



**Kaunas University of Technology**  
Faculty of Mechanical Engineering and Design

# **Design of Station for Autonomous Cargo Handling of Military UAVs**

Master's Final Degree Project

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Project author

**Assoc. Prof. Dr. Inga Skiedraitė**

Supervisor

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**Kaunas, 2026**



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Faculty of Mechanical Engineering and Design

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Mechatronics (6211EX017)

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**Kaunas, 2026**



**Kaunas University of Technology**  
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# **Design of Station for Autonomous Cargo Handling of Military UAVs**

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## Task of the Master's Final Degree Project

**Given to the student** – Karolis Maciejauskis

### 1. Title of the Project

Design of Station for Autonomous Cargo Handling of Military UAVs

*(In English)*

Autonominės krovinių valdymo stotelės kariniams bepiločiams orlaiviams projektavimas

*(In Lithuanian)*

### 2. Aim and Tasks of the Project

Aim: to design a mechatronic station for autonomous cargo handling of military UAVs.

Tasks:

1. to research cargo handling systems available commercially and present in scientific literature;
2. to define technical requirements and specifications;
3. to provide a conceptual mechanical and electrical design;
4. to design a prototypical control system;
5. to create a prototypical system.

### 3. Main Requirements and Conditions

The system should be portable, focused on logistics of food rations, basic medical supplies, light field equipment. Cargo load – 5 kg, should be able to handle 5 cargo units. Materials – commercially available, easy to produce.

### 4. Additional Requirements for the Project, Report and its Annexes

Not applicable.

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### **Summary**

A master's final degree project that is dedicated to the design of a mechatronic station for autonomous cargo handling of military unmanned aerial vehicles. The work is done due to the need of rapid adaption to the use of UAV drones in frontline logistics and other missions. This need became very apparent in the ongoing Ukraine war, where most supply related missions are now based on unmanned vehicle technology to remove alive personnel from the highest risk tasks. The absence of complementary autonomous cargo infrastructure that is deployable in field is the aim that is to be resolved within the project.

The work starts with a review of the military logistics followed by various station analysis available in commercial and scientific sectors. Commercial solutions are too heavy for military use, depend on external power and lack portability. While scientific stations are heavily dominated by battery swapping mechanism devices and not cargo handling. After the review, multiple technical requirements are drawn for the station. They include package weight of 5 kg, capacity of 5 cargo, worktime of 48 hours, portability, robustness, maximum weight of 25 kg.

With requirements established, a conceptual design for mechanical and electrical parts is developed. The station is designed as a cylindrical drum with top and bottom parts and internals within. The mechanism is driven by stepper motors with planetary gearboxes. Cargo detection is done with infrared phototransistor and diode. Two communication methods are established as optimal – LoRa communication and 4G. To finish, a functional prototypical control system is developed to control and test an actual 3D printed device. After initial testing, the concept is proven to be legitimate and that it can meet the majority of requirements at conceptual and prototypical design level.

Karolis Maciejauskis. Autonominės krovinių valdymo stotelės kariniams bepiločiams orlaiviams projektavimas. Magistro baigiamasis projektas, vadovė doc. dr. Inga Skiedraitė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija (E10), Inžinerijos mokslai (E).

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Kaunas, 2026. 67 p.

### **Santrauka**

Magistro baigiamasis projektas skirtas autonominės mechatroninės stotelės karinių bepiločių orlaivių krovinių valdymui suprojektuoti. Darbas atliktas dėl sparčiai didėjančio bepiločių orlaivių naudojimo karo fronto logistikoje bei kitose misijose. Šis poreikis ypač išryškėjo dėl karo Ukrainoje. Šiame kare didžioji dalis logistikos misijų jau vykdoma naudojant bepiločių transporto priemonių technologijas, siekiant apsaugoti personalą nuo pavojaus gyvybei keliančių užduočių. Pagrindinis projekto tikslas yra išspręsti esamos autonominės krovinių manipuliavimo infrastruktūros, tinkamos naudoti karinio fronto sąlygomis trūkumo problemą.

Darbas pradedamas karinės logistikos apžvalga, po to analizuojamos stotelės naudojamos komercinėje ir mokslinėje srityse. Komerciniai sprendimai yra per sunkūs kariniam naudojimui, taip pat jie priklausomi nuo išorinio maitinimo šaltinio, jiems trūksta mobilumo. Moksliniai darbai yra orientuoti į baterijų keitimo mechanizmus, o ne krovinių manipuliavimą. Atlikus apžvalgą nuspręsti reikalavimai stotelei. Vieno krovinio svoris iki 5 kg, stotelėje gali tilpti 5 kroviniai, stotelė gali dirbti iki 48 val., turi būti nešiojama, patikima ir sverti iki 25 kg.

Praeitoje dalyje nustačius reikalavimus, sukuriamas konceptualus mechaninės ir elektroninės dalies dizainas. Stotelė yra cilindrinės statinės formos, iš dvejų dalių, su papildomais komponentais viduje. Mechanizmas yra valdomas su žingsniniais varikliais ir planetinėmis pavarų dėžėmis. Krovinių aptikimui naudojamas infraraudonųjų spindulių foto tranzistorius ir diodas. Optimalūs komunikacijos būdai įvertinti LoRa radijo ryšys ir 4G. Galiausiai, sukurtas funkcionuojantis prototipas su prototipinė valdymo sistema. Prototipo paskirtis yra patikrinti valdymo sistemą ir 3D spausdintos stotelės patvarumą. Po pirmųjų bandymų nuspręsta, kad konceptas veikia ir gali atlikti didžiąją dalį iškeltų reikalavimų jau konceptualiam ir prototipiniam dizaino lygyje.

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## Introduction

The modern warfare has had an unprecedented change in the last ten years. While decade or two ago warfare would be thought of as a mass scale battle where heavy armoured machinery and infantry advances were the only way to push past the enemy. The ongoing conflict in Ukraine, and now in Iran and specifically the strait of Hormuz has proved that unmanned vehicle technologies caused a warfare renaissance per say. Various vehicles controlled remotely, for example unmanned areal vehicles have become a staple of fulfilling dangerous roles in military missions such as combat, reconnaissance and frontline logistics. Supply missions specifically have seen a large shift towards UAV and UAG use replacing human logistics. This allowed to minimise the risk of human personnel loss as the logistics operations are regarded as one of the most dangerous operations. In addition, this shift gave way to give to more morale-based supply runs for supplies that are not worth risking lives for. Despite this increase in safety, there is a lack of infrastructure supporting UAV logistics as most handling is done by hand, resulting in danger exposing moments where personnel must be present.

This existing possibility for danger exposition is the problem addressed within the project where a system capable of assistance is proposed. To get a grasp on what analogical solutions are present commercially available stations are reviewed and while they are advanced, they fail to meet crucial front-line requirements like portability, size, weight, cost. Scientific literature has more focus on battery swapping, making cargo handling stations rare or overlooked. The station is dedicated to address this gap in existing solutions. To be specific, the project presents a solution that is capable of handling military payloads and preparing them for pick-up.

The station is a portable, battery-powered, autonomous cargo handling station that contains pre-loaded cargo units within and be left unattended for an extended period of time in the front line. The station design uses cargo handling, portability and expendability as main pillars of evaluation with additional requirements established within work. To meet these evaluations and criteria, a conceptual design consisting of mechanical and electronical parts is done. To prove that the system can meet work and be sustainable a prototypical design is done and tested in real life. Additional notes on the manufacturing, testing process will also be provided with suggestions in that could be changed in further prototyping, manufacturing. The expectation of the work is to validate that the concept can be helpful for military personnel during frontline supply operations in turn extending the range and frequency of UAV operations. The station is expected to serve as a foundation for future development towards autonomous logistics networks.

Aim: to design a mechatronic station for autonomous cargo handling of military UAVs.

Tasks:

1. to research cargo handling systems available commercially and present in scientific literature;
2. to define technical requirements and specifications;
3. to provide a conceptual mechanical and electronical design;
4. to design a prototypical control system;
5. to create a prototypical system.

Hypothesis: A portable mechatronic station capable of autonomous operation can be designed to handle military payload cargo for UAV operations in the field, reducing personnel exposure in frontline environment.

## 1. Review of Cargo Delivery Systems and Military Logistics UAV Applications

The field of unmanned aerial vehicles had its origins at the creation of unmanned balloons in the middle 19<sup>th</sup> century when Austrians attacked Italy, following the creation, the next notable leap for technology was the usage of powered UAVs in WWI that further led this field towards pilotless winged, copter and other aerial vehicle designs aimed towards military applications during the 20<sup>th</sup> century [1]. The UAV research shifted towards commercial and scientific applications in the 1990s, for example, the first aerosonde (a UAV designed to collect weather data) to cross the Atlantic Ocean in 1998 named “Laima” by Juris Vagners after the Baltic deity of luck [2]. The 21<sup>st</sup> century has seen rapid advancements across all fields of unmanned aerial vehicles. In agriculture, UAVs are employed for field monitoring and fertilizer spraying. In construction, they are employed to inspect infrastructure and site surveying. Rescue forces have applied UAVs for search and rescue operations. Consumers use drones as recreational objects, for photography and videography. UAV research has grown substantially, and even between 2020 and 2023 the field had 47635 scientific documents related to UAV [3]. Unsurprisingly, the military sector, which was the main technology driving factor historically, remains dominant as seen in conflicts within the last century, predominantly the Ukraine war.



Fig. 1. "Baba Yaga" Military Logistics Drone With List of Common Uses [4]

The Ukraine war has prompted a significant shift in modern warfare, now characterized by the utilization of UAVs at an unprecedented scale, majority of which are small FPV drones that were intended for recreational use. Drone deployment has become so operationally critical that specialized drone units have been integrated within military brigades [5]. These vehicles are mainly used in military object elimination, reconnaissance and logistics, the latter being the focus of the study. An example of such UAV used in logistics is nicknamed “Baba Yaga” (Fig. 1) or the surge of unmanned ground vehicles that are estimated to handle the majority of logistics during the latest year of war, especially within heavy cargo loading, medical rescue operations. To properly evaluate the intended behaviour of the proposed system, this study draws upon both scientific research related to UAV and cargo manipulation, commercially available analogue systems and on the field experience from various military related sources.

## 1.1. Military UAV Logistics

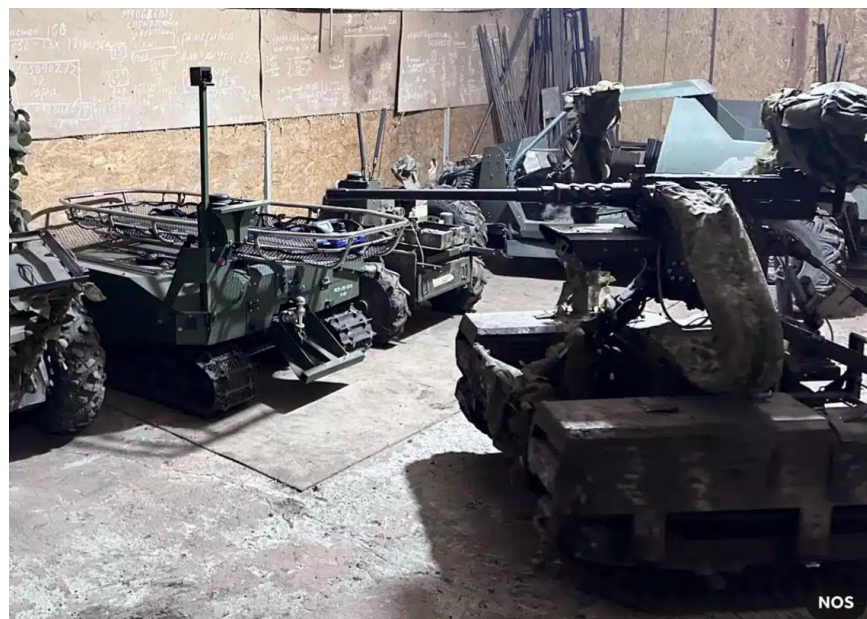
As stated in the introductory subchapter, the current shift in military warfare has turned towards UAV operations. Most of the discussion regarding the deployment of UAV and FPV drone is dedicated towards direct combat or reconnaissance while logistics is the least discussed application, possibly due to its supportive role. Although these missions are very common due to the nature of warfare where normal logistics are not possible due to constant surveillance. Common care packages consist of food, cigarettes, power banks, ammunition, medicine (Fig. 2).



**Fig. 2.** Contents of Deliveries [6]

As visible in Fig. 2, the supplies are not necessarily focused on warfare and can contain common food items like bread, water, sausages etc. These supply drops are not only used to give required resources for soldiers to last longer on the frontlines, but they additionally serve as important contributors to soldier morale. Due to this necessity, it is important to make such operations as safe as possible and normally supply route operations happen to be the most dangerous part of the operation [7]. For instance, manned convoys such as trucks, armoured vehicles have vital weaknesses: direct human vulnerability, predictable routes, susceptibility to human error, fuel and maintenance requirements, no terrain flexibility and communication difficulties. Deployment of UAV eliminates or minimises these difficulties, as they require no crew, can move through any terrain, are very cost effective, stealthy, can change directions instantaneously and have mostly no logistical footprint. Drones can still have communication difficulties; they are controlled by operators so human error still exists; they have short flight endurance and struggle during adverse weather conditions. Furthermore, their ability to operate across any terrain is significantly offset by limited payload capability. This weight capacity is one of the main dilemmas in UAV use as common commercial drones can be loaded with 0.5 – 10 kg, heavier industrial models can be loaded with 20-50 kg and largest military grade models can carry as far as 226 kg as was done by unmanned Black Hawk helicopter [8]. Naturally, the larger military grade models are far less common in warfare as they are expensive and most of logistics is done by the common commercial grade drones. Notably, some of the units dedicated towards unmanned systems saw their UAV deployment shift towards unmanned ground vehicle (UGV) logistics.

As the front line has become increasingly difficult to traverse due to the sheer number of UAVs in air the vehicle operations have shifted back towards ground [9]. This shift happened very fast, virtually in the second half of 2025. UGV overtook 90 % of logistics done in the frontline used by the 21<sup>st</sup> Regiment of Unmanned Systems, this moved UGV use from complementary to primary. It is important to note, that this drastic shift happened only for one regiment and while a similar trend is evident across the whole battlefield the UAV deployment in logistics will not disappear completely as UAV utilisation is still significant. As seen in Fig. 3, small, unmanned ground vehicles are very similar to general armoured vehicles, and they come with the previously discussed terrain flexibility, predictability difficulties, speed and range. Furthermore, UGVs are dedicated towards heavy payload deliveries that are more comparable to industrial grade drones like the “Baba Yaga”. Smaller payload deliveries done by commercial FPV drones still are very efficient and will be used in future operations.



**Fig. 3.** Unmanned Ground Vehicles Use in Warfare [29]

Furthermore, the article cited in reference [10] identifies additional emerging trends in UAV warfare that could potentially be implemented in UAV logistics as well. Such trends are the application of artificial intelligence and machine learning. For logistics this would allow complete autonomy, flight optimisation, fast problem solving during last steps of package delivery. Further advances in drone autonomy and swarming technologies will completely remove human interference. This would completely remove the difficulties of communications and the chance of human error that still exists in drone logistics. On the other hand, there is a possibility that counter measures will surpass the UAV use as this battlefield is developing at fast rates, a prime example being the rise of UGV use in logistics. This further illustrates how difficult it is to predict such trends with precision. On the other hand, trends in different sectors may shift towards warfare as was the case with FPV drones, which transitioned from commercial, hobbyist use into military application.

## **1.2. Commercial UAV Cargo Delivery and UAV Stations**

Apart from military applications, a prominent field that relates to UAV cargo delivery is the commercial parcel, supply shipping service. A notable example that filled both parcel and supply

shipping with UAV logistics is the company Zipline, that was started in 2016 with blood and medical product delivery across Rwanda that has many impassable regions with poor infrastructure, making standard transportation unreliable [11]. Generally, these drones are loaded with cargo manually within the distribution centres, after which they are launched with a sling type mechanism (Fig. 4) and then can autonomously travel to locations that require aid. First iterations of drones drop cargo from the air with parachutes, but as the name of the company may imply, the latest iterations do use ziplines to land the cargo. This cargo shipping done by Africa Zipline is taking flights in Rwanda (2016), Ghana (2019), Nigeria (2022), Kenya (2023) and Cote D'Ivoire (2023). The company has since expanded into USA, Arkansas (2023) and USA, Texas (2025) with more focus on parcel and food delivery. This expansion is a clear indication that the technology is viable, furthermore almost fully autonomous, apart from cargo loading.



**Fig. 4.** Zipline UAV Being Launched [12]

The latest iteration of zipline technologies also take a different approach of loading. In the newest designs, drones use containers attached to ziplines. The drone descends the container into the station where employees load it, after which it is retrieved and prepared for further delivery. Such docks can be implemented on rooftops and outdoors. Separate docks provide battery swapping, charging.

A similar calibre drone and general delivery service is Amazon and its Prime Air Drone Delivery [13]. Both companies share design overlaps, for example, the capacity goals are in the range of 2-3 kg, noise reduction is an important design aspect and apart from manual cargo loading systems are designed to be autonomous. The general algorithm of this delivery is likewise identical as the employees load cargo into the UAV manually, the UAV flies to the location and delivers the cargo. It is released mid-air, as opposed to Zipline's controlled landing mechanism. Further differences are evident in the results each company has achieved as Zipline proves itself to have more success, mostly from projects within Africa, while Amazon has setbacks that seem to exist from the start of the 2013 launch as the service is not as popular and has not scaled meaningfully. In general, while Amazon is an older service, Zipline had more success within the field because of its medical cargo delivery.

Matternet also provides cargo delivery services and has landing stations that can automatically load and unload cargo [14]. The station can be used by customers like a simple post-delivery station where objects are loaded into a locker machine similar to parcel machines that are seen within Lithuania. The first station was deployed in Switzerland, Lugano and as mentioned it is fully autonomous, the main achievement of this design is autonomous cargo and battery swapping of the design. It is

important to mention, that drones used with stations are specifically designed with payload and battery swap in mind and drones that do not belong to the Matternet system cannot be used. They are referred to as M2 drones that can carry payload of 2 kg and travel up to 20 kilometres. The loading system itself is 2.9 meters in height and has the diameter of 1.5 meters. It can handle 6 cargo units and 6 batteries, cargo and batteries can be temperature dependent as the bays control it. It also can store one drone within. Consumers can access the loading systems with RFID tags.

Volatus Aerospace provides drone nesting stations focused on operations during extreme weather and safety [15]. The primary technical specification of the system is the ability to withstand the weather conditions of -30 °C to 50 °C. It also features LTE SIM and SATCOM communication capabilities, has visual detection system, live view camera and a weather station. The design of the station is compact and weather protective, resembling a barrel shaped storage tank. (Fig. 5). Further technical information was not available online publicly, contacting for additional information was also unsuccessful.



**Fig. 5.** Volatus Aerospace Docking Station [15]

There are multiple commercially used UAV stations that are not capable of cargo handling, for example DJI Enterprise – DJI Dock 2 [16]. The station is weather resistant, but its primary appeal lies in its range of technologies within and size ratio. As it can track weather, interact with drones within 10 km radius, edit autonomous drone flights and plan routes. The weight of this dock is 34 kg while being 570 x 583 x 465 mm in size while closed. The main purpose of the station is to charge the drones specifically designed to interact with the dock. The system is completely fixed and non-portable while working, it requires a constant power wired power supply, maximum input power is 1000 W. Additional back up battery has 12 Ah capacity and can last for 5 hours at 25 °C. Operating temperature range is -20 °C to 45 °C (although temperature can be lower when tasks are not performed). The dock has network access via 10/100/1000 Mbps Ethernet communication standard and can support wind, rain, temperature, water, humidity sensors. The system is compatible exclusively with manufacturer designated drones, which enter the dock from above. The mechanical design features a box shaped enclosure with two doors opening upon drone approach (Fig. 6). Additionally, the drones themselves weigh 1.4 kg and can carry payload of ~200 grams. A new iteration of the dock is currently in production. However, technical data is not publicly available. The manufacturers claim improved environmental resistance compared to the second-generation dock.



**Fig. 6.** DJI Dock 2 [16]

A larger analogue station ecosystem version of DJI Dock is JOUAV Multirotor Hangar [17]. This station has a very similar box look with two doors opening at the top (Fig. 7). Other similar aspects are: wired power supply; communication interface (although it also supports optical fibre); functions of temperature, humidity, air pressure monitoring; live video feed. Unlike DJI Dock 2, the station does not charge drones directly but instead performs automated battery swaps. Additionally, the device measures 1700 x 1500 x 2200 mm and weighs 250 kg making it larger than its counterpart. The technical specifications that are publicly available are limited. The company specifies what industries this ecosystem can be applied to, for example, environmental inspection, emergency response and city smartification. The control system uses artificial intelligence to determine anomalies in the environment with data gathered via sensors and drones that are within the same appliance ecosystem. The UAV has only one notable specification available - the maximum payload capacity is 6 kg.



**Fig. 7.** JOUAV Multirotor Hangar [17]

Last station that will be discussed in the commercially available section is the A2Z AirDock [18]. It differs from other systems in that it features a completely open design. The drones are charged at the top, with the aid of a zipline system, drones can also be manually loaded with cargo. Hub has 5G, 4G and radio communications. With the manufacturer's provided product guide, accurate technical

information was gathered. There are four designs of AirDock. First two are Quad and Dual. As the name implies Quad has four wings at the top and Dual has two. The larger variant weighs 450 kg, is 6000 x 4300 x 4300 mm in size. Dual station can draw up to 2600 W power, while Quad – 5200 W. Two other designs are for single UAV; it is the Portable and Sheltered designs. Portable weighs only 40 kg, is the size of 1750 x 900 x 650 mm and has 1300 W max power, charge time is the same. Shelter weighs 500 kg, has the size of 2563 x 1853 x 2137 mm when closed. Max power is 450 W; it also has additional communication standards like ethernet and RS485.

**Table 1.** Summary of Commercial Drone Stations

Station	General Purpose	Portability	Cargo Handling	Weather Resistance	Size, mm	Weight, kg
Metternet	Parcel delivery, battery swapping	No	Yes	Yes	1500 x 1500 x 2900	Unavailable
Volatus Aerospace	Operations during extreme weather	No	No	Yes	Unavailable	Unavailable
DJI Dock 2	Environment tracking, drone controlling, charging	Yes	No	Yes	570 x 583 x 465	34
JOUAV	Environment tracking, emergency response, battery swapping	No	No	Yes	1700 x 1500 x 2200	250
A2Z AirDock Quad	Drone charging, manual cargo swapping	No	Partial	No	6000 x 4300 x 4300	450

Table 1 lists general comparable aspects for the stations that were described. In general, shared design aspects across all stations is the need for battery charging and swapping. This is not a surprise as this is one of the main hurdles in drone utilisation, however, as this work is focused on military drone use this need may be obsolete as smaller FPV drones in warfare are not expected to recharge and are treated as a disposable resource. For this reason the gap that is cargo loading can be substituted with battery assessment. When reviewing the station design choices it seems that almost all of them have a design focus on closed systems to withstand weather, this should be accounted for in the project's design as weather conditions can affect how logistics are done in the frontline. Additionally, all stations have another drawback – the size. All the mechanisms are large, even the smallest station is half a meter in all axes. In military conditions the stations would require stealth, they should not leave thermal footprint so the design in general should differ, especially from the larger stations like A2Z Air Dock. This also applies to the weight. Another aspect that is problematic in all stations is the power supply, military grade station should be capable of operating on its own battery, although DJI Dock 2 does have a safety battery that does allow it to work for some time after power shortage. Lastly, when comparing what should be done within the work, military focused station should be portable easily, DJI Dock 2 is the closest design in that regard.

Besides the overviewed solutions there are multiple additional docks, stations and drone with dock ecosystems. The overlapping and common design choices are the inclusion of drones making stations come with the whole package. Charging, battery replacement is the core goal of most designs. This makes sense as battery life is a vital drawback of autonomous UAV operations. While charging all the stations become docking stations with sheltered stations having the upper hand at weather resistance. Although as seen with AirDock, sheltered version can become a lot heavier than its

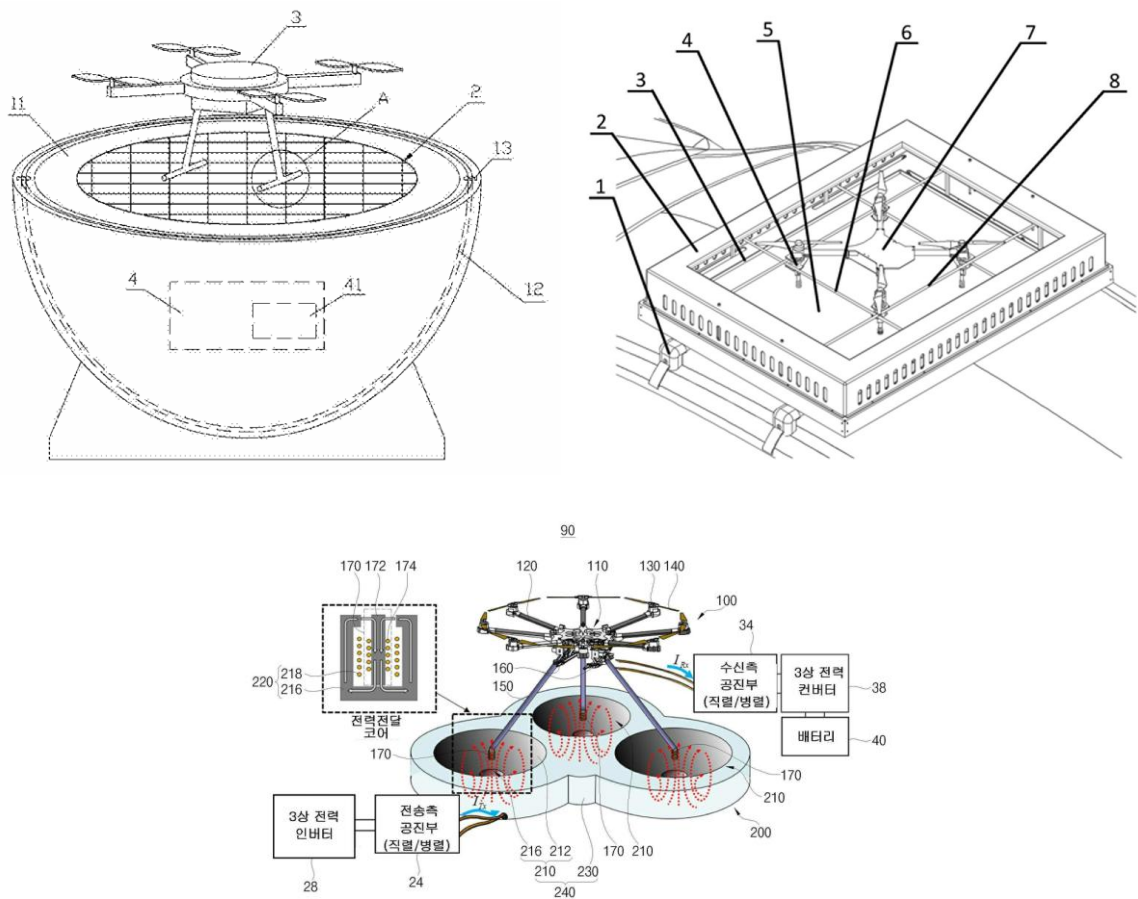
portable counterpart. Other portable stations require two operators to carry, it or even an SUV for transport. Finally, a key focus is implementation of AI within the stations. Reasoning behind AI is to provide an easy-to-use interface where you can read drone, station data. Furthermore, it seems that latest models all include some sort of AI; to better understand the motives behind this implementation, the following chapter will review current scientific literature on drone stations, systems and research trends.

### **1.3. Scientific Literature Related to UAV Cargo Manipulation**

To examine the subject of UAV cargo manipulation at a more insightful level, the trends regarding UAV research should first be analysed. The previously referenced paper provides an in-depth analysis of the existing research trends regarding unmanned aerial vehicles for three years (2020 – 2022) [3]. The largest share of research is attributed to antenna-related topics, accounting for 47% of work conducted in this direction. To expand more, antenna research was dedicated to better communication and designs made to withstand harsh environments, other aspects overlapped with different research directions. For example, three other connectivity and network related research directions are aircraft detection (12 %), remote sensing (8 %) and aircraft control (5 %). All four account for 34 241 references, which includes various keywords within titles, abstracts and keyword fields. The reasoning behind this scientific direction is not unprecedented as connectivity, coordination at long distances and environment where UAVs can be accounted to be core problems regarding the design, production and utilisation. These subjects delve into various communication technologies like commonly known Wi-Fi, Bluetooth, 5G; collision detection, perception and environment sensing with the help of LIDAR, optical cameras and other types of sensors. Another important trajectory is utilization of artificial intelligence, deep learning, reinforcement learning, internet of things and other aspects related to computer science. The sum of these attractions is 8 730 references. With a rapid increase in AI usage from 2023 up to 2026 it is fair to assume that these subjects should see an increase in popularity as well. More concrete examples on how AI is used can be shown within research of autonomous flight, landing and minimisation of human interaction. Conversely, research also exists on human-UAV interaction using AI, ML and DL, including hand gesture recognition and navigation around unpredictable human obstacles. The research paper also exemplifies that during the three-year trend AI surpassed antennas in popularity during the last year. The authors note that main future research directions for this fields may mainly be related to AI, integration of machine learning models even deeper into UAV design. Other fields mentioned are environmental monitoring, miniaturization, UAV swarm capabilities, suspension systems, and payload handling. These trends highlight core challenges that are relevant when designing UAV related products like a cargo loading system, this includes areas of connectivity, possible autonomous control, artificial intelligence integration.

A separate research paper specifically dedicated to analysing positioning mechanisms within UAV landing systems allows for a closer examination of subjects relevant to the project [19]. The papers that align most closely with the goals of this work will be examined in greater depth in the second part of this chapter. According to the authors, the primary motivation behind most landing systems is limited drone battery life and the difficulties of tackling this problem with simple solutions. Beyond charging, other, more specialized applications like cargo manipulation and data exchange require dedicated landing infrastructure. To segment further, such applications can consist of simple parcel, medical supply delivery services, geological, flight path and weather data uploads. The main goal of the paper is to analyse multiple landing mechanisms dedicated to the topic of UAVs and to classify

them. Authors divide mechanisms into classes that consist of platforms with and without positioning. Platforms without positioning are generally used as charging platforms. This design can address the issue of correct repetitive landing with compensation for errors via large charging fields that can be made from electrode grids, pads, wireless charging mechanisms. Platforms with positioning can be subdivided into active and passive mechanisms. As the name implies, active mechanisms employ means to catch, stabilise and guide the drones during landing with the primary design choice being active pushers that close in on the drone. Passive positioning systems have more variation such as conical funnel systems that require UAV to have protrusions which seat into funnels when landing; landing tracks that match the form of the UAV; overhead funnels that allow docking into nonstandard docks. Purely mechanical and moving part absent methods provide additional benefits of energy saving, simple and economic design. Each mechanism may have its individual strengths, to better understand the trade-offs within various landing systems, illustrative examples are provided in Fig. 8.



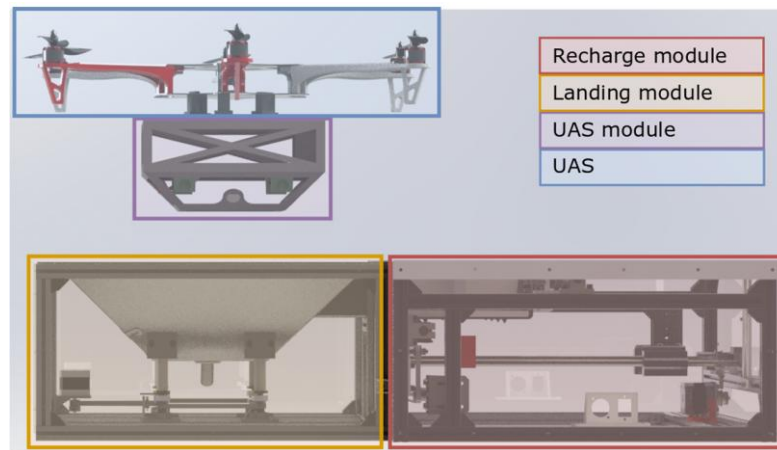
**Fig. 8.** Left: Platform Without Positioning [20]. Right: Platform With Active Positioning [21]. Bottom: Platform With Passive Positioning [22]

Platforms without positioning are structurally simple. This simplicity can give an economical benefit, easier scalability and adaptability to various drone designs. The primary design consideration for this type of mechanism is the electrode positioning style that can vary from simple rectangular contacts to vertically separated meshes. Even with the simple and adaptable design, the system is insufficient when weather conditions are extreme or for functions beyond charging. For example, cargo loading is never considered within the various designs presented within the paper. Package loading requires

an accurate contact point between the UAV and the container. Consequently, the latter two methods are considered more promising as they produce a predictable drone landing scenario. Active positioning uses various actuators to catch the UAV, many of which are identified as pushers that are divided into parallel, profile and rotating. Parallel pushers are considered optimal for size variations but have most moving components. Profile pushers generally have fewer elements, but drone adaptability falls short. Rotating pushers have the least elements, but the poorest adaptability. All pushers have a requirement for actuators, but minimisation of their amount is possible while making the pusher geometry more complex with a trade off in adaptability. On the other end of the positioning platform spectrum, passive funnels use no actuators at all. They can be subdivided by how they approach the funnelling method: for each leg, for all legs, for the whole body. All three options are less adaptable, than active pushing methods but do not need moving parts. Whole body basing has the most customizability, followed by all leg slotting which was used the most within the article. The least optimal of the three was the each-leg method, due to its rigid design being adaptable to only one leg configuration. Similarly, closed contour methods that are designed to fit UAVs are reviewed within the paper. They do not require legs when compared to previous passive methods, but most designs are quadcopter drones only. This orientation may not be a problem by itself, because all the designs can be redone to fit military drones like “Baba Yaga”. Parallel pusher and whole-body funnelling methods would provide the optimal results out of reviewed categories and subcategories.

Alternative categorisation used in another article portrays an approach to this problem by dividing stations into mobile and fixed [23]. Authors give additional brackets that can be used to differentiate various systems that are analysed. With consideration of the requirements raised for the project, main differentiations are positioning, package delivery, landing system design with secondary options being charging method, battery exchange etc. Some of the characteristics overlap with previously discussed article, like the landing system. Authors also subdivide this characteristic with active or passive designs, but additionally raise orientation as self-levelling, tilted or fixed as an important aspect. This feature is important when the station is portable and may be used where terrain is uneven. Portability does not mean that the station is mobile, just that it can be moved between locations, remaining stationary during operation. Additionally, when landing (especially autonomically) it is crucial to determine the positioning between targeted platform and the UAV itself. There are multiple methods to gather this positioning information for precision landing, for example, simple visual camera, wireless connection like 4G, 5G, sound waves etc. Furthermore, after landing the main purpose of most systems is battery charging or changing, as the goal of the work is to create a system that can swap cargo, battery charging should be investigated further. Thus, the analysis of this article will be an attempt to review battery changing mechanisms together with fixed and portable system overviews.

In the previous subchapter, almost every discussed station fits into the fixed station category. As reflected in the name and the discussed systems, the main aspect for this type of mechanism is the stationary nature. This stationarity does not innately mean that the system is completely immobile, for example, DJI dock weighs only 34 kg and two people can relocate it. Although, when operating, the station must be fixed. When authors are discussing such fixed systems, the first raised problem is docking approach and precise landing that is countered via various methods such as visual markers, complicated AI algorithms, radio, optic sensors etc. Other problems associated with fixed systems are the core design choices taken for systems and mechanisms within.



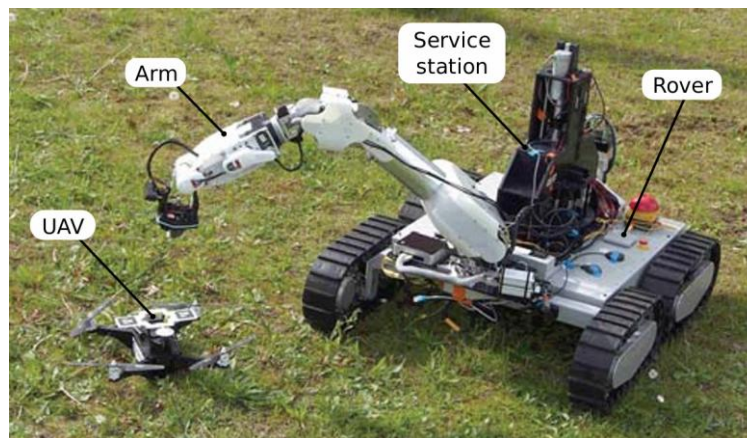
**Fig. 9.** Modular Battery Swapping Station [24]

For example, authors of an article focused on a docking station that may autonomously charge and swap batteries of drones made landing mechanism similar to already discussed methodologies [19]. The station consists of four individual parts: recharge module, landing module, UAS and UAS module (Fig. 9). Authors raise multiple criteria when designing the station. Firstly, it must fit multiple UAV, this is a logical requirement but as seen in commercially available devices, difficult or inefficient to implement. Secondly, modularity between the UAS and docking station, which complements multiple UAV compatibility. Lastly, robustness, which should be a universal requirement for all mechanisms due to fragility in UAV operations. The design itself requires a module that should be applicable to multiple drones, in this example, the module is cone shaped (similar designs were discussed during the analysis of article 14). The landing module matches the form of the cone to secure the landing. The module must still maintain individual compatibility with different UAV types, as the chassis dimensions may vary, maybe individual attachable legs could provide more compatibility in exchange for robustness. This is one of the main difficulties with UAS module designs. Recharge module handles safety, recharge and contains the recharge mechanism. Safety mechanisms consist of battery charge monitoring, UAS slotting alignment checking, autonomous decision making if swapping is required, it also keeps the UAS active during swapping. In terms of electromechanical hardware, the system is highly robust and as the authors conclude that in practice the device functions with multiple UAV types with acceptable robustness. The authors additionally aim to extend the swapping mechanism capabilities to payload swapping, which could potentially extend to the cargo swapping requirements of this project.



**Fig. 10.** Multi-Rotor UAV Power Relay Platform [25]

A second example of a fixed battery swapping station presents a similar design [25]. The authors call this system multi-rotor UAV power relay platform (Fig.10). The system, like the previous design, consists out of UAV and three parts, although the parts are called tarmac, battery and manipulator modules. The tarmac module does not have mechanical slotting; it is swapped with a simple platform with parallel pushers. This design limits compatibility to quad-rotor UAVs only but could accommodate other types if the pusher mechanisms were adjustable. Below the tarmac module, battery dock is installed. The dock is rotary and can contain multiple batteries that can be charged simultaneously. The rotary mechanism is spun via a separate NEMA motor. Although previous article authors do not describe the battery module in depth, this system appears more promising and adaptable to cargo dispensing. Both modules are connected via a manipulator that transfers batteries from the dock to the UAV. The manipulator is simple, as it only requires two degrees of freedom. It should be considered if aligning the tarmac and battery modules in one plane could remove the need for one degree of freedom, lessening the mechanical component amount, weight, complexity. Authors claim that the success rate of the system is 80 percent and that the main challenge is friction among the components. From the first look both systems may look the same, but as seen they do have differences in all steps of the design. Both approaches seem viable, but the limiting factor of both is that they are fixed and cannot operate while moving.



**Fig. 11.** SHERPA Mobile Ground Base [26]

Moving systems that overcome the limitations of previous designs do exist. As authors of the article [18] explain, there are three different moving station designs: ground stations, airborne stations and water stations. To assess the design of such stations, only ground stations will be analysed as it provides the closest solution to the scenario chosen for this project. An exact example of this system can be seen in Fig. 11. The portrayed service station is called SHERPA [26]. The device does not provide a landing platform per se, but the UAV has to land in the vicinity of the mobile ground base after which it is located and manipulated with the use of lidar, IMU and GPS. The rover contains an Intel NUC computer, can connect with Wi-Fi and operate for 6 hours. During the operating hours the station uses a robotic arm that has 7 degrees of freedom. As the UAV lands on ground, it is sensible to have a complicated manipulator, because limitations in movement may constrain the rover too much and it will not be able to access the UAV. On the other hand, the system is very complicated already, if the terrain where the UAV is to land can be predicted, a simpler manipulator implementation may be possible. Additionally, the drones used within the project are custom-built for simple battery access and gripping, which allows for further simplification. Currently the UAV is detected with cameras, picked up via gripper and docked at the service station where battery is

exchanged, then it is moved back on the ground. A direct exchange on the ground may be possible, similar in concept to the power relay platform discussed above. In general, this system is complicated, but the authors prove that the exchange is successful. Yet even though this analysis is done with cargo manipulation in mind, in all of the systems discussed none of the solutions are solely dedicated to this concept.



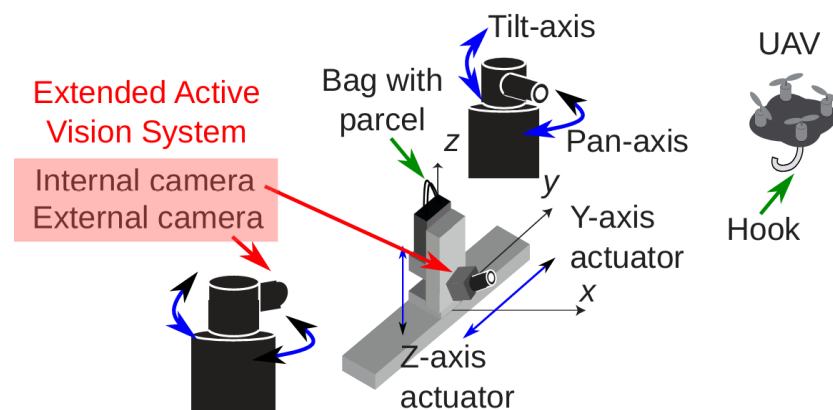
**Fig. 12.** Left: Automatic Item Pick-Up Gripper [27]. Right: RAPTOR Pick-Up Gripper [28]. Bottom: Hook Type Gripper [29]

The concept of parcel and cargo manipulation has been analysed.. The main design characteristics are often orientated towards payloads that are capable of grabbing and carrying cargo rather than full stations that may load the UAV with cargo, swap cargo and perform other tasks available in the previously analysed stations. To be exact, the designs are generally orientated towards gripper style systems (Fig. 12).

Looking from the left, the first shown system is an automatic gripper designed to manipulate objects [27]. The main aspect that differentiates this design from the other two is that the gripper can grab objects that are in front rather than directly below. The upside for this is that objects that cannot be held from the top or are in tight spaces are possible to manipulate, the downside is that heavy objects can disbalance the UAV easily as torque forces are introduced. The gripper fingers are made from polyurethane; this flexible material gives better grasping capabilities. The front moving system is controlled with belt pulleys and bars made from polycarbonate; the authors verify that the payload capability of such a system is 700 grams. Given that the gripper weighs approximately 1 kilogram even when designed for minimal weight, the additional torque from front gripping remains within a reasonable load range. A UAV with higher payload capacity would naturally mitigate this limitation. Electronic components are consumer grade; the main actuator control is done with Arduino Uno, and more complicated actions are done with Raspberry Pi. These complicated actions are the vision-based object detection and grabbing. Packages are detected with the use labels that are applied on them, a camera on the UAV captures the view of the package where aforementioned Raspberry Pi calculates

the area of the label to determine the distance to the object. This method is simple and optimal; a similar approach is employed in ISS free-flying robots Astrobees using AR tags [30]. The downside is that all packages must be marked beforehand, thus a combination of radio, ultrasonic sensor could assist in measuring distance. Yet, apart from the two main drawbacks being the torque from the gripper design and the limitations of visual distance determination, the gripper does provide a capable solution that is considerably cheap as all of it is built from commercially available materials.

The gripper shown on the right takes the design to grabbing objects directly below itself [28]. Compared to the previous mechanism, it can grab different objects from different axes. The advantage being that there are no additional torque forces and elements like additional bars, motors, pulleys. The authors elaborate in depth on the software used for the gripper mechanism and on the middleware called Robot Operating System – ROS. This operating system is referred to as middleware as it assists in individual part communication within the system. At the end they choose to design their own alternative middleware as it would be more targeted towards the required task, thus increasing speed of computing. This alternative is the better option and should be followed similarly within this project, as simple Arduino IDE code implementation could suffice for simple tasks while ROS can generally be overcomplicating the system. The authors mechanically modified an existing UAV to accommodate the gripper, this was achieved through the addition of a PLA mount. Compared to the previous design, this mount is considerably more compact, furthermore PLA is lighter, but less durable. The drawback is that mount has to be redesigned for each individual UAV, this also applies to the previous gripper and the battery swapping station in article 24. The gripper itself is designed based on Fin Ray design, that is designed to wrap around objects when grabbing. Fingers are moved with the help of servo motors that are controlled by an Arduino Nano which receives commands from a Raspberry Pi. This micro computer handles all of onboard calculations and communications. Additionally, the drone contains Pixhawk 4 flight controller that assists in flight trajectory analysis. Additional offboard control is provided via standard computers to supplement onboard computational power; this also includes the visual camera that provides information for flight path calculation as the drone itself does not have sensors for object grabbing. This highlights a core design difference between the two gripper systems, as the latter system implements additional hardware off the drone as opposed to the first system where the hardware is contained solely on the UAV. Then again, both mechanisms require a considerable number of components to function, the computation must account for flight path, object location, gripper location and synchronisation when grabbing the object.



**Fig. 13.** Hook Type Mechanism Working With a Station Dedicated for Parcel Pick-Up [29]

The last article presents a far simpler design that requires less components on the UAV but contains parcel pick-up station [29]. The authors choose this hook style method due to the difficulties of energy inefficiency and complicated controls when using the previously discussed systems. The whole concept of this design is visible in Fig. 13. As said, the UAV itself has less components; to be exact it only contains a hook mounted on it. This increases the UAV flying time without additional payload which also can be larger as the hook does not weigh a lot, the downside is that the object must have a handle that could be grabbed with a hook. Besides the hook, the station contains two actuators for cargo height and position along y axis adjustment. The whole system has three cameras, two of which are externally mounted and can rotate. The UAV position is triangulated via the feedback from all three cameras, then actuators can adjust the location of the parcel along the two axes to match the flightpath of the UAV, making the system fully autonomous and adaptable to UAV flight. In general, this system draws upon key characteristics from several previously discussed methodologies, it uses a simple UAV add-on and the station itself is not very complicated. On the other hand, it requires additional camera mounting locations, current design would not withstand harsh weather as it is completely open. Although this weather vulnerability is self-evident, the simplicity of such UAV payload design can be heavily compensated in station complexity. When looking at all three manipulators, the two grippers and a hook, it seems that simplification of UAV attachments may require more design resources in the station itself as it must accommodate for the pick-up. For military logistics, simple and robust methods are more reliable; therefore, hook-type or passive gripper designs represent the more suitable solution.

#### **1.4. Chapter Summary**

Drone usage has shifted towards military warfare in the last decade due to the Ukraine war where commercial (0.5-10 kg payload), industrial (20-50 kg payload) and military drones (up to 226 kg payload) are being used. This includes combat, reconnaissance and logistics, the latter encompassing food, cigarettes, power banks, ammunition and medicine packages. They are now generally done by unmanned vehicles as they reduce the risk of human loss, can traverse difficult terrain and are less predictable. Latest reports see a shift towards unmanned ground vehicles used as the main transport method while future trend predictions see AI and ML integration, full autonomy and defence against UAV as the most realistic. Commercial drone cargo delivery was pioneered by Zipline in Rwanda from 2016, initially focused on medical supply transportation. Currently UAV deliveries have moved towards city parcel delivery where systems are loaded manually and drop cargo automatically. Various stations are used, with the main design focus being weather resistance, battery charging and swapping. None of the stations can fully be applicable for military use, but DJI Dock 2 comes the closest as it is relatively compact and portable. In scientific literature the research trends are mainly focused on antennas, aircraft detection, remote sensing. In station papers the main motivation behind designs was limited battery life. Landing mechanisms can have no positioning, active and passive positioning. Stations alternatively can be divided into mobile and fixed. Many methods use battery swapping that can be changed into cargo loading. There are gripper focused designs that are dedicated to cargo manipulation. Complicated grippers do not require stations, while passive hooks need a more complicated mechanisms on ground to compensate. The reviewed literature provides a sufficient foundation for the design requirements of the proposed system. Key takeaways include the need for weather resistance, compact form factor, cargo handling capability and compatibility with commercial UAV platforms. These requirements will be further developed in the following chapter, where the design process of the cargo loading system is outlined.

## 2. System Requirements and Draft Design

During the overview done in the previous chapter it is evident that there is a broad shift towards UAV and UGV use in logistics as an alternative to current personnel handled operations. This transition from personnel-handled logistics towards unmanned vehicle operations is natural with the increase in research regarding UAV and UGV. With future trends being related to complete autonomy, machine learning, artificial intelligence it is evident that a strong factor of this change is the requirement of human error removal that comes with manual labour. Commercially available solutions show that UAV based delivery has potential to become a standard part of life, although these solutions do not meet the military needs that are focused on within the project. For example, all stations require constant external power supply, this constraint does not allow portability and in frontlines, being stationary for extended periods of time is detrimental. Furthermore, commercial stations are massive, A2Z AirDock is 6 meters tall, while the smallest DJI Dock is around 0.5 meter in height, length and width. While DJI Dock is probably the closest acceptable design, the other stations do have large visual signatures and are completely immovable after installation, a process that itself can take hours or days. Even after installation, the cost of upkeep and the risk of expensive equipment loss render stations impractical. To summarise, the size and limited portability of commercial stations represent the largest drawback when it comes to military use context, that drawback has been only partially addressed in scientific literature.



**Fig. 14.** Logistic Drone Use in Military Operations [31]

Within the scientific literature field, there are numerous options that should be considered during the conceptual design process. For instance, some UAVs that are used in tandem with stations require massive additional payloads for basing on loading or charging platforms. As seen in Fig. 14, the drones used in military logistics generally have very minimal number of additional payloads as this allows it to carry more weight. In these images the weight of packages is around 10 kg [31]. Few works address that gap from the perspective of gripping mechanisms, but it was deduced that complicated grippers will not fit the need as they reduce the available payload weight. Furthermore, the drones visible in Fig. 14 appear to utilise hook-type attachments in operation. Apart from complicated payloads it is also visible that most of scientific literature is rather focused on battery swapping as opposed to cargo loading. This gap is one of the main goals that are to be addressed in the work. On the other hand, when compared to commercial stations there are more portable variants available and built, even the fixed stations seem a lot lighter visually than commercial stations. This allows the reasoning that light and possibly portable stations are possible and should be addressed

from a military perspective. Additionally scientific literature stations seem to ignore the factor of harsh environment operations that is one of the main talking points during commercial station technical specification analysis. This suggests that the literature works at cross purposes, where similar requirements are overlooked due to differing problem contexts. Finally, there are some points that are lacking in military field and on the contrary are not applicable or not thought through military operations perspective.

Looking at this from military point of view, there is no similar UAV cargo infrastructure and most of the work is done manually. While it could be argued that this is because there is no need for such devices, it could also be looked at differently. UGV use saw its rise in the last half a year, now it is described as unprecedented and unexpected. Before the shift it was regarded as only complementary method to UAV. This demonstrates that unconventional approaches may prove viable as it can change the landscape of the battlefield. Additionally, UAV logistics (and now UGV) are used widely, but not as discussed within academically as most of the focus seems to be towards combat and reconnaissance operations, while the rise of UGV use show that UAV logistics may need improvements to ensure safety and operation success. To make those improvements, by identifying both the gaps and strengths within the reviewed literature, it should be possible to establish the main requirements to the station that should be designed in the further chapters.

## 2.1. Technical Specifications and Requirements

To visualise the general reasoning, most of the requirements will be assessed from the reviewed literature, this includes both choices that are deemed useful and gaps that seem missing. For example, the hook design that is very robust and applicable, weather resistant covers that protect the stations and UAV, or the lack of cargo loading methods that is visible in most literature. Another important requirement aspect is the military context that is established throughout the project, like weight of military packages. Lastly, some constraints are imposed within the project title pages, they also influence the direction of the design. It should be noted that the requirements and design choices outlined in this and subsequent chapters serve as a conceptual guideline. As this work concerns a prototype-level design, exact specifications are subject to change during the development process and should not be treated as finalised parameters.



**Fig. 15.** AN/PRC-117G Manpack Radio [32]

A general summary of the requirements that could be raised from the review of commercial and scientific solutions consists of various points. Almost all stations prioritised battery charging and swapping over cargo and as said previously, this should be one of the primary considerations when establishing design requirements. Additionally, other factors like robustness should be accounted for as it also is an important factor within UAV and military fields. To address it, passive mechanisms, minimal electronics, simple designs should be prioritised. These simplification priorities will also provide minimal weight increase when designing the product and making it possible to compare it to other military grade portable systems like AN/PRC-117G manpack radio [32] that weigh around 6

kg (Fig. 15). While requirements are mostly established in literature are important, there are some requirements that should be raised from individual operational requirements.

As military infrastructure of this kind is virtually non-existent, there are relevant aspects that cannot be fully addressed through literature alone. These factors include the length of unattended operation which must exist as it is one of the overlying reasons for this project. Additionally, systems should be expendable and inexpensive, how this is approached should be discussed. How personnel operate, carry and transport such systems are questions that must also be addressed. To be exact, many issues absent from scientific and commercial literature may prove critical in the field. The following pages are dedicated towards this examination of what requirements should be met when designing the station for autonomous cargo handling.

**Table 2.** Summary of Requirements

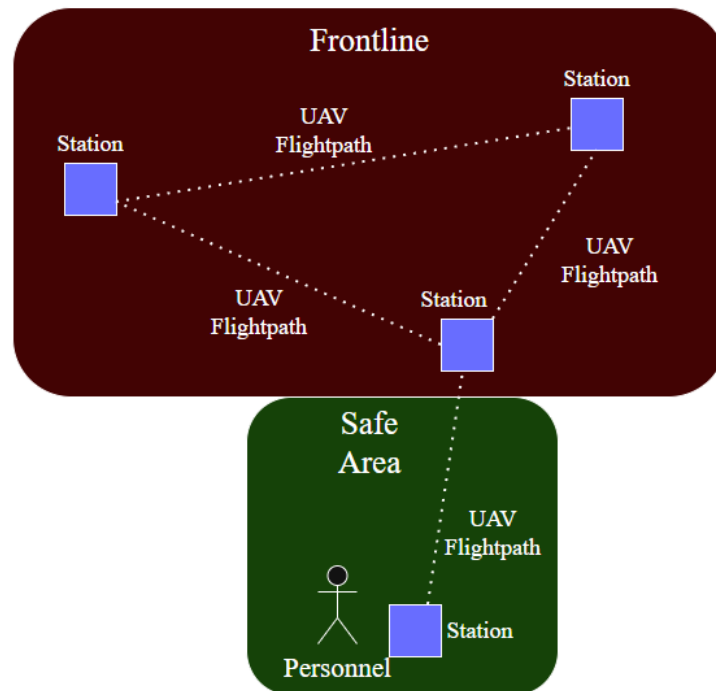
Requirement	Specification
Package Weight	Maximum 5 kg per package
Package Capacity	Minimum 5 packages
Unattended Operation	Minimum 48 hours
Power Supply	Internal
Weather resistance	Rain and wind resistance
Deployment	Portable
Pick-up	Robust, simple
Station Weight	25 kg without cargo
UAV compatibility	FPV class
Personnel Exposure	None during drone operations
Materials	Cheap to produce
Cost	Expendable if destroyed

Table 2 presents the requirements of the station gathered throughout the literature review and when analysing individual military needs. The first requirement that should be addressed is the package description. Previously it was discussed that the focus for this system was FPV style drones that can handle the payloads of 0.5 - 10 kg. An example of a package was shown in Fig. 3, where food, medicine, power banks are portrayed. The weight of such a package is expected to be around 10 kg as it was stated in resource 31. To make the system lighter, 5 kg will be taken as the first benchmark weight for the system. This will ensure that the components can be cheaper and require less power, while the packages in actual world can be divided into two parts. Additionally, the station should be able to contain five packages at the same time, this will allow the station to last longer and be reusable. In total the weight of cargo will be 30 kg; it is expected that cargo will be loaded upon deployment and replenished periodically. The station itself must be portable, allowing its position to be changed to reduce the risk of detection. A realistic maximum weight for the station should be up to 25 kg, preferably the station could be carriable like a backpack, or fit into one.

The time gap between rearms should also be established. For instance, it would be beneficial if the system could work unattended for a minimum of 48 hours. This gives enough time to reasonably assess the system as autonomous. Due to the nature of battle the system will require the rearming, but this amount of time can assist. To ensure this, the power supply of the station must be internal and

battery based. The battery must last at least this long, and operators should have clear access to replace batteries when needed.

Mechanically the system must have weather resistance, especially rain and wind. Other effects such as UV exposure are of lesser concern, as such systems are not expected to remain deployed long-term. To expand on this, it should be accounted for that in warfare, equipment is lost. As the primary reason for the station is personnel safety, the loss of the station itself should not be inconsequential. That is why the material for the station should be cheap, the cost of manufacturing should be so inexpensive it could be counted as expendable equipment.



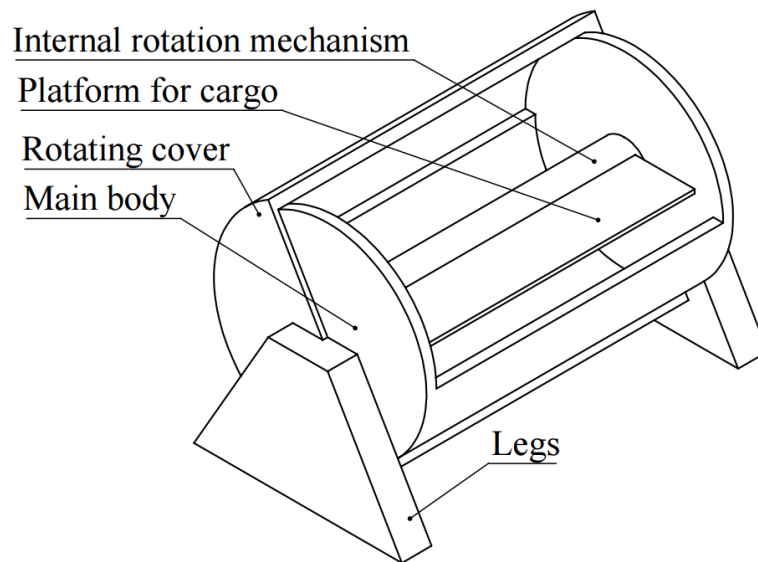
**Fig. 16.** An Example of Completely Autonomous Logistic Station Web

The last aspect of the requirements is the autonomy of the system. As established in chapter 1, the FPV class drones are the most commonly used in the battlefield, the system should therefore be focused on this class. Additionally, the FPV class drones are deemed to be fragile, to counter that, the rest of the system should be robust. Passive pickup is essential; a very simple landing mechanism, or none at all, is preferable. To further push autonomy, the personnel exposure minimisation is vital. It was stated before that the system is interacted with only during deployment and reloading of cargo operations. Where previously each individual package required both deployments, now it is required every five packages. Future designs could minimise it even further. A web of such stations could result in complete autonomy, where stations are loaded by UAV themselves virtually eliminating the loss of human lives. An example is shown in Fig. 16, where a station that is currently deemed to be in safe area is interacted with by personnel and other stations are interacted by UAVs. With the requirements established, the initial conceptual designs of the system are presented in the following subchapter.

## 2.2. Mechanical Draft Design

The core goal of this subchapter is to take the discussed factors and translate them into an actual concept that will be worked on and improved in further development. When designing simplicity,

robustness and expendability are the main driving factors. The system must have as little of moving parts as possible; the materials must be cheap. The overviewed commercial stations (except A2Z dock which is completely incompatible with the requirements) designs share a closed case for weather protection. This principle should also be applied to this station. Preferably Volatus type design as it is simple, does not require additional isolating material along the seams as the top drum works as a roof at the same time. Additionally, all station type systems do have a landing of some kind, this should be excluded if possible as it adds the need for positioning, adds unnecessary complexity and cost. In the review of hook type gripper mechanisms, it is shown that landing mechanisms are not a necessity and pick-up can happen from ground to air. The design must incorporate a pickup mechanism that is installed on UAV, following the established philosophy, it must be simple, passive. To summarise, the mechanism must eliminate unnecessary complexity from the analysed designs and only keep the essential parts to ensure optimal working conditions as it will allow for cheap, sustainable and long-lasting mechanism manufacturing.



**Fig. 17.** Sketch of the System

As the main goal of the project is to focus on the station it is assumed that the passive grabbing mechanism that will be installed on UAVs is a simple hook for the sake of simplicity and that further research should explore this concept further. To visualise the station, the general concept of it is a drum like system that is similar to a barrel (Fig. 17). The reasoning for this is that the shape provides great cover from weather and requires only one motor to control the opening mechanism. Additionally, this design allows the internals to be arranged in a circular configuration naturally giving a way to implement multiple platforms. The rotating internal mechanism also requires only one motor, which makes the system controllable with two motors only. The platforms themselves should be connected to the sides of the main body where tracks for basing and horizontal orientation ensuring are implemented. As the estimate number of packages is five and they are estimated to be depleted within 48 hours, the speed of rotating can be slow, consequently, minimal cargo strapping will be used to facilitate pickup. The main body also should contain legs that preferably are adjustable or interconnected to have stability on uneven surfaces. Additionally, components like shoulder straps so it could be used as a backpack, location for electrical components and so on has to be overlooked. Besides that criteria of cheap material was required, few manufacturing and material options are:

- Injection moulding, casting nylon, polycarbonate, PVC or other plastics. This option may have high initial costs as it would require mould, but in later stages it would arguably be the cheapest method to mass produce mechanical components. Furthermore, this method allows the use of virtually any plastic, so even further robustness, price and resistance balancing is possible.
- 3D printing of plastics allows the production of virtually any geometry at the cost of dimensional accuracy and strength, especially when discussing FDM printing. Other methods such as SLS printing may yield better results as they are more industrial focused. In general, this manufacturing technique is optimal for initial prototyping but should be replaced with a more reliable method for mass production.
- Metal constructions, like aluminium and stainless steel. Very robust and the most expensive. From the first glance the design could be done from sheet metal and tubes. The processes would consist of sheet rolling, bending, welding, lasering and so on. The number of resources compared to the previous methods is marginally larger.
- Composite materials like glass fibre and carbon fibre. Best strength to weight ratio, but a lot of manual work if general layup process is used. However, alternative processes such as filament winding are more efficient, furthermore this process could also be used together with injection moulding, to strengthen the moulded parts.

In general, the complete manufacturing process should combine injection moulding with composite reinforcement. For the purposes of this work 3D printing plastics should be chosen. While the general mechanical concepts are clear, the electrical side should also be drafted.

### **2.3. Electrical Component Draft Design**

The basis for the electrical component draft design is the required robustness. As the system requires five action repetitions (as there are five pieces of cargo) the robustness is not as difficult to abide by. The general working path is to check for items, move a full chamber into position, open lid, wait for pick-up, close, repeat. Design paths to determine if items are in position can go two ways. Using one sensor at the pick-up position, with a check happening at each internal rotation or using multiple sensors, one at each chamber and determining if they are empty simultaneously. The later design introduces a lot of components leading to more room for error due to faulty mechanisms. Additionally depending on design choices made further on and due to internal rotation required there may be a need for a slip ring with wires for each chamber which is an additional point of possible error, component to design around. The first one has only one component. If it were to breakdown the whole system breaks apart. On the other hand, if cost is considered, five cheaper sensors may be inferior to one quality sensor. Additional variation could use no sensors at all, but this choice is invalid as having feedback is a feature that is easy to implement, gives information that is very important, especially if it is difficult to track how many packages are there in each individual device. For these reasons, the initial design is done with a single sensor while the internal rotational mechanisms move each chamber into detection position.

To move the internal rotational mechanisms and the outside cover there is a need for two motors. There are two motor options to be considered: stepper motors and servo motors. As the lid motor would have less requirements because it only controls one component, the main basis for choosing is the internal rotator while lid motor will match the design. Stepper motors are brushless motors that rotate in steps, they can rotate 360 degrees, provide a large amount of torque at low speeds and are

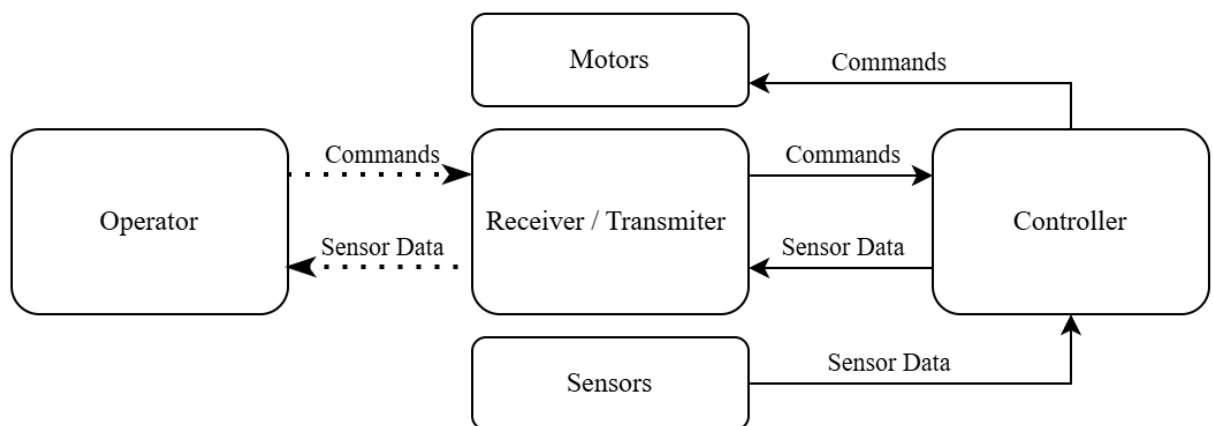
suitable for low-speed and high precision control [33]. Although, they are open loop so they require additional components for feedback. Servo motors do have feedback, they also can rotate 360 degrees, but they are more expensive at the high-end and more difficult to prototype with, as inexpensive servo variants offer either speed control with 360-degree motion or position control with limited range. They will provide high torque, accurate control and enough feedback should be gathered from the chamber sensor.

Both the feedback sensors and the motors use data to communicate between the station and the operators. As the station would be in the frontline the distance for communication should be long. When reviewing the commercial stations the Metternet station can communicate up to 20 km and DJI dock can communicate within 10 km. A similar range is required for this station but a specific communication technology will be selected in the detailed design part.

The last part of the design is the controller which has choices described as follows:

- Microcontrollers like Arduino [34] and ESP32. The cheapest method, additionally both controllers and their other analogues are very simple to use and program. Such controllers do not consume a lot of power, so 48-hour requirement would not be a struggle. Although, this simplicity also contains a drawback as the controllers are very limited in processing power.
- Single board computers like Raspberry Pi [35]. They are a lot more powerful, can handle complicated controls. In scientific literature there some of the papers used them as main controllers while microcontrollers were used for actuator control.
- Programmable logic controllers like SIMATIC S7-1200 PLC [36]. Very powerful and expensive. In general, not a realistic option as they would require industrial components to be used together with the rest of the system making it very expensive and overly complicated.

As established in the mechanical draft design, it is expected that the mechanism will contain two motors. Besides that, there is a need for sensor to detect cargo and communications which can be chosen to be simple digital input/output components as they only need to determine if the platform is clear, send signals to operator. A microcontroller can fulfil all these functions and represents the most cost-effective and easily replaceable option. The combination of all components in work as an actual concept can be seen in Fig. 18.



**Fig. 18.** Draft Control System Design

The microcontroller gets commands and sends data through a receiver/transmitter. The commands then are sent to the motors their position does not have feedback, that is determined by implemented sensor. Which additionally gives the platform data, that is sent to the operator to know if the package is empty. In general, the system design is simple and will be complimented with a control algorithm in the next subchapter.

#### 2.4. Control Algorithm

Firstly, the algorithm starts when the system is deployed in field. After the end it is assumed that it must be relocated, reloaded or left. The algorithm can be observed in Fig. 19.

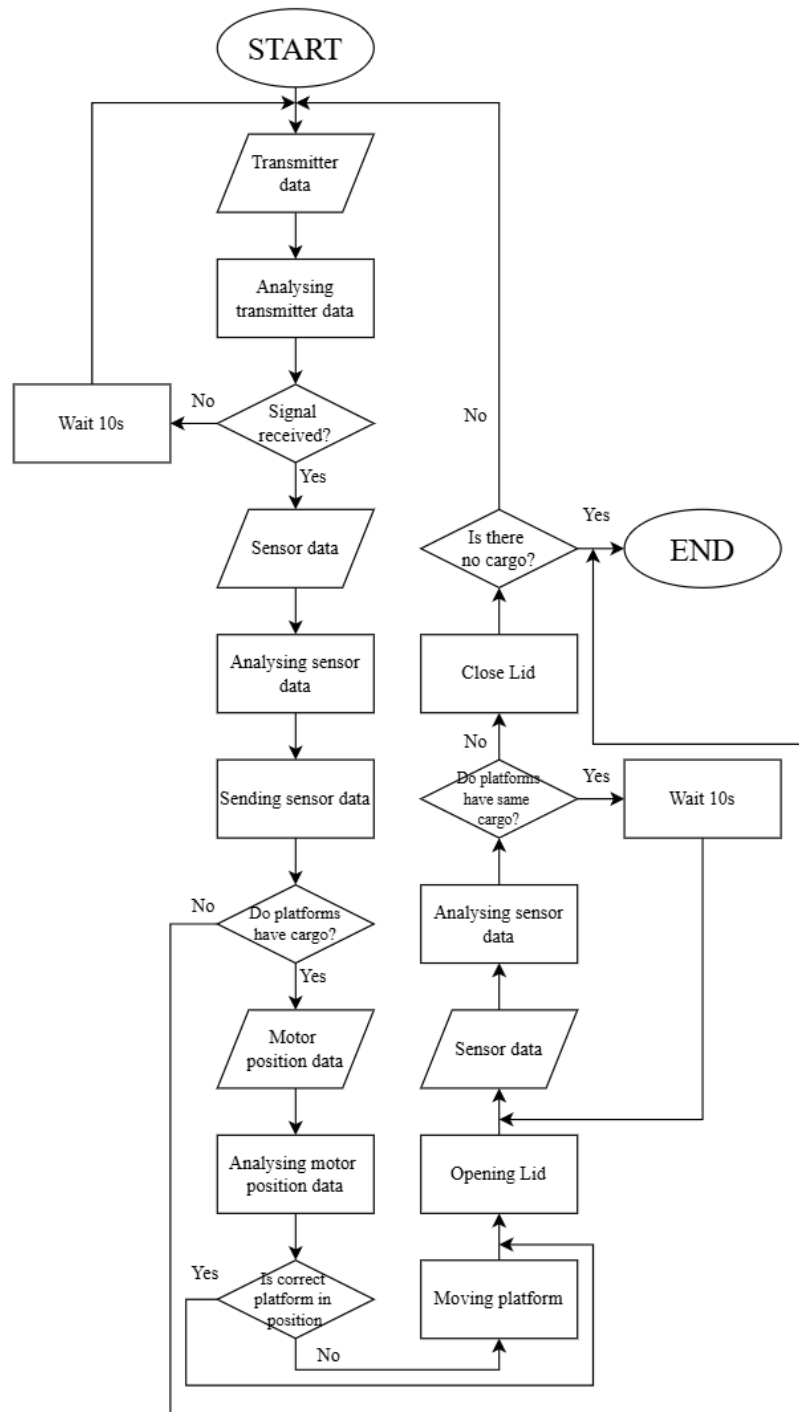


Fig. 19. Control Algorithm

The algorithm operates as follows:

- Once deployed the system is turned on and on the very start it starts to look for a signal from operators. If there is no signal it is checked every 10 seconds.
- If there is a received signal, the system reviews sensor data and sends it back to the operator. If for some reason the system is active while all chambers are empty, the system turns off. If not, the motor position data is reviewed.
- During the analysis of the motor position, it is determined if the correct platform is in the pickup position, if it is not, then platforms move and if it is, then this step is skipped. After it the lid is open.
- While the lid is open the system analyses the platform sensor data every 10 seconds. If during any iteration of analysis one platform has no more cargo the lid closes as it is assumed that the cargo was taken.
- If there is no additional cargo the system turns off. If there is additional cargo the cycle repeats.

The algorithm does not have many error checks. Main reason behind this is that errors require personnel maintenance and it is not possible with the raised requirements. In addition, a manual control method must be considered, as it may help to fix miniscule mistakes. In general, the algorithm is designed to be simple like the rest of the product, but further research or prototyping iterations may give improvements.

## **2.5. Chapter Summary**

When analysing the results of chapter one, there were multiple gaps found in design. Commercial stations were too large, the power supply was external and in general they were too expensive. Scientific literature on stations largely neglected cargo loading, focusing primarily on battery swapping and charging. Passive payloads used for cargo manipulation were determined to be optimal. Multiple requirements were established for the station. Maximum package weight 5 kg; maximum package amount – 5; unattended operation time – 48 hours; power supply should be internal battery; device is rain and weather resistant, portable; pickup method should be simple, robust; the station itself must weigh 25 kg; main focus is FPV class drone computability with minimal personnel exposure; materials are to be cheap and expendable. The mechanism itself consists of an internal rotation mechanism that is rotating platforms with cargo, the other moving part is the rotating cover, besides that mechanically the mechanism has a main body and legs. The optimal material for this product is injection moulding and composite addition combined, but for purposes of prototyping 3D printing is enough. Electrical system controller is drafted to be a microcontroller as it is simple and cheap to use. Other electronic components are motors, sensors and a receiver/transmitter used to communicate between the operator and the system. The algorithm is designed with possibility for manual control in mind, as errors in the system will be considered terminal if not remotely fixable. The system will await a signal from the operator, execute the cycle, and return to standby; any deviation from the expected sequence results in automatic shutdown. The draft design presented in this chapter serves as a foundation for further detailed development. Subsequent chapters will refine the mechanical, electrical and algorithmic components through iterative prototyping, with each subsystem being evaluated against the requirements established in this chapter.

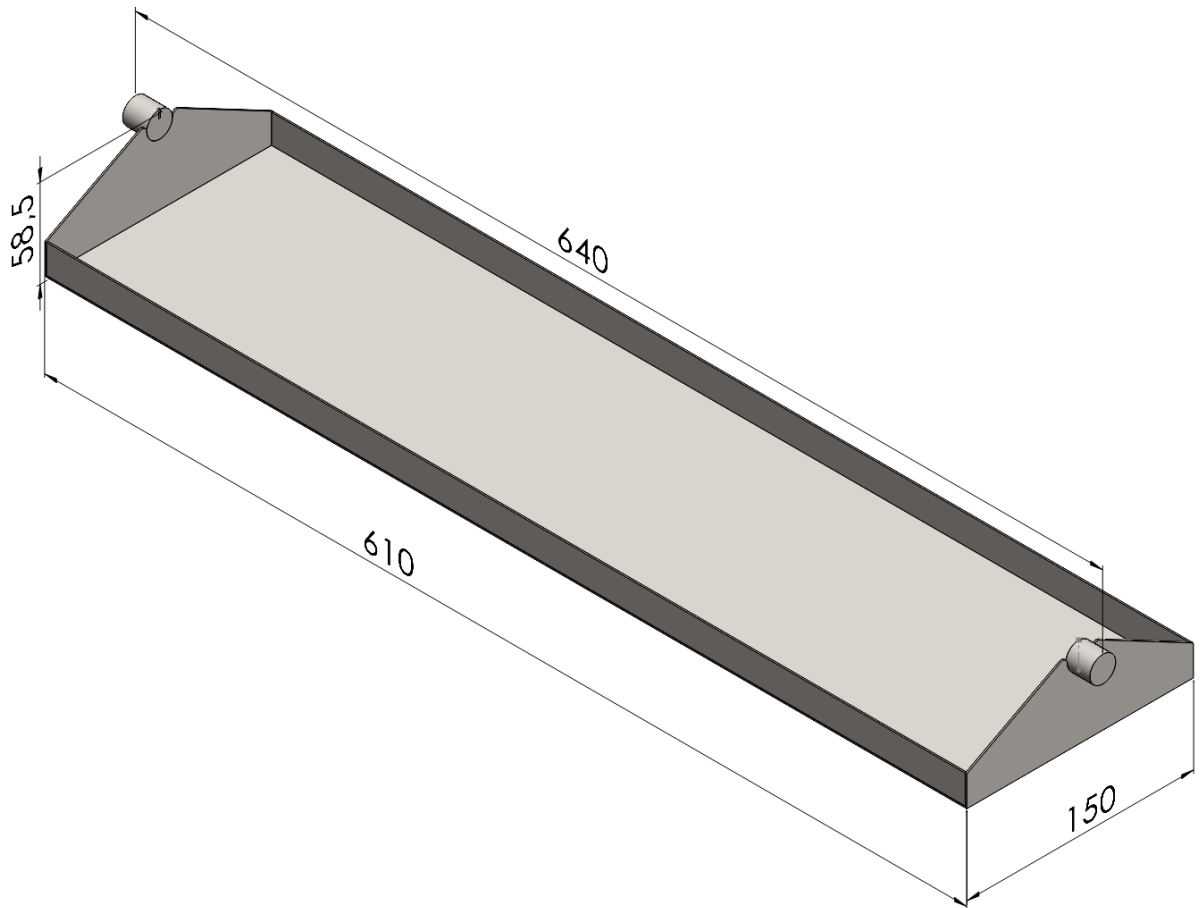
### 3. Conceptual System Design

This chapter is dedicated towards modelling of the system which will be done via SOLIDWORKS 2024 cad programme. This is supposed to be a conceptual design. To establish what this means, such things as manufacturing tolerances, in-depth assembly processes, accessorial parts like gaskets, washers will not be considered. However, the overall manufacturability of the product, vital purchasable components like bearings, fasteners, motors and other elements deemed important will be evaluated. This also applies to the forces, stresses and other values that are deemed important or unimportant accordingly. Furthermore, previously established constraints are crucial and must be discussed at this stage. Mechanical conceptual part will differentiate in scale and manufacturing process from the prototypical analysis of the product. Main differences will be highlighted during the prototype analysis.

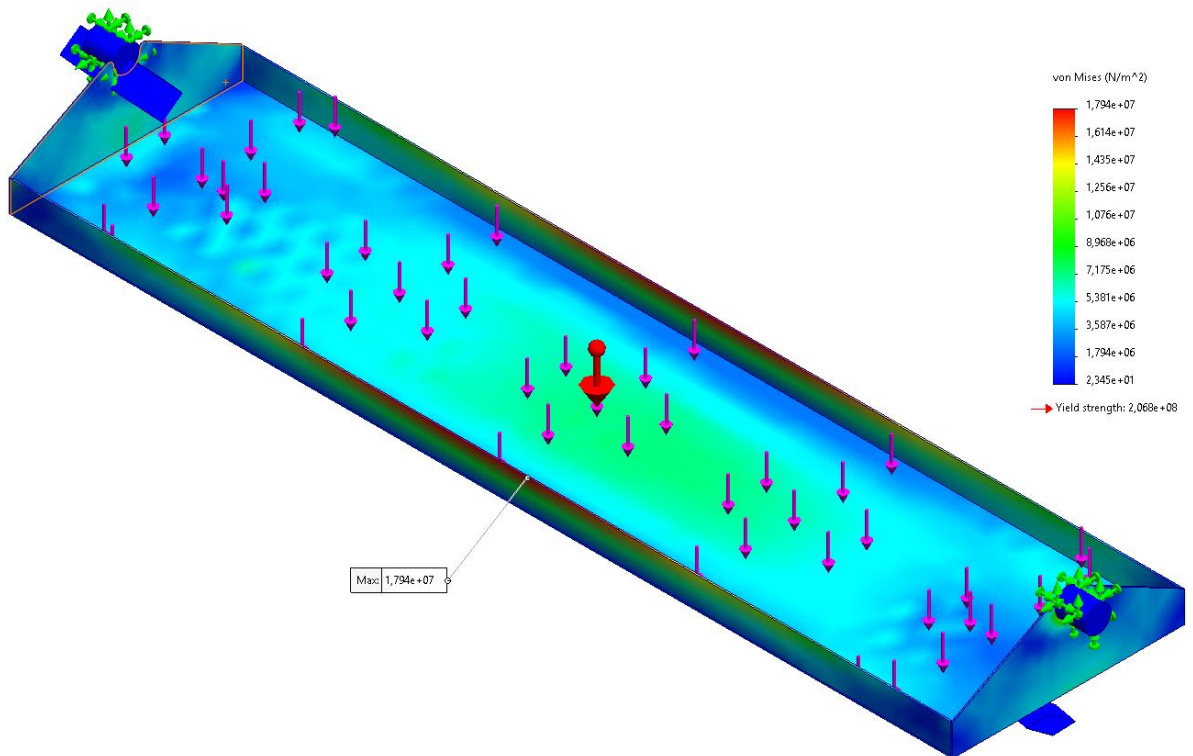
Electrical component design will be fully examined. As the goal of the electrical system design is to keep conceptual and prototypical parts as close as possible, both designs will be evaluated simultaneously with differences highlighted. The control system code will not be done for conceptual design and will be focused on prototype only as it is the only way to confirm if the system design is valid.

#### 3.1. Mechanical Conceptual Design

The main problem at the start of mechanical design is the shape and volume of the packages that are to be delivered. As the only constraint that is established is the 5 kg weight, it is difficult to convert this into actual volumetric information. A reasonable approach is to use parcel weight calculations provided by shipping services [37]. Although, as the calculation is focused on lightweight package estimations and uses  $200 \text{ kg/m}^3$  (claim within shipping service calculations) which is five times lighter than a water-equivalent package it is safe to assume that currently calculated weight which is 1.88 kg at package size 100 x 150 x 610 mm can be multiplied to match the required 5 kg. The package itself is not designed, as the pick-up mechanism is a hook and for it the main point of contact would be a through hole with additional consideration that in military UAV logistics packages are made from makeshift materials already it appears to be unnecessary. While a container holding the package must be designed (Fig. 20). The platform is designed from AISI 304 sheet and round metal. As an example of manufacturing process, the part can be welded with TIG welding process with additive material. The sheet thickness is 1 mm and the part weighs 1.06 kg. Static simulation results (Fig. 21) show that the maximum stress for the platform when there is 5 kg package on it and the platform stress due to self-weight under gravity is 17.9 MPa at the side walls of the platform. This leaves a safety factor of 11.5 which can be considered overengineered, but from manufacturability standpoint – making the parts slimmer or smaller will make welding processes require unnecessary handling of miniature parts. Furthermore, actual welding would be stitching welding instead of straight lines across the whole platform, leaving more stress points that seen in actual calculation. In general though the part may be considered overengineered in terms of stress, it will be straightforward to manufacture. With the platform design established, the internal rotation mechanism can be calculated and examined next. This confirms that the platform design is both structurally adequate and practical to manufacture. After establishing the platform structure, the next stage of the conceptual design process focuses on the internal cargo manipulation mechanism and actuator integration.

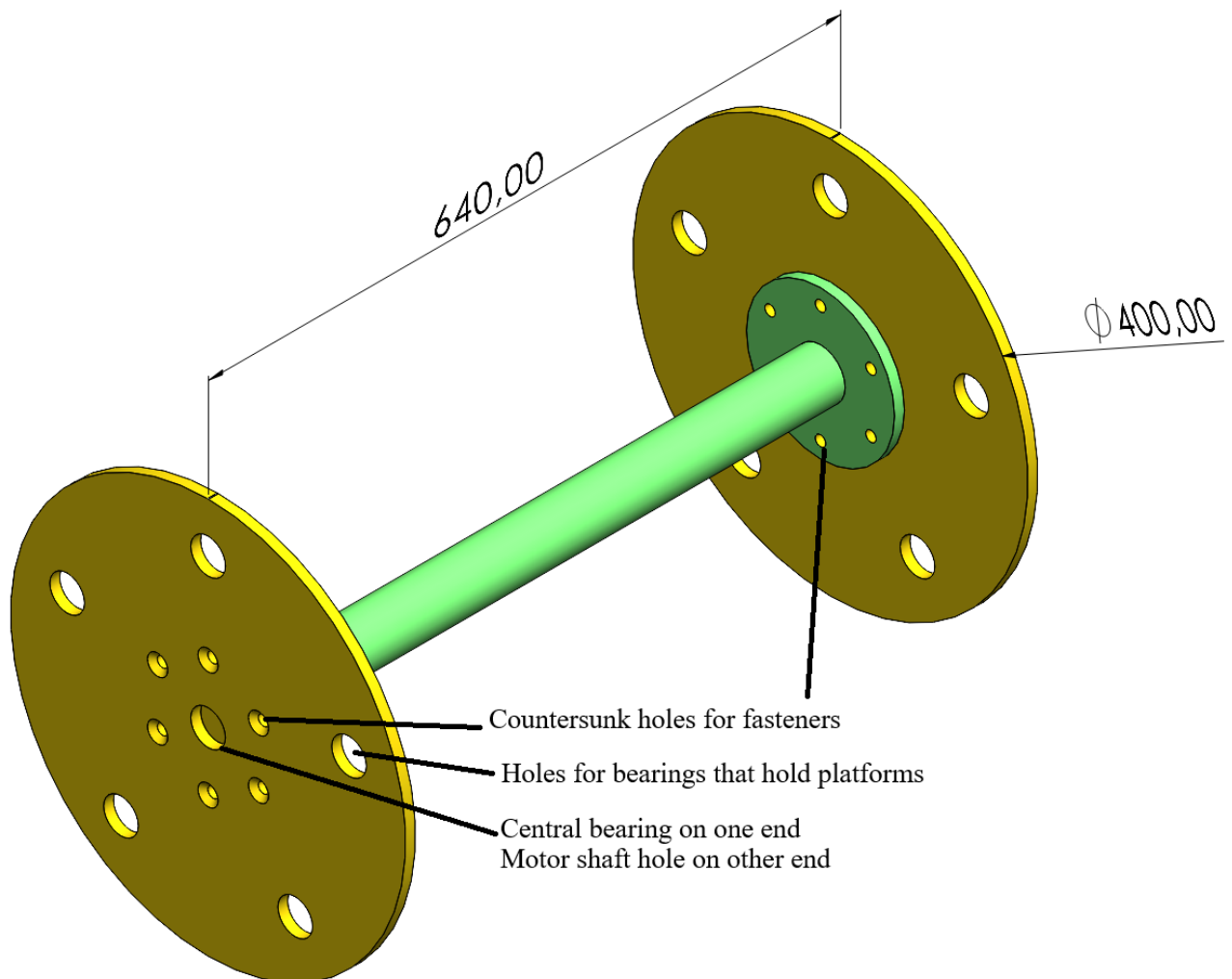


**Fig. 20.** Holding Platform



**Fig. 21.** Holding Platform Stress Calculation Results

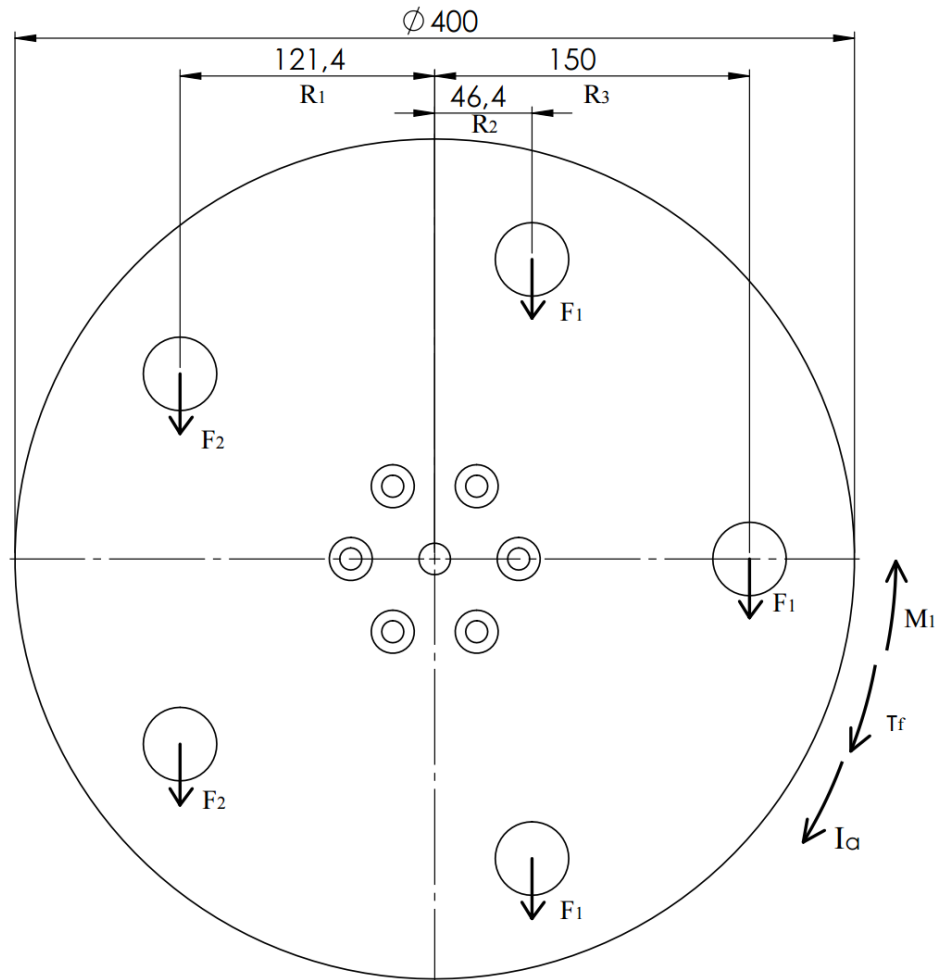
The internal rotation mechanism has three individual parts (Fig. 22). Two shafts coloured yellow, both are almost identical with the exception being that one has a hole for a bearing and the other a hole for actuator shaft. Both are designed to accommodate five additional bearings used to hold the platforms. Platforms are held on bearings and designed to have centre of mass lower than the bearings. As the accelerations within the system will be very low this should be enough to keep platform horizontal. During the initial stages of modelling another design path was examined, where only one end has bearings while the other has three tracks. Instead of symmetrical platforms, one end would have three prongs that would fit into each track. To visualise this system would be more akin to a vertical lift conveyor. However, due to the tight tolerances required to produce such a system at prototype stage, this approach was not selected as if the gaps are too large or too small the platforms would twist instead of rotating horizontally. Additionally, the track would be difficult to produce with injection moulding due to complicated geometry, assembly tolerances could similarly present difficulties. The current design could be cast or injection moulded from polycarbonate with relative ease; alternatively, a stainless steel version would also be straightforward to produce as the design has one shaft and four flanges.



**Fig. 22.** Internal Rotation Mechanism

To correctly evaluate the required motor for this mechanism acceleration of the mechanism must be evaluated. Initially this parameter was estimated prior to prototype development, although during prototyping the operational acceleration of 30 RPM/s ( $3.14 \text{ rad/s}^2$ ) was chosen. The central bearing

is also evaluated as 6003-2RSH. The primary selection criterion for this bearing is its dimensions, which satisfy the exact requirements and as this is generally low speed and torque operation other parameters are satisfied with a considerable safety margin. With this addition, the central bearing torque friction was estimated to be 0.032 Nm via calculator provided by SKF [38]. The remaining value estimated without manual calculation is the moment of inertia that is  $1.98 \times 10^{-4} \text{ kg} \cdot \text{m}^2$ . This value is found via SOLIDWORKS evaluate command with platforms, bearings and rotation mechanism enabled.



**Fig. 23.** Torques and Forces Acting Upon the Rotation Mechanism

To obtain the forces acting upon the system it must be established that  $F_2$  represents platforms acted upon by self-weight only, while  $F_1$  represents platforms with an additional 5 kg payload (Fig. 23). The force formula is based on Newton's Second Law of Motion and as follows:

$$F_n = m_n g; \quad (1)$$

here  $m_n$  – the mass of the platform with or without the payload;

$g$  – the gravitational acceleration.

Force estimations:

$$F_1 = m_1 g = (1.06 + 5) * 9.8 = 59.4 \text{ N};$$

$$F_2 = m_2g = 1.06 * 9.8 = 10.4 N;$$

The final calculation step is to convert the gravitational force of each platform into torque which is done with multiplication with the length of the lever arm. Additionally in this step of the calculation friction of the central bearing and inertial force are evaluated in the equation which is:

$$M_1 = ((2F_1 * r_2 + F_1 * r_3 - 2F_2 * r_1) + \tau_{f\ bearing} + I\alpha) * SF; \quad (2)$$

here  $r_n$  – lever arms corresponding to the respective forces;

$\tau_{f\ bearing}$  – estimated friction force 0.032 Nm;

$I$  – moment of inertia estimated to be  $1.98 \times 10^{-4} \text{ kg} \cdot \text{m}^2$ ;

$\alpha$  – acceleration chosen during prototyping  $3.14 \text{ rad/s}^2$ ;

$SF$  - safety factor of 1.2, applied to account for unforeseen parameters.

This formula shows that the required torque is:

$$M_1 = (2 * 59.4 * 0.046 + 59.4 * 0.15 - 2 * 10.4 * 0.12) + 0.032 + 1.98 \times 10^{-4} * 3.14) * 1.2 = 14.27 \text{ Nm};$$

To satisfy this torque requirement, a NEMA 23 2 Nm motor (23HE30-2804S) was selected with an additional planetary gearbox 10:1 (MG23-G10-D8) to increase the torque [39, 40]. Technical specification of the elements (Table 3):

**Table 3.** Tech. Spec. of 23HE30-2804S Motor and MG23-G10-D8 Plan. Gearbox [39, 40]

Technical Data	Value
Number Of Phase	2
Step Angle	1.8°
Holding Torque	2 Nm
Rated Current per Phase	2.8 A
Phase Resistance	1.17 $\Omega$
Motor Size	57 x 57 x 76 mm
Motor Weight	1.2 kg
Gear Ratio	10:1
Gearbox Size	57 x 57 x 55.5 mm
Gearbox Weight	0.75 kg

Another part that that requires a stepper motor for control is the top lid. When calculating the required torque for the lid motor, the actual weight was found to be dominant by several orders of magnitude, the contribution does not even reach 0.5 %. For the next calculation these values are excluded. To get the required values SOLIDWORKS was used, the mass of this component is 2.97 kg, the centre of mass required for calculations is 139.5 mm away from the fixed point (Fig. 24). The formula used for this calculation:

$$T_c = m_c * l_c * g * SF; \quad (3)$$

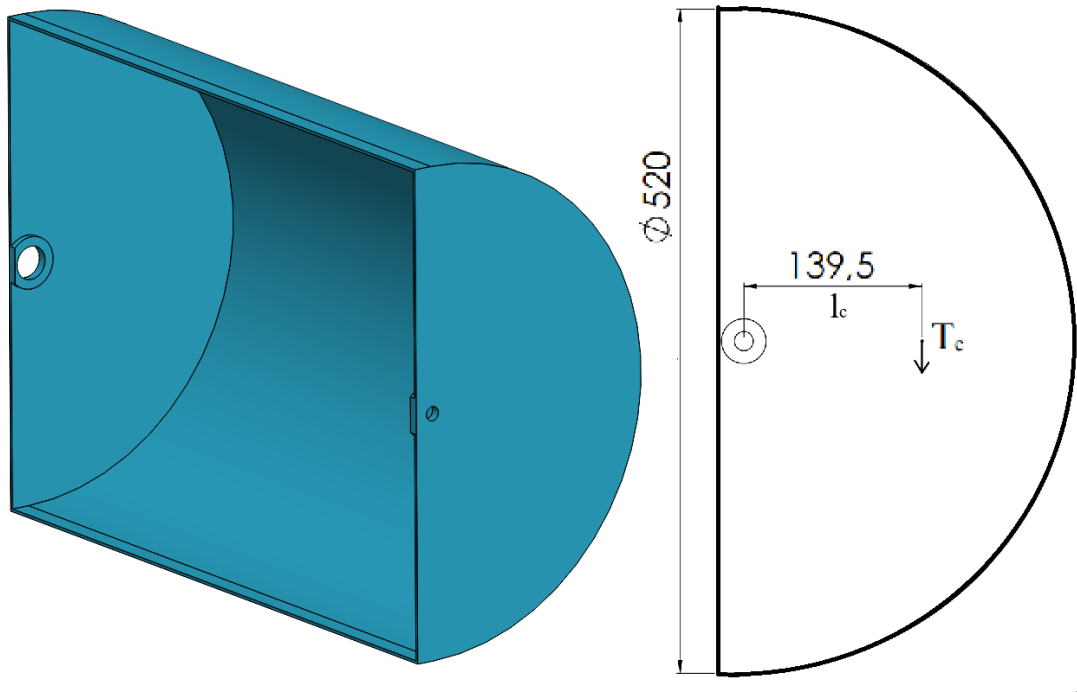
here  $m_c$  – mass of the lid;

$l_c$  – length of the lever arm to the mass centre;

After getting all values the torque is:

$$T_c = m_c * l_c * g = 2.97 * 0.139 * 9.8 * 1.2 = 4.85 \text{ N};$$

Compared to previous calculation the torque is almost three times smaller, which is reasonable considering the part is made from plastic only.

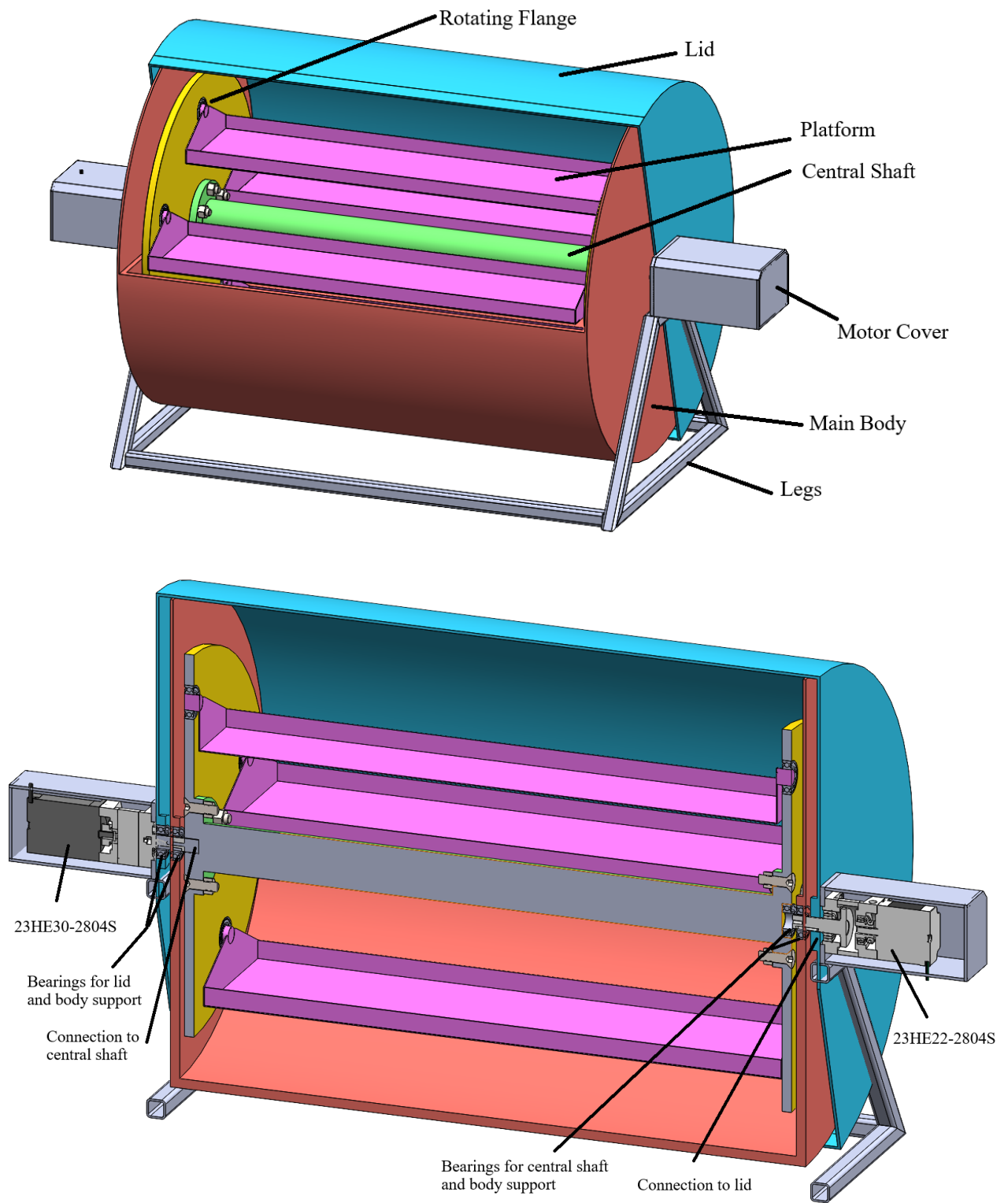


**Fig. 24.** 3D Lid Model and Centre of Mass Forces Acting Upon the Lid

For this torque a NEMA 23 1.24 Nm motor (23HE22-2804S) is chosen with an additional planetary gearbox 10:1 (MG23-G5-D8) to increase the torque [41, 42]. Technical specification of the elements (Table 4):

**Table 4.** Tech. Spec. of 23HE22-2804S Motor and MG23-G5-D8 Plan. Gearbox [41, 42]

Technical Data	Value
Number Of Phase	2
Step Angle	1.8°
Holding Torque	1.24 Nm
Rated Current per Phase	2.8 A
Phase Resistance	0.9 Ω
Motor Size	57 x 57 x 54 mm
Motor Weight	0.8 kg
Gear Ratio	5:1
Gearbox Size	57 x 57 x 55.5 mm
Gearbox Weight	0.75 kg



**Fig. 25.** Conceptual 3D Model of the Station With a Cross Section Below

A full conceptual model is illustrated in Fig. 25. As planned in drafting, the main body is composed of two halves. Both are made from polycarbonate, the lid is marked blue, the body is marked red. On both sides of the cylinder there are DC motors with their respective gearboxes, both are in a polycarbonate box to shelter from weather. Each platform is marked purple and were discussed in-depth before. The legs of the station had least contemplation within design, as a place holder they are

simple polycarbonate tubes and should be improved on in further research beyond conceptualisation. In the cross-section the inside workings are displayed. 23HE30-2804S supports two bearings for lid and the body, they prevent rotation of all parts except central rotational mechanism which is tight fitted to the gearbox shaft. On the other side a similar procedure is done with 23HE22-2804S swapping the lid and central shaft as the part with a bearing. Total mass of the object is 23.86 kg without additional cargo, the dimensions are 1010 x 520 x 600 mm. With the mechanical part concept being clear, the next part is electrical control.

### 3.2. Electrical Conceptual Design

Main components connecting mechanical and electrical design concepts are the DC motors that were established in the previous section. Naturally, these components require control and power supply. Both motors have specified rated current per phase and its resistance, although manufacturers do not provide nominal working voltage. Required voltage that can be derived from specifications with Ohms law is 3.3 V for 23HE30-2804S and 2.5 V for 23HE22-2804S. Such voltage does not represent the true minimum, as inductive resistances within the coil must also be considered. A more realistic approach would be to use a 12 V or 24 V power supply, as the device is designed to be used with microcontrollers which tend to have voltage ranges of up to 12 V a corresponding power supply is selected. To determine the appropriate power supply, the remaining components must first be selected with the first being a drive for DC motors, multiple options are shown in the Table 5.

**Table 5.** Comparison of DC Motor Drives Technical Specifications

Name	Nominal Current, A	Peak Current, A	Driver Voltage, V	Logic Voltage, V	Interface Type	Price, EUR
L293D [43]	0.6	1.2	4.5 – 36	5	GPIO	10.1 [44]
DRV8825 [45]	1.5	2.5	8.2 – 45	2.5 - 5.25	GPIO	8.95 [46]
L298N [47]	1	2	3.2 - 40	3.3 - 5	GPIO	6.9 [48]
TMC2209 [49]	2	2.8	4.75 – 29	3.3 – 5	GPIO or UART	11.9[50]

As it was mentioned at the start of this chapter, the electrical conceptual design will also include prototype design. As the prototype was assembled from readily available materials, including stepper motors 17HE19-2004S [51] sourced from other projects, the following discussion addresses both conceptual and prototype designs. Technical specifications of prototype stepper motor are shown in the Table 6.

**Table 6.** Technical Specification of 17HE19-2004S Motor [51]

Technical Data	Value
Number Of Phase	2
Step Angle	1.8°
Holding Torque	55 Ncm
Rated Current per Phase	2 A
Phase Resistance	1.3 Ω
Motor Size	42 x 42 x48 mm
Motor Weight	0.8 kg

L293D drive is rated only for 0.6 A, this is the biggest drawback of this drive, as besides this it has very simple controls. A further drawback of this drive is the absence of 3.3 V logic signal support, as this makes use of 3.3 V based microcontrollers like ESP 32 require a buck converter to step down the logic voltage. L298N has the same issue of peak current that is too low for conceptual design motors, although it can control two motors at the same time, which would be an optimal fit from this standpoint. DRV8825 is chosen for prototypical design, mainly for its peak current being larger than rated motor current per phase. Another highlight is the possibility for 3.3 V or 5 V logic, making the drive more adaptable. Both parameters give flexibility, although the drive tends to overheat very fast on higher current, so high power operations can only be short or require good ventilation. TMC2209 is chosen for the conceptual design, it also supports the same spectrum of logic voltages, additionally it has UART (universal asynchronous receiver-transmitter) interface for better diagnostics, dynamic configuration. Peak current of the motor matches the required motor current, and this module does not have such thermal difficulties as DRV8825, so it can reliably be used in short bursts which are done within the project. On the other side of a microcontroller a module for communications must be chosen. Table 7 presents various modules with different communication methods.

**Table 7.** Comparison of Communication Module Technical Specifications

Name	Communication	Range	Interface Type	Supply / Logic Voltage, V	Price, EUR
SIM7600 [52]	4G	Limited by infrastructure	UART, USB, I2C, GPIO	5	93.45 [53]
LSM100A [54]	Sigfox / LoRa	Up to 40 km [55]	UART, SPI, I2C	3.3	-
RYLR896 [56]	LoRa	Up to 15 km	UART	3.3	35.95 [57]
CC1101 [58]	ISM radio band	Up to 1 km	SPI	3.3	12.71 [59]

There are only a few long-range communications that can fulfil the established requirement for ranges of 10 – 20 km. Additionally, having only one way of communications can prove to be inefficient due to various signal jamming techniques. For example, SIM7600 is a 4G telecommunications module, functionally, it operates similarly to a mobile phone. This module is limited by the service provider infrastructure, so the range in urban areas is virtually infinite, however, destruction of this infrastructure disables communications entirely. The module has multiple interfaces, but for the complexity of this product, UART is more than enough for reading message commands. Logic and supply voltage of this module is 5 V, so integration with ESP 32 is problematic as L293D. Other two modules that have a different communication method are LoRa based RYLR896 and LSM100A. This is long range radio communication that has a theoretical range of up to 15 km, although realistic conditions approximate it to 10 km [60]. LSM100A has additional Sigfox LPWAN communication method that can provide ranges of up to 40 km [55]. Although probably a more realistic length would be half of that, additionally, compared to LoRa this connectivity is subscription based and Sigfox infrastructure dependant. Most other communication modules have shorter ranges, for example, CC1101 can only reach up to 1 km, making it insufficient compared to the other modules presented in the table. To conclude, the optimal design choice for this device is 4G, as the range possibilities are most suitable; therefore, SIM7600 is selected for the conceptual design. In rural areas without telecommunication infrastructure LoRa is the next best choice, although the range limitations are apparent. Additionally, the SIM7600 modules are expensive for prototyping where proof of concept is enough, it is safe to test RYLR896 for prototyping, while further research could combine the use of both modules. Furthermore, research on military grade communication technologies could also be

done. To complete component analysis the last additional component – the sensor – is examined, with several types compared in Table 8.

**Table 8.** Comparison of Sensor Module Technical Specifications

Name	Type	Range	Material	Interface	Supply / Logic Voltage, V	Price, EUR
LTR-3208 [61]	Infrared	-	IR Signal	GPIO	2 – 30	0.2
HC - SR04 [62]	Ultrasonic	2 cm – 4 m	Solid	GPIO	5	3.90 [63]
B3F-4000 [64]	Mechanical	Touch	Any	GPIO	< 24	0,29 [65]
TTP223 [66]	Capacitive	Touch	Any	GPIO	2 – 5.5	1.6 [67]

The main difficulty of sensor analysis is not being able to use platforms as sensor locations, due to the slip ring inclusion evaluation as overengineered. Both B3F-4000 and TTP223 can be installed on the platforms and are compatible with virtually any material. B3F-4000 is a mechanical switch and is portrayed as a placeholder for any microswitch available and suitable for this purpose as there are numerous iterations of such module. TTP223 is capacitive sensor, it generally works with all materials. A caveat is that it is primarily designed as a human touch sensor; however, it appears suitable for this application. Both sensors also can work at any logic voltage a microcontroller produces. Meanwhile, HC - SR04 is an ultrasonic sensor that can detect distance, it does need sound reflective surface which is generally a solid. It operates on a 5 V power supply. While it is a distance sensor it can be implemented as a detector, although there may be difficulties to detect objects in closed container. A similar difficulty may happen with LTR-3208, an infrared transistor which requires an IR light source, such as IR LED. Although inaccuracy from reflection can be countered with low, focused light, absorptive material. For this reason, both prototypical and conceptual designs will use this sensor and a LED light. This combination will be used as an IR light break sensor, where loaded cargo will break the light between the module and LED. With complementary components evaluated the main component for the electrical system, microcontroller is left to examine (Table 9).

**Table 9.** Comparison of Controller Technical Specifications

Name	Architecture	Clock Speed, MHz	Flash	Ram, KB	GPIO pins	Interface	Logic Voltage, V	Price, EUR
Uno R3 [58]	8-bit	16	32 KB	2	14	UART, SPI I2C	5	29.3
Uno R4 [59]	32-bit	48	256 KB	32	14	UART, SPI I2C	5	30.5
Mega 2560 [60]	8-bit	16	256 KB	8	54	UART, SPI I2C	5	52.8
Nano ESP32 [61]	32-bit	240	16 MB	512	22	UART, SPI I2C, Wi-Fi, BT	3.3	21.6
Nano 33 IoT [62]	32-bit	48	1 MB	256	22	UART, SPI I2C, Wi-Fi, BT	3.3	31

Unlike previously evaluated entries, that were from various vendors, each microcontroller is produced and sold by Arduino. The reasoning behind this choice is that Arduino boards ensure consistent quality with no unforeseen design deviations, i.e., 29.3 EUR board may have the same schematic as

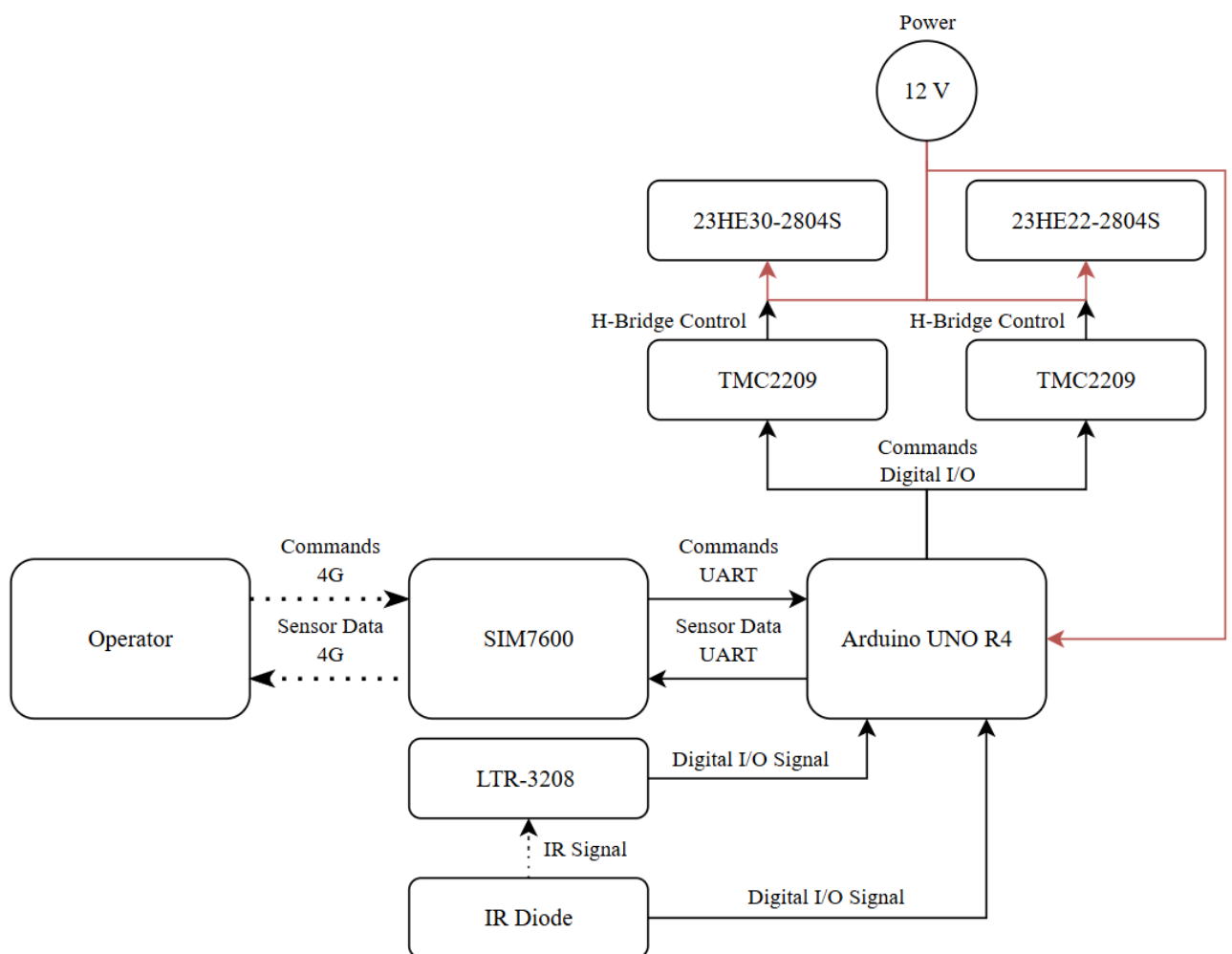
a 5 EUR clone, but components may be low quality. While ensuring that different type of communication module or a sensor would be compared within the same ecosystem appears impossible, or difficult. Beginning with the comparison, the Uno R3 is the simplest microcontroller in the range. It has an 8-bit architecture, meaning that it can process 8 bits at one tick. While this is not necessarily a problem with the number of components and the complexity of the system, there may be difficulties when upgrading, adding components. Same problem arises when evaluating flash and RAM size (program memory and working memory). On the contrary, R3 has a magnitude of research on it already and there are thousands of R3 shields that are headers to increase its capabilities. Furthermore, the clock speed may be the least important for this station as it is innately slow and existing interfaces are compatible with all of the evaluated components. Nevertheless, the last specification that can affect the choice is the 14 GPIO pins, from which there may be limitations when using 2 stepper motors, drives, a sensor and a communications module.

This problem is mitigated with Mega 2560 which has GPIO 54 pins. Additionally, when evaluating connections for Uno R3, there was an limitation that Mega 2560 overcomes. Uno R3 does support UART interface, but technically D0 and D1 pins are dedicated for this hardware serial communication. These pins are also tied to the chip that is powered by the USB, which can be used for serial monitor for live debugging. When using modules that use UART you can not use these pins if you want to have live feedback on your computer, you technically can use other pins for a similar, software serial. Although, it is not as reliable at higher baud rates (above 9600) which may be required by fast communication modules. Mega 2560, besides having more pins, more RAM and flash, does not have this problem as it also has four UART channels, three of which are completely free of use. For a same form factor solution Uno R4 also overcomes this hindrance as it uses separate hardware serial for USB and pins, while keeping the price relatively the same as R3. Additionally, the Uno R4 has a better specifications on all fronts apart from GPIO amount, albeit this choice is done on purpose for efficient upgrade integrability. Alternatively, there are smaller form factors available.

Nano ESP32 and Nano 33 IoT both are smaller than R3 and R4. Both modules operate at 3.3 V, while this is neither inherently beneficial nor detrimental, it should be kept in mind that 5 V components require a step-down converter, as discussed previously. Nano IoT is more comparable to Uno R4 specs wise, but it has more flash and RAM which at the current prototypical program size may excessive. To highlight similarities further, both R4 and IoT are 32-bit, 48 MHz which is considerably faster than the older R3 and Mega analogues. ESP32 variant is much more powerful than the rest of the modules, furthermore, it is the most cost-effective microcontroller of the five. Both 33 IoT and ESP32 have additional interfaces like Wi-Fi and BT, but ESP32 can handle more complicated tasks due to additional RAM, flash, speed. A major drawback for ESP32 chip is the quality of analogue pin resolution which is less reliable than ATmega chips which are used in rest of the modules. Although, as all of the evaluated sensors use digital GPIO signals this is not a problem as long as analogue sensors are not used in further research. While it may appear optimal in isolation, this choice should be evaluated in the context of the complete control system (Fig. 26).

Within the presented image, the main conceptual design microcontroller that is chosen is Arduino UNO R4. This is the optimal choice due to easy SIM7600 implementation via a shield for R4/R3 format. The shield platform uses D0, D1 and D12 pins, and that leaves enough GPIO pins to use for other components while providing wireless communications. The microcontroller additionally will be able to control two motor drives TMC2209. As established, the choice behind such drives is peak current that can match the requirements of the chosen stepper motors. Sensor choice is the infrared

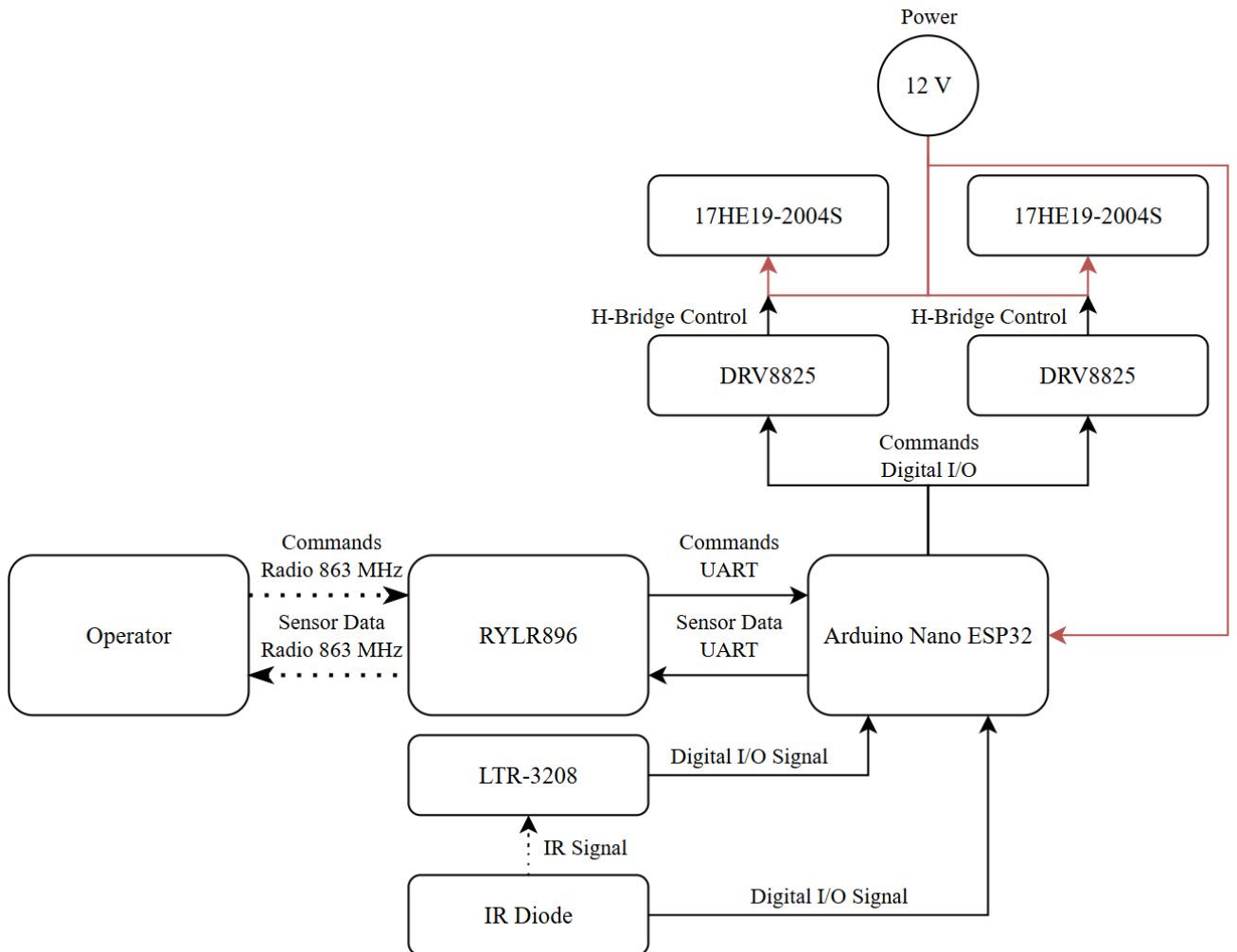
diode and phototransistor combination that can be used as a break sensor. This method is very reliable if both diode and phototransistor have small angles of receiving and transmission and the internal material of the system is IR absorptive, which black-coloured material can provide. In total, the system utilises 12 pins (leaving 6 analogue pins that can be used as digital and 2 digital pins), the main operating logic voltage is 5 V. The use of a Nano ESP32 is also a viable option, but implementation of an SIM7600 shield made for Arduino specifically may offer more advantages in faster assembly, easier integration. Additionally, LoRa module is not used even though it was mentioned, that use of both 4G and LoRa could be optimal. This choice is made due to a UART bottleneck, where SIM7600 uses the only UART available for free use, but further research should review the possibility of the use of both modules by using software serial with slower baud rates. While this design uses more expensive modules, for a prototypical design the tests were done with cheaper alternatives to prove that the concept may work (Fig. 27).



**Fig. 26.** Conceptual Control System Design

As visible, the main microcontroller is switched to Nano ESP32. This choice is made because testing was conducted using the cheaper RYLR896 LoRa alternative which does not have a shield analogue. Additionally, there is some doubt of the SIM7600 module working as intended with Lithuanian telecommunication service providers which would be problematic on a short time frame for prototype designing, manufacturing and testing. It is worth noting that besides both modules using UART channel they also share AT command protocol (SIM7600 has a more elaborate command list due to

it being more complex). Another difference for the control systems is the used motor drives DRV8825 that are chosen to match the prototype stepper motors. Of course, the working method of both TMC and DRV modules is very similar with working amperage being the main choice reasoning. While the only shared part is the break light design that can easily be implemented into prototype. As an ending note, the system uses 3.3 V logic instead of the conceptual 5 v logic, also as the system uses weaker motors it uses less power that should be addressed.



**Fig. 27.** Prototypical Control System Design

The power usage will assist in determining what power supply battery should be used for the system. The calculations will be done for conceptual design only as prototype will have a wired power supply for ease of use. To estimate the required battery capacity each element power must be determined first. The main power consumption will be done by stepper motors whose power can be calculated with formula 4 [73]:

$$P = V * A * n; \tag{4}$$

here  $V$  – voltage of the power supply,

$A$  – amperage per phase,

$n$  – number of phases;

This allows to estimate that the power for one motor is:

$$P = V * A * n = 12 * 2.8 * 2 = 67.2 W;$$

Other module peak power is also estimated from datasheets or standard electrical power formula calculations (Table 10.).

**Table 10.** System Power Estimates at Peak Operation

Part	Operating Current	Operating Voltage, V	Power, W
23HE30-2804S	2.8 A	12	67.2
23HE22-2804S	2.8 A	12	67.2
TMC2209	7.5 mA	5	0.0375 (x2)
SIM7600	2.3 mA [74]	5	0.0115
IR Diode	100 mA	1.2	0.12
LTR-3208	4.8 mA	5	0.024
Arduino UNO R4	96 mA	12	1.152

The results of power consumption are a rough estimate. Especially for Arduino, as the 8 mA per pin from technical data sheet were used. A more accurate power usage should be calculated by measuring the actual drawn current and voltage with a multimeter which is not available for the conceptual design. To further the calculations, the estimated working cycle of the system in prototype analysis lasts around 2 minutes, there are 5 cycles throughout the 48-hour period for each chamber, giving an estimated 10-minute work time. The total battery capacity can be calculated with a modified formula from source [75]:

$$C = \frac{P_{all} * t}{V}; \quad (5)$$

here  $P_{all}$  – the power of all elements in the system,

$t$  – the time the system works,

$V$  – voltage of the system;

This allows to estimate that the capacity required is:

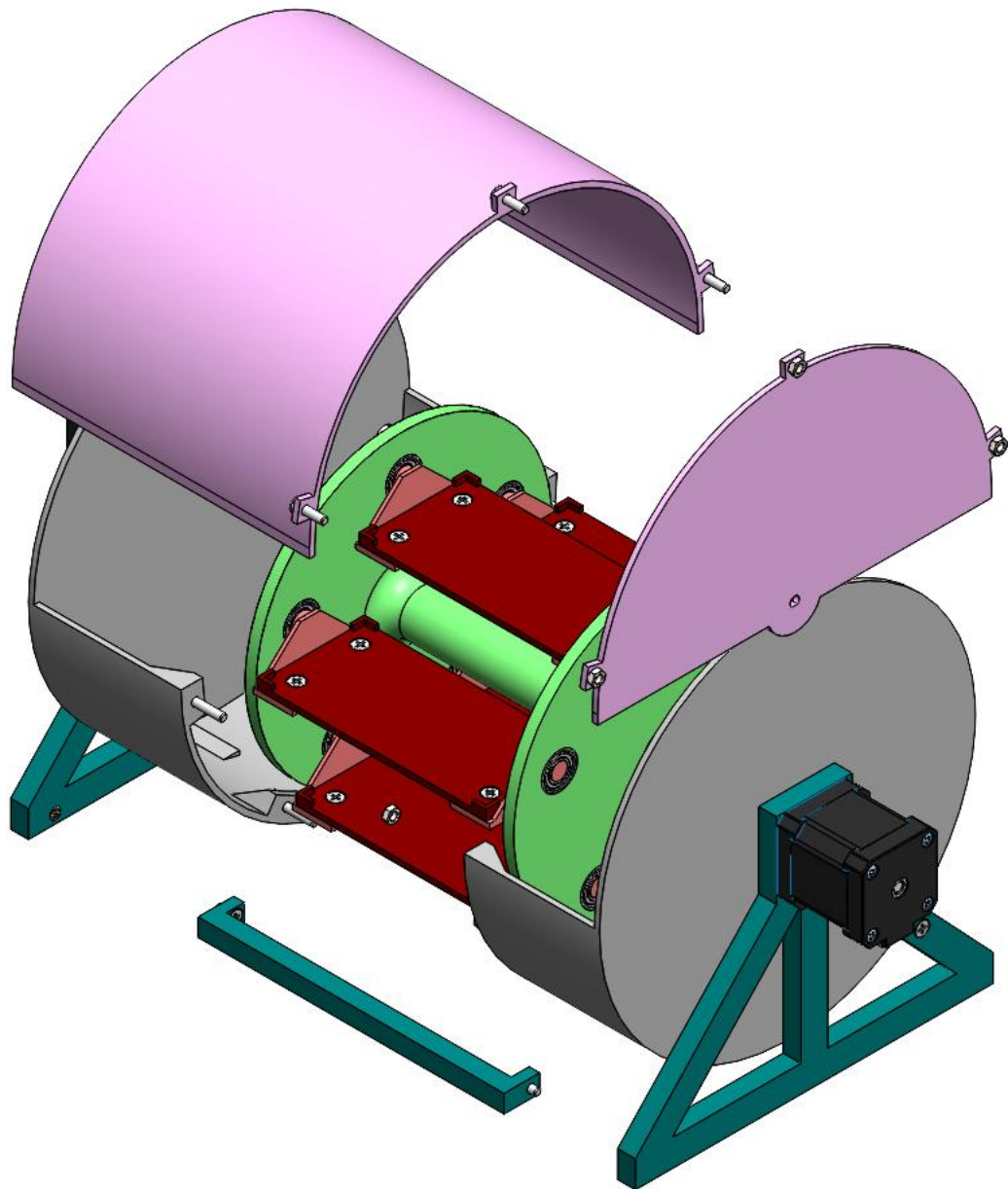
$$C = \frac{P_{all} * t}{V} = \frac{135.8 * 0.167}{12} = 1.88 Ah;$$

Furthermore, during the 48 hour period there is downtime where system still must be standby. As most component technical specifications do not show current during sleep modes, a multiplier of 1.5 is used to accommodate for power consumption leaving the capacity at 2.82 Ah. Meaning that the battery has to have ~3 Ah capacity which is low and can be met with most accumulators. For the purpose of conceptual design a 12 V 7 Ah lead battery is chosen [76]. With most components discussed the manufacturing and testing of a prototype is left.

### 3.3. Prototype Design and Testing

This chapter describes the prototype design, manufacturing and testing. The reasoning behind the prototype is to test if the design is valid mechanically, if it is possible to control the system with the

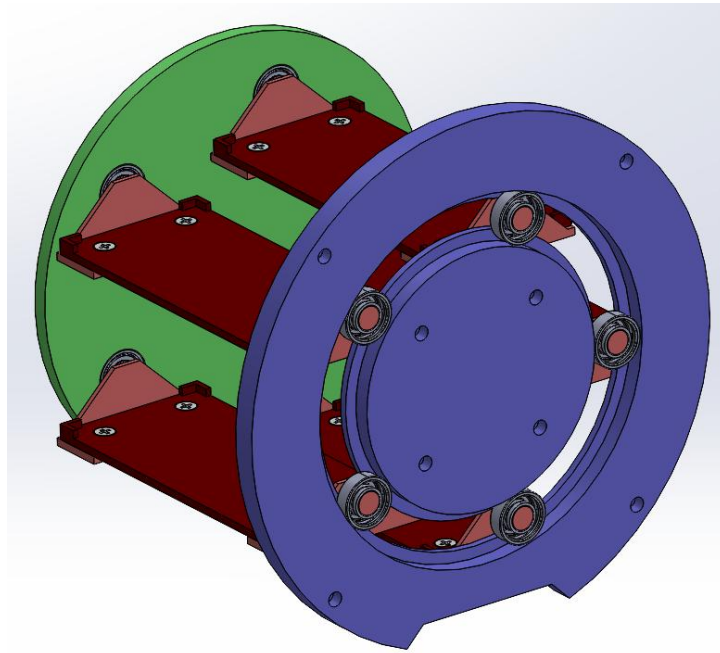
established design and to observe design flaws that were not visible in previous design steps. It should be noted that the prototype is in its third iteration due to two design breaking flaws that were found in manufacturing process and will be discussed further. The first flaw was observed in mechanical validation part. To compare, the last iteration design is shown in Fig. 28.



**Fig. 28.** Exploded View of the System

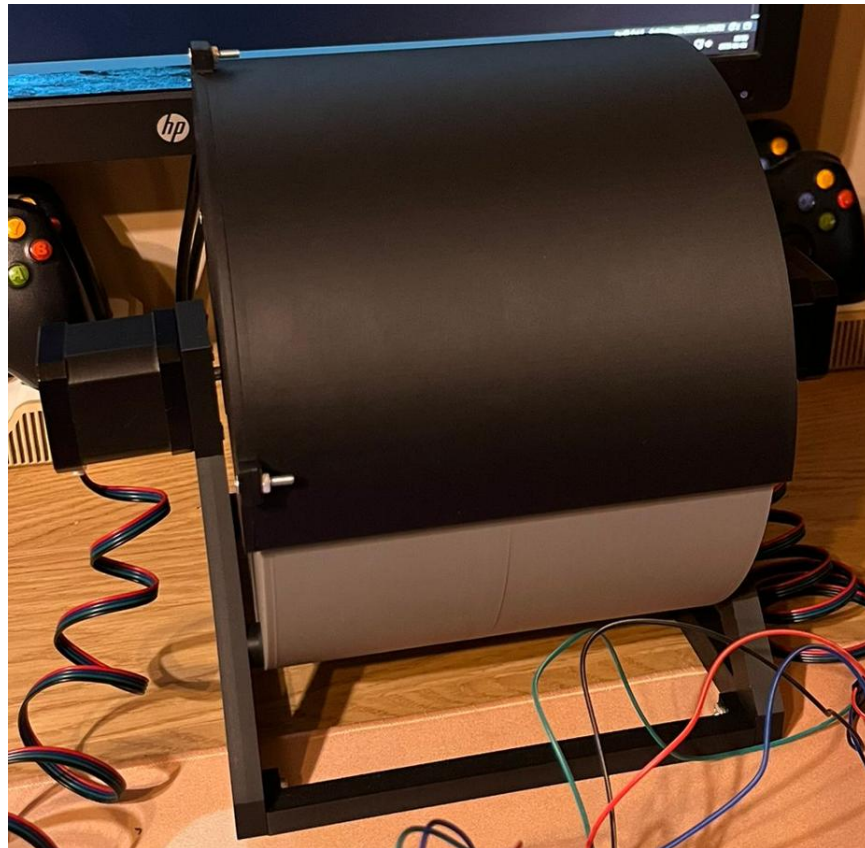
Full dimensions of the prototype are 286 x 234 x 238 mm. The device was 3D printed with PLA with Bambu Lab P1S and assembled with fasteners (DIN 965 screw and DIN 934 nut). This method was limiting due to the nature of the FDM printing, for this reason the casing (and other parts) is made from two sides instead of one uniform part. This saves a lot of material that would be wasted on supporting materials. There is one exception to this rule which is the central rotating shaft which is 3D printed as a uniform part. This part was made uniform as it transfers most power along the shaft, additionally this will allow for uniform rotation. In the first iteration an oversight was the use of a track instead of interconnected flange/shaft (Fig. 29). The design had no central shaft and was based on bearing rotation only, in theory it may work with very tight tolerances that would keep the

platforms stiff. The 3D printing tolerances are too loose for this, and the system locks up instead of providing constant straight rotation.



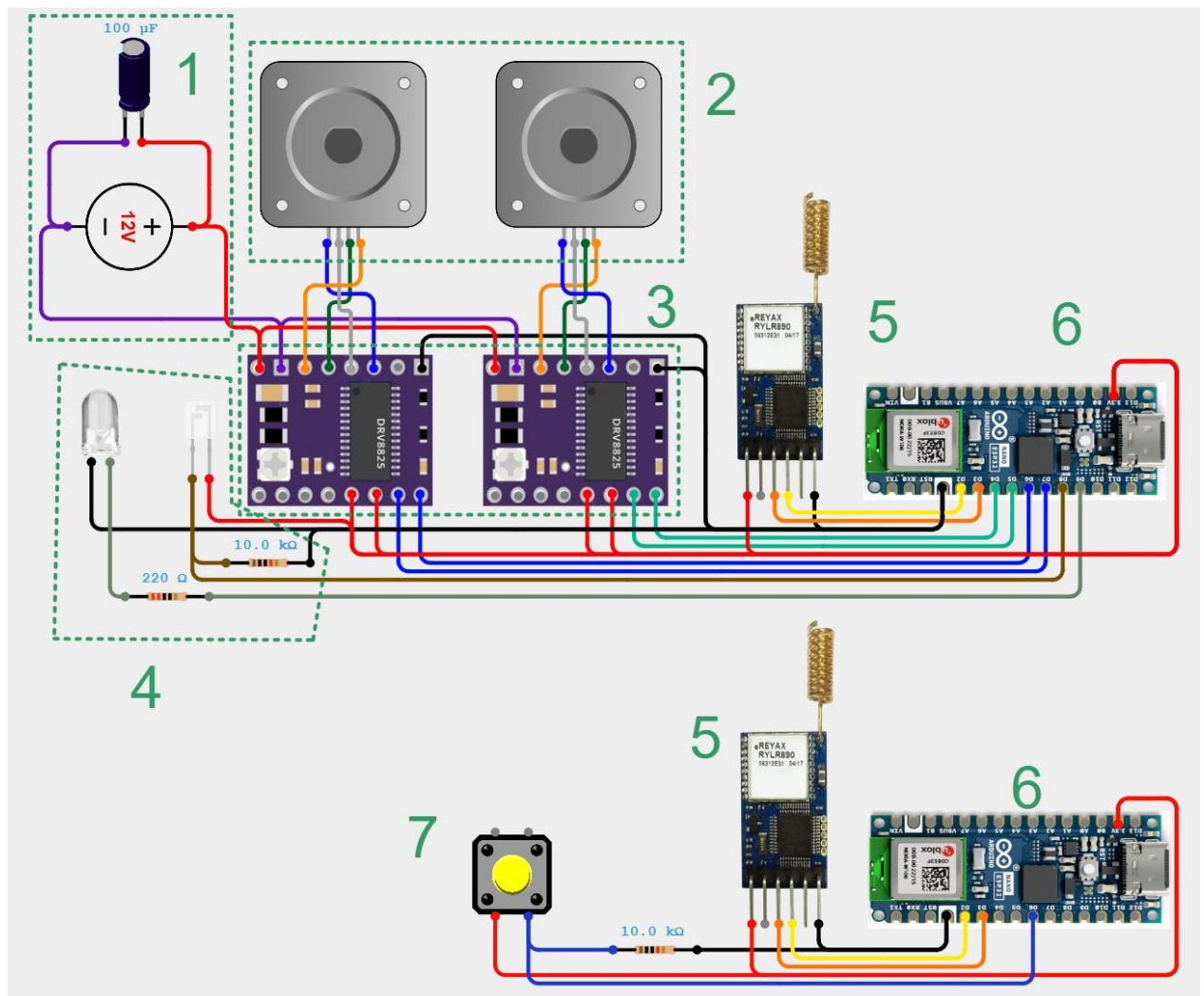
**Fig. 29.** First Iteration of the Design

The resulting 3D printed, assembled prototype is shown in Fig. 30.



**Fig. 30.** 3D Printed, Assembled Prototype

The next prototype step is to create the electrical control system. The electrical component connection visualisation is shown in Fig. 31.



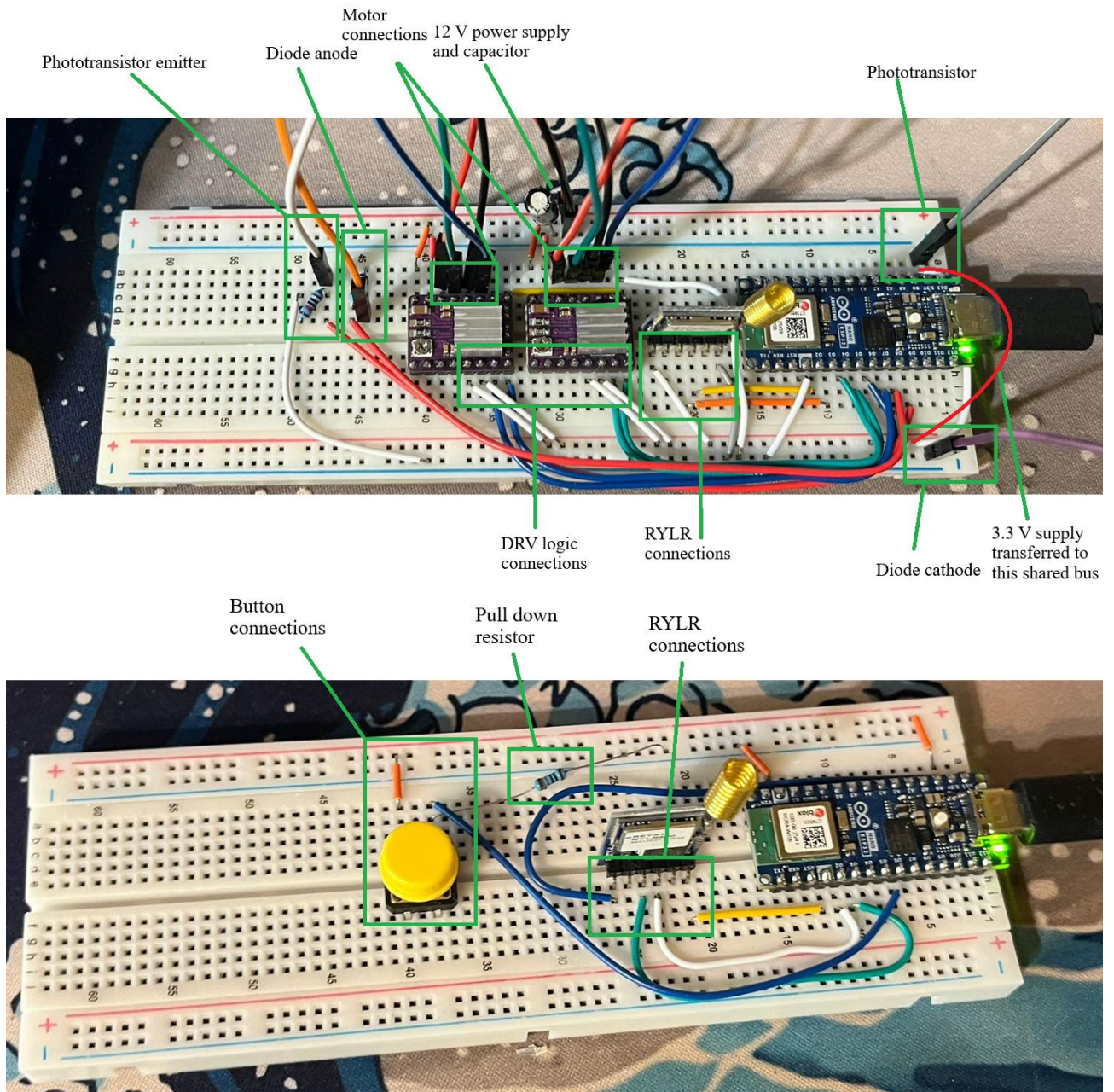
**Fig. 31.** Prototype Electrical Connection Visualisation

The schematic works as follows:

6. 12 V, 6 A power supply is connected to an outlet and DRV8825 motor supply pin. For prototype it was decided to not use a battery supply as the main focus is to test if other components can work in synchronisation and not if the station can last 48 hours. Additionally, a 100  $\mu\text{F}$  capacitor is used to soften the electrical fluctuations which can damage DRV8825 as per manufacturers recommendations.
7. Motors are connected to DRV8825 via the four wires (two per motor phase). During initial setup it is mandatory to correctly adjust the potentiometer which is used for drive power control. The general rule is that the voltage between the potentiometer and the logic ground should be a direct value half of the required motor amperage. I.e. it was decided to feed 1.5 A to motor, thus voltage was adjusted to 0.75 V.
8. DRV8825 modules have multiple not usable pins, at the top it is FAULT pin which is unnecessary for basic operation as prototype testing. At the bottom, from left EN pin is active LOW, meaning having it disconnected enables the system (could be connected to GND, but seems to work either way) and three micro stepping pins that are disconnected as maximum step is used.
9. IR diode and phototransistor connections. Diode requires resistance to limit the current going through it, otherwise it may overheat. Phototransistor requires a resistor to not short signal to GND when signal is HIGH.

10. RYLR 896 modules connected to Nano ESP32. There are two separate boards, one is the main board that receives the signal for operational start and a secondary board to imitate the operator work.
11. Two Arduino Nano ESP32, they are powered by a USB from personal computer, which is not visualised in the graph. Each belong to separate board.
12. A button to send a start signal, uses a resistor for the same reason as a phototransistor.

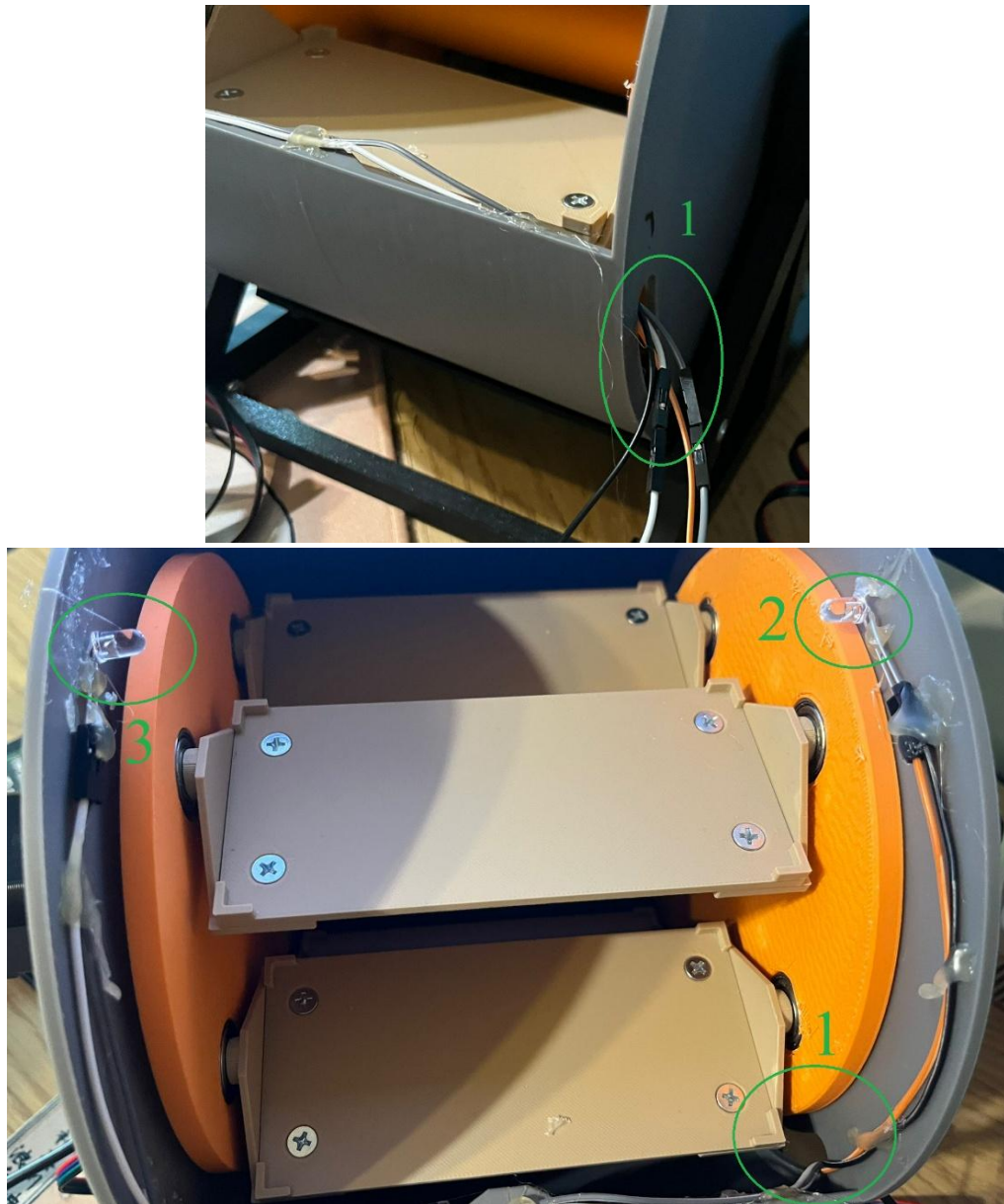
Actual connections on breadboard can be observed in Fig. 32. Apart from connections explained in the visualisation 3.3 V electrical connection is transferred to breadboard positive buss with a white wire that is difficult to see, because of this, it is marked red and noted.



**Fig. 32.** Electrical Connections on Breadboard

Additional connections made on the 3D printed device can be observed in Fig. 33. The parts are hot glued directly to the inside of the shell. To exclude positioning geometry within the shell during

mechanical design was intentional, as it was decided that prototyping will allow to better visualize how wiring should be done optimally.



**Fig. 33.** Electrical Connections on Device

The figure portrays:

1. A predesigned hole for electrical wiring implementation.
2. IR LED hot glued to one side of the casing.
3. IR phototransistor connected to another side of the casing.

Last step in prototype design is to create a code to control each element of the system. This code can be observed in appendixes 1 and 2 for main and secondary boards. The program used is Arduino IDE. First code was built with a combination of sources [56, 77, 78] and insights gathered from various online forums, community discussions, which, not directly citable, but did contribute to the overall implementation. Second code was built from information gathered during the writing of the first code and internal Arduino IDE libraries. An algorithm that displays how the main code works can be observed in Fig. 34.

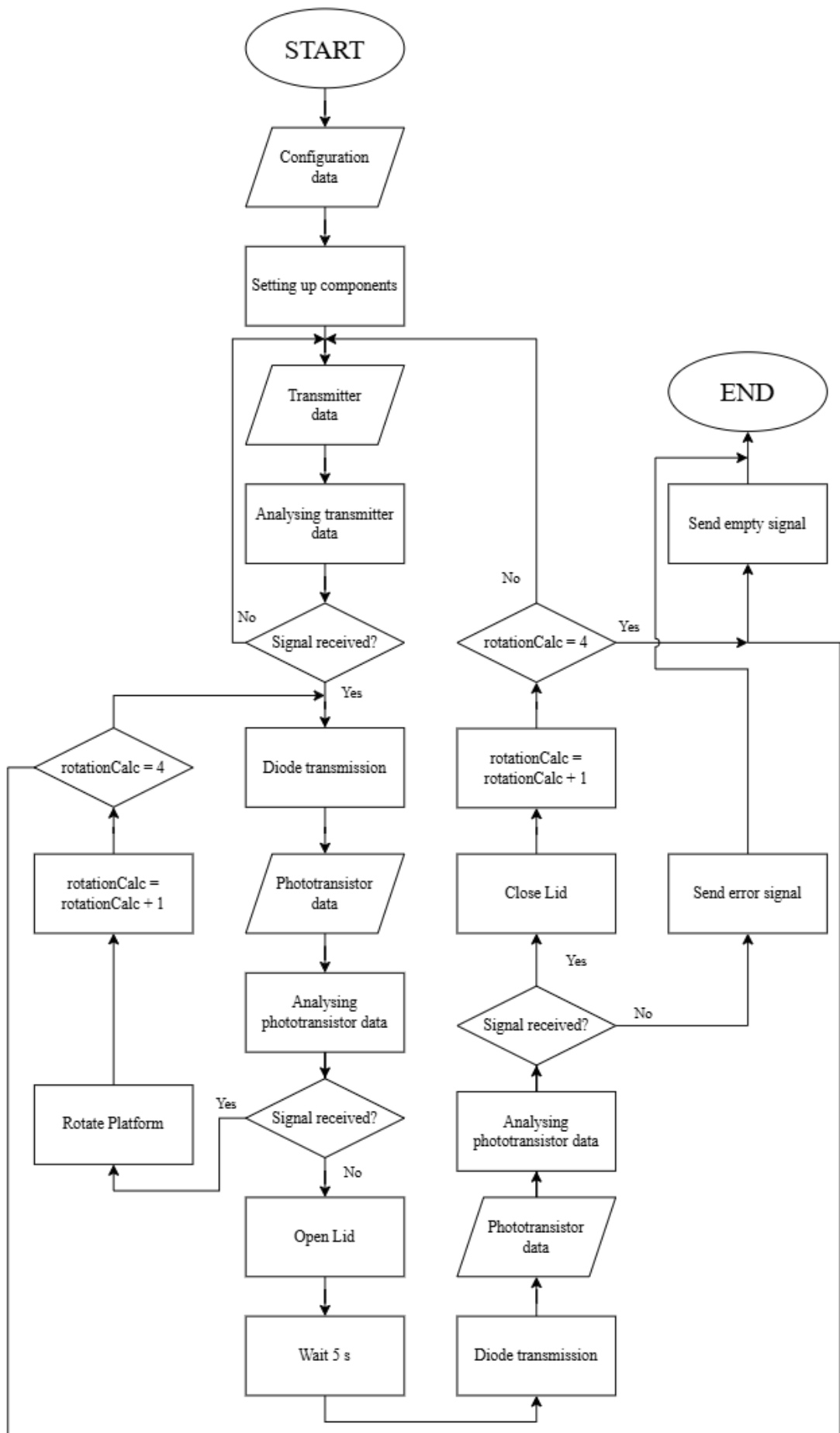


Fig. 34. Program Code Algorithm

Firstly, the algorithm end is done manually within the prototype. This is on purpose to test various scenarios in quick succession without requiring to reset the station. The cycle starts with set up of various configuration data that is chosen manually, this consist of speed, acceleration, pin modes, LoRa settings and other settings related to components. After transmission the cycle starts with waiting period where a signal from the other module will be found. If the signal is found the diode and transistor data is processed, during which platforms are rotated up until the last platform if there is no items on platform, else the lid is opening. The wait time is set to 5 seconds as the pick-up was done by hand and not a UAV. Further research should determine the required amount for adequate pick-up time. After pick-up the transistor-diode data is processed again. If signal is received the lid closes, rotation calculation updates and if it has not reached four (fifth chamber is emptied, because first one starts at rotation zero) it resumes cycle. If it has reached fourth rotation it additionally sends a signal that it is empty, if the phototransistor data claims that there was no pick-up during the timed period, an error signal is sent. Each time the cycle repeats if required it is ended manually. Additionally, when observing the code, there can be noticed that not all messages are sent back to the small breadboard controller. This is done because using empty and start signals is enough to test LoRa signal, writing unnecessary lines was determined redundant for testing at this stage. The results of the testing can be observed in Fig. 35.

```

12:33:40.087 -> +RCV=69,5,START,-52,51
12:33:42.142 -> Chamber 1 Empty
12:33:44.147 -> Chamber 2 Empty
12:33:46.233 -> Chamber 3 Empty
12:33:48.229 -> Chamber 4 Empty
12:33:50.587 -> Lid Open
12:33:57.907 -> AT+SEND=69,5,EMPTY
12:33:58.915 -> Lid Close
12:33:58.915 -> +OK

12:34:05.488 -> +RCV=69,5,START,-50,40
12:34:07.526 -> Chamber 1 Empty
12:34:09.846 -> Lid Open
12:34:17.147 -> Chamber 2 Empty
12:34:18.176 -> Lid Close

12:35:33.460 -> +RCV=69,5,START,-48,43
12:35:35.539 -> Chamber 3 Empty
12:35:37.822 -> Lid Open
12:35:45.142 -> Chamber 4 Empty
12:35:46.174 -> Lid Close

12:35:51.048 -> +RCV=69,5,START,-50,40
12:35:53.337 -> Lid Open
12:35:58.563 -> AT+SEND=69,5,ERROR
12:36:01.678 -> +OK

```

Fig. 35. Program Results

The results are divided into three sections:

1. First cycle had object in last chamber only (the object is a black 3D printed box high enough to block the sensors). Each chamber was checked as empty, last check confirmed an object, thus lid opening sequence was done. "+OK" is a reply from RYLR module to confirm that "EMPTY" message was sent.

2. Second and third cycles had objects in chamber 2 and chamber 4. The cycle stops at each chamber and requires a start from operator breadboard which can be observed at received signal “START”.
3. Last cycle had an object in the chamber 5. This time the object was not removed during the pick-up stage to simulate error state, the “ERROR” was sent to the controlling module.

The main take away from the prototype testing is that the design is grounded in reality and could be done in theory and practice. To further validate this conclusion further, Table 11 provides the requirements established previously and comments on what was addressed by how much.

**Table 11.** Verification of Requirements

Requirement	Specification	Comment
Package Weight	Maximum 5 kg per package	Met in conceptual design. Not met in prototype.
Package Capacity	Minimum 5 packages	Met in both designs.
Unattended Operation	Minimum 48 hours	Met in conceptual design. Not met in prototype.
Power Supply	Internal	Met in conceptual design. Not met in prototype.
Weather resistance	Rain and wind resistance	Partially met in both designs
Deployment	Portable	Partially met in both designs
Pick-up	Robust, simple	Met in both designs.
Station Weight	25 kg without cargo	Met in both designs.
UAV compatibility	FPV class	Met in both designs.
Personnel Exposure	None during drone operations	Met in conceptual design. Not met in prototype.
Materials	Cheap to produce	Met in both designs.
Cost	Expendable if destroyed	Met in both designs.

The package weight was evaluated only for the conceptual design, this choice is made as the prototype material is 3D printed and accurate calculations are not possible due to various settings within the G-code program like wall loop amount, infill amount, infill pattern, orientation of 3D print. These settings can alter the strength of the part by large margins, while there are no concrete formulas to calculate everything accurately. Package capacity is met in both designs; they both can hold packages in 5 internal packages. Unattended operation is only addressed with conceptual design; prototype was tested and attended to during the whole time. Same conclusion can be drawn to power supply design as conceptual design has a 7 Ah battery, while the prototype is powered by an outlet for testing purposes. Weather resistance was the least focused object of research; it should be addressed in further research in more detail. Currently the only design choice that addresses rain cover is the round design and stepper motor covers in conceptual design. Pick-up is simple, station only places the parts in position for pickup, rest would be done with a passive gripper. Copter UAVs are compatible with the station as they can stay still in air to adjust for the pick-up. Personnel exposure correlates with unattended operation. Materials are cheap on both designs, the most expensive parts are the motors, making the system expendable.

During the analysis there were multiple things found that could be improved on. For example, the current mechanical design does work as intended, but platforms are basically a swing. Method that

always keeps the platforms horizontal in a more reliable way should be found. One suggestion would be to lower the mass centre of each platform by making them from thicker materials, another suggestion would be to swap the internal design to a track with a rotation mechanism on one side only, if properly accounted for bending forces when platform is not held on both sides the system could use a track and rotate without twisting. Another design adjustment would be adjustable feet at the bottom; uneven surfaces could cause the system to fall. Lastly, the core idea was to have electronics inside the drum core below the rotation shaft and platforms, during assembly it became apparent that this idea is futile as the assembly is difficult as is. A separate weatherproof casing is a better solution while keeping the hole for internal wiring. Which additionally raises a task to improve the assembly of the system.

The electrical design also could have improvements, during the second prototype iteration instead of LoRa there were attempts to use SIM800L module for communications [79]. The module did not work as intended, presumably because the 2G communication which the module uses is not as available anymore [80] or there were incompatibilities with telecommunication service providers. Following this, SIM7600 use should be explored. Additionally, the motor drives were configured to not use micro stepping, while for lid control it was acceptable, the internal rotation backlash was large. In further research micro stepping should be used for internal rotation to make the system more reliable. Additionally, more sensor implementation could be of benefit, for example the previously denied combination of slip ring with sensors for each chamber and mechanical sensors for zeroing coordinate system for motors.

The control system was mainly focused on component testing, further improvements would consist of implementing the cycle end. Communication between more than two communication modules. Additional functions like just checking the number of packages that are still within the system. Communication between UAV and station implementations. Use of additional sensors reading, or multiple reading iterations could be more accurate, although there were no problems during prototyping. Time out mode where system goes to power saving mode should also be done.

### **3.4. Chapter Summary**

The chapter is dedicated to conceptual and prototype design development and analysis. The first part of the chapter analyses conceptual design platforms that are 100 x 150 x 610 mm and experiences 17.9 MPa stress from the cargo and self-weight. The internal rotation mechanism that is 640 x 400 x 400 mm is evaluated in the most unbalanced scenario, the torque required to move the mechanism is 14.3 Nm. Additional calculation for lid (700 x 280 x 520 mm) is made where estimated torque is 4.86 Nm. Finally full conceptual design is presented. For electrical system each component alternatives are evaluated. For final conceptual design Arduino UNO R4, SIM7600, TMC2209, 32HE30-2804S, 32HE22-2804S, IR diode and LTR-3208 are chosen. For prototype Arduino Nano ESP32, RYL896, DRV8825, 17HE19-2004, IR diode and LTR-3208. Additionally battery capacity was calculated for the conceptual system and 12 V 7 Ah battery was chosen. In prototype design, the 3D model dedicated for 3D printing was presented together with first iteration which failed explanation and real life image of the printed result. Same concept was done for electrical components, where a prototype visualisation was done firstly with actual images showing elements in real life following. Lastly the control system code was shown together with an explaining algorithm, it was established that system has to end manually on purpose of testing. Results were confirmed to be as expected, most of requirements were met and improvements for the system suggested.

#### **4. The Impact of the Designed System**

To completely assess the system that was designed it is important to analyse how the chosen decisions prove valid from the perspective of social, economic and environmental angles. Each angle must have both drawbacks and benefits that can assist in analysis. The system is evaluated as a conceptual design first, and as a proven prototype later if there is no way to accurately do the evaluation with conceptual design information only.

##### **4.1. Designed System from Economic Angle**

This is the most difficult evaluation to do on a conceptual design. Reasoning being, that the discussed conceptual design manufacturing and components differ from an actual prototype that was designed. To prove the point, it was determined that cast or injection moulded parts would be used in conceptual design. Moulds for injection moulded parts can cost a few thousand EUR as a minimum. While this may look as economically unviable, the reasoning to prove wrong is, that under mass production the cost per part is miniscule. Same concept could be applied to electronic component manufacturing, where each component would require manual assembly, the circuit can be manufactured as a simple PCB (printed circuit board). For example the prototype design has eight pins used in total. It is both not difficult to design such PCB and possible to manufacture with small scale production requiring investments of 2200 EUR (for Eurocard format) [81]. Making the electrical circuit small, concise and easy to implement.

The most expensive part for conceptual design is the SIM7600 module which costs 93.45 as established in design phase. Apart from this part other components are very cheap to mass produce, additionally there are options to use even cheaper elements, for example, instead of Arduino original parts, there are alternative vendor designs. As discussed, they may be not as reliable, but the possibility still stands. There are other mechanical components like bearings and screws that can be so cheap they basically have no influence on the overall price. Another electromechanical part, the motor is also one of the more expensive parts. Although this price in the context of military use is cheap.

This cheap cost has a slight downside. When comparing to commercial products it is evident that cheap design lacks most features other stations had. This includes, charging, UAV control, flightpath analysis. It is not economically viable to include such features as the system is designed to be expendable rather than a full-time product. However, from a military point of view, a system which can be abandoned and destroyed without a financial loss is very economically viable when compared to commercial products that require recovery, maintenance and cost thousands. Of course, this expandability does have additional drawback when it comes to environmental impact.

##### **4.2. Designed System from Environmental Angle**

It is unarguable that from environmental angle the design is detrimental when overviewed individually. Having the design expendable, leaving battery, plastic, metal in environment can not be twisted to be as a benefit. While the prototype is made from PLA which is a biodegradable plastic at specific conditions and not when simply left outside. Although there are alternatives PLA solutions with different composite materials used within that may assist in biodegradation [82]. The conceptual design uses non-biodegradable components, which would be left till someone can clean what is left of the station which can happen a week later or years later. An indepth research on various types of

plastics should be done as there are alternatives even from PLA, like starch-based plastics, cellulose-based plastics, protein-based plastics etc. [83]

Additionally worth noting that warfare by itself is very disastrous to the environment and there should be ways to address the environmental damage caused. These actions would consist of strict monitoring of physicochemical properties, extracting heavy metals from soil, removal of plastics etc. [84]. Further research could research the implementation of more biodegradable materials, additional GPS tracker black boxes to track components after breaking down and so on. Although with this designed product priority comes to social impact which is by far the most influential.

### **4.3. Designed System from Social Angle**

The main reasoning behind the expandability and autonomy is the removal of soldier – machine interaction. This dedication is focused on saving lives by removing human interaction. As it was established in 1.1 chapter, the logistics have already become practically only done by UAV and UAG. This further minimises the time of rearming drones, makes drone, cargo and personnel locations more asymmetrical in front lines. Of course, the use of autonomous machinery does raise ethical concerns. Despite the fact, the design is focused on logistics and not warfare and reconnaissance operations and as shown, logistics can be for food, cigarettes, water and any other necessities.

Use of logistics for such necessities not only improves morale, it has psychological benefits of providing reliable supplies without risk of life loss. Minimising the risk of exposing oneself to enemy UAV is very important. As previously explained, supply missions are one of the more dangerous parts of missions. Predictable movement and patterns of movement make personnel exposed to dangers that can be overcome with the removal of human presence during the reloading operations. On the contrary, there still are moments where human interaction is required, that should be addressed with additional drones loading the system instead. Making five reloading cycles theoretically indefinite.

One of the drawbacks that can happen with the use of the stations is communication jamming, especially with RF based LoRa technologies. Same or similar technologies are used for drone control, and RF jammers are very common in battlefields, such devices could be used on stations. Although there multiple anti-jamming technologies developed [85] That is why the discussed use of 4G and LoRa may be beneficial. Additionally, there are stress induction from the drone operating itself, where half of operators in a study reported being stressed or extremely stressed [86].

### **4.4. Chapter Summary**

All in all, the conceptual design would have high initial costs but it is easy to mass produce in further manufacturing processes. Many components would have uninfluent costs with probably the most expensive parts being SIM7600 module and stepper motors. Although in general the station is very cheap but lacks features that are common to stations available for commercial use.

The station is not beneficial from environmental angle as it was not the focus of the project. But further research should address this, additionally preventative methods after use should be made.

Socially the station has most use, it can save lives by preventing human, machinery interaction. This in turn would create an ease on psychological difficulties during war. There are further possibilities to make system work indefinitely. A difficulty can be jamming technologies used in warfare.

## Conclusions

1. Commercially available cargo delivery systems were available from 2016 in Rwanda. Main focus of cargo handling systems commercially are city parcel delivery. There are multiple designs for stations in commercial sector, main design focuses are on weather resistance, battery charging or swapping. In scientific literature stations, the focus is battery charging, changing. Stations have multiple styles of landing mechanisms such as no positioning, active or passive positioning. Gripper focused designs are more dedicated to cargo manipulation, complex grippers do not require stations, and passive grippers require complex stations to compensate.
2. Main requirements and specifications drawn from previous reviewed literature are: maximum 5 kg per package, minimum 5 packages, unattended operation of 48 hours, has to have internal power supply, be weather proof, have portable deployment. The pick-up method must be robust and simple, the station itself weigh 25 kg without cargo, should be compatible with first person view drone class, have no personnel exposure during drone operations. Station should be cheap to produce from expendable material if it were to be destroyed.
3. The conceptual mechanical design was designed to be cylindrical, housing an internal rotating mechanism with horizontal platforms. The total mass is 23.86 kg, the dimensions are 1010 x 520 x 600 mm. Platforms that are 100 x 150 x 610 mm and experiences 17.9 MPa stress from the cargo and self-weight. The torque required to move internal rotation mechanism that is 640 x 400 x 400 mm is 14.3 Nm. The torque required to move the lid is 4.86 Nm. For final conceptual design Arduino UNO R4, SIM7600, TMC2209, 32HE30-2804S, 32HE22-2804S, IR diode, LTR-3208 and 12 V 7 Ah battery are chosen. For prototype Arduino Nano ESP32, RYLR896, DRV8825, 17HE19-2004, IR diode and LTR-3208.
4. The prototypical control system is designed around Arduino Nano ESP32. Motor control is handled by DRV8825 drives. Cargo detection is done through IR diode and IR phototransistor combination. Communication is done with RYLR896 LoRa Module. The control code represents all these features. Within the presented algorithm that explains the control code it is shown that the code does not have end of the cycle on purpose.
5. A functional prototype was manufactured using 3D printer with PLA material. The prototyping took three design iterations to get a functional result. The first flaw was the track for rotation design, the second was the use of SIM800L module. Prototype testing shown that each component can operate as intended with the write code. Raised additional requirements are met or partially met both in prototype and conceptual designs.

For future research it is recommended to further develop the model to meet all of the requirements raised within the project. Additional in field testing are also required. Use of SIM7600 also is recommended in future testing with possibility of LoRa communication addition. Conceptualisation of a hook system to work with the station and possibility of additional functionality implementations should be assessed. Additionally, recommendations within 3.3 chapter conclusion should be followed in next prototype design.

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## Appendices

### Appendix 1. Code for Main Breadboard

```
#include <AccelStepper.h>

// stepper pins
#define STEP_PIN_LID 7 // Step pin
#define DIR_PIN_LID 6 // Direction pin
#define STEP_PIN_IN 5 // Step pin
#define DIR_PIN_IN 4 // Direction pin

//sensor pins
#define transmitter 8
#define receiver 9

// Steps per revolution for the motor
const float stepsPerRevolution = 200;

// AccelStepper instance in driver mode
AccelStepper stepperLID(AccelStepper::DRIVER, STEP_PIN_LID, DIR_PIN_LID);
AccelStepper stepperIN(AccelStepper::DRIVER, STEP_PIN_IN, DIR_PIN_IN);

// Function to calculate steps based on desired rotations
float convert_rotational_position_to_steps(float rotations) {
    return rotations * stepsPerRevolution;
}

String message = "";
bool start = false;
int rotationCalc = 0;

void setup() {
    float MaxRPM = 10; // Max speed in rpm (revolutions per minute)
    float Max_Speed_StepsPerSec = stepsPerRevolution * MaxRPM / 60; // Max speed in steps/sec (converted from RPM)
    stepperLID.setMaxSpeed(Max_Speed_StepsPerSec);
    stepperIN.setMaxSpeed(Max_Speed_StepsPerSec);

    float AccelRPMperSec = 30; // Acceleration in rpm/sec
    float Accel_StepsPerSec2 = stepsPerRevolution * AccelRPMperSec / 60;
    stepperLID.setAcceleration(Accel_StepsPerSec2);
    stepperIN.setAcceleration(Accel_StepsPerSec2);

    // Move to position 0 as the starting point
    stepperLID.setCurrentPosition(0);
    stepperIN.setCurrentPosition(0);

    pinMode(transmitter, OUTPUT);
    pinMode(receiver, INPUT);
}
```

```

Serial.begin(115200); //communication with PC through USB
Serial2.begin(115200, SERIAL_8N1, 2, 3); //setting second UART channel,
SERIAL_8N1 sets data transmission format. In this scenario - 8 bits, no error
checking and stop bit amount per one transmission.
}

void loop() {

while (Serial.available()) {
Serial2.write(Serial.read());
}
//reading what PC and sending to RYLR module used for debugging

while (Serial2.available()) {
char c = Serial2.read(); //declares c as a character to attach one letter to
per look
Serial.write(c);
message += c; //adds each character to a string
if (c == '\n') { //LoRa ends each message with \r\n, \n
is counted as one character "new line"
if (message.indexOf("START") != -1) { //if \n is found the message is
overviewed for START condition
start = true; //start of the motor cycle
}
message = ""; //clears the message string
}
}
if (start) {
digitalWrite(transmitter, HIGH);
delay(200);
if (digitalRead(receiver) == HIGH) {
stepperIN.move(convert_rotational_position_to_steps(1.0f / 5)); // Rotate
platforms 1/5th of a circle
while (stepperIN.distanceToGo() != 0) {
stepperIN.run();
}
delay(500);
rotationCalc = rotationCalc + 1;
Serial.print("Chamber ");
Serial.print(rotationCalc);
Serial.println(" Empty");
digitalWrite(transmitter, LOW);
if (rotationCalc == 4) {
Serial2.println("AT+SEND=69,5,EMPTY");
Serial.println("AT+SEND=69,5,EMPTY");
start = false;
rotationCalc = 0;
}
} else {

```



## Appendix 2. Code for Secondary Breadboard

```
int button = 6;
int buttonState = 0;
int buttonLatch = 0;

void setup() {
  Serial.begin(115200); //communication with PC through USB
  Serial2.begin(115200, SERIAL_8N1, 2, 3); //setting second UART channel,
  SERIAL_8N1 sets data transmission format. In this scenario - 8 bits, no error
  checking and stop bit amount per one transmission.
  pinMode(button, INPUT);
}

void loop() {
  buttonState = digitalRead(button); // read the state of the pushbutton value:

  if (Serial.available()) {
    Serial2.write(Serial.read());
  }
  //reading what PC and sending to RYLR module used for debugging

  if (Serial2.available()) {
    Serial.write(Serial2.read());
  }
  //reading what RYLR module writes and showing on PC also used for debugging and
  seeing if everything is correct

  if (buttonState == 1 && buttonLatch == 0) {
    Serial2.println("AT+SEND=70,5,START");
    Serial.println("AT+SEND=70,5,START");
    buttonLatch = 1;
  }

  if (buttonState == 0) {
    buttonLatch = 0;
  }
  delay(50);
}
```