh}{g}\right) \times Efficiency} \tag{3}$$

Out of equation (3) a fuel consumption of 125,12 [g] hydrogen per hour is calculated. So, for a flight time of minimal 60 minutes the drone needs a cylinder with a volume of at least 6,8 [L] which can hold 140,3 [g] hydrogen. If the fuel cell is compared to LiPo batteries a difference of around 4 times is found in weight to energy ratio, this is the main reason that the fuel cell was chosen.

Design

The design is made with the use of Topology Optimization (TO) what the software does with TO is it creates a material layout within a given/assigned design space, for a given set of loads and constraints, in the most efficient way to meet the design goals. Through the calculations, chosen components and the requirements all the loads and constraints are known for the TO. Since the chosen concept will use twelve coaxial motors the drone can be divided within six pie charts of 60° these pie charts will also represent the design space. The radius of the pie chart will be 750 [mm] this is determined with the diameter of the propellers and the minimum distance between the propellers of 40 [mm]. Next up the design constraints must be chosen these are rotational symmetry, material spreading and self-supporting. The rotational symmetry is used to revolve the pie chart six times around the z-axis thus creating a complete body. The material spreading is put on 100% this means that the program will make strut like structures as much as possible. And the last one is the self-supporting this one is specifically used as an 3D printing option this function will try to generate a result which tries to make the overhang angle as small as possible so that the 3D printer doesn't need any or much less support to print the body.

The constraints that are used are fixed constraints on the positions of the motors this is done because this must be a rigid piece of the body and the second constraints are linear sliders in the z-axis so up and down sliders these are used on the body itself to demonstrate the forces on the body. A force of 90 [N] in the z-axis is used per pie chart to represent the forces of the motors and another 10 [N] is put on the x-axis to give it a bit more strength and stiffness in the x direction. The idea was to first try to simulate one arm and eventually after that a full body. After some trials and errors to understand the program and playing around with dimensions, forces, constraints and materials some decent results were coming out of the topology optimization as seen in figure 3.

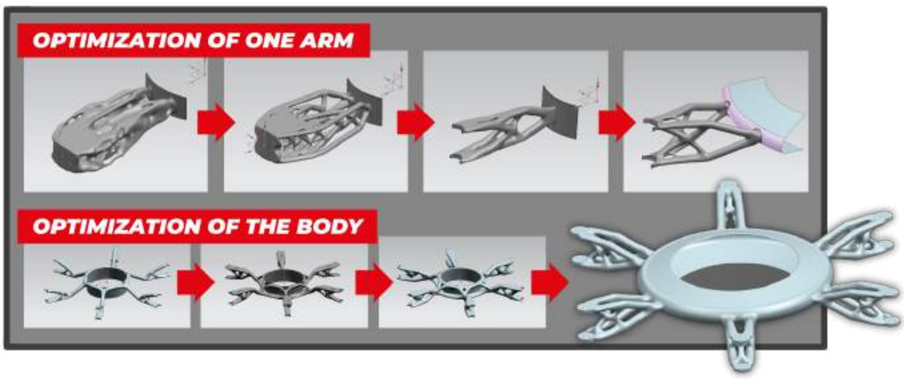

Figure 3 results of topology optimization

The process of development is seen in figure 3 this figure clearly shows that the first step of development was trying to create 1 viable arm for the drone and eventually a complete body. In the first and second pictures of figure 3 is seen that there isn't much reduction of volume later was found out that the length in the z-axis was of great importance this length should be as large as possible. The result of increasing the length within the z-axis is seen in pictures three and four of figure 3 there is a lot of volume reduction within these two pictures and thus a better result. After the realization of 1 arm of the drone the rotational symmetry was added within the design constraints so that the topology optimization would multiply the pie charts 6 times and revolve them around the z-axis to create the drone body. The development of the body is seen in figure 3 under optimization of the body within the first results a circle with a thickness offset is used to create a solid body for the arms to seize on. After some results it was increasingly getting more important to look into aerodynamics because the air resistance should be as small as possible in order to achieve the decreasing of air resistance an ellipse form body was added instead of a round body with a flat surface.

After the approval of the final design there is a function within the topology optimization which will give a FEM analysis result for displacement in figure 4 and stresses in figure 5. Within figure 4 the displacement is shown, as is seen the maximum displacement would be around 0,06 [mm] and figure 5 shows that the maximum stresses would be around 0,19 [MPa] compared to the tensile strength of nylon PA11 CF (carbonmide) [7] which is around 66 [MPa] the body should be strong enough to hold the forces.

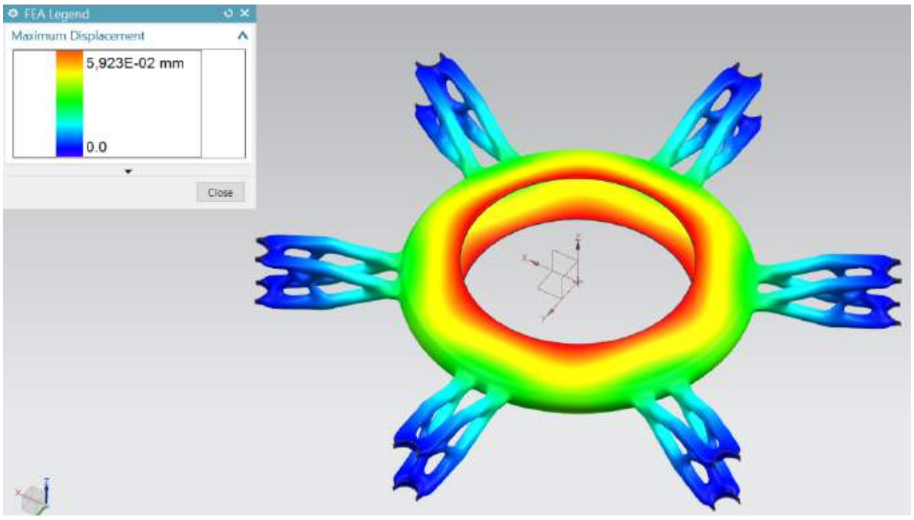

Figure 4 the maximum and minimum displacement of the drone body in [mm]

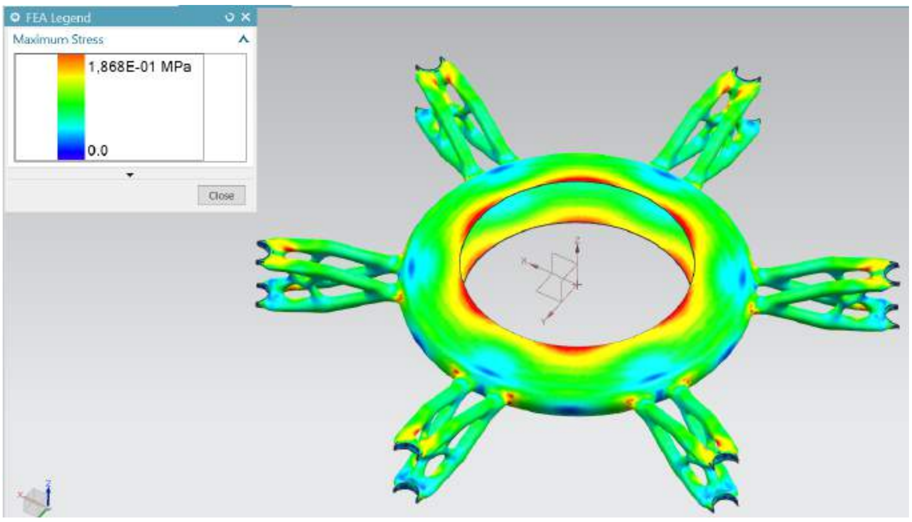

Figure 5 the maximum and minimum stress within the drone in [MPa]

BUSINESS

Within the development phase of the drone a market research has been done for the drone market. An element of the market research is a patent research with the use of Espacenet [8], while doing this research not only patents for rescue drones are researched for but also for delivery drones. The result of this research is that there already are multiple existing systems for localizing victims, the best-known methods for this are through use of infrared cameras and through use of GPS tracking systems. For the delivering and dropping of life saving resources there are also existing systems. Most of these systems make use of a cable attached to a box/container or just simply putting the box on the ground with supplies. However, a new system can be developed to make this easier and safer for the victim. Furthermore, out of this patent research it turned out that these drones only were able to fly during calm weather conditions so with low wind speeds and without rainfall. So, there is an opportunity for developing a drone for bad weather conditions, the RescueAir drone.

During the patent research there is looked at how much patents are requested over the last year with the use of WIPO [9]. As is seen in figure 6 since 2014 a rising line of patent requests for rescue drones is seen. From 2014 the requested patents are rising with an average of around 80 per year this means that this market is still growing so there is still room for start-up companies to get involved within this market. The next thing that is looked at is where these patents were requested from this is shown within figure 7. Most of the requests were from the United States of America (USA) the difference between Europe and USA is more than 1000 patents. This shows that there is little activity within the European market for rescue drones and this is a big opportunity for a company to put a product on the market.

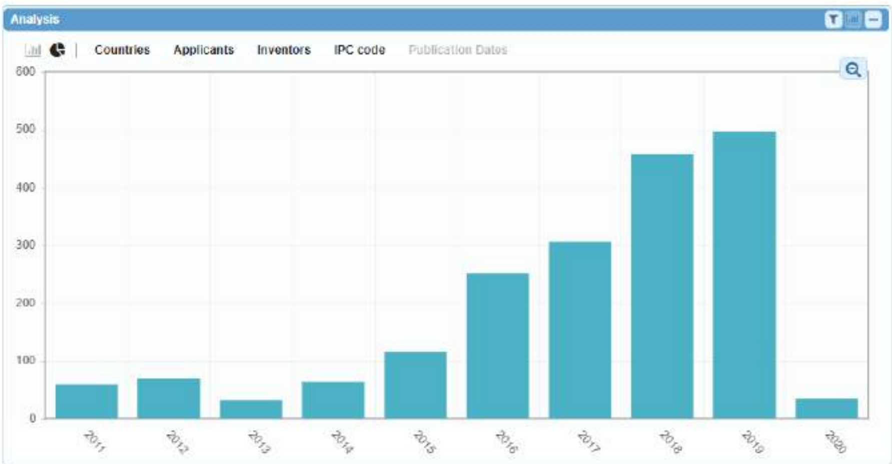

Figure 6 Requested patents last years

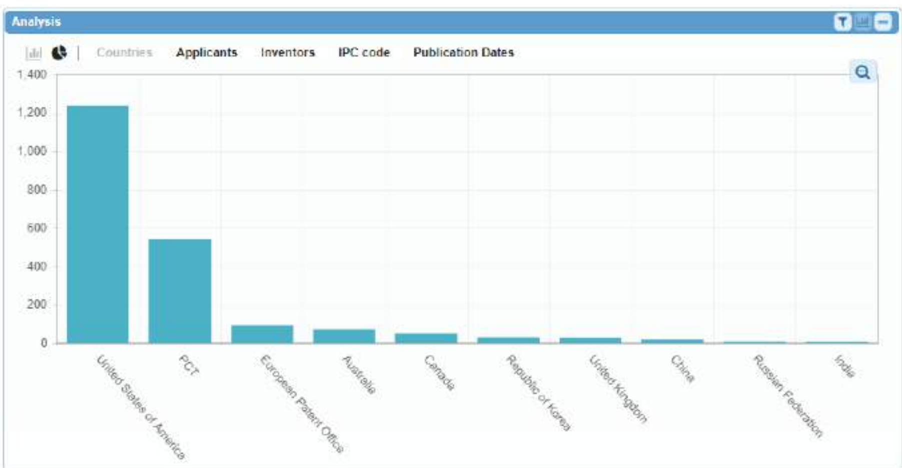

Figure 7 Patent requested per authority

The market that wants to be reached initially is the Netherlands. After the Netherlands it will expand to the European market. The potential external stakeholders are police- and ambulance services, fire brigade and the military. The need of the external stakeholders is the demand for a support system that can be used during rescue operations to support victims. This support system should reduce risks and costs compared to using a rescue helicopter for a rescue operation. An analysis was also made of possible competing companies through the Porter Five Forces Model. A few companies have been investigated that specialize in drones. Then there is looked at companies that are specialized in making and developing rescue drones. The services and products these companies currently provide for search and rescue drones are mostly similar to the rescue drone. The competitors have developed a drone that can be used during search and rescue missions. Compared to the drones of the competitors, the RescueAir drone also has a camera and a sound delivering system. Besides, this drone also has an high payload which can be used to deliver medicines, blankets and other lifesaving products directly to the victim. The key function of the RescueAir drone is that it can fly during bad weather conditions. The RescueAir drone is unique compared to the competitors because it is able to carry a high payload during bad weather condition.

To get insight in the business that will be started by this project there is made an investment plan and a financing plan, figure 8. Also the expected income statement of the first three years are taken along. The investments at the beginning of the business are a company car, machinery and inventory. The building will be rented, and the 3D printing will be outsourced to a specialized company. The finance will be a personal contribution from €8.000,- and a an annuity loan of the bank, this is a loan of € 200.000,-. This loan will be repaid in 60 months with an interest of 6%.

The expected number of drones sold in the first year will be 5 [10]. The total costs of one drone in the first year will be €76.512, -. The selling price of the drone would be €72.000, - in the first year. The first year there is a loss of €27.560, -. Year two will compensate the loss of year one, the loss of year one is due to the required investments. Also more drones will be sold in the second year. Due to the expected increasing growth of the company, two new employees are hired in the second year.

RESCUE DRONE			
Balance			
Januari 1, 2020			
Fixed assests		Equity	
Company car	€ 40.000,00	Equity	€ 8.000,00
Machinery	€ 20.000,00		
Inventory	€ 84.000,00	Long-term debt	
		Loan	€ 200.000,00
Current assests			
Liquid assets	€ 64.000,00		
Total Assests	€ 208.000,00	Total liabilities	€ 208.000,00

RESCUE DRONE			
Balance			
December 31, 2020			
Fixed assests		Equity	
Company car	€ 33.000,00	Equity	€ 4.300,63
Machinery	€ 15.500,00		
Inventory	€ 84.000,00	Long-term debt	
		Loan	€ 164.639,37
Current assests			
Liquid assets	€ 36.440,00		
Total Assests	€ 168.940,00	Total liabilities	€ 168.940,00

RESCUE DRONE			
Balance			
December 31, 2021			
Fixed assests		Equity	
Company car	€ 26.000,00	Equity	€ 347.204,73
Machinery	€ 18.750,00		
Inventory	€ 168.000,00	Long-term debt	
		Loan	€ 127.097,77
Current assests			
Liquid assets	€ 261.552,50		
Total Assests	€ 474.302,50	Total liabilities	€ 474.302,50

Figure 8 Global investment plan and the finance plan and also the balance sheets of the first 2 years [10]

Due the growth of sold drones the expected net income in the second year will be €225.112,50 [10]. As shown in figure 8 the equity will be €347.204,73 at the end of year. As described earlier, the company will enter a market that is still growing. As a result, the expected number of items sold will continue to grow. As a result, the company will earn back the investments and can grow further.

DISCUSSION AND CONCLUSION

The goal of this project was to design a drone that can support rescue teams during search and rescue operations despite bad weather conditions. The main reason behind this goal is that the rescue workers won't be in any danger during operations. After extensive research and calculations, a final concept was generated the most important features of the final concept are: twelve coaxial DC brushless motors, a fuel cell and gas tank and a 3D printed carbon fiber body. The final concept should be able to meet the most important functional requirements given within table 1.

The focus of the project was developing a theoretically working drone with a body made through topology optimization. Within table 1 were 7 of the most important requirements stated and in the end 3 (S9, S16 and S20) of the 7 requirements were met and the other 4 requirements could be met through testing them with a working drone but this was out of scope for the project.

Through calculations requirements S9 and S20 are met with the use of the chosen components. With the combination of these components the drone should theoretically be able to fly around 82 minutes with a maximum weight of 25 [kg].

In theory the current body generated through topology optimization would be around 14,5 [kg] which would be too heavy if all the components would be included within the weight because the fuel cell and gas tank would be around 8 [kg] so that would mean that the weight would be 22,5 [kg] excluding the vision systems so in short way to heavy. The solution for this would be to reduce the mass of the body this would be done by not 100% filling in the body but for example filling the body by 60% this would reduce the mass to around 10 [kg] but the filling could also be brought down by 40% and then the mass would be around 8,5 [kg]. the one thing that must be kept in mind is that the strength of the body would go down but when we take the measured stresses within figure 5 as a guideline this probably wouldn't go over the limit of 66 [MPa]. The solution with the infill could be tested but due to lack of time this wasn't feasible. It is not clear yet if the allowable stresses and deflections of a body with 60% or 40% infill would be under the maximum allowable stresses of 66 [MPa] and the deflections of 5 [mm] in z-direction. The second thing that has to be kept in mind is that topology optimization is still heavy in development within Siemens and due to the low value's seen in figures 4 and 5 this outcome isn't fully trusted but again due to lack of time it wasn't feasible to put the body through a regular FEM analysis to get more reliable results.

The other most important requirements (S2, S3, S7, S17) couldn't be tested due to that the production and testing of the complete drone was out of scope for this project.

For the market research conclusion, the added value of this product to our stakeholders is delivering medical and communication supplies in hard to reach areas, reduction of search time and to provide support during a rescue operation in bad weather conditions. Looking to the competitors the product is specially designed for rescue operations in the way of an optimized drone body which results in a strong drone body. With the use of a fuel cell the flight time of the rescue drone is extended and more efficient compared to competitors who use batteries for their drone. For support during a rescue operation a drone will be much cheaper than a rescue helicopter.

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Increasing the lifetime of 3D-prints

Innovation Engineering project 3D printing – paper

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Abstract – This paper lays out an innovation to improve FDM 3D printed products. Research is done on how to improve the mechanical properties of these printed products. The system inserts metal wire reinforcements in a 3D printed product. This solution is a step to a brand-new market of 3D printing which only can be improved further. As well as a technical research, a business advice is given, which can give opportunities for a business with this technology.

Keywords – 3D-printing, FDM printing, additive manufacturing, cutting mechanisms, heating elements, product innovation, business innovation.

Introduction

This project is set up as a part of the course Innovation Engineering, a differentiation in the seventh semester at the Fontys University of Applied Sciences of Eindhoven. To make the project more interesting and a better learning experience it is a part of a collaboration program between the Fontys and the University of Applied Sciences Technikum Wien.

The team of students consist of four full-time Mechanical Engineering students from the Fontys, a third-semester part-time Commercial Economy student form the Fontys and three fifth-semester part-time Business Engineering students from the Technikum.

Design possibilities have been surpassing production methods and 3D-printing has offered a great solution so far. Fused deposition modelling (FDM) is one of the more popular methods. An FDM machine extrudes or deposits filament layer by layer. These layers, due to the residual heat of the extruded filament, bond together to create a solid part. However, due to this method to build up the parts one layer at a time, a part can be vulnerable to transversal stress or tension in the layer direction. The layers peel apart due to low adhesion forces or low fusion of the printed material to itself for certain applications. [1]

Finding a solution for this problem is the aim of this project. Desk research has pointed out that a design for vertical wire inserts will be a viable way to tackle beforenamed problem because of its innovative and complex nature. [2]

The goal is to increase the strength of 3D-printed products in a way that engineers who use prototyping and tooling in the development of their projects could benefit. The mission for the company that rolled out of this project: *Providing care to service every innovator in the rapid prototyping industry by making sure their end products are of extensive quality for a fair price.*

The product is a fused filament printer with an added unit, called *Zpike*, creating increased shear strength for when the product experiences transversal stress, which is in the layer direction. The *Zpike* unit pushes metal inserts into the 3D-printed parts while the print is busy. These metal wires will go through several previously printed layers. It uses heat to melt and to push the metal wire through the polymer to create interlayer anchoring. Once in place the unit cuts the wire and the printing continues and the cycle repeats until the print is finished and several reinforcing wires have been inserted. It is a slower process than regular printing, but it will increase the mechanical properties.

For the *Zpike* unit a proof of concept will show the working of the system and subsystems. Furthermore, development of the prototype with the final design choices will be worked out in a computer aided design (CAD) program.

The following research question has lead research throughout the product innovation part:

> *How can the implementation of the wire insertion unit improve mechanical properties of 3D-printed products?*

To support the design of the innovation several business aspects are researched as well, because only in combination with a good business plan the idea can merely be classified as an innovation. When there is an invention but there is no market or financial support feasibility, it will remain only an idea. Building a good business around it makes it an innovation, which is the goal of this project. The results of the business plan are the basis of the second part of this paper. The market and the ability to make a creative new product from there will be assessed.

For this aspect of the project a new research question needs to be defined. The following research question has brought the results found in the Business Innovation part:

> *How can the idea for a wire insertion unit like Zpike be made into a business?*

Product Innovation

The goal of this project is to do research on a possible product in the area of the 3D printing market. To find an invention in 3D-printing systems, there has been used different kinds of methods. The reason for the idea of a wire insertion unit is that the project group thought that this idea is the most achievable/innovative idea with the knowledge and resources that are available. By using a morphological scheme there has been made decisions for this concept. The following criteria have been considered to design the subsystems listed below: costs, availability, safety, sustainability and quality of the product.

Subsystems

Feeding unit – This unit pushes the heated metal wire into the 3D-printed layers. The feeding of the wire is powered by an electric stepper-motor. The wire will be heating up when it slides through the nozzle. The nozzle is surrounded by an electric powered induction coil that heats the wire to a temperature where it can be inserted in the printed layers. This size of the coil has been chosen so that it will heat the wire to a point where it cannot burn the plastic or cause unsafety. When the wire is pushed to the required depth into the material it needs to be cut. This depth is decided by the requirements. More local reinforcements will receive a longer or multiple wire. The cutting will be done by the cutting unit.

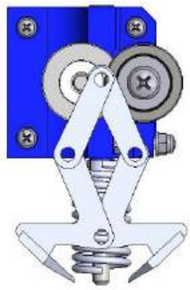

Figure 1 Cutting mechanism

Cutting unit – The cutting unit cuts the wires that are inserted into the product directly after insertion. This system is activated when the wire is at the required depth in the 3D-printed part. The shape resembles a pincer. Extension of the servomotor that drives the cutting unit makes the two metal blades cut. This is carried out just about 0,05 mm above the plastic layer. The axis of the moving mechanism and the blades are positioned in line with the wire feeder so that no further movement is required. The mechanism is as shown in the figure 1.

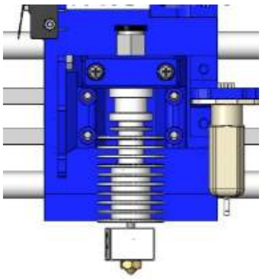

Figure 2: Printing nozzle

Printing head – The function of the printing-head is to heat and melt the filament that flows through the nozzle. This part of the product is a standard 3D-printer extruder. It uses a heating element around the nozzle. It’s possible to replace the nozzle for maintenance and if it’s needed to change the nozzle for another with a different diameter.

Working – The general setup of the hole system can be seen in figure 3. The printing-bed stays stationary in the unit. The combined system, being the merged unit, can move in the directions X, Y and Z. The movements will be powered by stepper motors and driven by belts. The housing of the total system is constructed out of aluminium profiles and steel sheets metal parts. The printing head which is seen in figure 4 will just print a some layers after that it will stop printing and the metal wire will insert some needle wires in the plastic layers. The metal wire will be heated so it can penetrate the printed plastic layers. When there are a few wires inserted the printing-process continues with more layers and this process will repeat until the product is finished.

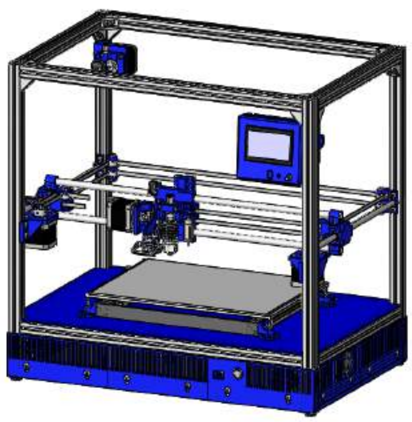

Figure 3: Overview full system

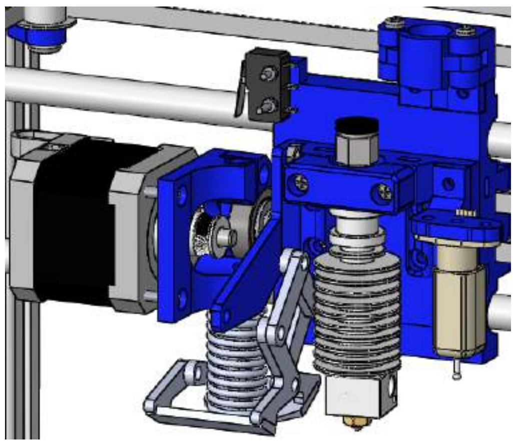

Figure 4: Close up of the assembly

Proof of concept

A proof of concept is needed for a couple of reasons. For each sub-system it is critical to know if it will work. For the whole assembly, it is important to see if it works together. The advantage of a proof of concept is that tests can be carried out without having to fully build the prototype. Changes can be made easily when the product is not integrated like it will be in the prototype. The proof of concept described below has been manufactured in Vienna by the students of Technikum Wien.

The proof of concept is without the printing head. Tests of creating test subjects can still be done separately from a regular printer. This is done to keep the sequence of developing the parts simple. Cutting the wire is done with a different cutting device in the proof of concept. The unit can be seen in the left of figure 5. It is a more primitive and basic system with no specially designed blades to encourage simplicity. This is a regular scissor system based on a set of shears. This is less accurate due to the movement than the proposed working system but can serve the test of the proof of concept as it just needs to cut in order to show the accuracy and the sequence of the process. Product inaccuracies due to this cutting mechanism can be post-processed and has no effect on the working of the system.

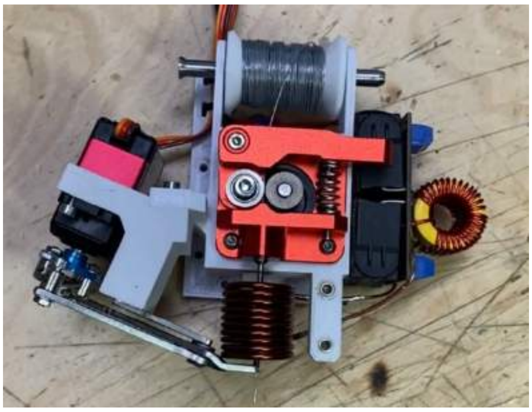

Figure 5: Front view proof of concept

The feeding unit is a copy of the extrusion system of the printer. The feeding is established by the 2 feeding wheels in the center of figure 5. These wheels guide and press the wire into the product and rolling it off the spool on top. The wire spool will be not functioning and moved to the side in the final design and is integrated onto the printing unit. The induction heating coil seen on the bottom of figure 5 heats up the wire to get at a proper temperature to be able to penetrate the printed product.

This has shown the working of the concept and gave the opportunity to make some testing parts to show the improvement metal wire inserted 3D prints and that the strength of the improved samples are higher than the samples without the wiring reinforcement. Results of the tests can be found below.

Tests and test results

To compare the regular tensile stress with that of the parts created by Zpike some test subjects are made. These are bars with a notch in them. This notch will ensure that the maximum stress will take place in the area of the reinforced part of the bar. A schematic view of the part is as seen in figure 6. The blue vertical striped indicate the wire inserts and the orange horizontal lines are the printed layers.

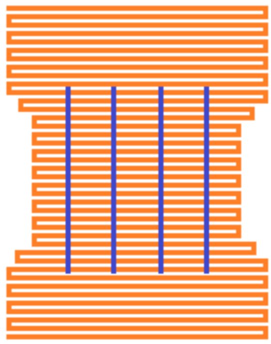

Figure 6: Cross section of schematic drawing of the printed test subjects.

Five test subjects are made without metal wires in them, four are made with four metal wires at the location of the notch and two are made with five wires. Doing a tensile test would have indicated a strength improvement factor. However the parts did not break at the same location so the measured tensile stress results cannot be compared. The parts with the inserted wires fail at the place where the wire ends, while the normalized parts without nails do break at the notch.

It can be concluded that the parts are stronger at the notch because of the fail location. The test did not indicate what the initial goal was, however it still can be said that the innovation idea works which makes the 3D printed parts stronger than the 'normal parts'.

Figure 7: Tested subject with four wires. Part failed above the wire location.

Business plan for wired enforced 3D printed products

The business plan is devised to look at the market and to make a creative new product from there.

At the moment plastic printers, metal printers and double head printers are available, it is an opportunity for Zpike to respond to the existing market with an inventive solution using a double-headed multifunctional printer head. The two most interesting market target area's which can buy the 3D-printer are 3D printing production companies and hobbyists. To see what customer needs, it is important to look at the current product range of 3D-Printers. Currently anyone can buy a 3D-printer, but there are differences in requirements regarding quality, strength and price. The 3D-printing market is steadily growing and developing.

For different kinds of innovation, different business strategies are needed. First, established 3D-printer manufacturers are already busy with their own development. Furthermore, there is competition between existing companies which are trying to improve their own 3D-printers. This market rivalry is out of the league of the developers of Zpike. Thus, the developers of Zpike cannot compete in quality of the filament extrusion system. This brings *Zpike* to the solution to integrate the innovative unit into the designing phase of current 3D-printers in development. This is what the company of *Zpike* will sell, the aid in implementation of the extra unit. For the first six through twelve months the research team assists the customer in the development. They will do this on site at the customer's company to keep the relationship close and from their activities will take place from an own office to increase efficient work time. Because the main research site and possible clients are situated in the same area, namely the Brainport of Eindhoven, the continuation of the business research will take place in this area as well. This collaborative way of working is a Business to Business (B2B) relationship.

To protect the idea a patent is applied to the research and product itself. This way the company of *Zpike* avoids threats and generates another revenue stream. The direct customer will have to purchase or license the patent.

Metal 3D printing is the main method to guarantee strength that companies use [3], however this technique is still too expensive for some customers that wish to use 3D-printing. With Zpike, the price of a strong printed part will be much lower than a metal printed part which is advantageous for a lot of companies. This could mean that more companies will start using 3D-printing technologies in the way of designing more easily, which in turn benefits the overall innovative industry.

The value is what has driven this research, namely the increased strength of the 3D-printed parts. As it could result in a longer lifetime, this is a sustainable aspect of this innovation which makes it attractive to not only engineering bureaus or otherwise engineering departments. Governmental bodies are a proponent of sustainable solutions. As mentioned before *Zpike* responds to the existing market of FDM- and metal 3D-printers. This response is an intermediate option to get the best of both options, which are costs and higher strength. More about the value can be viewed in the SWOT analysis diagram devised in the business plan. [4]

Most companies and individuals that the project group interviewed at the Dutch Design Week and various conferences were enthusiastic about the Zpike product. These companies include TNO, VDL, NTS, Hiwin, Maxon, CCC-engineering amongst others. They see a big use for the unit because of tooling. These are simple, quick built, single or limited use products so they want this to be as cheap as possible. The additional strength Zpike offers is exactly what the interviewed companies were lacking. [5] The market is good, and many companies and competitors sell a lot. The branch is not dominated by one single supplier. However, they contribute to the quality of the eventual product and compete for low margins of costs.

All beforenamed aspects can be viewed in the Business Model Canvas. This is an overview of what makes the *Zpike* company.

<table>
<tr><th>Key Partners</th><th>Key Activities</th><th>Value Propositions</th><th>Customer Relationships</th><th>Customer Segments</th></tr>
<tr><td rowspan="3">None</td><td>Sell the Patent
Help the customer in research for implementation</td><td rowspan="3">Unique product
Help with processes the first year</td><td>One relationship (B2B)</td><td rowspan="3">B2B market
One year service contract with customer company, who purchases the patent</td></tr>
<tr><td>Key Resources</td><td>Channels</td></tr>
<tr><td>Entrepreneurs (three engineers from Vienna, four engineers from Eindhoven and one specialized in business)</td><td>Fairs
Internet
Network</td></tr>
</table>

Cost Structure	Revenue Streams
Start-up costs Laptops Research resources Promotion Systems Employees	Investment universities (Fontys Eindhoven & Technikum Wien) Loan Patent proceeds Royals

Figure 5 Business Model Canvas

An estimate is made from the liquidity budget, for what size of investment is needed to satisfy the salaries of the employees, development costs and unexpected costs. When working through the liquidity budget around €200.000 - should be enough. [6] The liquidity budget states the expected income and expenses. Zpike expect to have a revenue of €250.400 in the first year. This income is based on the free cash flows calculated in the financial balance. After deducting all costs, this results in a profit of €18.780,00.

Two scenarios will be the short-term vision of the company:

- The project is successful, and it is finished within a year. In which case, we pay back the loan in full and are left with an estimated profit of up to €20.000.
- The customer wishes to proceed with research, in which case we pay back half of the investment and keep going in this collaboration.

Conclusion

When looking at the initial research question "How can the implementation of the wire insertion unit improve mechanical properties of 3D-printed products?" the following can be said; the strength of 3D-printed products has increased in comparison to ordinarily printed products.

To enforce this statement the proof of concept is a working system and provides enough input for a prototype design. This design has been made as seen in the product innovation part. The design includes a series of decisions and solutions derived from the encountered problems.

- The design incudes a wire extruder based on the filament feeder unit. This unit includes a feeder gear which introduces a profile onto the wire. Theoretically this would aid in adhesion to the part when inserted.
- In the design there is a heating part which ensures enough melting properties when feeding the wire into the (partly) printed part.

- To finish the insertion of the wire it must be cut for which a specially designed snipping unit, based on a design of a pair of pliers, has been added.
- All functions have been encapsulated in a fitted and organized assembly.

Furthermore, preliminary tests have indicated the functionality of the concept and an improvement in overall strength. The version of the proof of concept has pointed out that the subsystems function the way they should. Further tensile stress tests have indicated that the 3D-printed subjects are stronger due to the fail location which is not at the wire location anymore. Together with the workings of the proof of concept the design of the wire insertion unit can be called an innovation if it can be made to enter the market.

Finally, it can be stated that the next move in the development of 3D-printers has been made, which makes this project a success. This research can be used to further study the areas on which 3D-printers can be improved.

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Developing an Aerial Tracking Device: The Inverse Dynamics Controller and Redesign

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Abstract— **The S.W.A.T.D. is a system developed to track aerial threats to increase security for organizations. This paper discusses the chosen solutions for the inverse dynamics controller and redesign, and also provides the next steps to be taken. The next group of engineers tasked with fully realizing this design now have a solid foundation to build upon.**

Index terms— Drones, Tracking, Airspace, Security, Torque control.

I INTRODUCTION

With the rapid progress in technology, drones are becoming more accessible and commonplace. Fitted with recording equipment, they can pose a privacy and security risk especially for high profile individuals as well as organizations. They can also cause dangerous problems in areas needing clear airspace like airports, potentially causing hundreds of thousands of Euros in damage. The *SmartWrist Airspace Tracking Device (S.W.A.T.D.)* is a system designed to tackle this problem and provide the value of security and privacy to big organizations as clients. This paper will focus on the technical challenges, approach, and chosen design decisions to realize such a system from a mechanical engineering standpoint.

II BACKGROUND

The device is built on the concept of the SmartWrist which was the project done by a previous team at Fontys for the Delta Advanced Automation Contest hosted and sponsored by Delta Electronics (figure 1). The SmartWrist is a unique positioning system as it adjusts its tilt angle by rotation of two adjoining discs, positioned at an angle with respect to each other. This makes it very fast and very precise for positioning. It secured first place in the contest due to the innovative interfacing between the ROS and CodeSYS platforms.

Due to its success, it was decided by Fontys and Delta Electronics to further develop this concept by building an innovative and valuable application for it, by semester 7 students. To successfully showcase the unique selling points of the SmartWrist concept (speed and precision), the idea of an aerial tracking device was chosen. This was later named as S.W.A.T.D.

(**a**) Zero position. (**b**) SWATD under an angle.

Fig. 1: Operating the smartwrist

III KINEMATICS

Fig. 2 illustrates a schematic representation of the SmartWrist manipulator. The manipulator consists of three parts of a cylin-

der attached to each other. Every piece can rotate with respect to the other. The angle of the uppercut makes it possible to obtain different orientations of the end effector which will be used to point the camera to the drone. The Denavit Hartenberg convention is used to derive the forward kinematics.[1] The inverse kinematics of the two joint angles is derived for the orientation of the end effector. With a predetermined orientation, a desired direction of the camera is achieved.
In the schematic representation of the SmartWrist manipulator as depicted in figure 2, the angle of the upper disk is denoted with the angle ψ. All dimensions are parameterized as open values which can be used by the future group to obtain the controller information. The disks 1 and 2 rotate with angles θ_1 and θ_2 respectively. These angles are the angles where the entire kinematics is based on. With those two angles, the forward kinematics will be solved. With the inverse kinematics, these angles need to be calculated for the predetermined orientation.

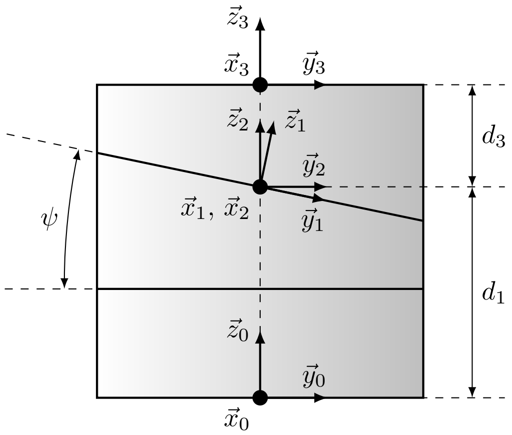

Fig. 2: SmartWrist

A. *Denavit Hartenberg*

The forward kinematics of the SmartWrist manipulator is obtained with the Denavit Hartenberg (DH) Convention. The problem of the forward kinematics is the relation between the joint angles and the end effectors position and attitude. The DH Convention is a systematic procedure to derive the forward kinematics.
The attached frames to each link are placed as depicted in Fig. 2. Due to the angle of the disk, frame $\vec{o}_2\vec{x}_2\vec{y}_2\vec{z}_2$ is added to fulfill the DH constraints. The parameters, that are used to derive the homogeneous transformation matrices, can be obtained,

- a: Translation in the x_i direction until the origin of frame $i-1$ coincides with frame i.
- α: The amount of rotation of frame $i-1$ around x_i to get z_{i-1} on z_i.
- d: Translation in the z_{i-1} direction until the origin of frame $i-1$ coincides with frame i.
- θ: The amount of rotation of frame $i-1$ around z_{i-1} to get x_{i-1} on x_i.

which has to be found for each frame. Now, the Denavit Hartenberg parameters of the SmartWrist manipulator results in: (*variable)

Table 1: DH parameters for the SmartWrist.

	a_i	α_i	d_i	θ_i
1	0	$-\psi$	d_1	θ_1^*
2	0	ψ	0	θ_2^*
3	0	0	d_3	0

B. *Forward-Kinematics*

The forward kinematics of the end effector is the displacement vector as shown in (1) of frame ($\vec{o}_3\vec{x}_3\vec{y}_3\vec{z}_3$) with respect to the inertial frame ($\vec{o}_0\vec{x}_0\vec{y}_0\vec{z}_0$).

$$d_3^0 = \begin{pmatrix} d_3 s_\psi (c_{\theta_1} s_{\theta_2} - c_\psi s_{\theta_1} + c_\psi c_{\theta_2} s_{\theta_1}) \\ d_3 s_\psi (c_\psi c_{\theta_1} + s_{\theta_1} s_{\theta_2} - c_\psi c_{\theta_1} c_{\theta_2}) \\ d_1 + d_3 (c_\psi^2 + c_{\theta_2} s_\psi^2) \end{pmatrix} \tag{1}$$

This vector is plotted for all values of θ_1 and θ_2 in figure 3 which represents a workspace plot.

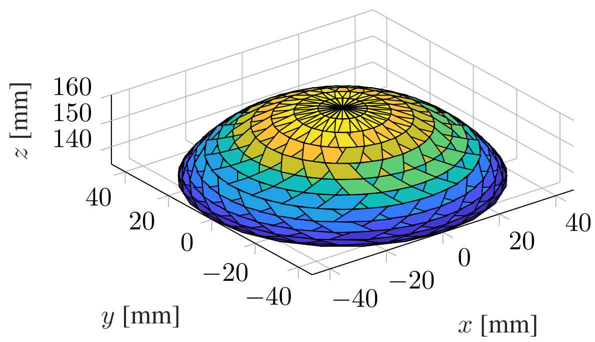

Fig. 3: Workspace plot of the SmartWrist.

C. *Inverse-Kinematics*

With the inverse kinematics, the joint angles will be derived out of the desired attitude. Beforehand an intuitive orientation will be computed. The chosen sequence will be the rotation around its axis with α and look upward with a defined angle of γ. *Assume, the desired lift angle γ is the cut angle ψ. As can be seen in figure 4 the second link has to be rotated by a little more than $\pi/2$. Since the camera lens is in the $\vec{y}_3$ direction, the shift around its axis is introduced with $\tilde{\alpha}$. As can be seen in figure 4 this angle is a little less than $\pi/2$ at ψ. Therefore the first link needs to compensate this with $\theta_1 = \alpha - \tilde{\alpha}$.*

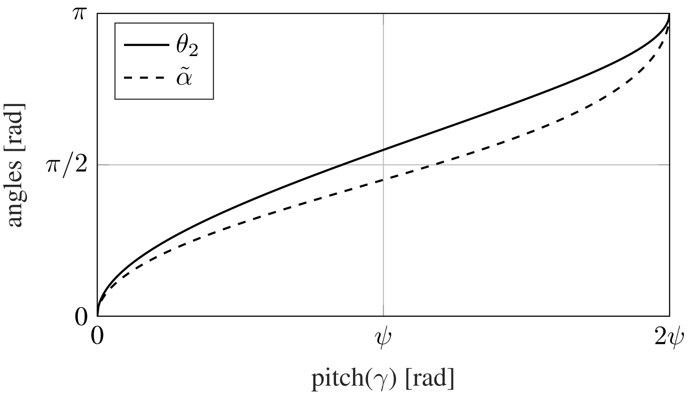

Fig. 4: Inverse-Kinematics

The inverse kinematics is a function of the pitch and yaw angles. The function of the inverse kinematics, IK(yaw(α),pitch(γ)) is represented in (2) where ψ is the cut angle of the wrist.

$$\begin{cases} \theta_1 = \alpha - \arccos\left(\frac{\sin(\psi)-\cos(\psi)\sin(\gamma)}{\cos(\gamma)\sin(\psi)}\right) \\ \theta_2 = \arccos\left(1 - \frac{2\sin(\gamma)}{\sin(2\psi)}\right) \end{cases} \tag{2}$$

IV DYNAMICS, LAGRANGE EQUATION

The dynamics of the SmartWrist manipulator will be derived to obtain the relation between joint torques and motion. Hereby, the Lagrange equation will be used to find the equations of motion. These equations of motion are needed to simulate and design, the control algorithms. The generalized coordinates $\underline{q}^T = [\theta_1, \theta_2]$ are defined as the two joint angles. The Lagrange equation can be rewritten in matrix form.

$$D(\underline{q})\underline{\ddot{q}} + C(\underline{q}, \underline{\dot{q}})\underline{\dot{q}} + g(\underline{q}) = \underline{\tau} \tag{3}$$

The matrix $D(\underline{q})$ is the robot (generalized) inertia matrix with dimensions $n \times n$ with $[J_{vi}, J_{\omega i}]^T$, the Jacobian matrix of each links center of mass.

$$D(\underline{q}) = \sum_{i=1}^{n} \left(m_i J_{vi}^T(\underline{q}) J_{vi}(\underline{q}) + J_{\omega i}^T(\underline{q}) R_i(\underline{q}) I_i R_i(\underline{q}) J_{\omega i}(\underline{q})\right) \tag{4}$$

The effects of gravity in $g(\underline{q})$ i.e. the gravity vector which is the Jacobian of the potential energy V with respect to the generalized coordinates $\underline{q}$.

$$g(\underline{q}) = \frac{\partial V}{\partial \underline{q}}, \tag{5}$$

The centripetal and Coriolis effects are taken into account in the matrix $C(\underline{q}, \underline{\dot{q}})$ which are known as the Christoffel symbols (of the first kind). These can be determined with,

$$\Gamma_{ijk} = \frac{1}{2}\left(\frac{\partial d_{kj}}{\partial q_i} + \frac{\partial d_{ki}}{\partial q_j} - \frac{\partial d_{ij}}{\partial q_k}\right) \tag{6}$$

where the matrix position of $C(\underline{q}, \underline{\dot{q}})$ represents:

$$c_{kj} = \sum_i \Gamma_{ijk} \dot{q}_i. \tag{7}$$

V CONTROLLER DESIGN

Within this section, the controller architecture will be evaluated as depicted in Fig. 5. The controller is chosen to be a PD compensator for each joint. Herein, P and D term corresponds to the joint angle and joint velocities respectively. To speed up the SmartWrist and react more aggressively to disturbance, a feed-forward controller is implemented. This feed-forward controller follows a trajectory planning where different methods are examined. The closed-loop system with the controller will compensate for the unmodelled dynamics.

A. *Trajectory planning*

The path is defined by polynomials of order k with an initial position $\underline{q} \in \mathbb{R}^n$ and velocity $\underline{\dot{q}}$.

$$\underline{q} = \begin{bmatrix} a_{10} & a_{11} & \cdots & a_{1k} \\ a_{20} & a_{21} & \cdots & a_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n0} & a_{n1} & \cdots & a_{nk} \end{bmatrix} \begin{bmatrix} 1 \\ t \\ t^2 \\ \vdots \\ t^k \end{bmatrix} \tag{8}$$

With this set of equations, the solution of the column $\underline{a}$ has to be obtained since all other variables are known. Due to the tracking application, the initial and final velocities of the joint are always zero. Hence, the path is not a function of the velocities or accelerations. Since the full continuity of the acceleration is necessary, a quantic trajectory planning is introduced. Herein, the acceleration is 3rd order polynomial which will result in a less shocking response at t_0 and t_f.

$$\begin{bmatrix} 1 & t_0 & t_0^2 & t_0^3 & t_0^4 & t_0^5 \\ 0 & 1 & 2t_0 & 3t_0^2 & 4t_0^3 & 5t_0^4 \\ 0 & 0 & 2 & 6t_0 & 12t_0^2 & 20t_0^3 \\ 1 & t_f & t_f^2 & t_f^3 & t_f^4 & t_f^5 \\ 0 & 1 & 2t_f & 3t_f^2 & 4t_f^3 & 5t_f^4 \\ 0 & 0 & 2 & 6t_f & 12t_f^2 & 20t_f^3 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} = \begin{bmatrix} q_0 \\ \dot{q}_0 \\ \ddot{q}_0 \\ q_f \\ \dot{q}_f \\ \ddot{q}_f \end{bmatrix} \tag{9}$$

To solve the constants in $\underline{a}$ Finally, in the situation of the SmartWrist, there are two generalized coordinates and a fifth-order polynomial. Therefore, $n = 2$ and $k = 5$ which has to implemented for (8).

B. *Inverse Dynamics Controller*

The controller for the SmartWrist will be an inverse dynamics controller which is a nonlinear feedback controller which finally results in a linear closed loop system. Where the error of the system can be obtained with (10). As can be seen, the time derivative of the error is simply the error of the joint velocities.

$$\begin{cases} e \triangleq y^d - y \\ \dot{e} \triangleq \dot{y}^d - \dot{y} \end{cases} \tag{10}$$

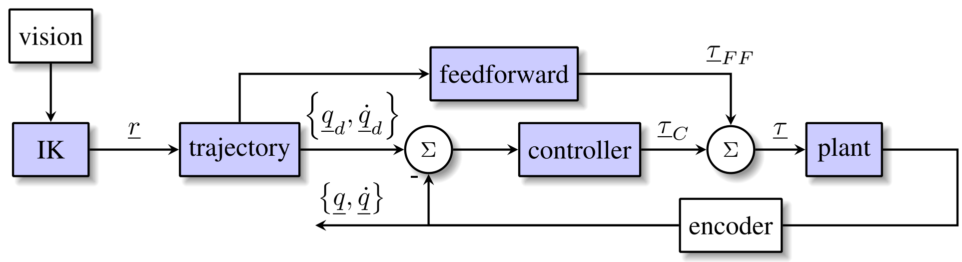

Fig. 5: Overview of the control architecture of the SmartWrist. Purple colored boxes are covered in this paper.

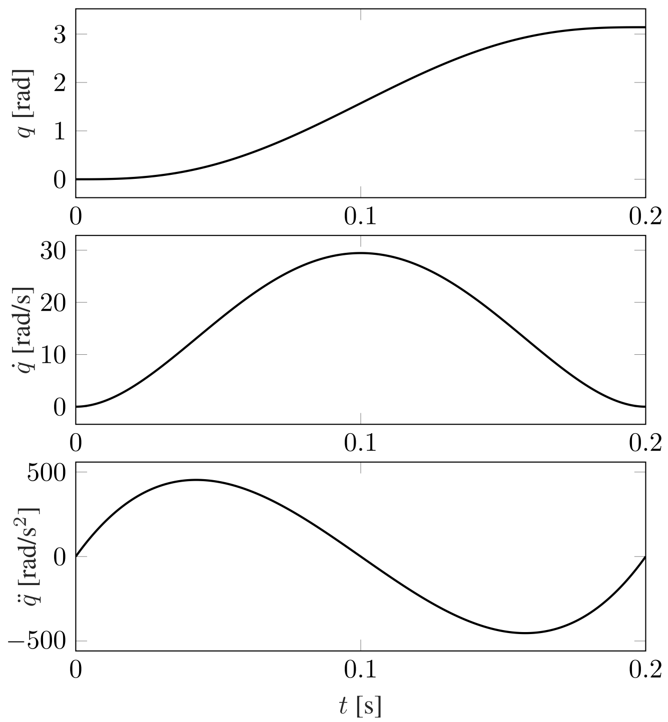

Fig. 6: The quantic polynomials solve the discontinuity of the acceleration. Herein, the jerk is still a second-order polynomial.

For a nonlinear system is quite hard to find a non linear controller. For manipulator dynamics the controller will become easy when u is chosen as in (11).

$$\underline{u} = D(\underline{q})\underline{a}_q + C(\underline{q}, \dot{\underline{q}})\dot{\underline{q}} + g(\underline{q}), \tag{11}$$

simplifying this system with (3) where the inertia matrix $D(\underline{q})$ is invertable results in a double integrator system.

$$\ddot{\underline{q}} = \underline{a}_q \tag{12}$$

Herein, the term a_q can be chosen to control the system. A big advantage of this method is that it resulted in linear decoupled systems. The term $\underline{a}_q$ can be chosen as,

$$\underline{a}_q = \ddot{\underline{q}}^d + K_P\underline{e} + K_D\dot{\underline{e}} \tag{13}$$

This is just an feedforward controller with a PD-compensator for the joint positions. Since the velocities are directly controlled by K_D, the positions does not need to be differentiated in the software. By substituting (13) into (12), n linear second order systems are obtained.

$$\ddot{\underline{e}} + K_D\dot{\underline{e}} + K_P\underline{e} = \underline{0} \tag{14}$$

Where the matrices K_D and K_P represents,

$$K_P = \begin{bmatrix} -\omega^2 & 0 \\ 0 & -\omega^2 \end{bmatrix}, \; K_D = \begin{bmatrix} -2\omega & 0 \\ 0 & -2\omega \end{bmatrix} \tag{15}$$

The frequency ω represents the natural frequency, of a critically damped second order linear system. Which indicates something about the speed of decay of the error.

VI MOTOR CHOICE

The system needed to have enough power so that the S.W.A.T.D. was fast enough to track multiple drones. That is why it was important to make the right choice for the motors since these were the source of the movement. There were certain motors with the right transmissions needed to achieve the right speed. The first step in choosing the right motor was to look at what was available. This resulted in a list of available motors with their data as shown in table 2. The next step was to estimate how much torque was needed in the redesign. The torque can be calculated with the moment of inertia (I_g) and the angular acceleration (α). The angular acceleration is calculated in the chapter

Table 2: Motor types former group.

Motor	Max. torque (Nm)	rated speed (RPM)
ECMA C2 0401 SS	0,96	3000
ECMA C2 0602	1,92	3000
ECMA C2 0604	3,82	3000

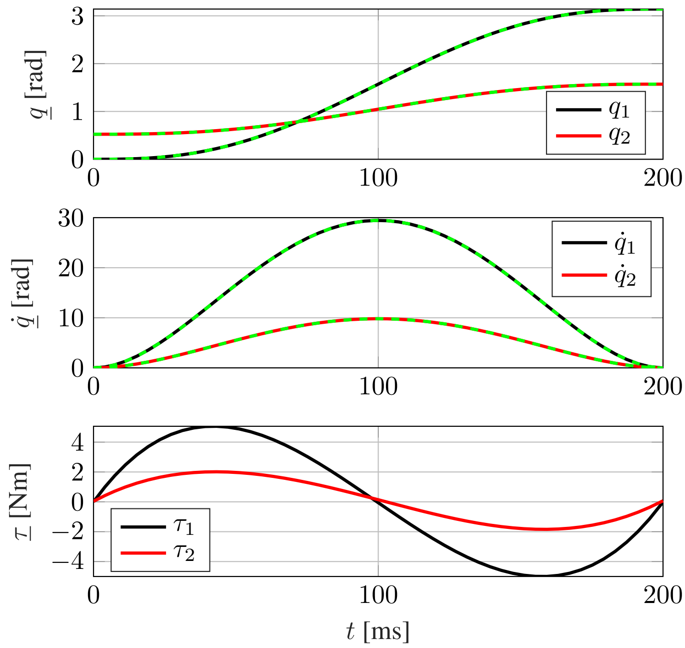

Fig. 7: The simulation results for the controller as described in (11). Green dashed line represents the quantic polynomial tracking.

about the controller design. The moments of inertia were calculated with Solid Works. With this data, the torque for the top and middle disc could be estimated with the following formula.

$$M = I_g \alpha \tag{16}$$

This resulted in a required torque of 3,3 Nm for the top disc and 1,8 Nm for the middle disc with the current transmission. When the torque was calculated, it was a matter of choosing the motors and eventual gears to achieve this torque. There was close collaboration with the redesign team to make sure that the chosen motors and gears could be implemented in the design. The choice was made for the motor ECMA C2 0604 for the top disc and ECMA C2 0401 for the middle disc. These choices come with the transmission of 44:100 for the middle disc and 1:1 for the top disc to achieve the required torque. It was unfortunately not possible to implement a transmission for the top disc. That is why the top disc is powered with a relatively powerful motor.

VII Redesign

The redesign was conducted on the existing SmartWrist to make the design more suited for the S.W.A.T.D. The SmartWrist, as delivered to the new team, has some flaws. The play in the wrist is high and is not desirable for high precision purposes which the wrist could have been designed for. This play mostly originated from the 3D-designed custom bearings, and the irregularities and minor mistakes during manufacturing. The bearings were chosen with the Design for Excellence method. The bearings are ranked on the basis of reliability, quality, manufacturing, assembly, and costs. In the end, it turned out that the radial bearing was the best bearing for most parts of the design. After some research, we chose for an option recommended by the previous group - an LER bearing which is specialized in axial and radial accuracy.

Another major problem on the SmartWrist is the backlash that is created by the gears and fitting of the shaft. This problem can mostly be solved with a transmission fit between the motor and the shaft and a loose fit between the gear and the shaft. The fittings are chosen with the help of the book, Roloff/Matek machineonderdelen [4]. The connected gears also need to be connected as tight as possible to reduce the backlash. The gears are also from the same module, so the teeth intertwine smoothly. The last step towards a low backlash is a high stiffness in the shaft. If the shaft causes a deformation, the gears could not be as intertwined as intended and the backlash would increase.

There are also some issues with the SmartWrist that are not necessarily a problem, but could be optimized. Those are issues regarding the weight and accuracy of the SmartWrist. At first, the material choice of the old SmartWrist was researched. Even though the material was mostly chosen because of the availability at the time, the chosen material was one of the best materials regarding stiffness, density, and manufacturability. The next step, to reduce weight, is to decrease the thickness of the layers. This thickness is halved in some cases. The height of the SmartWrist is reduced with a compact internal design. The accuracy of the universal joint is also considered to be increased. After some research, there were two other possibilities - the bellow joint and the velocity joint. The bellow joint did not fulfill those needs due to low torque. The velocity joint is a better option than the universal joint, but could not meet our requirements with the new 60 degrees angle. This is why the universal joint stayed in the redesign.

Besides improving the SmartWrist, the new wrist must also be suited for the S.W.A.T.D. One of the biggest challenges is to get a power supply to the Raspberry Pi on top of the wrist. The power supply must be a 5 volt cable that can not be strangled on the shafts. The shaft and the cable must move together to prevent the strangling. A slip ring with a bearing is used to keep the cable static on the static part and rotating with the shaft on the upper part of the wrist. This is also visible in figure 8.

For the sensors, camera and raspberry pi itself a case has to be developed. The raspberry pi itself has a case, but the camera could not be mounted with this case. The lower part of the case could still be used and drawn. The upper part is designed as a box with a hole for the camera and has holes for screws to mount the camera on the top part. The LIDAR sensor is placed with holes for the attachments. This case is visible in figure 9. Lastly, there needed to be some alterations in the design, because the motor of the upper part could not meet the requirements in the SRD. The first option to change the gear transmission from 1:1 to 1:4

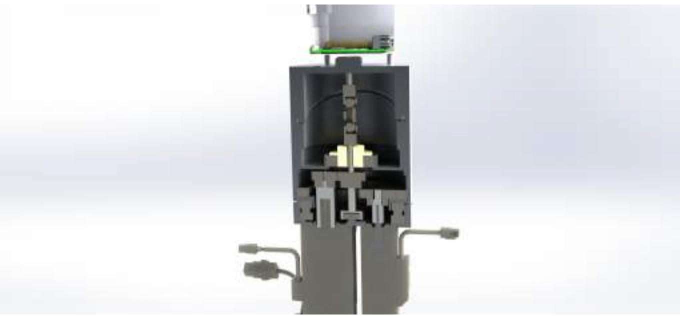

Fig. 8: Cross section of the S.W.A.T.D.

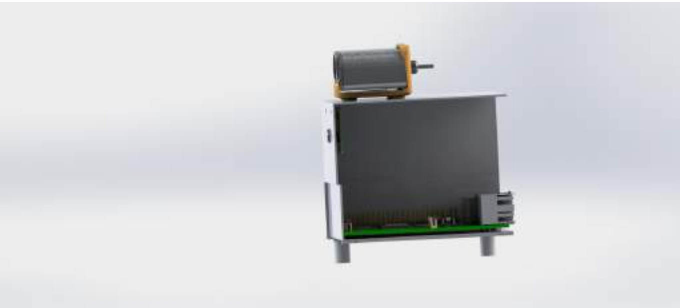

Fig. 9: Pi case used for the Vision System

could not be realized, because the spur would have a diameter of 12 mm and the shaft has a diameter of 8 mm. The second option was to replace the 100W motor with a 400W one. This process had some difficulties with implementing the new motor without increasing the outer diameter. This problem was solved, but the changes might make it difficult to manufacture one or two parts.

VIII Conclusion & next steps

Using the top-down methodology of design to obtain the specifications from the user requirements, a fully functioning system design was successfully developed, with each module capable of individual performance as well as total integration and compatibility. The next group of engineers tasked with fully realizing this design now has a solid foundation to build upon.

The future group may consider to leave the gravitational term in the inverse dynamics controller out of the algorithm. Since there is no friction modeled, the second link will always need torque when it is out of equilibrium position. This may be not the case in practice since the friction of each link.

To maintain the high standards that are needed for the S.W.A.T.D. and maintain the play-free design, the best option is to let the parts be milled by professional machines which are very precise and accurate, and to make sure none of the parts come loose due to the operation of the device.

Another recommendation for the next group will be to implement the algorithm that is in the Teensy directly into the provided motion controller from Delta Electronics. Since the inverse dynamics controller needs real time calculations of the mathematical model, the computer architecture needs to be able to do this. This would be very innovative as there is no current solution to do complex mathematical calculation in the motion controller so the possibility of this needs to be investigated, and if so, be implemented.

Acknowledgment

First and foremost, we would like to thank our extremely supportive mentors Nico van der Aa and Willem van de Groep for their guidance with the technical challenges of the project as well as the administrative and organizational ones.

Thanks to Delta Electronics, namely Jack Tsai and Ufuk Ozer, for their support, for giving us the opportunity to work on the SmartWrist concept, and for their willingness to provide us with resources.

We are very appreciative of the opportunity and platform that is given to us by Fontys Hogescholen, and it has greatly prepared us for our careers in the real world after the completion of our studies. Special thanks to our group leaders Tom Kerkhofs and Teun van der Coer who worked tirelessly to form a cohesive and forward-stepping group, finding solutions to all of our hurdles.

Lastly, the development of this project wouldn't have been possible without the focus, commitment, and teamwork of our colleagues who worked together to ensure progress.

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Fontys School of Engineering

Developing an Aerial Tracking Device: Computer Vision, Sensors and Drivetrain

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***Abstract*— The S.W.A.T.D. is a system developed to track aerial threats to increase security for organizations. This paper discusses the chosen solutions for the computer vision, sensors, and drivetrain modules, and also provides the next steps to be taken. The next group of engineers tasked with fully realizing this design now have a solid foundation to build upon.**

***Index terms*— Drones, Tracking, Airspace, Security, OpenCV.**

I Introduction

With the rapid progress in technology, drones are becoming more accessible and commonplace. Fitted with recording equipment, they can pose a privacy and security risk especially for high profile individuals as well as organizations. They can also cause dangerous problems in areas needing clear airspace like airports, potentially causing hundreds of thousands of Euros in damage. The *SmartWrist Airspace Tracking Device (S.W.A.T.D.)* is a system designed to tackle this problem and provide the value of security and privacy to big organizations as clients. This paper will focus on the technical challenges, approach, and chosen design decisions to realize such a system from an electrical engineering standpoint.

II Background

The device is built on the concept of the SmartWrist which was the project done by a previous team at Fontys for the Delta Advanced Automation Contest hosted and sponsored by Delta Electronics. The SmartWrist is a unique positioning system as it adjusts its tilt angle by rotation of two adjoining discs, positioned at an angle with respect to each other. This makes it very fast and very precise for positioning. It secured first place in the contest due to the innovative interfacing between the ROS and CodeSYS platforms.

Fig. 1: The different tilt angles of the (previous) SmartWrist

Due to its success, it was decided by Fontys and Delta Electronics to further develop this concept by building an innovative and valuable application for it, by semester 7 students. To successfully showcase the unique selling points of the SmartWrist concept (speed and precision), the idea of an aerial tracking device was chosen. This was later named as S.W.A.T.D.

III APPROACH AND THEORETICAL BACKGROUNDS

The system uses a camera for detection and tracking of aerial threats (such as drones). Using this visual information, the SmartWrist quickly and accurately positions the mounted camera to keep the target in the line of sight. This application brings many new technical challenges that are grouped into five work packages – **Vision, Sensors, Drivetrain, Control, and Redesign**. The first three of these will be discussed in this document.

A. Vision

This part of the system is responsible for the detection of the drone, tracking of the drone, and computing its coordinates. The images (video) from the camera are analyzed using an algorithm to accurately detect a drone (identification) and precisely track it (prediction). This can be done using an open-source computer vision library in C++ called OpenCV which already has many tracking and detection functions built-in. When it comes to tracking, there are many different techniques (algorithms) to choose from, some of which can even involve machine learning. However, machine learning approaches are hard to implement despite their robust results. Since the program will run on a microcontroller, the performance of the program in terms of speed should be kept in mind and optimized.
The output of this program will be the drone's coordinates relative to the camera frame. These coordinates will be converted to actionable values for the motor drivers to accurately move the wrist to by the drivetrain.

B. Sensors

The sensors in the system are the distance sensor (for measuring the distance of the drone from the S.W.A.T.D.) and the angle sensor (to measure the final tilt angle created by moving the discs of the SmartWrist). The rotation angle of each disc will need to be measured to accurately position it, so homing sensors are also a consideration.

C. Drivetrain

The drivetrain is responsible for converting the data output (target location coordinates) into information capable of controlling motors and thus moving the wrist to the desired location. A control algorithm is made in MATLAB that can calculate its path, and the Teensy tracks the movement of the wrist. This control algorithm is translated into C++ and put in a microcontroller. As all the sensor data is available in the microcontroller, a control loop has been generated to have error correction in the movement of the wrist. With this approach, it is possible to have the wrist move very fast and precisely according to the specifications.

IV ARCHITECTURE & COMMUNICATION

The distribution of the five work packages, along with the component choice and the communication protocols between them, was chosen after much consideration. The most popular interfacing choice was I2C since it was the easiest to implement. Therefore, it was used for all the communication within the Vision and Sensors work package, as well as the communication between the Teensy and the Programmable Logic Controller (PLC). The interface between the PLC and the motor drivers is done using Modbus, which is a serial communication protocol developed by Modicon since it is the de-facto standard for connecting industrial devices. The motor drivers send power to the drivetrain which results in movement of the wrist.
The final total architecture of the system, including both the electrical and the mechanical work packages, can be seen in figure 2.

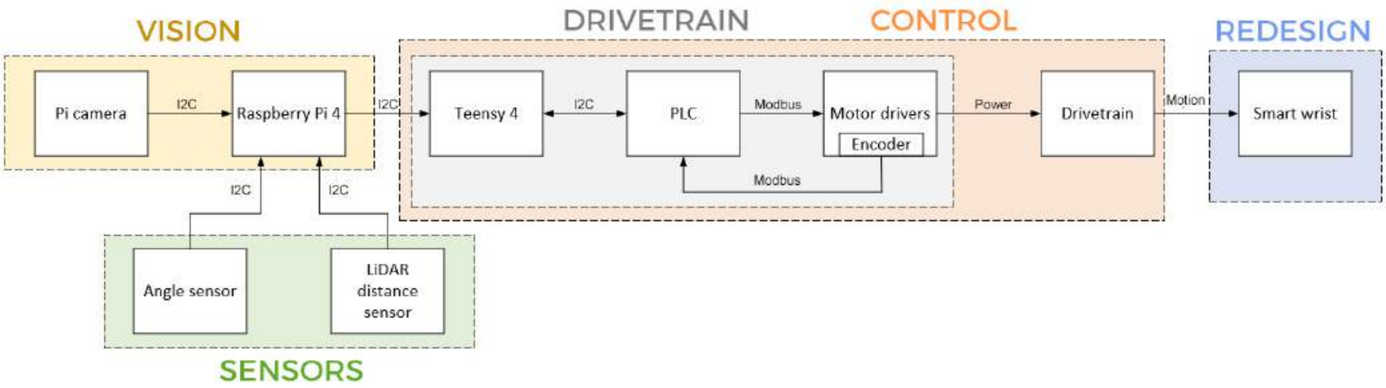

Fig. 2: Total Architecture and Communication

V DESIGN

A. *Vision*

The OpenCV code runs on the Raspberry Pi 4 which outputs a drone's coordinates relative to the center of the frame to the Teensy 4.0, interfaced via I2C. The Teensy will do the calculations for converting the coordinates to accurate values for the motor drivers.
For the detection and tracking algorithms, a machine learning approach was considered but due to the limitations in knowledge about training the data set, a more basic method – *Discriminative Correlation Filter with Channel and Spatial Reliability (CSRT)* - was used, and provides the best results for our application. This tracker works by training a filter with patches containing the object as well as nearby patches that do not contain the object. This allows the tracker to search the area around the previous position and exploit the fact that nearby patches are likely to contain the object. It performs well with unpredictable patterns of motion, can tolerate intermittent frame drops, adapts to scale and rotation, and can recover from failures when the object hasn't moved much.
The camera used is the *Raspberry Pi Camera Module v2* and has the following specifications:

- Optical Size: $1/4$"
- Video resolution and frame rate: 1080p30, 720p60 and 640 $\times$ 480p60/90
- Horizontal field of view: 62.2 degrees
- Vertical field of view: 48.8 degrees

A..1 Software

The flowchart in Fig. 3 gives an overview of the functions and the interaction between them.

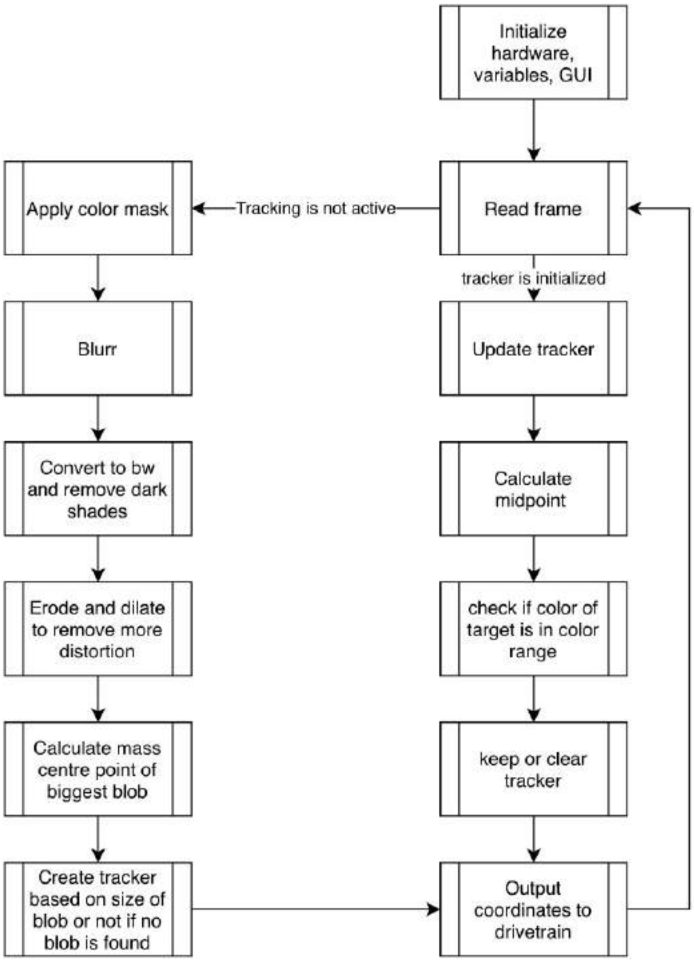

Fig. 3: Compact Flowchart of the Vision Software

B. Sensors

The distance sensor chosen is the *LW20-B LIDAR* sensor keeping in mind the distance range and the accuracy to fulfill the system requirement of a 50-meter range. It was later decided that the distance sensor can be used to aid the Vision work package in the detection (identification) of a drone upon initializing the system. The distance sensor has the following specifications:

- Accuracy: $\pm$ 0.01m
- Range: 50m

The angle sensor chosen is the *MPU9250* sensor which contains a gyroscope, an accelerometer, as well as a magnetometer which is needed to measure the rotation in the Z-axis.
Initially, it was decided that homing sensors would also be needed to be able to measure the rotation of each disc, but the chosen motors already contain encoders, so homing sensors are not needed.

C. Drivetrain

The microcontroller chosen is the Teensy 4.0 because of the high number of calculations that it needs to do, making it the preferred solution over Arduino or Raspberry Pi. Due to its high clock speed of 600 MHz and its relatively big RAM of 1024 KB, it is the most suitable controller for controlling the wrist. The Teensy is also supported by the Arduino IDE platform which makes it easier to program.
The Teensy communicates via an analog interface to the motor controllers. The feedback out of the motor controllers - an encoder that gives out pulses - is as an analog input into the microcontroller. Below in 4 is a flowchart of the control loop that is inside the Teensy 4.0. The program checks if a new position (coordinates) has been received from the Raspberry Pi. When there is a new position, the program gets the current position from the sensors and does calculations to find out the movement to make. This new

position is sent as commands to the motor drivers and the program continuously checks whether the correct new position has been reached.

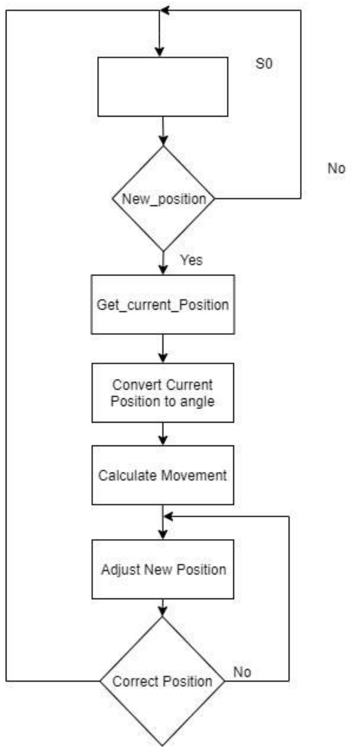

Fig. 4: Flowchart of Drivetrain Software

VI VERIFICATION RESULTS

A. Vision

The vision work package is a unique one since it can always be improved in terms of robustness and processing speed. The current vision system processes images at a rate of 10 frames per second which is sufficient for our prototype for detecting and tracking drones and outputting the coordinates.
Figure 5 shows the red circular object being correctly detected in the middle image while the other objects and colors are not. Then once it is detected, the tracking starts in the right image.

Fig. 5: Original Image (Left), Detection Result (Middle), Tracking Result (Right)

This is done through different stages of filtration as shown in figure 6. Starting from the top left, the first image shows the result of filtering out a specific set of values in the HSV color space. After this, it is blurred to remove edge imperfections and surface discoloration. Then it is converted to grayscale in order to convert it into black and white. This image is then “eroded” which results in smoothing out the edge and then increased back in size (“dilate”).

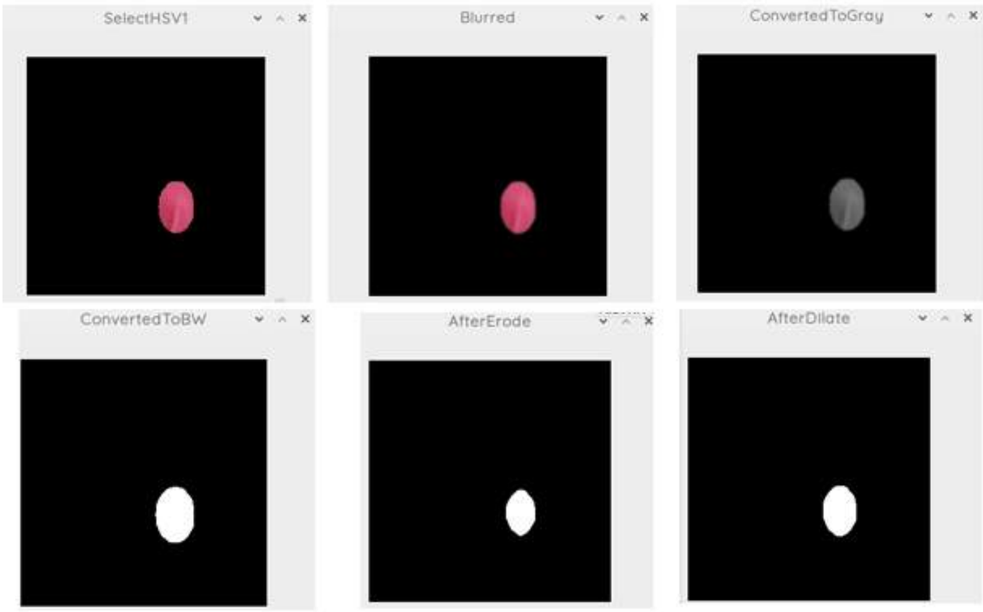

Fig. 6: The Different Stages of Filtration

B. Sensors

Using the LightWave software we can see the area that the sensor reaches. Figure 7 shows that an object is detected at a distance of 0.5 meters. The sensor can measure up to 50 meters and has a very high scan rate - about 388 readings per second. The accuracy of the sensor differs depending on the color of the target. A white target will absorb part of the wave and will cause false readings. The tests while the sensors are connected to the Raspberry Pi have yet to be done.

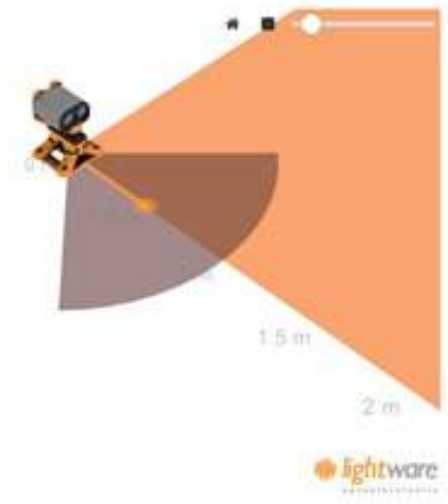

Fig. 7: LightWave Simulation of Distance Sensor

C. Drivetrain

All the individual modules work correctly - the control algorithm can run on the Teensy 4.0 and the Teensy can control the wrist. Unfortunately, the feedback of the rotary sensors could not be implemented due to the loud noise that is generated inside the motors. The combined drivetrain system does not yet work properly.

VII Conclusion & next steps

Using the top-down methodology of design to obtain the specifications from the user requirements, a fully functioning system design was successfully developed, with each module capable of individual performance as well as total integration and compatibility. The next group of engineers tasked with fully realizing this design now has a solid foundation to build upon.
For future work, the design can still be tweaked and tested to enhance the robustness and reliability of the performance. This most applies to the vision work package, since this is the beginning of the chain of command-flow and the quasi “mastermind” of the system. The CSRT algorithm relies on searching the area around the last known position of the object in successive frames and therefore doesn’t incorporate motion into its estimation. This can be a problem for faster drones. The current processing rate is an average of 10 frames per second which can be significantly improved by using a better microcontroller or finding a better algorithm, e.g. KCF which can improve the frame rate but may reduce performance. This must be tested and fine tuned by the next group. Sometimes the system may be fixated on a color other than the target color, thus making it less reliable in certain situations. Also, to improve performance in differently illuminated areas, a flashlight can be attached so that the target is illuminated uniformly in various lighting conditions.
Another solution for this vision system is to make use of machine learning. Transfer learning could be used for tracking and detection, that should also work better for longer distances and varying environments. The downside of this method is that the system must include hardware like a neural network stick to have sufficient processing power and also requires a certain level of expertise. With a neural network stick, the OpenCV tracker GoTurn can also be used, which is a tracker that learns the object in a given box. The downside is that it can’t automatically detect what it should track. If needed, the official library of “picamera” can be used for more advanced control of the camera, like camera resolution, framerate, and rotation.
It is advisable for the next group to implement the Teensy algorithm directly into the provided motion controller from Delta Electronics. This would be very innovative as there is no current solution to do a 4-way matrix calculation in the motion controller so the possibility of this needs to be investigated, and if so, be implemented.

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Lastly, the development of this project wouldn't have been possible without the focus, commitment, and teamwork of our colleagues who worked together to ensure progress.

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[1] S. . P. team. *SWATD-01*. University of Applied sciences Fontys Eindhoven, 2019.