Forest seedling transporter

Skogforsk & SCA

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Abstract

300-400 million seedlings are planted manually each year by the Swedish forest industry. During this process workers walk an average distance of 20 km a day, in rough terrain, to resupply seedlings from the closest road. Due to this, Skogforsk in association with SCA, has given the task to develop and construct a seedling transporter capable of traversing rough terrain on primarily electric power. This report contains a state of the art of current technologies deemed relevant to this project as of 2022, a concept design for the proposed solution and a chapter for future work during the remainder of the project. The proposed solution is a hybrid of the designs studied in the state of the art. For suspension it utilizes pendulum arms. It uses a split chassis with split tracks for increased stability and to even out ground pressure. The chassis and track combination enables efficient differential steering, driven by electric motors. This project will be designed, constructed and evaluated during late spring and autumn of 2022.

Acknowledgments

Special thanks to the team at Skogforsk, Linnea Hansson & Morgan Rossander, for their assistance during the spring as well as our coaches, Tobias Vahlne & Gustav Sten.

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1 Introduction

This part of the report covers the background of the project, as well as what is required for the project to be considered a success.

1.1 Background

The Swedish forest industry is the world's fifth largest exporter of pulp, paper and sawn timber. Planting at least 380 million trees annually, a large majority of the planting process is done by manual labour. Today seedlings are delivered to the forestation sites by traditional vehicles using the gravel roads going through the forests. From the drop-off point the seedlings are carried by humans either in backpacks or satchels across the site to be planted. This means that a large part of a planter's days consist of walking back and forth between the drop-off point and the site.[14]

Skogforsk is the forestry research institute of Sweden whose mission is to develop and communicate knowledge, services and products to support greater sustainability in forestry, now looking into improving the tree planting process on site. There are many projects which investigate possibilities for improving the planting process, such as using automatic planting vehicles or drones for the transport of seedlings. At the request of Skogforsk this report will evaluate and develop a land vehicle for transporting seedlings. [1]. The goal is to alleviate the load of the workers currently completing this task.

1.2 Scope

The scope of this project is to design and construct a remote controlled vehicle capable of carrying seedlings trough rough terrain. To this end the final design should aim to have as low ground pressure as possible while having good mobility and stability. The vehicle should be able to operate under normal working conditions for an extended period of time. Additionally, the vehicle should have some kind of self righting feature so that the cargo remains leveled as well as the means to extract itself should it become stuck in the terrain.

There are several limitations placed upon this project which are presented in the requirements section in full. However there are several points of lesser importance to the stakeholders that still can be pursued, time and budget allowing. This is due to this project being part of a larger push from Skogforsk to develop a fully automated forest industry. To this end sensors and cameras could be fitted to the vehicle and connected to the ROS family of software. Alternatively, room could be allocated on the vehicle to support their future implementation and be used by another project down the line.

1.3 Requirements

Skogforsk provided several technical requirements which proved not to be exhaustive and left a lot of room for different solutions. Additionally, in talks with Skogforsk it came apparent that some of these requirements were considered more as guidelines, and that as long as the primary purpose of the vehicle was met some requirements could be ignored.

1.3.1 Stakeholder Guidelines

The stakeholders requirements were simply to designs and construct a remote controlled vehicle capable of carrying seedlings across rough terrain. The vehicle should have good mobility, stability, reliability and be able to keep up with walking pace. To that end several requirements were given as follows:

- Diameter of each wheel must be more than 300 mm.

- The speed of the vehicle should be in the interval of 0 to 3 m/s, i.e. walking pace.
- The vehicle should be capable of a ground clearance of at least 500 mm.
- All wheel drive (or at least 75 percent of the wheels).
- Ability to operate on soft soil (peat soil).
- Operational temperature of 0 to 40 degrees.
- Maximum unloaded weight of 200 kg.
- Load capacity matching or exceeding 50 kg.
- Weather protection of at least IP54 for parts exposed to the ground and IP44 for higher placed parts.
- Remotely controlled by user in close proximity.
- Utilizing the ROS interface.
- Maximum hardware cost of 50 000 SEK.
- The vehicle should fit inside a standard trailer.
- The vehicle should be electric.

1.3.2 Technical Requirements

After considering the list made by the stakeholders, and an analysis of the problem, the final technical requirements are as follows:

- The speed of the vehicle should be in the interval of 0 to 3 m/s, i.e. walking pace.
- The vehicle should be capable of a ground clearance of at least 500 mm.
- All wheel drive (or at least 75 percent of the wheels).
- Ability to operate on soft soil (peat soil).
- Operational temperature of 0 to 40 degrees.
- Maximum unloaded weight of 200 kg. It should be easily recoverable if it gets stuck.
- Load capacity matching or exceeding 50 kg.
- Weather protection of at least IP54 for parts exposed to the ground and IP44 for higher placed parts.
- The vehicle should be remotely controlled by user in close proximity.
- Maximum size while transported of 250x130 cm.
- The vehicle should be able to climb a slope of 20°.
- The vehicle should utilize the ROS interface.

2 State Of The Art

The State of the Art includes an analysis of previous work concerning similar projects.

2.1 Relevant Solutions

This section displays an analysis of different solutions to similar problems, which might be applicable to the final solution.

2.1.1 Mars Rover

Mars rovers are moving vehicles used for exploration on the surface of Mars. Until now, seven rovers around the world have successfully landed on Mars and conducted exploration work. Mars rovers are typically used to travel over uneven terrain, climbing over rocks and obstacles, while maintaining vehicle balance and moving smoothly. The difficulties that the rover needs to overcome are in line with what this project is looking for. Therefore, a design similar to the Mars rover could be an option for this project. Figure 1 shows a typical 6-wheel Mars rover.

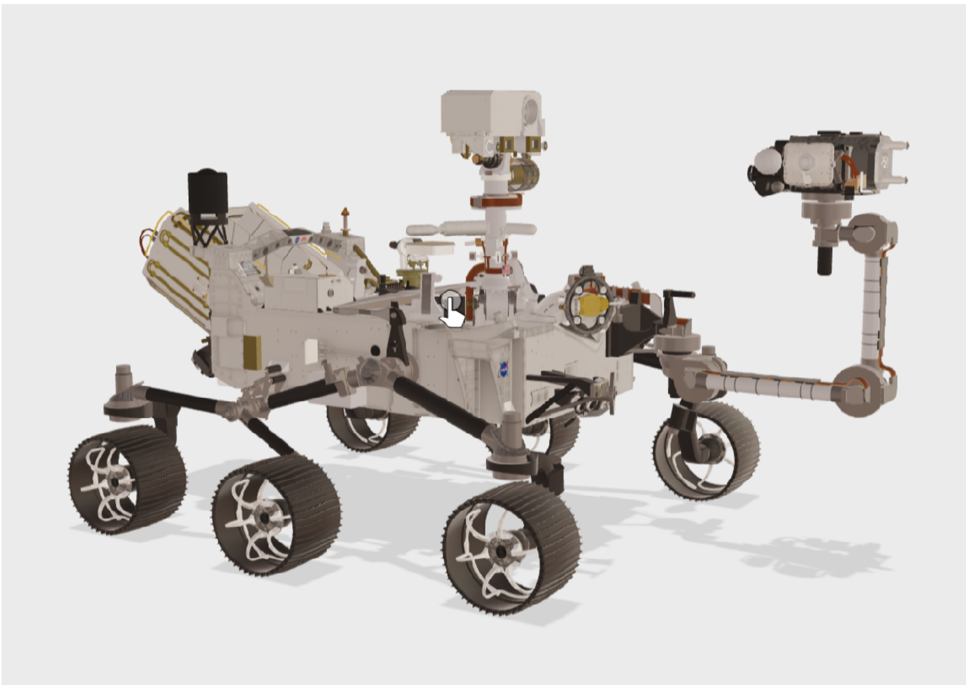

Figure 1: Overall figure of a Mars Perseverance Rover

According to Cox et al. [3] there are three essential driving mechanisms typically used by Mars rovers in order to be capable of traversing obstacles: rocker-bogie suspension system, differential pivot, and 6-wheel Ackermann steering.

The rocker-bogie suspension system allows all six wheels to maintain contact with the ground when encountering an obstacle. If some of the wheels are unable to stabilize when an obstacle is encountered, the rest of the wheels can still maintain the balance of the body. The rocker-bogie design allows the rover to have maximum contact area with the ground when the angle of the wheels is different, thereby increasing the friction to keep the vehicle in balance.

Moreover, differential pivot is an essential mechanism for the design of the rover. Differential pivot can mechanically offload the weight from one side of the rover to the other side while it is climbing. The

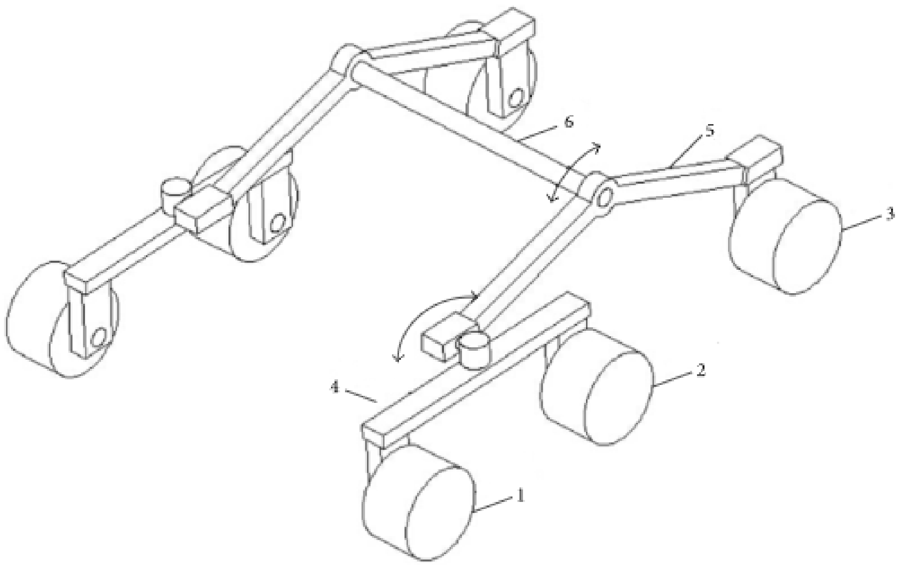

Figure 2: Rocker-Bogie suspension system

last required driving mechanism for the Mars rover is the 6-wheel Ackermann steering. Each wheel is a separate entity, and each wheel has its own individual motor for driving and steering. Using the Ackermann steering geometry, the speed and angle of each wheel can be calculated from the radius of the turn.

However, the Mars rover also has some drawbacks. The construction of the rover has many articulated joints, and in the actual application of this project, there are puddles, swamps, and other types of terrain where a Mars rover may not be able to fulfill the requirements.

2.1.2 Chassis with an articulated body with 3 degrees of freedom and installed luffingwheel-legs

The first report by Zhu et al. [17] presents the design of a chassis with three degrees of freedom. The separation between the front and back of the chassis improves the effectiveness of differential steering by allowing the front and back sections to align similarly to Ackermann steering. Additionally, the construction allows the individual parts to handle rotational movement when surmounting one sided or tilted obstacles.

The second report by Zhu et al. [4] presents a solution which consists of taking the chassis from their first report, and adding luffingwheel-legs to increase the suspension capabilities of the vehicle. The luffingwheel-legs, which are the main focus of the report, utilize a knee joint to manage the height of the wheel relative to the chassis. This construction enables the vehicle to keep the chassis stable, keeping the connected parts relative displacement significantly lower than the construction using no suspension.

The separation of the chassis into several parts greatly increases the vehicles capability to handle a series of different sided obstacles without tilting the entire vehicle one way or the other. This is greatly applicable when crossing uneven surfaces such as those expected from the requirements.

The utilization of luffingwheel joints can be applied to most chassis, and enables an efficient control of the pendulum arm between the chassis and the wheel, enabling controlled suspension. Applying such a design to the project vehicle would greatly increase the stability of the chassis, even if the chassis is different from the one in the reports by Zhu et al.

2.1.3 3D Printed Robot Dog Climbs Over Obstacles

The concept of walking robots is based on biomimicry. The intention of such mimicry is to mirror the movement of animals in nature to overcome obstacles that occur in their environment. There are many reports discussing walking robots, such as that by Zhong et al. [16] which compares different design concepts for quadruped robots. An advantage of most quadruped designs is that they provide significant ground clearance, and high mobility. Thus, the robot provides the necessary tools to traverse terrain. The possibility of crossing difficult terrain for quadruped robots is further explored in the article by Raibert et al. [11] where a quadruped robot is built for crossing rough terrain. The article shows that the robot can cross several types of rough terrain. However, it is also mentioned that the load is limited, and that the terrain it is able to cross is not very complex.

Conclusively, it would be possible to create a quadruped robot which satisfied the requirements. However, the time required to create such a robot is not available, so it is not feasible to use such a construction. It is also most likely that the components required for such a construction do not fit within the available budget.

2.1.4 TRIDEC - All Terrain Hydraulic Axle Suspension

The TRIDEC hydraulic axle suspension is a solution intended to handle a large variety of problems that arise when designing and using larger vehicles. The suspension is built using one hydraulic piston on each side of the vehicle for every axis as seen in Figure 3 which are used to manage terrain and improve driving conditions. [6]

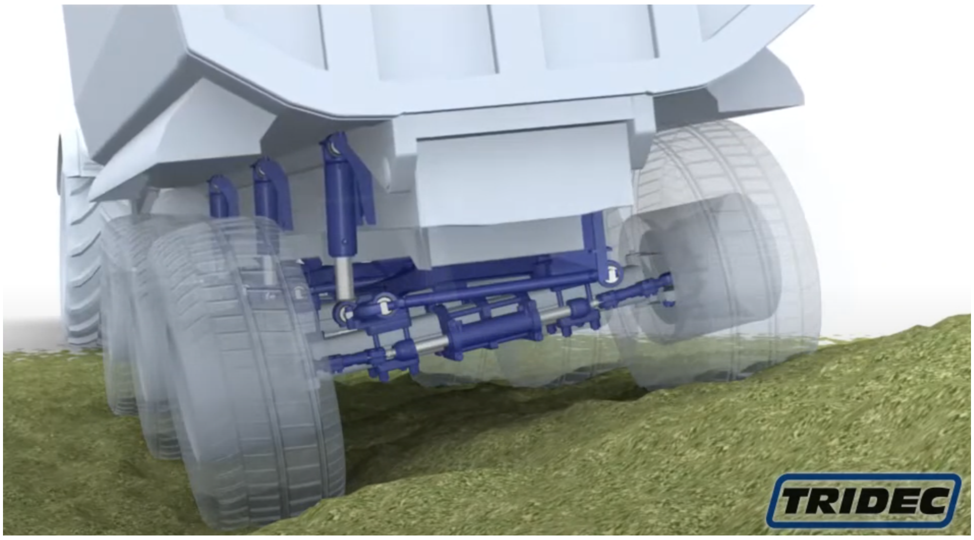

Figure 3: TRIDEC - Hydraulic pistons on each side of every axle

For example the suspension can help level the cargo and cab of the vehicle to improve corner stability, it enables retraction of wheel pairs when they are not used. But the most relevant usage of this suspension is of course its ability to handle varying terrain. As every wheel has a piston there is a lot of versatility. The hydraulics acts as a passive suspension while also giving the operator the option to extend each piston independently to surmount difficult obstacles, this could come in very handy if larger obstacles are encountered in the forest. Another great thing about this solution is the use of axles as it enables the possibility for geometric steering, in this case Ackermann-steering as seen in Figure 4.

Even though the axles create a great solution for steering it also becomes the largest drawback due to ground clearance. Unless some other contraption is used to transfer torque between the axles and wheels, the axles will limit the ground clearance to approximately the radius of the wheel. A wheel with large

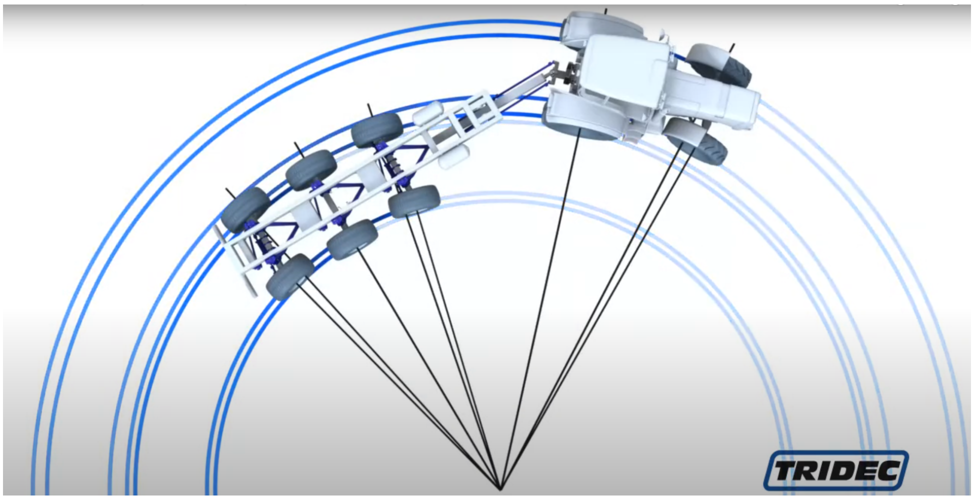

Figure 4: TRIDEC - Ackermann-steering

enough radius and width to achieve appropriate ground clearance and ground pressure could prove to become too large or too heavy to be feasible, especially as every wheel will be fitted with a piston and associated components. Although, given that it is possible mechanically the solution is feasible both from an economical and a labour-intensity stand point.

2.1.5 Hyundai Ultimate Mobility Vehicle Concept

Though the specifications are missing in Hyundai's presentation of their Ultimate Mobility Vehicle Concept [7], there is still much to be gained from analysing it. The presented robot utilizes a construction of legs with wheels, thus gaining both the advantages of having wheels when crossing simple terrain, and the advantages of having legs when crossing rough terrain. However, there are several parts of the design which seem vulnerable to branches and bushes and other such things that can get stuck in the joints. This means that the concept is workable, but that changes to the design would have to be made to avoid the before mentioned problems.

2.1.6 Centipede robot for uneven terrain exploration

The centipede robot for uneven terrain exploration [9] presents an additional solution to the issue of rough terrain mobility. The report shows how the robot could navigate very rough terrain, relative to its size. The terrains and the navigation of the robot through one of them are shown in Figures 5 and 6 respectively. The construction of a larger version of such a robot would ensure that the terrain could be traversed. However, many changes would have to be made to achieve the desired functions of the final vehicle. The robot has no inbuilt steering, and the construction would have to be modified to ensure that it can carry load. Since the construction is modular, it is feasible economically, labour intensively and technically to design a vehicle based on the centipede concept as its length can be adjusted.

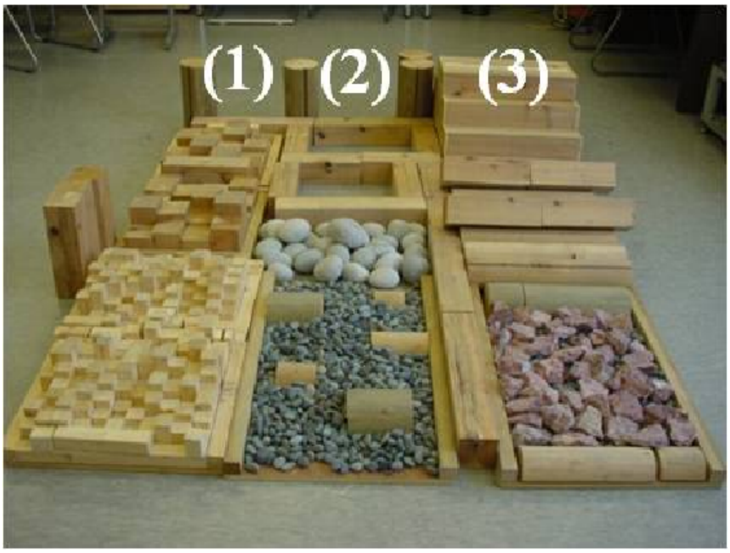

Figure 5: Terrains navigated by centipede robot.

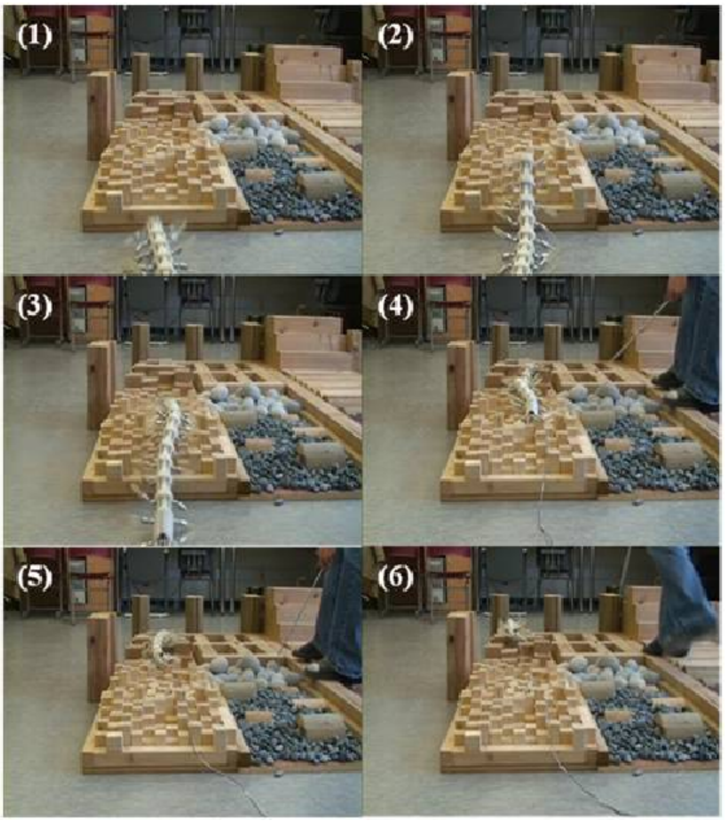

Figure 6: Centipede robot traversing one of the terrains.

2.1.7 The Multiscope UGV

The Multiscope UGV, made by the Estonian company Milrem Robotics [15], is a remote controlled multi-purpose tracked vehicle. The system is based on the military vehicle THeMIS by the same company. The vehicle utilizes a hybrid diesel electric power solution to drive its two tracks by electric motors. Due to the use of tracks and the relatively powerful motor the vehicle demonstrates good off-road performance and maneuverability in challenging terrain.

Demonstrated as well by the company is the adaptability of the platform in a wide array of roles. This due to the design of the cargo area seen in Figure 7. One of these adaptations is a forest machine carrying seedlings and associated planter very similar to the final design goal of this project.

Figure 7: Multiscope UGV by millrem robotics

Due to the two above stated key performance aspects, the fact that a version capable of carrying seedlings already exists this vehicle is highly relevant to this project. However the system does have some noticeable drawbacks. First is the weight, at 1630 kg base the system exceeds our own limit by 1400 kg. Second is the size, no data is provided but from videos the vehicle can be observed as much wider than our own limit. Third is the lack of adjustable suspension. The last of witch provides a bumpy ride across uneven terrain.

From this system we can make some observations of a tracked vehicles performance and implementation. Namely that tracks provide good mobility, lower ground pressure and the advantages of differential steering. These advantages comes at the cost of weight, and need of at least two more powerful motors compared to wheeled designs, and finally complexity.

2.1.8 XT28 - Self leveling pendulum arm terrain transport vehicle

The XT28 [12][13] is a terrain transport vehicle that uses pendulum arms to level it self in order to stabilize itself and reduce ground pressure to be more gentle on terrain. This vehicle is a prototype developed in 2016 by the same organization as the one funding this project and features many of the requirements set on this project but with a different scope, which makes it quite relevant to this project. The self leveling is done by using built in pressure sensors in the hydraulics that control the lifting of the wheels together with a gyroscope. This also allows for the vehicle to "step" over obstacles by lifting the wheels on at a time, in some cases making it possible to pass an obstacle without any pitch or roll change of the cabin/payload.

Figure 8: XT28 climbing over a rock

The vehicle is made up of the different modules with two wheels mounted on pendulum arms each, where the front module has the steering cabin mounted and the middle and rear module share a payload bed. Figure 9 shows how the XT28 steers.

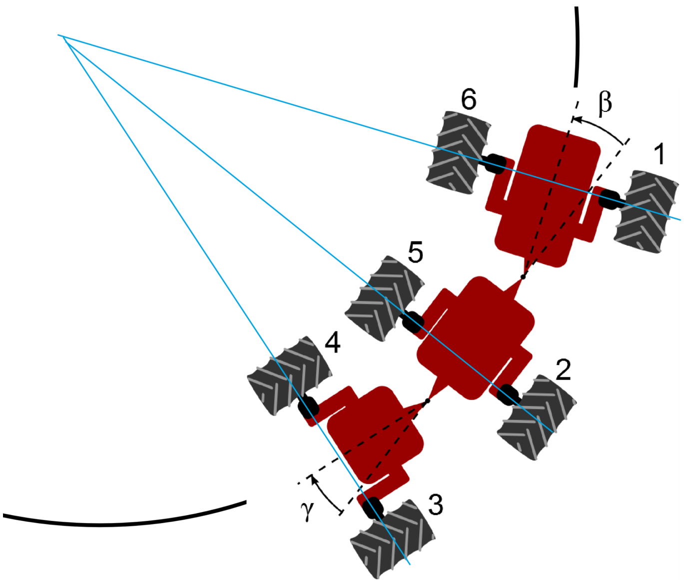

Figure 9: XT28 - Sketch of steering geometry

The XT28 is of great relevance to this project even though this vehicle was designed for a different purpose than this project. Much of the design could be simplified for this project as the payload for this project will be smaller and more rectangular rather than very long and thin. The suspension should then be very feasible to build both from a technical and labour standpoint, as well as from an economical standpoint.

2.1.9 Kyosho Optima Mid 4WD - Single motor 4WD RC Car

The Kyosho Optima Mid [10] is a RC vehicle that uses a single DC motor to achieve 4WD with a scale 1:10 car model, shown in Figure 10. The driving mechanism combines one motor with a central belt drive that connects the motor to the rear and front axis, see Figure 11. There are two pulleys that can be manually adjusted with two screws, to keep the desired tension in the belt, reducing friction and slip.

Figure 10: Kyosho Optima Mid 4WD, overview

Use of one motor while still producing 4WD is feasible from two aspects: firstly, it reduces both cost and weight as one large motor generally is cheaper and weighs less than four equivalent, smaller motors. Secondly, the central belt drive is a simple way to obtain 4WD and only requires one motor driver.

Figure 11: Kyosho Optima Mid 4WD, belt drive

However, 4WD with only one motor for all four wheels comes with a few drawbacks. Firstly, that the single motor has to be powerful enough and produce enough torque to replace four motors. Secondly, that control of each wheel's movement is limited, if not non-existing. The third is that with a central belt drive, the vehicle settles with a low ground clearance or requires additional shafts on both rear and front axis to distance the chassis from the ground, such as in the Kyosho Optima Mid, seen in Figure 12. Finally, this solution requires Ackermann steering, which is discussed in earlier sections.

Figure 12: Kyosho Optima Mid 4WD, rear shaft

2.1.10 Suspended forestry machines for sustainable forestry

There are many different existing solutions for handling tough and uneven terrain, and the designs are all suited for particular cases. Abbos Ismoilov concluded in his doctoral thesis [8] from previous research that forest machines should make use of either tracks, bogie or pendulum arms. This is necessary to satisfy stability requirements while encountering large obstacles and steep slopes as well as maintaining a functional vehicle without damage from intrusive branches and the like.

Another aspect to consider when designing an unmanned terrain vehicle is to minimize its impact on the environment. A common problem with heavy forest machines is rutting and soil compaction which can be reduced by lessening the ground pressure through an increase in contact area and by evening out the pressure throughout that area. Tracked vehicles tend to have a larger contact area than their wheeled counterparts [2] but with the drawback of causing large sheering of the ground, notably when driving in rough terrain or changing the driving direction.

2.1.11 Rating the solutions

The solutions above were evaluated base on three criteria:
Technical - Does it solve the problem? Does the competence exist to build it?
Economical - Are the parts to expensive? Does it need a lot specialized parts?
Labour - Is there enough time to build it? Would constructing it be difficult?

Topic	Technical	Economical	Labour	Sum	Additional comments
Mars Rover	7	3	5	15	Possible solution
3 degrees of freedom chassis	8	6	6	20	Useful chassis concept
- with luffingwheel-legs	6	4	6	16	Possible suspension solution
Quadruped robots	4	2	2	8	-
TRIDEC	6	8	8	22	Limited terrain adaptability
Hyundai	4	4	4	12	-
Centipede	4	4	6	14	Useful chassis concept
Multiscope UGV	8	6	8	22	Useful tracked and steering concept
XT28 pendulum arms	8	8	8	24	Useful suspension concept
4WD RC car	4	6	6	16	Problem with ground clearance

Table 1: Feasibility ratings of each design discussed in the SOTA, rated from 0-Impossible to 10-Perfect

3 Design Concept

After researching and reading about different concepts in a state of the art analysis, the most useful and feasible solutions were condensed to a design concept for the project, seen in Figure 13. This chapter covers the different parts of the vehicle and what design solutions that were chosen to solve the problems at hand.

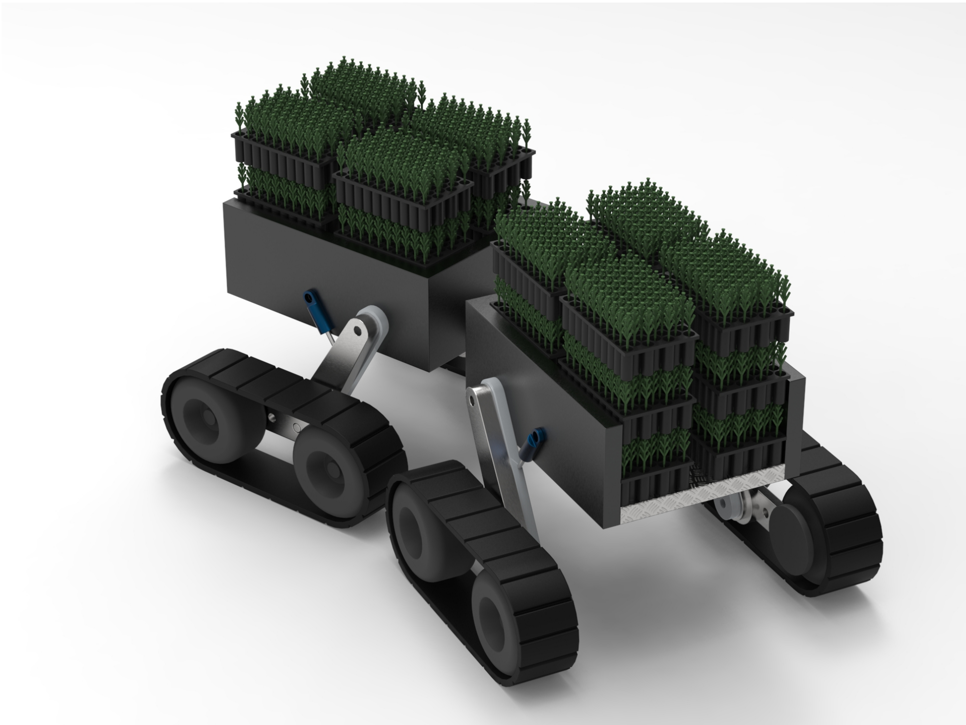

Figure 13: Design concept after state of the art analysis.

3.1 Suspension

There are three main types of suspension, passive suspension, active suspension and a hybrid of these two. Passive suspension most often comprises of springs and dampeners while active suspension usually uses some kind of linear actuator like a hydraulic piston often giving some built in dampening. For the purposes of this project, passive suspension would be quite trivial to implement as there would be no additional computational logic to implement for after installation and the system would work all by itself. The main reason this type of suspension is used in vehicles is to absorb most of the forces generated from driving over uneven road or terrain for the comfort of the driver, where the springs absorb the forces and the dampeners limit oscillations generated from those forces. Although that is great, if the vehicle were to stand still on an incline the suspension would settle at an equilibrium where the vehicle would be tilted in the same direction as the incline. This together with the low target speed of the vehicle to be constructed in this project would mean that there would not be a need to absorb a large amount of forces. With active suspension, the length of the suspension arm has to be continuously calculated and would probably not be ideal for faster road vehicles as the computer would have to be very fast and rely on very accurate sensors in order to absorb those forces. However, when going slowly or standing still, even a slow computer with minimal use of sensors would be able to accurately make the vehicle keep level with the horizontal plane and keep equal ground pressure between all wheels and the ground. For these reasons both passive and hybrid suspension will be discarded from this project in favor of active suspension as it will better fulfill the stability and ground pressure requirements. An example of active suspension can be seen in Figure 14.

Figure 14: Active pendulum suspension on the XT28 showing ability to control each wheel individually.

3.2 Steering

For this project there were two different types of steering types considered. The first type of steering would be turning the front wheels of the vehicle like a road car and the second type would be differential steering. Differential steering would not require any additional parts other than the suspension holding the wheels in place and the ability to power each wheel independently. Together with the turning radius being smaller and being able to steer it equally in both the forward and backward direction makes it the best candidate for this project.

3.3 Electronics

The overall electronic layout will consist of a Raspberry Pi, a Pixhawk microcontroller, electric motors, ESCs, a receiver, a DC-DC converter, and a battery, using the preliminary electronic diagram shown in Figure 15.

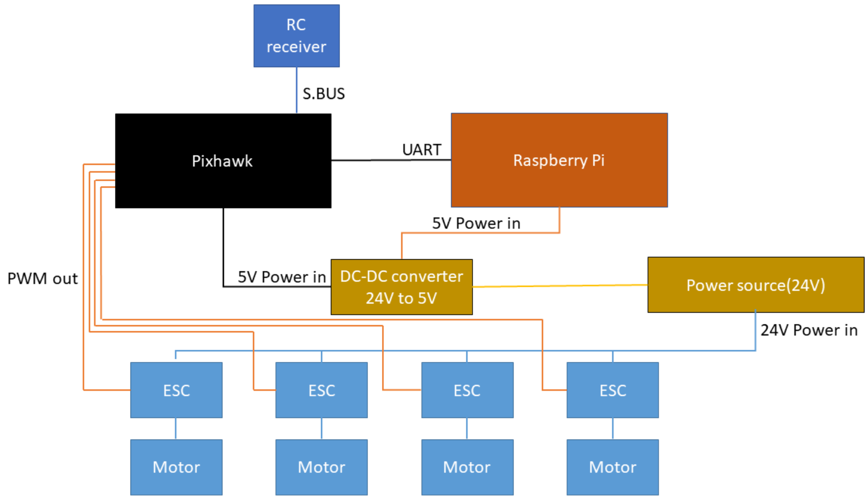

Figure 15: Preliminary electronic diagram

As in the diagram, the battery bank will have a 24V output, which will be converted to 5V by the DC-DC converter for all the low power electronics and a direct connection to the power input to the ESCs to drive the motor.

3.3.1 Microcontrollers

In the design concept, a high level microcontroller like Pixhawk will be used for its ROS compatibility. The Pixhawk 4 was chosen with its 8-16 PWM outputs for the drive of motor, and a S.Bus for the RC receiver. It also has a telemetry port for connection to the companion Raspberry Pi to enable ROS as per the requirement.

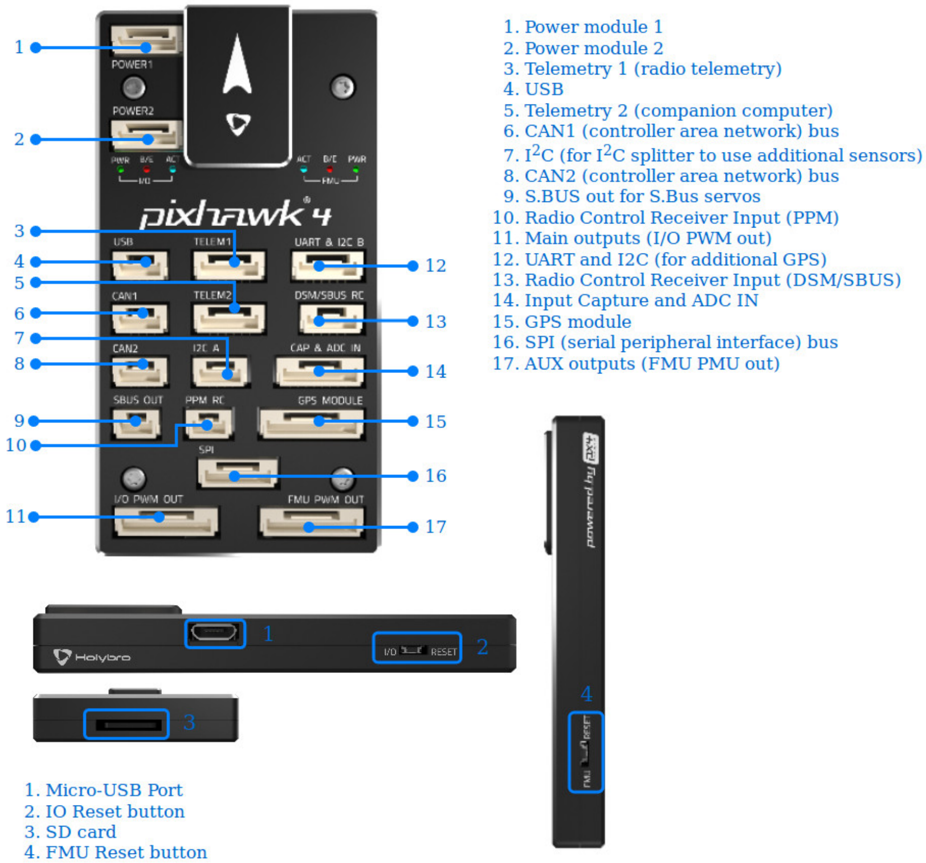

Figure 16: Connectors for Pixhawk 4

As shown in Figure 16, multiple configured ports are built in Pixhawk 4, which can favor future expansion.

3.3.2 Software

The Pixhawk will be deployed and tuned using the ground station software Q-Ground-Control(QGC), where each parameter can be tuned in the GUI. Without additional modules, QGC can already map an RC controller and tune the motor settings, such as PWM output and PID value. Live ground station would also be achievable with an additional telemetry module if required.

According to the stakeholder, the system should have ROS enabled. Raspberry Pi was chosen for its relatively low cost and power consumption with well-documented guides for integration with ROS also easily accessible. Linux and ROS would be installed on the Raspberry Pi. The preliminary connection is shown in Figure 17.

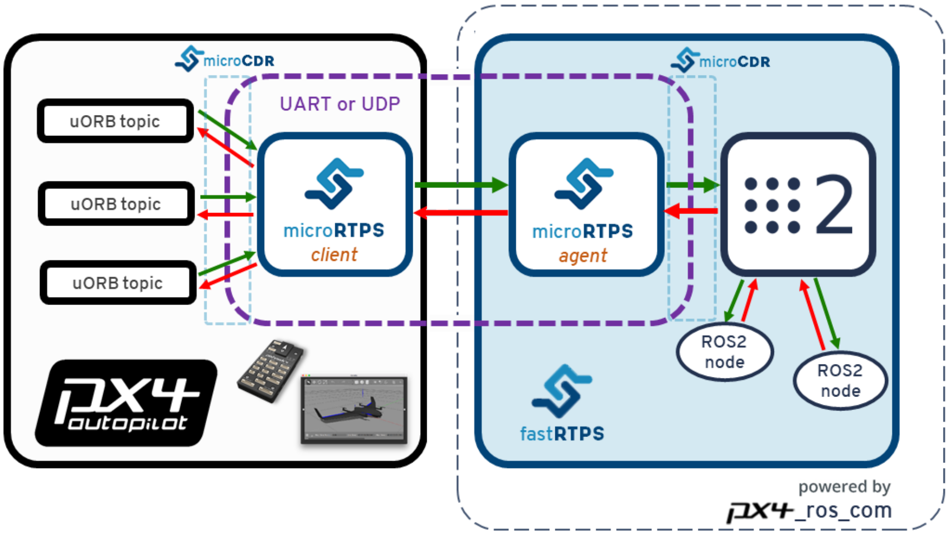

Figure 17: ROS and Pixhawk connection

It shows how a ROS2 node can be built on the Raspberry Pi and be used to control the Pixhawk.

3.4 Driveline

This part of the report covers the implementation of energy, motors and transmission of torque through the vehicle.

3.4.1 Motor

Per request, no fossil fuel is to be used in the primary design of the vehicle. This leaves electric and hydraulic motors as the feasible alternatives. As the maximum speed of the vehicle is walking speed, the ideal motor would be high torque and low speed. Hydraulic motors are often favoured in robust designs, especially in high torque low speed applications. But due to the small size of the vehicle, the hydraulic motors are simply too expensive to be economically defensible. And as the vehicle will use a DC power source, the ideal motor would be a high torque low speed brushless DC motor.

To calculate the minimum requirements for the motor a test case is created where the vehicle is considered to be positioned on a slope with the given inclination attempting to climb it. Based on the estimated data of Table 2, given no losses and that all wheels are in contact with the ground, the minimum torque to climb the slope is 42.0 Nm. The required power to climb the slope at 3 m/s is 630.0 W.

Data	Value
Mass [kg]	250
Incline [°]	20
Wheel diameter [mm]	400
Number of wheels [#]	4
Maximum velocity [m/s]	3

Table 2: Estimated vehicle data

Looking at the XT28 as a benchmark for forrest vehicles, the torque to mass and power to mass ratio of the XT28 can be seen in Table 3. The values gives an estimate of requirements on the motor, given the vehicles presumed mass, including load $m = 250kg$, the ratios yields a torque of 10.5 Nm and a power of 1.66 kW.

Ratios	Torque	Power
Mass	23.77 [kg/Nm]	0.15 [kg/W]

Table 3: Torque and power to mass ratios of the XT28

As the initial calculations were done regarding no losses and all wheels in contact with the ground a safety factor of 4 gives a more realistic worst case scenario where only two wheels have traction or only half of the energy is translated to forward velocity. This results in a torque requirement of 167.9 Nm and a power requirement of 2.5 kW which is reasonable compared to the XT28 ratio calculations as the inclination can be large for forest terrain.

3.4.2 Transmission

Electrical motors generally have a lot higher speed than necessary for this application, hence the transmission will need a large gear ratio. The transmission will consist of a chain and cog, and possibly with a dedicated gearbox depending on the required gear ratio. Figure 18 shows a simplified theoretical illustration of how the motor and the gears are connected using chains for the purpose of speed reduction.

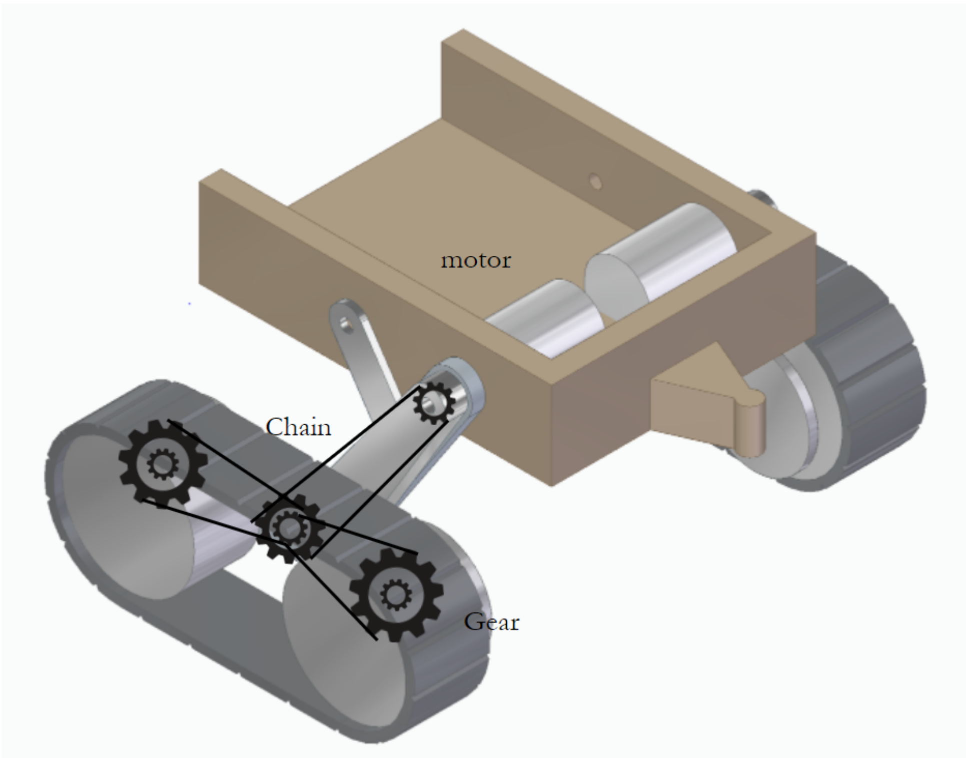

Figure 18: Overall figure of transmission system

3.4.3 Energy Storage

By far the most common way to power electric vehicles is through stored energy in batteries. For this project the most important aspects to consider for the batteries is energy density and cost as well as safety and reliability. Different types of lithium-ion (li-ion) batteries are the most common for their relatively high energy density and continuous decline in cost. For this project the chosen battery type is lithium iron phosphate (LFP) which has many desirable features compared to other types of li-ion batteries such as nickel cobalt aluminum (NCA) and nickel manganese cobalt (NMC). Among the advantages are things like lower cost, longer life cycle and lower chance of explosions and fires as well as not containing any nickel or cobalt which are expensive and have a high environmental impact [5]. The most notable disadvantages are the lower energy density and operating voltage compared to other li-ion types, but the advantages easily outweigh the slight disadvantages in this case.

3.5 Chassis

With differential steering as the most promising option, and the electrical driveline decided, the chassis specifications could be specified. A simplified chassis design can be seen in Figure 19.

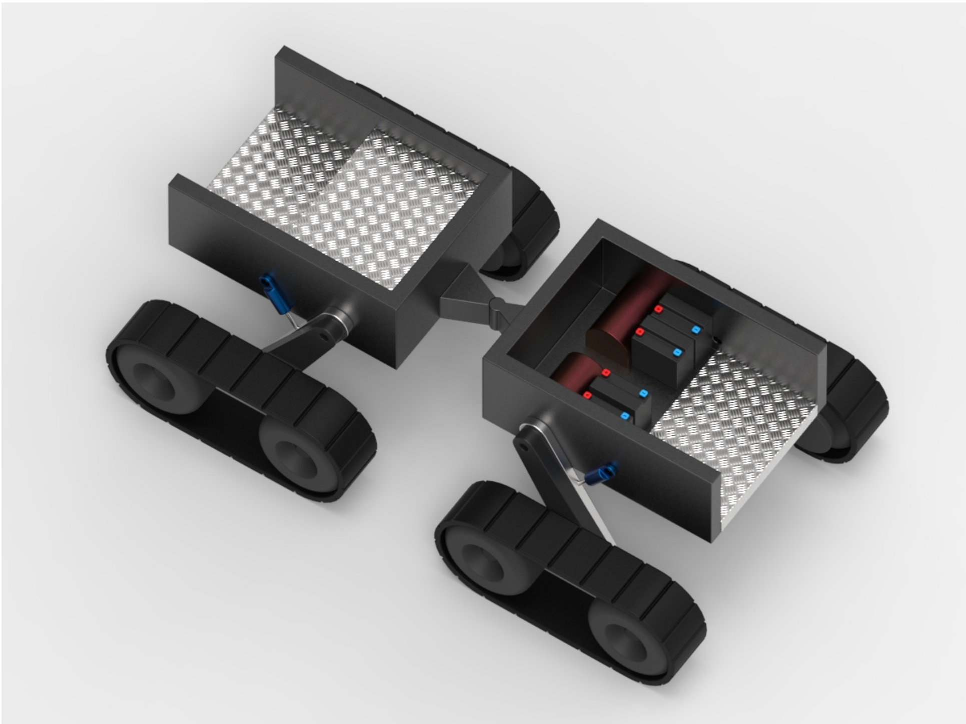

Figure 19: Overview of the chassis design, with battery and motor placement.

3.5.1 Split wagon

In order to increase stability, the weight is preferably distributed over a larger area, and so the vehicle was split into two wagons. This was also advantageous together with differential steering, due to the different cart being able to rotate independently from each other, thus creating an Ackermann-like steering motion between the two wagons. A split wagon-design also enables the vehicle to clear narrower gaps in the terrain, as well as increasing vehicle area, thus increasing stability.

3.5.2 Torque transmission

Electrical motors for this application, as mention in section 3.4.2, requires a large gear ratio, thus a gearbox or a line of gears has to be fitted onto the frame. A chain along the arm, to transmit torque, was chosen and gears chosen to achieve the desired gear ratio. In the potential case that the chain gear ratio is not high enough, a second gear-stage could be added in the bogey.

3.5.3 Low centre of mass

The main components of the vehicle are quite heavy; four brushless DC motors, batteries, gears and sturdy frame. In order to make a sturdy vehicle, the centre of mass should be as low as possible. Therefore, placing the motors and batteries in the lower part of the chassis is feasible, and for this purpose, hub motors prosper. However, there are a few drawbacks of hub motors compared to motors on the main body. These include the motors having to be more resilient to water and dirt, and a lack of torque with limited gear ratios. For a non-hub motor, the gearing could be placed at the pendulum arms or at the wheels, which also moves weight further down.

In this regard, the only components of the vehicle unable to be moved outside of the main frame, would be the batteries and the controlling electronics. During construction further into the project, these things have to be considered.

4 Future Work

So far, after studying and discussing different solutions, the general direction of the project has been determined and will be further investigated in the fall semester. In this chapter, there will be a discussion about the project plan, the budget and technical risks.

4.1 Project plan

After deciding on the direction of the design concept for this project, it is time to determine the components needed and order them. Due to the uncertainty of the required parts inventory and transportation time, it is necessary to order the required products as early as possible. Therefore the plan is to finalize a number of orders for the necessary parts before the start of the summer holidays. This will allow enough time to ship the required parts before the start of the fall semester. When the fall semester begins, the prototype stage of work can begin directly.

In addition, the work after the summer will be divided into smaller groups. Each group will be dedicated to one field of work, which includes multiple tasks. A weekly summary of the week's progress will be consolidated to keep each group on track. Furthermore, communication with the coach and stakeholder will be continued on time to ensure that the project is completed within the required time schedule. A more detailed schedule will be discussed after the summer, and a more reasonable allocation of time will be planned at that time.

4.2 Budget

The total budget for the project is 50 000 SEK, which will be used to order the necessary components for the project. Some of the parts can be manufactured on location. Due to the uncertainties of the parts needed in the pre-production phase, it is difficult to calculate the cost of the whole project now. Therefore, component ordering will be done with care and consideration under the condition that it seams reasonable for the budget.

4.3 Technical Risk

There is currently no equipment on the market that fully fulfills the requirements of this project. Therefore, there is a lot of uncertainty in the feasibility and practical application of the design concept for this project.

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