TALLINNA TEHNIKAÜLIKOOL
MEHAANIKATEADUSKOND

Department of Mechatronics

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THE MOBILE STAIRS CLIMBER VEHİCLE

MOBIILNE ASTMETE ÜLETAMISE VÕIMEKUSEGA LIIKUR

MSc thesis

The author applies for
master's sciences of technical
academic degrees

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2016

AUTHOR'S DECLARATION

I declare that I have written this graduation thesis independently.

These materials have not been submitted for any academic degree.

All the works of other authors used in this thesis have been referenced.

The thesis was completed under .... supervision

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The thesis complies with the requirements for graduation theses.

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLES

FOREWORD

This thesis is made as completion of the master degree in Mechatronics. The work was executed at the Tallinn University of Technology. The work is purely in a field of handicap technology and consists of electronic, mechanical, data communication integration. The main purpose of this work is to help creating a barrier-free life and designing a mobile stairs climber vehicle. I would like to thank the following people, without whose help and support this thesis would not have been possible.

Firstly, I like to show my gratitude to the people of departments of Mechatronics. My supervisor Prof. Mart Tamre for his suggestions, encouragements, and guidance in writing the thesis and approaching the different challenges during the thesis.

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Tallinn, May 2016,

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EESSÕNA

Käesolev magistritöö on valminud mehhatroonika eriala lõputööna. Antud projekt viidi läbi Tallinna Tehnikaülikoolis. Töövaldkonnaks on invatehnoloogia ning töö hõlmab endas elektroonika ja mehaanika integratsiooni läbi andmevahetuse.

Magistritöö põhieesmärgiks on aidata kaasa piirangutevaba eluviisi levikule ning kavandada mobiilne liikur treppide mugavamaks kasutamiseks. Ma sooviksin tänada järgnevaid inimesi, ilma kelleta selle lõputöö ei oleks valminud.

Esiteks tänan ma mehhatroonika osakonna rahvast ning oma juhendajat professor Mart Tamret tema soovituste, julgustuste ja juhendite ning erinevate probleemikäsitlustele lähenemiste eest selle magistritöö kirjutamise ajal.

Tänan ka Ülkü Mehmet Metinit väärtuslike panuste ja visioonide eest ning Muhammed Emin Yildizi, kes jagas nii abistavaid teadmisi kui ka praktilist abi liikuri kavandamisel.

Tänaksin veel Admir Hoxhat parima saadaoleva informatsiooni ja praktilise toetuse eest kontrollsüsteemide alal.

Viimasena tänan oma perekonda ja sõpru nende püsiva toetuse eest oma õpingute jooksul.

Tallinn, Mai 2016,

Hamid Mesud Aydin

1. INTRODUCTION

The main goal of this thesis is to contribute to barrier-free life. In this content, in order to usage by people with disabilities or older people, a mobile vehicle which can climb and descend stairs can minimize their problems.

1.1. Problem definition

Elevator systems or escalators make disabled people's life easier as much as possible, which are situated in some houses, hospitals, shopping centres. However, such systems do not exist in every part of the social environment; therefore, the systems have many shortages. For instance, a disabled person has difficulty in one go on to the pavements, get on the bus or his/her own car or go uphill. The vehicle is unobservant in a social environment; makes easy life of the users, the most important matter the vehicle is an engineering design example that provides disabled people going outside lonely, overcoming obstacles and "their own obstacles". Thus, speed bumps, pavements, steep staircases can be surmounted easily. The most important point is that; disabled people are never going to be needed attendants who take care of them. Therefore, some companies began for fabricating such vehicles. By determining lack of those vehicles, within the system which provides the seat's moving up-down carefully, user friendliness and moveable as an alternative tracked system for making easier life of disabled people.

Everyone should have the right of the barrier free living. The number of people with disabilities in the world is so much that would not be negligible. Should not be disregarded that not only the quantity, but also in quality at a high level. Yet these people cannot handle even the smallest needs of themselves without the help of others. Because of that reason, those people can less contribute to community, humanity and our world. Imagine that, who cannot provide their own small needs how can provide the needs of people. Hence, the engineering is not only solving individual issues or problems of one section of society and also solving indirectly whole social problems to incorporate missing part of society unfortunately which is ignored.

1.2. Historical progress

Throughout history, all the time people have developed new things to provide their needs. The existing was more developed and innovations were built on the experience from the past. It must be the most beautiful metaphor relay race.

In the past, people carried the knowledge and technology to further than they who received them carried to even further and somehow we who 21st century human received cumulative knowledge and experience. Now how long we can carry

In the same way that the historical development of innovation to facilitate the life of people with disabilities can be listed as follows:

1.2.1. Crutches

Crutches have been always used any of one form or another to assist them who get around when they have any injury, illness or made walking difficult or impossible. The use of crutches dates really to back ancient times. Those who needed crutches cut off branches of trees or fashioned them from timber and added padding to the underarm support to make them more comfortable. **(1)**

Emile Schlick received a patent for crutches that supported the forearms. Schlick combined walking stick with an arm brace that users could slip their arms into. It could be called the first commercially produced form of crutches. In this design there was a support for the upper arm to rest on. **(2)** However, it was A.R. Lofstrand, Jr. who patented the first deign for crutches that could be adjusted to suit the height of the user. The design of the forearm crutches is accredited to Thomas Fetterman, who contracted polio in the 1950’s when he was only 8 years old. Because of the dangers associated with continuous use of underarm crutches, such as slipping and falling and possible nerve damage it the armpit area, he set about designing crutches that he could use safely. He knew that crutches needed a greater ability to grab the ground and developed a crutch tip with a shock absorbing gel cap. This type of crutch went into production in 1988 and now is the most recommended crutches by orthopaedic specialists. **(1)**

1.2.2. Wheelchair

No one knows exactly when the first wheelchair was invented, however its origins date back to ancient times. The earliest records of a wheeled transportation device were found in a stone carving in China and an image of a Greek vase of a wheeled child's bed. The first known wheelchair purposefully designed for disability and mobility was called an "invalid's chair". It was invented in 1595 specifically for King Phillip II of Spain. The chair had small wheels attached to the end of a chair's legs and it included a platform for Phillip's legs and an adjustable backrest. It could not be self-propelled but most likely the King always had servants transporting him around. **(3)**

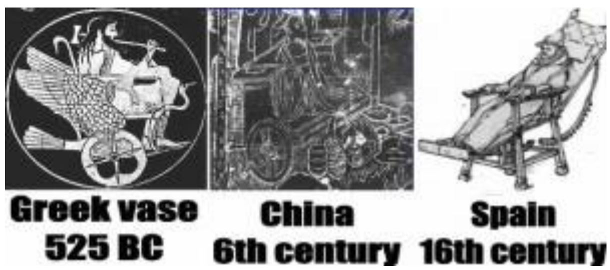

Figure 1.1. The earliest records of a wheeled transportation device

Skipping forward to 1655, Steven Farffler was a young German watchmaker with a disability that limited his mobility. He is the first known person to invent and use a wheelchair that could be independently propelled. It was a stable chair mounted on a 3-wheeled chassis with attached handles on both sides of the front wheel used to propel the chair forward **(3)**

Figure 1.2. The first known person to invent and use a wheelchair

In 1783, John Dawson of Bath, England invented a wheelchair and named it after his town. The Bath wheelchair had two large wheels in the back and one small one in the front. The user would steer the chair with a stiff handle, but all the Bath designs had to be pushed or pulled by a donkey or horse, as they were heavy. Then, in the 1800s, the first wheelchairs that are more similar to today's designs were developed. In 1869 a patent was taken out in a wheelchair that could be self-propelled and had large wheels at the back. Wheelchairs were starting to get less bulky but still were not easily transportable until 1932 when the folding tubular steel version was made by Harry Jennings.**(3)**

Figure 1.3. The Bath wheelchair

1.2.3. Power wheelchair

Electric-powered wheelchairs were invented by George Klein and others to assist injured veterans after WWII. As it is known, designs since then have consistently improved in size, weight and to adapt to an individual's needs. **(3)**

And now smart disability vehicle or as we called in this work the mobile stair climber vehicle.

Figure 1.4. The current wheelchairs

1.3. Summary

After deeply research of academic papers and analyse of products which exist in the market, various shortcomings have been identified. Some of the foremost deficiency is that the most of current vehicles on the market cannot climb high stair steps and do not allow to climb the spiral staircase. In addition, there is a restriction on weight of the user. Furthermore, the absence of a common standard of ladder height is the one of the greatest barriers. A new model of designing of mechanism which more functionality, more secure and has high stability, is developed to meet requirements of disabled people. In order to do this work is desired that to improve and to broaden the living conditions of people with disabilities.

The designing, realizing of the vehicle which can climb up and down stairs to ensure the safety requirements must be completed. Unless there is abnormal, the vehicle should be climbed steep stairs. At least it must be provided minimal aesthetic requirements and unobservant in a social environment

The vehicle is unobservant in a social environment; makes easy life of the users, the most important matter the vehicle is an engineering design example that provides disabled people going outside lonely, overcoming obstacles and “their own obstacles”.

2. PROJECT DESIGN CONFIGURATION

When studying the locomotion system of track-wheel vehicle, the relative position of the tracks and wheels or the track shape can usually be changed to enable or disable wheel contact with the ground. **(4)**

2.1. Designing Criteria

The most important thing to consider when creating a vehicle for people with disabilities, how making accessible area and to improve the mobility and manoeuvrability, make arrangements to allow them to act as independently as possible. Primarily, it is necessary to know some of the details and dimensions for this. **(Fig. 3.1-2-3)** there are some standard organizations like ISO, ANSI and RESNA **(5)**

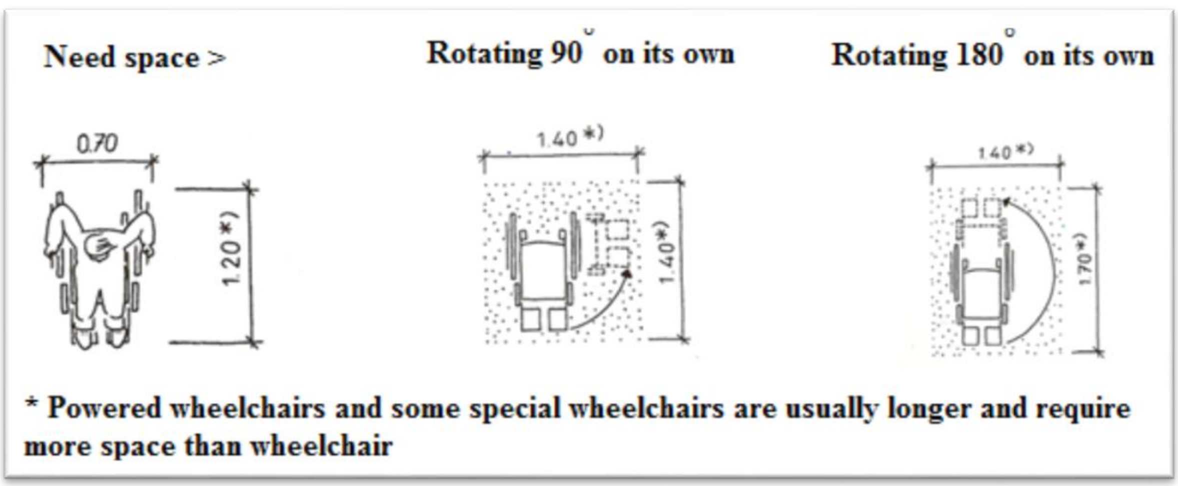

Figure 2.1. Mobility and manoeuvrability on wheelchairs **(6)**

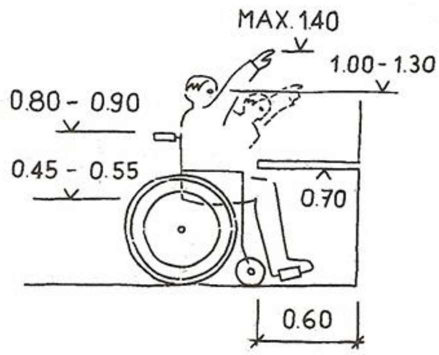

Figure 2.2. Illustration of reach-point by hand

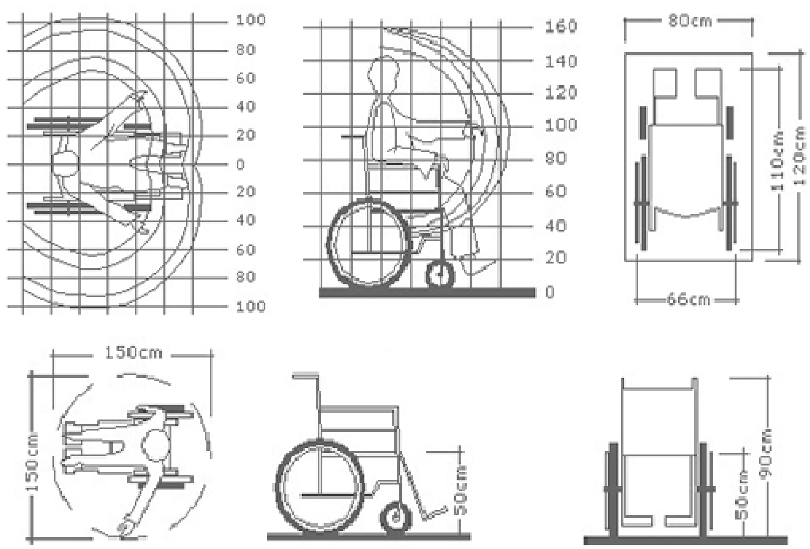

Figure 2.3. The general dimensions of wheelchairs

After investigating of general standards typical wheelchairs, some dimensions are decided. The width should be between 66-80 cm, the length should be less than 120 cm, the height should be between 45-55 cm that illustrated in fig. 3.4

2.2. Final design description

The final design could not be reached only one attempt. It was reached repeatedly results of many attempts, modifications, improvement. Based on result of designing criteria, the dimensions of length, width and height are determined orderly 102, 80 and 100 cm that illustrated in fig. 2.4.

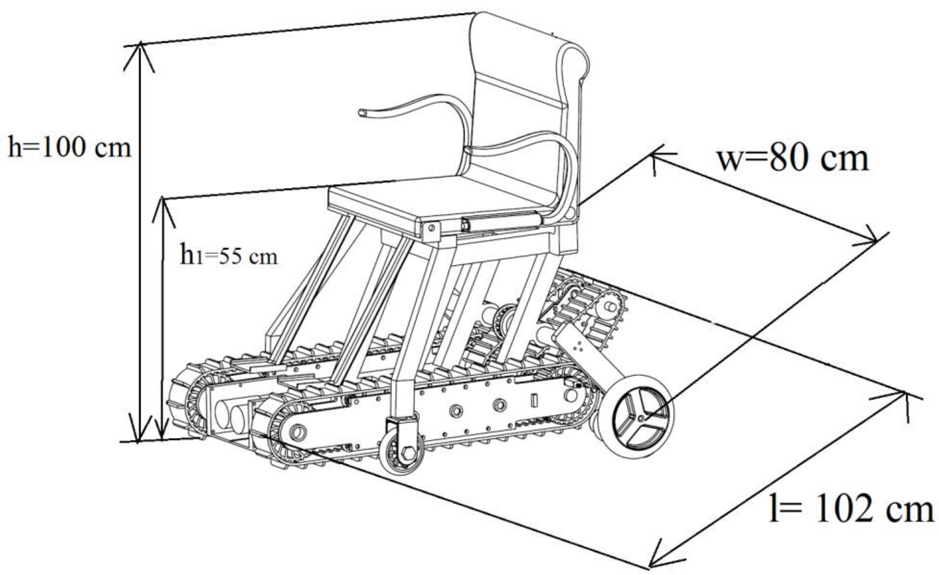

Figure 2.4. Result of designing that the dimensions of length, width and height

Firstly, it was planned a combine system as a wheel-track vehicle. When it climbs on the stairs, it uses tracks, during moving on straight road, it uses wheels. For the purpose of determining pitch of the stairs and lifting up user to the user's eye level, in case user needs to get something from a shelf or higher floor, the system provides him this opportunity helping by assistant tracks. At the same time, in order to lifting up chair to keep balance of vehicles permanently on stairs and reaching user eye’s level on a straight road, mentioned above, used linear actuators. Providing get a combine system wheel-track, it is needed that front and rear wheels should be lifted up and down. For the purpose of connecting the front wheels to a chair, while the chair is lifting up meanwhile front wheels are lifted up and rear wheel’s shaft to chassis of the vehicle, when the shaft manipulators by DC motor with timing gear and belt rear wheels are lifted up. They are illustrated in fig. 3.5 and 3.6

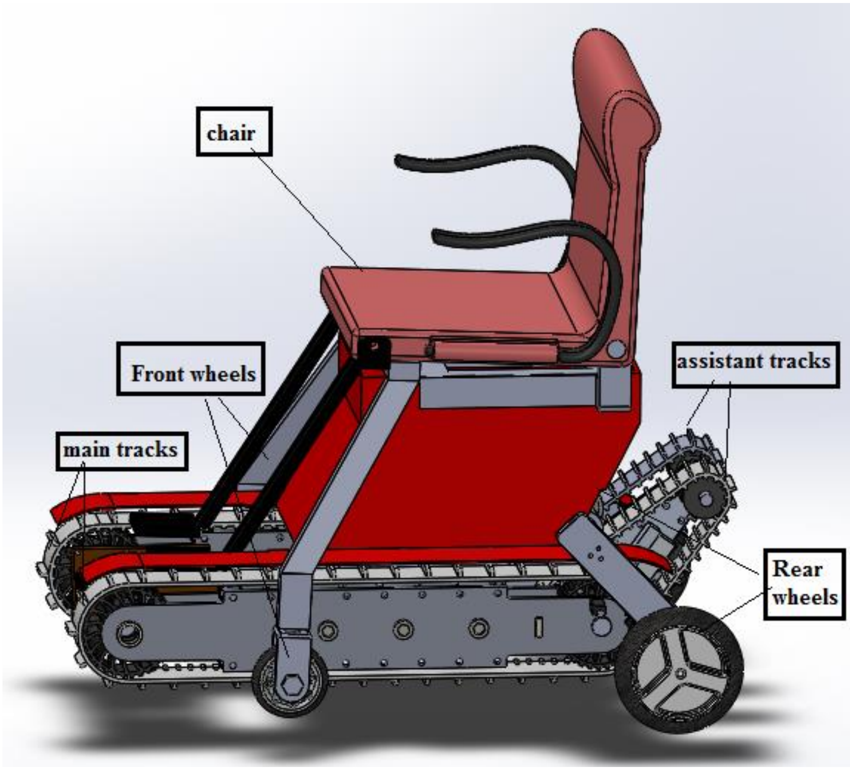

Figure 2.5. A side view of the mobile stairs climber vehicle

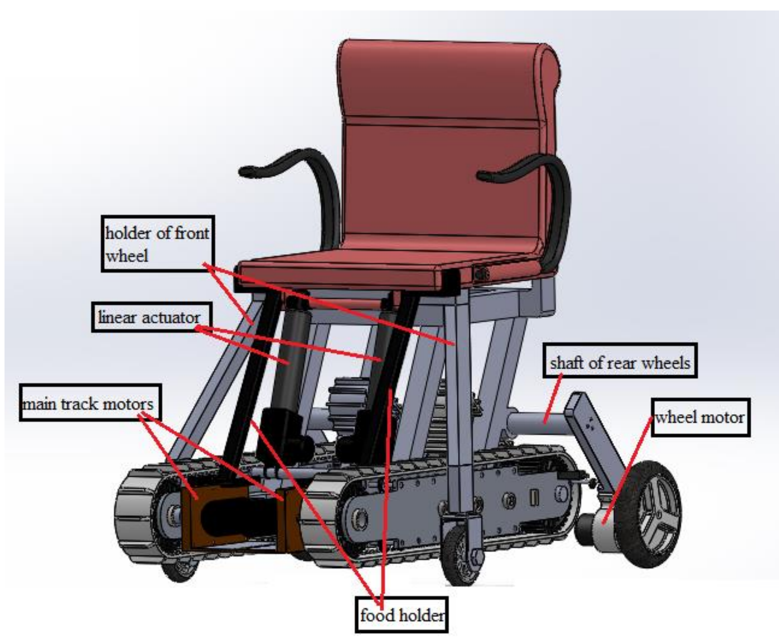

Figure 2.6. An isometric view of the mobile stairs climber vehicle

2.3. Components

2.3.1. Motors

Motors do not illustrate in this chapter. It decided to define them after power calculation. Therefore, they are shown chapter in power calculation section of selection motors.

2.3.2. Linear actuators

Linear actuators do not illustrate in this chapter as well, due to same reason of which explained above heading of the motor.

2.3.3. Main track

There are 2 main track mechanism consist of which are shown below in fig. 3.7.

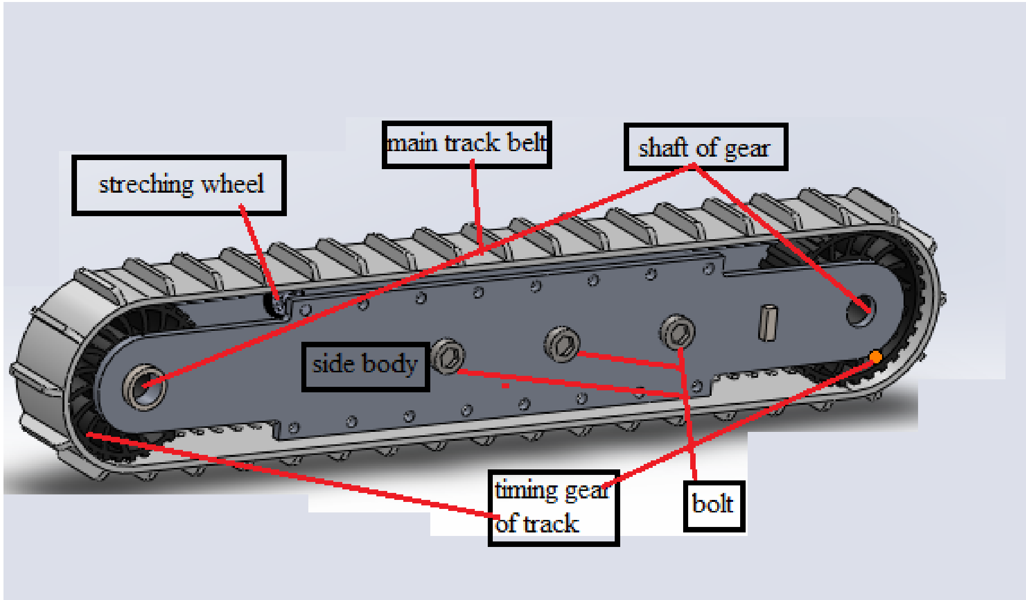

Figure 2.7. Main track

a. Side bodies

- **Main track side body**

There are totally 4 main track side bodies which are connected chassis and keep the main gear at fig 3.8.

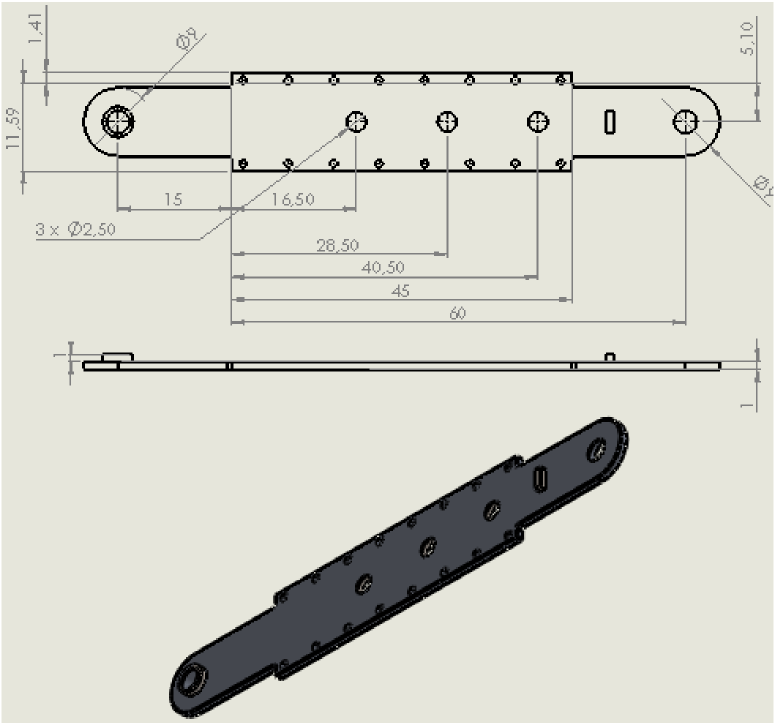

Figure 2.8. Side body with dimensions

b. Stretching wheels

As is evident from its name, they keep track stretched. It is working an active idler mechanism (**Figure 3.9.)**

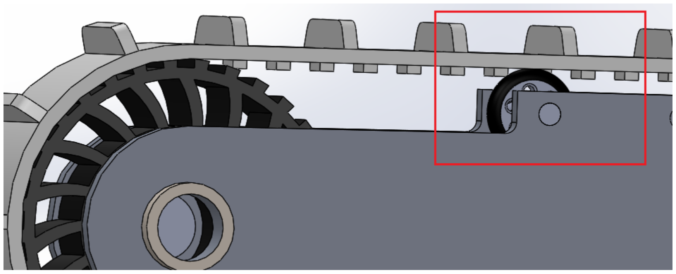

Figure 2.9. The stretching wheel

c. *Timing gear of main track*

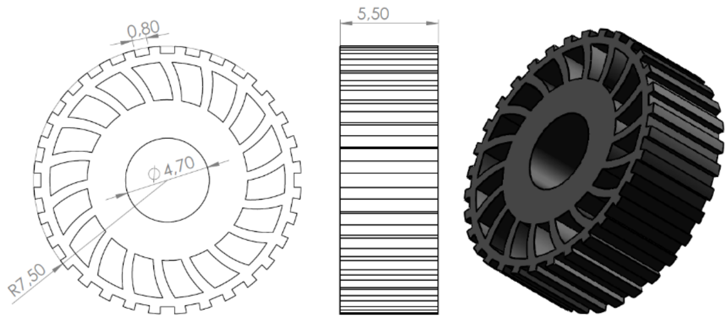

Figure 2.10. The timing gear of main track

2.3.4. Wheels

The wheel mechanism consists of component which are shown in fig. 3.11. and 3.12.

a. Front wheel

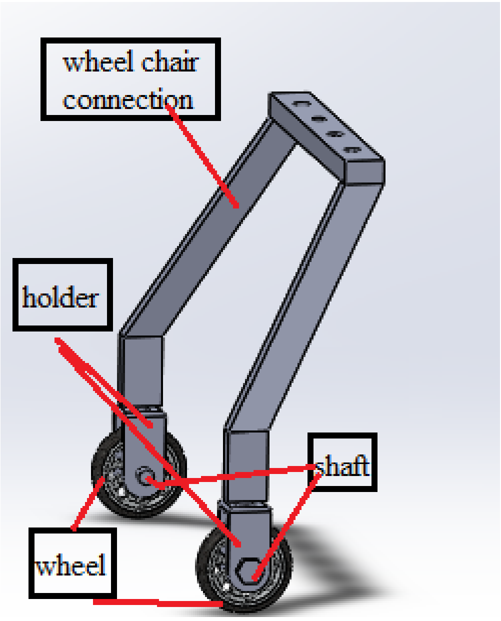

Figure 2.11. Front wheel

b. Rear wheel

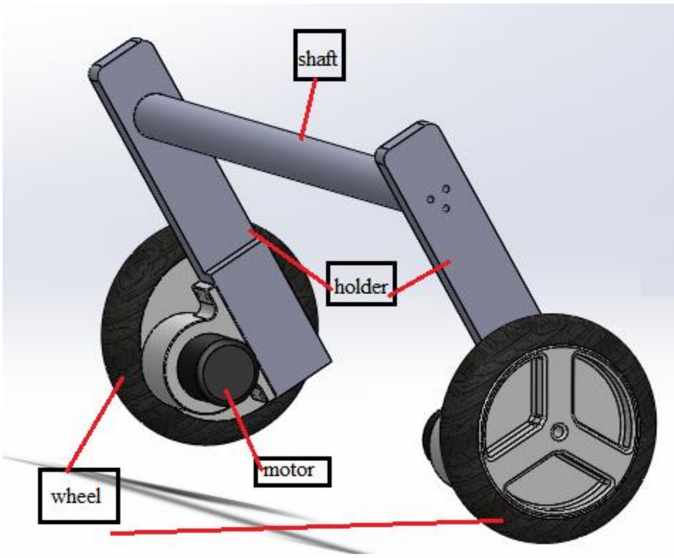

Figure 2.12. Rear wheel

2.3.5. Chair

The chair consists of components which is shown in fig. 3.13

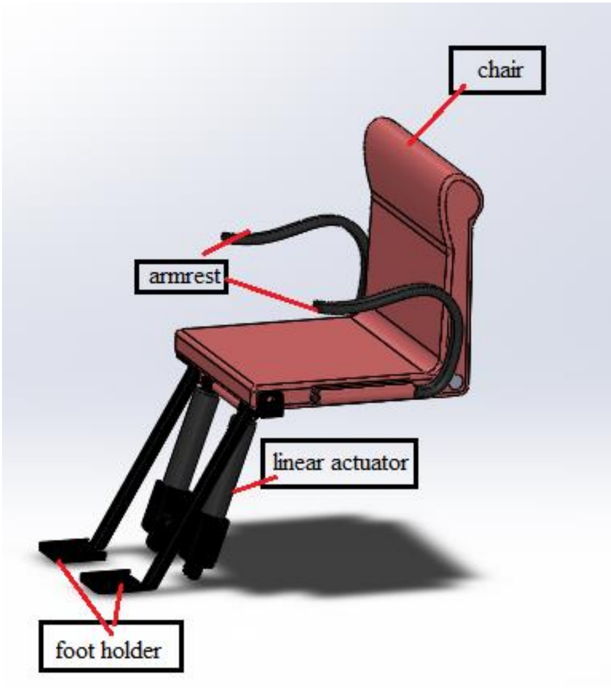

Figure 2.13. The chair

2.4. Summary

In this chapter, firstly, designing criteria is defined. The most important point here is width of the vehicle. It must not be bigger than 80 cm, this is quite a hard challenge because when it considers all components, designing should be made as compact as possible. The front wheels connected to the chair latterly, before front wheels were connected with a shaft and this shaft was manipulating a DC motor. Lifting up a chair and the front wheels were simultaneous. Therefore, they were connected to chair and in this way, one motor and its gearbox were removed.

3. POWER CALCULATION

3.1. Define motors

We have 6 motors and 2 linear actuators which are shown below in fig. 4.1 and 4.2.

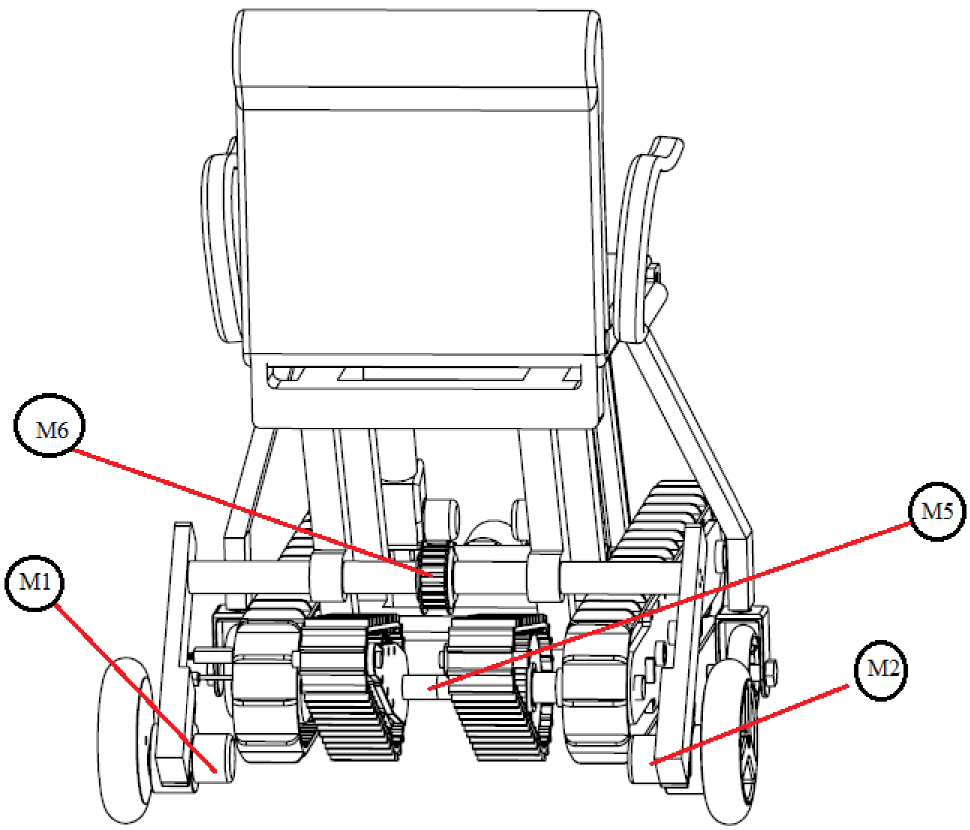

Figure 3.1. The schematic illustration of motor of vehicle

6 different motors are placed on a vehicle which is shown in figure 4.1. Duty of these motors are specified below.

M1 and M2: They are manipulated of rear wheels. They are specifically used for Powered wheel chairs. Although their dimensions are smaller and they are compact, they have high torque values. Inside of mechanism, there are two bevel gears that allows to rotate rotating shaft 90 degree.

M5: This motor is used for lifting assistant tracks up and down with helping of timing gear which is fixed on the shaft of assistant tracks. Here DC motor is preferred.

M6: This motor is used for lifting the rear wheels up and down with helping of timing gear which is fixed on the shaft of rear wheels. The stepper motor is preferred because of angular sensitivity.

As it is shown in figure 4.2, Motor-3, Motor-4 and Linear actuator 1, 2 are placed on the vehicle. The duty of these motors is specified below.

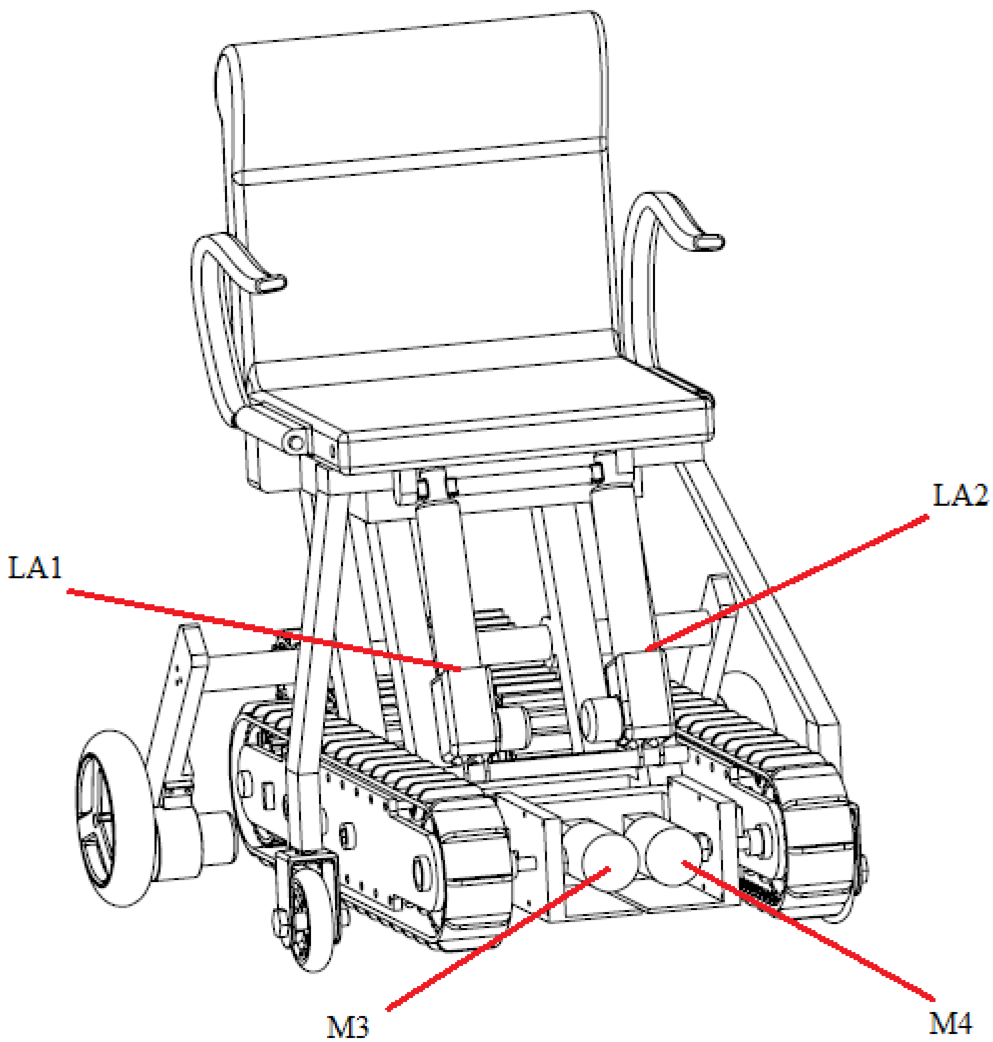

Figure 3.2. The position of M3-4 and LA1-2 on Vehicle

M3 and M4: They are manipulated of the main tracks. They are DC motors. More specifications are going to be mentioned after results of calculations.

LA1 and LA2: These are linear actuators and they are used for lifting chair up and down through with its function of pushing pulling.

3.2. Define desired moments and forces for each of mechanism

Firstly, the aim of defining desired moment is to find necessary power and torque which parameters are needed to choose a proper motor. Thus, on this chapter, all assumptions are presumed considering the worst-case scenario. Some assumptions are counted on below:

1- Mass of user: 100 kg
2- Mass of vehicle: 60 kg
3- Mass of battery 20 kg

3.2.1. The moment of rear wheels

a. Straight road

$$F_{TR}= F_{AD} + F_{ROLL} + m \text{ x } a \quad (3.1)$$

Where F_{AD} – aerodynamic drag force,

F_{ROLL} – rolling resistance force,

m – mass, 180 kg

a – acceleration, 0.2 m/s^2

$$F_{TR}= \rho/2 \text{ x } C_D A_F V^2 + mg(C_0+C_1 v^2) + m \text{ x } a$$

Where ρ – Density of air, 1,18 kg/m^3

C_D – The aerodynamic drag coefficient, 0,2

A_F – The frontal area, 1 m^2

V – Velocity, 2,5 m/s

C_0, C_1 – The rolling resistance coefficient, C_0 =0,008 and C_1 = 1,6x10^{-6} s^2/m^2

g – Acceleration due to gravity, 9,81 m/s^2

F_{TR} = 1,18/2 x 0,2 x 1 x 2.5^2 + 180x9,81(0,008+ 1.6x10^{-6}x2,5^2) +180x0,2

F_{TR}= 0,7375 + 14,144 + 36 = 50,88 N this number is traction force on without sloping road

V_{max} = 2,5 m/s

P= F x V (3.2)

P= 50,88 x 2,5

P=127,2 Nm/s

d. uphill road

Maximum slope for power chairs should be *1,5"* rise to *12"* length (*7,1-degree angle; 12,5% grade*).

$F_{TR} = \rho \times 0,5 \times C_D A_F V^2 + mg(C_0 + C_1 V^2) \times \cos(\arctan(1,5/12)) + mg \sin(\arctan(1,5/12)) + m \times a$

F_{TR} = 1,18 x0.5x 0.2 x 1 x 2.5^2 + 180 x 9.81(0.008+ 1.6 x 10^{-6}x 1^2) x 0.99 + 180x9.81x0.124 +180 x 0.2

F_{TR}= 0,7375 + 14 +218,96 +36

F_{TR} = 269,7 N

P= F x V (3.2)

P= 269,7 x 1

P= 269,7 Nm/s

The higher number one should be selected. Thus P= 269,7 W

This power manipulates by two motors. Therefore, at least each one of motor with power of 134,85 W is necessary.

3.2.2. The moment of main tracks

Firstly, the transaction force overcome all resistances and also to get an acceleration should provide equation which is shown below.

a. The situation which needs the most power

a=40° – stair angle: arctan(h/l)

$F_{TR}= F_{AD} + F_{Fri} + m \times dv/dt + mg \times \sin(\arctan(h/l))$ (3.1)

$F_{TR}= \rho \times 0.5 \times C_D A_F V^2 + mg \times \cos(a) \times \mu + mg \times \sin(a) + m \times a$

$F_{TR}= 1{,}18/2 \times 0{,}2 \times 1 \times 0.075^2 + 180 \times 9{,}81 \times 0{,}766 \times 0{,}85 + 180 \times 9{,}81 \times 0{,}642 + 180 \times 0{,}3$

$F_{TR}= 2337{,}36$ N

$P = F_{TR} \times V_{max}$ (3.2)

P= 2337,36 x 0,075

P= 73,11 Nm/s

b. The situation which needs the average power

a=36.4° – stair angle: arctan(h/l)

$F_{TR}= F_{AD} + F_{Fri} + m \times dv/dt + mg \times \sin(\arctan(h/l))$ (3.1)

$F_{TR}= \rho \times 0{,}5 \times C_D A_F V^2 + mg \times \cos(a) \times \mu + mg \times \sin(a) + m \times a$

$F_{TR}= 1{,}18/2 \times 0{,}2 \times 1 \times 0{,}039^2 + 180 \times 9{,}81 \times 0{,}805 \times 0{,}85 + 180 \times 9{,}81 \times 0{,}593 + 180 \times 0{,}3$

$F_{TR}= 2309{,}37$ N

$P = F_{TR} \times V_{max}$ (3.2)

P= 2309,37 x 0,075

P= 173,2 Nm/s

This force manipulates by two motors. Therefore, one of motor with power of 87,65 W is necessary.

3.2.3. The moment for lifting up assistant tracks

As it is shown in figure 4.3, the vehicle is lifted up position and in figure 4 is represented initial position. For calculation It should be taken into account initial position for the calculation because the motor has to produce bigger torque.

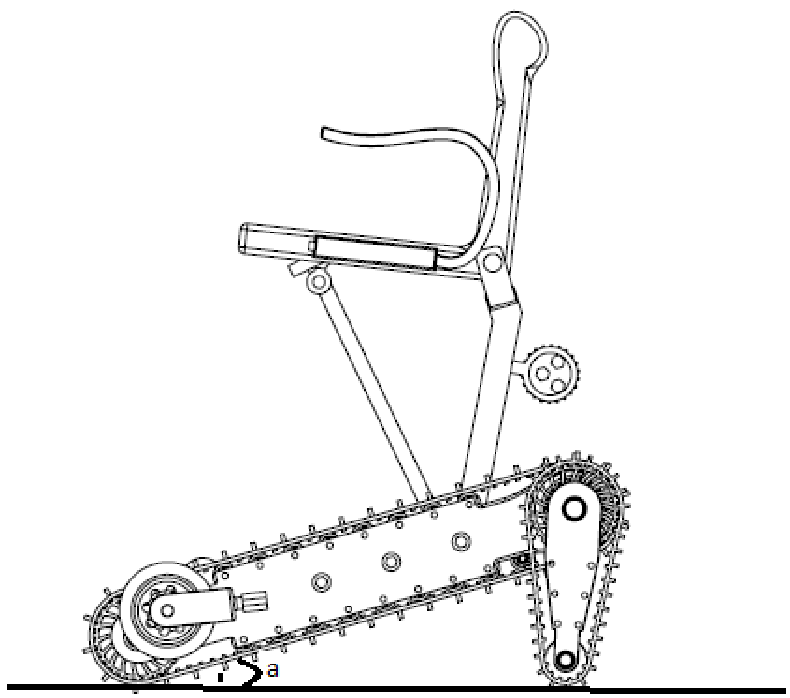

Figure 3.3. The lifted up pos. a = 15,45 °

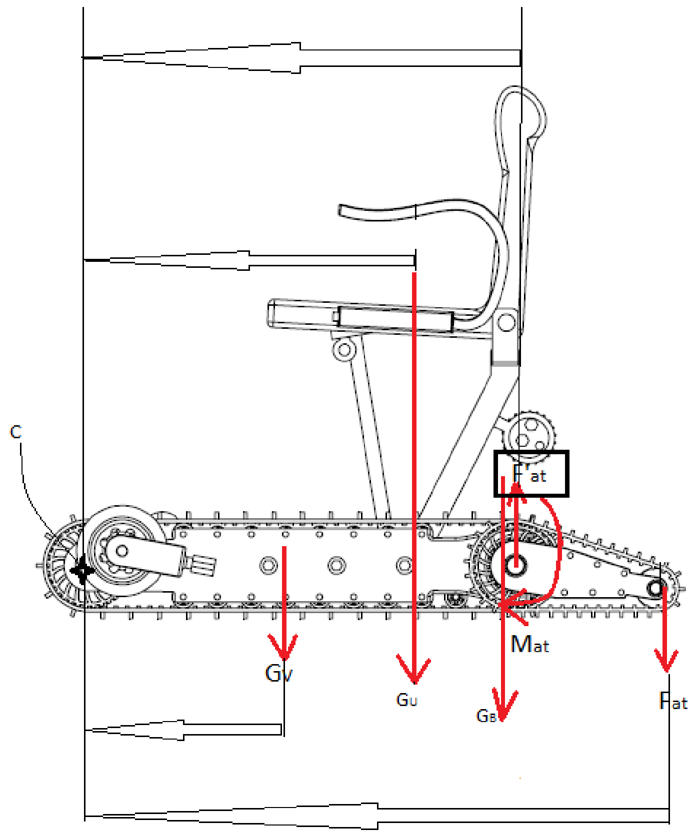

Figure 3.4. The initial position

At point of B, there is moment (M_{at}), this moment creates a force (F_{at}) which pushes ground to raise up on AB link, its equivalent on BC link is F'_{at}. If point of C is taken as a fixed point and take moment based on there; **(fig. 4.4.)**

$$\sum M = 0$$

$$F'_{at} x l_{BC} - G_V x l_{VC} - G_U x l_{UC} - G_B x l_{BC} = 0 \tag{3.3}$$

$l_{UC} = 55.47\ cm,\ l_{VC} = 35{,}78\ cm,\ l_{BC} = 75\ cm,\ l_{AB} = 25\ cm$

$$F'_{at} = \frac{G_V x l_{VC} + G_U x l_{UC} + G_B x l_{BC}}{l_{BC}}$$

$$F'_{at} = \frac{60x9{,}81x35{,}78 + 100x9{,}81x55{,}47 + 20x9{,}81x75}{75}$$

$$F'_{at} = F_{at} = 1202{,}55\ N$$

$$M_{at} = F_{at} x l_{AB} \tag{3.3}$$

$$M_{at} = 1202{,}55 X 0{,}25$$

$$M_{at} = 300{,}64\ Nm$$

The shaft should be rotated 301Nm Torque. The motor which has high torque usually maximum 30 Nm. The motor is manipulated shaft, transmitting by a gear or gearbox which should be roughly 1:12 ratio.

3.2.4. The moment for lifting up rear wheels

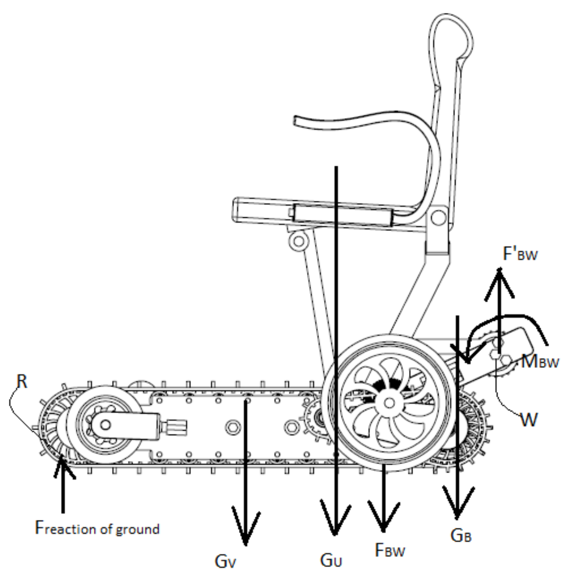

Figure 3.5. The position of lifting up rear wheels

At point of W, there is moment (M_{BW}), this moment creates a force (F_{BW}) which pushes ground to raise up on rear wheel link, its equivalent on link of rear wheel is F'_{BW}. If point of R is taken as a fixed point and take moment based on there; **(fig. 4.5.)**

$$\sum M = 0$$

$$F'_{BW} x l_{WR} - G_V x l_{VR} - G_U x l_{UR} - G_B x l_{BR} = 0 \tag{3.3}$$

$l_{UR} = 55{,}47\ cm,\ l_{VR} = 35{,}78\ cm,\ l_{BR} = 75\ cm,\ l_{WR} = 85{,}17\ cm,\ l_{BW} = 24\ cm$

$$F'_{BW} = \frac{G_V x l_{VR} + G_U x l_{UR} + G_B x l_{BR}}{l_{WR}}$$

$$F'_{BW} = \frac{60x9{,}81x35{,}78 + 100x9{,}81x55{,}47 + 20x9{,}81x75}{85{,}17}$$

$$F'_{BW} = F_{BW} = 1058{,}96\ N$$

$$M_{BW} = F_{BW} x l_{BW} \tag{3.3}$$

$$M_{BW} = 1058{,}96\ x\ 0{,}24$$

$$M_{BW} = 25415\ Nm$$

The shaft should be rotated 254,15 Nm Torque. If it assumed as 24 Nm motor. The motor is manipulated shaft, transmitting by a gear or gearbox which should be roughly 1:12 ratio.

3.2.5. The force for lifting up chair

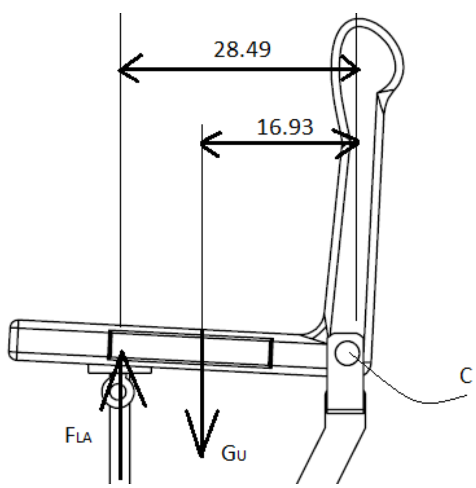

Figure 3.6. The position of lifting up chair

If point of C is taken as a fixed point and take moment based on there; **(fig. 4.6.)**

$$\sum M = 0$$

$F_{LA} x l_{LAC} - G_U x l_{UC} = 0$ (3.3)

F_{LA}x 28,49-130 x 9,81 x 16,93 =0

$F_{LA} = 757{,}84\ N$

At least a linear actuator which has stroke of 800 N bi-directional pull-push system is needed.

3.3. Selection of motor

3.3.1. The motor of rear wheels (m1-m2)

The best option for electrical power wheelchair to using Hub motor because it is manufactured for such kind of vehicles and they are offering 2 hub DC motors, its controller and joystick together. Thus, easily implement the system. **(fig. 4.7.)**

Figure 3.7. 24V brushless wheelchair hub motor 250W

Mass: 4,1kg

Type: Permanent Magnet Brushless Gear Motor

Torque: 3N.M

Reducer speed ratio: 1:22

Price: 100 dollars for a pair of motors

3.3.2. The motor of main tracks (M3-M4)

As a main track motor, this motor is selected. Power calculation shows that 308 W power required with quite slowly speed. The formula 3.2 shows that if power is constant and velocity is low, the torque should be high. This motor is provided characteristic of the main tracks. **(Fig. 4.8.)**

Figure 3.8. 12V DC single speed motor

Mass: 4 kg

Type: Permanent Magnet Brushless Gear Motor

Torque: 91,7 Nm

Price: 170 dollars

3.3.3. The motor of rotating of assistant tracks (m5)

Assistant track should be angularly sensitive. This stepper motor is known in market as a high torque stepper motor. The main reason of selection of this motor. **(Fig. 4.9.)**

Figure 3.9. Nema 42, 30 Nm torque

Max current: 6,5A

Holding Torque: 30 Nm

Mass:10 kg

Price: 85 dollars

3.3.4. The motor of shaft of rear wheels (m6)

This motor has high torque number, 41 Nm. Motor control is very simple. Controlling of this motor very simple and it has single speed. **(Fig. 4.10.)**

Figure 3.10. 12VDC Gear Motor

Voltage: 12VDC

Torque: 41 N-m

Dimensions: 8 x 8 x 5 inches

RPM: 6 s^{-1}

Price:110 dollars

3.3.5. Linear actuator

Figure 3.11. Linear actuator

A pair of linear actuator, has also controller. **(Fig. 4.11.)**

Maximum load push: 600N

Maximum load pull: 600N

Self-lock: 600 N

Full load current: 3A

Speed at no load: 56 mm/s

Speed at rated load: 39 mm/s

3.4. Battery selection

Table 1. *Energy Consumption*

						MAX	avarage		MAX	avarage
Number	Force [N]	Torque [Nm]	Rpm [s.^-1]	Current (A)	Speed [mm/s]	Power [W] [Nm/s]		Working hour [%]	Energy [Wh] [VAh]	
M1		3				135	76.5	85	114.75	65.025
M2		3				135	76.5	85	114.75	65.025
M3		91,7	5			87.65	73.11	10	8.765	7.311
M4		91,7	5			87.65	73.11	10	8.765	7.311
M5		41	6			189	125	3	5.67	3.75
M6		30		6.5		230	175	1	2.3	1.75
LA1	380				56	212.8	165	3	6.384	4.95
LA2	380				56	212.8	165	3	6.384	4.95
								Total	267.768	160.072

The electric charge Q(mAh) in milliampere-hours (mAh) is equal to the energy E(Wh) in watt-hours (Wh) times 1000 divided by the voltage V (V):

$$Q = E \times 1000 / V \quad (3.4)$$

So milliamp-hour is equal to watt-hour times 1000 divided by volts:

milliamp-hour = watt-hour × 1000 / V

or

mAh = Wh × 1000 / V

2 x 12V 65Ah Gel Solar batteries are selected [Fig. 8]

2x 12 x 65 = 1560 VAh

With maximum consumption, total energy per hour is 267,768 VAh/1h

Thus 1560 / 267,768 = 5,83 h

With average consumption, total energy per hour is 160,072 VAh/1h

Thus 1560 / 171,77 = 9,74 h

Figure 3.12. 12v 65Ah deep cycle gel battery

Advantage of sealed gel batteries **(fig. 4.12.)**

- Deep Cycle: Premium sealed batteries capable of up to 1000 cycles.
- Gelled/Suspended Electrolyte: No liquid of any kind; battery is completely sealed. Safe in any position (except upside down).
- Safety: Sealed batteries have a special re-sealing vent system that prevents excessive internal pressure; thus they cannot explode under normal conditions. **(9)**

3.5. Recalculation of desired moments and forces

As it mentioned in section 2, some values are assumed likely: weight of battery, vehicle and user. Based on these assumptions, desired torques are calculated and proper motors which are able to meet powers are defined. Coincidentally, proper batteries are specified. After the result of calculation, mass of motors is changing the weight of the vehicle and also the weight of batteries changed. Hence new calculations are needed to define the powers of each motor. New values are shown below:

- Mass of user: 100 kg
- Mass of vehicle: 77,5 kg
- Mass of battery 40 kg

3.5.1. The moment of rear wheels

a. Straight road

Firstly, the transaction force overcome all resistances which are a force of aerodynamic drag and rolling resistance and also to get an acceleration should provide equation which is shown below.

$$F_{TR} = F_{AD} + F_{ROLL} + m \times a \qquad (3.1)$$

Where F_{AD} – aerodynamic drag force,

F_{ROLL} – rolling resistance force,

m – total mass, 217,5 kg

a – acceleration, 0,2 m/s^2

$$F_{TR} = \rho/2 \times C_D A_F V^2 + mg(C_0 + C_1 v^2) + m \times a$$

Where ρ – Density of air, 1,18 kg/m^3

C_D – The aerodynamic drag coefficient, 0,2

A_F – The frontal area, 1 m^2

V – Velocity, 2,5 m/s

C_0, C_1 – The rolling resistance coefficient, C_0 =0,008 and C_1 = 1,6x10^{-6} s^2/m^2

g – Acceleration due to gravity, 9,81 m/s^2

$F_{TR} = 1,18/2 \text{ x } 0,2 \text{ x } 1 \text{ x } 2,5^2 + 217,5 \text{ x } 9,81(0,008+ 1,6\text{x}10^{-6}\text{x}2,5^2) +217,5 \text{ x } 0,2$

$F_{TR}= 0,7375 + 17,09 + 43,5 = 61,33$ N this number is traction force on without sloping road

$V_{max} = 2,5$ m/s

$$P= F \text{ x } V \quad (3.2)$$

P= 61,33 x 2.5

P=153,32 Nm/s

a. uphill road

Maximum slope for power chairs should be *1,5"* rise to *12"* length (*7,1-degree angle; 12,5% grade*).

$F_{TR}= \rho \text{ x } 0,5 \text{ x } C_D A_F V^2 +mg(C_0+C_1V^2) \text{ x } \cos(\arctan(1,5/12)) +mg \sin(\arctan(1,5/12)) + m \text{ x } a$

$F_{TR} = 1,18 \text{ x } 0,5 \text{ x } 0,2 \text{ x } 1 \text{ x } 2,5^2 + 217,5 \text{ x } 9,81(0,008+ 1,6 \text{ x } 10^{-6}\text{x}1^2) \text{ x } 0,99 + 217.5\text{x}9,81\text{x}0,124 +217,5 \text{ x } 0,2$

$F_{TR}= 0,7375 + 16,94 +263,73 + 43,5$

$F_{TR} = 324,9$ N

P= 324,9 x 1

P= 324,9 Nm/s

The higher number one should be selected. Thus P= 324,9 W

This power manipulates by two motors. Therefore, at least each one of motor with power of 162.45 W is necessary.

3.5.2. The moment of main tracks

Firstly, the transaction force overcome all resistances and also to get an acceleration should provide equation which is shown below.

a. The situation which needs the most power

a=40° – stair angle: arctan(h/l)

$F_{TR} = F_{AD} + F_{Fri} + m \times dv/dt + mg \times \sin(\arctan(h/l))$ (3.1)

$F_{TR} = \rho \times 0{,}5 \times C_D A_F V^2 + mg \times \cos(a) \times \mu + mg \times \sin(a) + m \times a$

$F_{TR} = 1{,}18/2 \times 0{,}2 \times 1 \times 0{,}0615^2 + 217{,}5 \times 9{,}81 \times 0{,}766 \times 0{,}85 + 217{,}5 \times 9{,}81 \times 0{,}643 + 217{,}5 \times 0{,}3$

$F_{TR} = 7{,}375 \times 10^{-3} + 1389{,}316 + 1371{,}5 + 65{,}25$

$F_{TR} = 2826{,}1$ N

P= F x V (3.2)

P= 2826,1 x 0,064

P=180,87 Nm/s

b. The situation which needs the average power

a=36.4° – stair angle: arctan(h/l)

$F_{TR} = F_{AD} + F_{Fri} + m \times dv/dt + mg \times \sin(\arctan(h/l))$ (3.1)

$F_{TR} = \rho/0.5 \times C_D A_F V^2 + mg \times \cos(a) \times \mu + mg \times \sin(a) + m \times a$

$F_{TR} = 1{,}18/2 \times 0{,}2 \times 1 \times 0{,}25^2 + 217{,}5 \times 9{,}81 \times 0{,}805 \times 0{,}85 + 217{,}5 \times 9{,}81 \times 0{,}593 + 217{,}5 \times 0{,}3$

F_{TR}= 7,375 x 10^{-3} + 1459,77 + 1265,27 + 65,25

F_{TR}= 2790,29 N

P= 2790,29 x 0.064

P= 178 ,58 Nm/s

This force manipulates by two motors. Therefore, at least one pair of motor with power of 90,435 W is necessary.

3.5.3. The moment for lifting up assistant tracks

At point of B, there is moment (M_{at}), this moment creates a force (F_{at}) which pushes ground to raise up on AB link, its equivalent on BC link is F'_{at}. If point of C is taken as a fixed point and take moment based on there; ***[Fig. 4]***

$$\sum M = 0$$

$$F'_{at} x l_{BC} - G_V x l_{VC} - G_U x l_{UC} - G_B x l_{BC} = 0 \qquad (3.3)$$

G_V=77,5 kg G_U=100 kg G_B=40 kg $l_{UC} = 55{,}47\ cm, l_{VC} = 35{,}78\ cm, l_{BC} = 75\ cm,\ \ l_{AB} = 25\ cm$

$$F'_{at} = \frac{G_V x l_{VC} + G_U x l_{UC} + G_B x l_{BC}}{l_{BC}}$$

$$F'_{at} = \frac{77{,}5x9{,}81x35{,}78 + 100x9{,}81x55{,}47 + 40x9{,}81x75}{75}$$

$$F'_{at} = F_{at} = 1480{,}65\ N$$

$$M_{at} = F_{at} x l_{AB} \qquad (3.3)$$

$$M_{at} = 1480{,}65\ x\ 0{,}25$$

$$M_{at} = 370{,}64\ Nm$$

3.5.4. The moment for lifting up rear wheels

At point of W, there is moment (M_{BW}), this moment creates a force (F_{BW}) which pushes ground to raise up on rear wheel link, its equivalent on link of rear wheel is F'_{BW}. If point of R is taken as a fixed point and take moment based on there at fig.

$$F'_{BW} x l_{WR} - G_V x l_{VR} - G_U x l_{UR} - G_B x l_{BR} = 0 \qquad (3.1)$$

$$l_{UR} = 55{,}47\ cm,\ l_{VR} = 35{,}78\ cm, l_{BR} = 75\ cm, l_{WR} = 85{,}17\ cm,\ l_{BW} = 24\ cm$$

$$F'_{BW} = \frac{G_V x l_{VR} + G_U x l_{UR} + G_B x l_{BR}}{l_{WR}}$$

$$F'_{BW} = \frac{77{,}5x9{,}81x35{,}78 + 100x9{,}81x55{,}47 + 40x9{,}81x75}{85{,}17}$$

$$F'_{BW} = F_{BW} = 1303{,}85\ N$$

$$M_{BW} = F_{BW} x l_{BW} \qquad (3.3)$$

$$M_{BW} = 1303{,}85\ x\ 0{,}24$$

$$M_{BW} = 312{,}92\ Nm$$

3.5.5. The force for lifting up chair

If point of C is taken as a fixed point and take moment based on there; ***[Fig. 8]***

$$\sum M = 0$$

$$F_{LA} x l_{LAC} - G_U x l_{UC} = 0 \qquad (3.3)$$

F_{LA}x 28,49-130 x 9,81 x 16,93 = 0

$$F_{LA} = 757{,}84\ N$$

At least a linear actuator which has stroke of 800 N bi-directional pull-push system is needed.

3.6. Recalculation of battery consumption

Table 2. The Upgraded Energy Consumption

						MAX	avarage		MAX	avarage
Number	Force [N]	Torque [Nm]	Rpm [s.^-1]	Current (A)	Speed [mm/s]	Power [W] [Nm/s]		Working hour [%]	Energy [Wh] [VAh]	
M1		3				162.45	90	85	138.0825	76.5
M2		3				162.45	90	85	138.0825	76.5
M3		91,7	5			90.435	89.29	10	9	8.929
M4		91,7	5			90.435	89.29	10	9	8.929
M5		41	6			197	136	3	5.91	4.08
M6		30		6.5		250	185	1	2.5	1.85
LA1	390				56	212.8	165	3	6.384	4.95
LA2	390				56	212.8	165	3	6.384	4.95
								Total	315.3865	186.688

2 x 12V 65Ah Gel Solar batteries are selected **(fig. 4.12.)**

2x 12 x 65 = 1560 VAh

With maximum consumption, total energy per hour is 315, 4 VAh/1h

Thus 1560 / 315,3865 = 4,9 h

With average consumption, total energy per hour is 186,7 VAh/1h

Thus 1560 / 186,7= 8,36 h

3.7. Summary

In this chapter, firstly mass of the vehicle was predicted and desired moment and force for each of mechanism are defined. Motors are selected based on obtaining value of torque and power. When motors and linear actuator are selected, mass of vehicle change and power calculation is recalculated. The battery is selected and energy consumption and how long batteries lasts are found.

4. CONNECTION OF MOTORS

Table 3. Connection of Motors

Motors	Desired torque or power	Selected motor	Number of stages	Type of power transfer
M1 and M2	162.45 W	250W	1	Bevel gear
M3 and M4	89 Nm	91,7 Nm	1	Chain gear
M5	370.64 Nm	28 Nm	3	Spur gear
M6	312 Nm	41,7 Nm	2	Spur gear

4.1. Hub DC motor (M1 and M2)

Power of M1 and M2 motors has already provided requirements. Thus, they do not need a gearbox.

4.2. Main track motor (M3 and M4)

M3 and M4 connected main gear of track by couplings **(fig. 5.1.)**

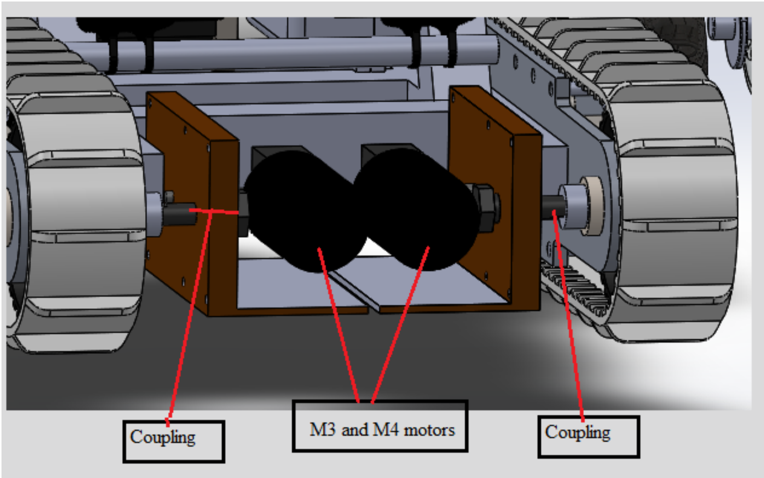

Figure 4.1. Connection of Motors of M3 and M4

4.3. Rotating of rear wheels (M6)

In order to define the appropriate designing of gears; firstly, working conditions of gears should be determined and type of gears should be correspondingly selected. After the type of gears are determined, an optimum combination of gears' parameters should be defined by using iteration or restrictions of mechanism.

After power calculation, desired torque is obtained as 312,92 Nm (see power calculation) and motor is selected 28Nm (see motor selection). Thus If it is assumed that perfect conditions are provided, we would just have needed 312,92/41= 7,632 ratio. However, we do not have these conditions, we should choose an efficient power transfer. We could take it as μ=0,9 between two gears. Thus, (312,92/28) / 0,9 = 8,48 ratio

Now, this step number stage should be decided. As it seen 1: 8,48 ratio is really high to transfer only in one stage. Therefore, the number of stage could be taken as 2 and now ratio change again as; (312,92/28) / (0,9 x 0,9) = 9,42 ratio

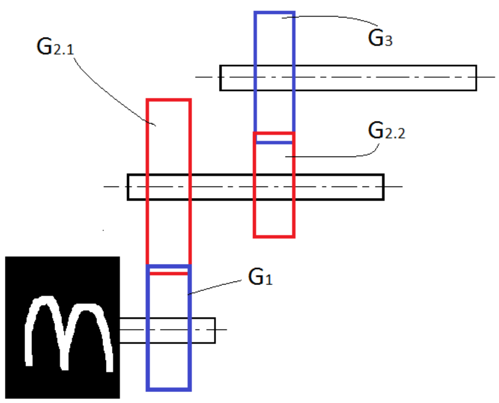

Figure 4.2. Schematic of spur gears gearbox of rotating rear wheel

Moment and revolution per minute of G_3 are orderly 312,92 Nm and 6 s^{-1}.

$$w_3 = \frac{2 \, x \, \pi \, x \, n_3}{60} \qquad (4.1.)$$

$$w_3 = \frac{2 \, x \, \pi \, x \, 6}{60}$$

$$w_3 = 0,628 \, rad/s$$

Moment and revolution per minute of $G_{2.2}$ shall be as it shown below;

$$M_{2.2} x Z_3 x \mu = M_3 x Z_{2.2} \quad (4.2)$$

Where M– Module,

Z– number of teeth,

$M_{2.2}$ x 31 x 0.9 = 312.92 x 10

$M_{2.2}$ = 112,16 Nm

$$N_{2.2} x Z_{2.2} = N_3 x Z_3 \quad (4.2)$$

Where N– revolution per minute, rpm

$N_{2.2}$ x 10 = 6 x 31

$N_{2.2}$ = 18,6 s^{-1}

$$w_{2.2} = \frac{2 x \pi x n_{2.2}}{60}$$

$$w_{2.2} = \frac{2 x \pi x 18{,}6}{60}$$

$w_{2.2}$ =*1,948 rad/s*

$$i_2 = Z_3 / Z_{2.2} \quad (4.3)$$

i_2 = 31 / 10

i_2 = 3.1

$i = i_1 x i_2$

i_1 = 9,42 / 3,1

i_1 = 3,038 so we can choose it as i_1 = 3,1

Number teeth and revolution per minute of $G_{2.1}$ shall be as it shown below;

$i_1 = Z_{2.1} / Z_1$

$Z_{2.1} = 3{,}1 \text{ x } 10$

$\underline{Z_{2.1} = 31}$

$N_1 \ x \ Z_1 = N_{2.1} \ x \ Z_{2.1}$

$N_1 \text{ x } 10 = 18{,}6 \text{ x } 31$

$N_1 = 57{,}66 \ s^{-1}$

$$w_1 = \frac{2 \ x \ \pi \ x \ N_1}{60}$$

$$w_1 = \frac{2 \ x \ \pi \ x \ 57.66}{60}$$

$w_1 = 6{,}038 \ rad/s$

4.3.1. Control of Strength power transmission between G3 and G2.2

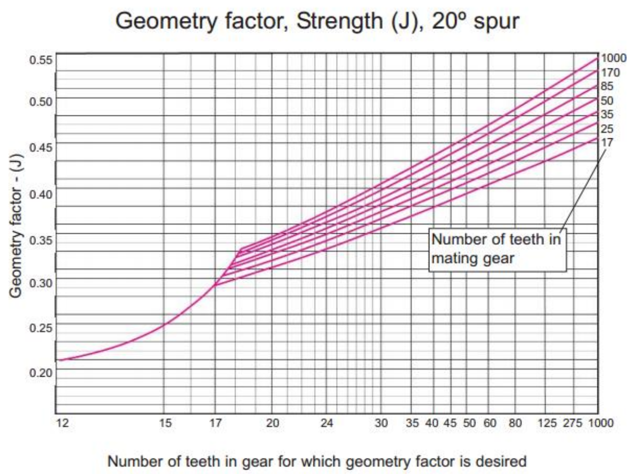

Figure 4.3. Geometry factor **(7)**

$P_{2.2} = M_{2.2} \ x \ w_{2.2}$ (4.4)

$P_{2.2} = 112.16 \ x \ 1.948$

$P_{2.2} = 218{,}49$

$$Fs_{2.2} = \frac{P \times 60{,}000}{\pi \times M \times Z \times N} x \; C_s \quad (4.5)$$

Where P – power, Nm/s

C_s – constant gain,

$$Fs_{2.2} = \frac{218{,}49 \times 60000}{3.14 \times 3 \times 10 \times 18{,}6} x \; 1.25$$

$Fs_{2.2}$ =7481,942 N

$$F_t = \sigma_s \text{ x b x J x M} \quad (4.6)$$

Where σ_s – yield strength, N/m^2

J – Geometry factor, **(fig. 5.2.)**

F_t =462 x 30 x 0,228 x 3

F_t = 9480,24 N

$F_{t\text{-max}} = F_t \text{ x } C_V$

$$V = \frac{\pi \; x \; M \; x \; Z \; x \; N}{60{,}000} \quad (4.7)$$

$$C_V = \frac{3}{3 + V_t}$$

$$V_t = \frac{3.14 \; x \; 3 \; x \; 10 \; x 57{,}66}{60{,}000}$$

V_t = 0,0905 m/s

$$C_V = \frac{3}{3 + 0{,}0905} \quad (4.8)$$

C_V = 0.971

$F_{t\text{-max}} = F_t \text{ x } C_V$ (4.9.)

$F_{t\text{-max}}$ = 9480,24 x 0,971

$F_{t\text{-max}}$ = *9202,55* N

$Fs \leq F_{t-max}$

$7481{,}942 \leq 9202{,}55$ so strength of gears which $G_{2.2}$ and G_3 are secure.

4.3.2. Control of Strength power transmission between G_1 and $G_{2.1}$

$P_1 = M_1 \, x \, w_1$

$P_1 = 41 \text{ x } 6.613$

$P_1 = 185{,}164 \text{ W}$

$F_{S1} = \frac{P \times 60{,}000}{\pi \times M \times Z \times N} \, x \, C_s$

$F_{S1} = \frac{185{,}164 \times 60{,}000}{3.14 \times 3 \times 10 \times 63.18} \, x \, 1.25$

$F_{S1} = 2333{,}4 \text{ N}$

$F_t = \sigma_s \text{ x b x J x M}$

$F_t = 462 \text{ x } 30 \text{ x } 0{,}228 \text{ x } 3$

$F_t = 9480{,}24 \text{ N}$

$F_{t-max} = F_t \text{ x } C_V$

$V = \frac{\pi \, x \, M \, x \, Z \, x \, N}{60{,}000}$

$C_V = \frac{3}{3 + V_t}$

$V_t = \frac{3.14 \, x \, 3 \, x \, 10 \, x \, 63{,}18}{60{,}000}$

$V_t = 0{,}0992 \text{ m/s}$

$C_V = \frac{3}{3 + 0{,}0852}$

$C_V = 0{,}968$

$F_{t-max} = 9480{,}24 \text{ x } 0{,}968$

$F_{t\text{-}max} = 9176{,}87$ N

$Fs \leq F_{t\text{-}max}$

$2333{,}4 \leq 9176{,}87$ so strength of gears which $G_{2.1}$ and G_1 are secure.

Power transmission between shaft of rear wheel and M6 motor are illustrated in figure 5.4.

It consists of 12V DC motor, gearbox, timing gear, timing belt and shaft.

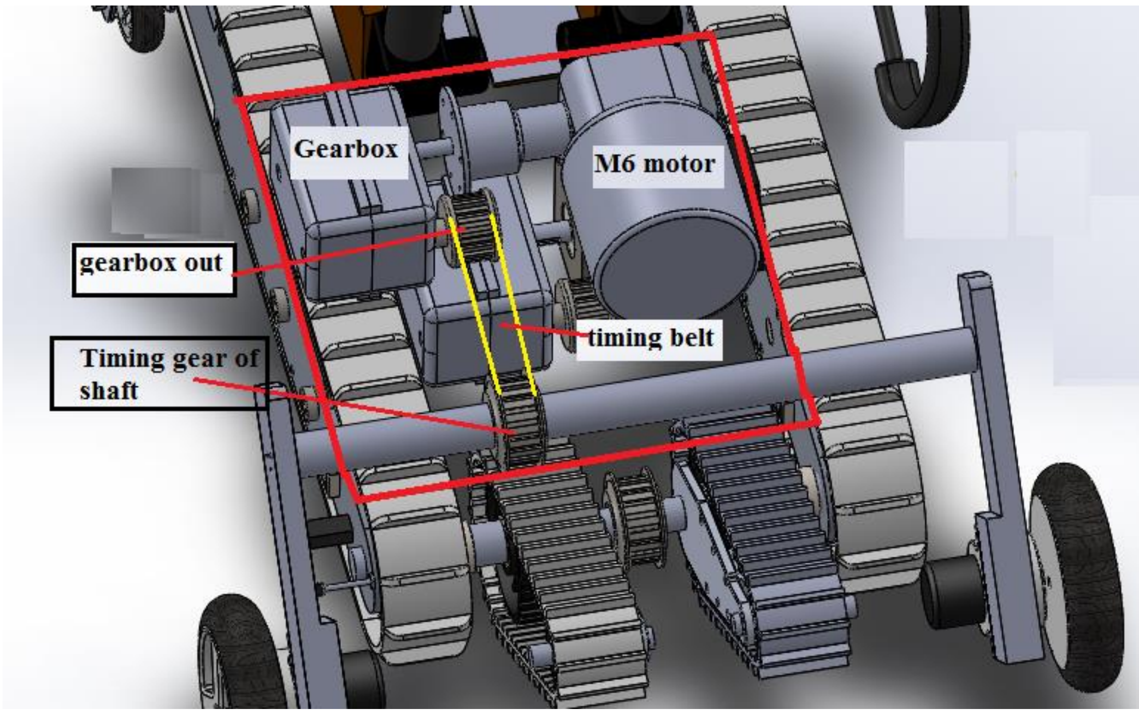

Figure 4.4. Illustrated of gearbox of rotating rear wheel

After the result of appropriate gears' diameter face with a number of teeth are defined and according to calculation, a gearbox is designed which is shown in figure 5.5, 5.6 and 5.7.

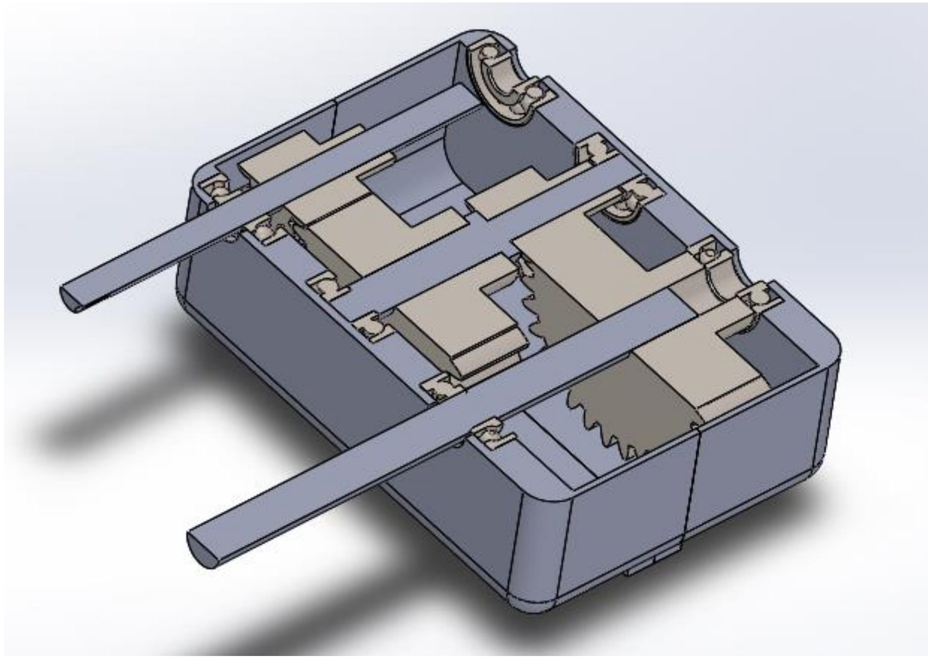

Figure 4.5. The gearbox design for shaft of rear wheel

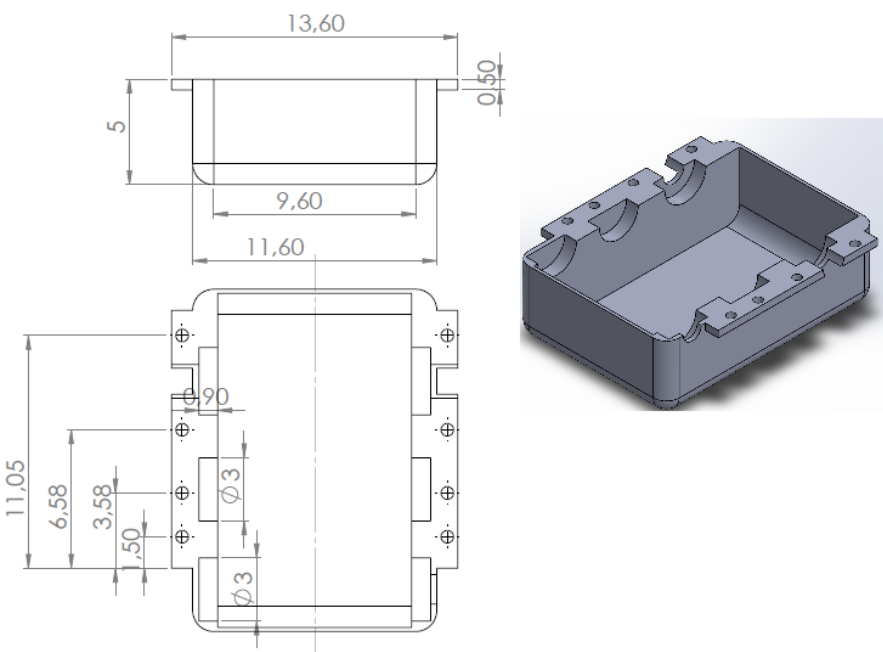

Figure 4.6. The gearbox design for shaft of rear wheel with dimensions

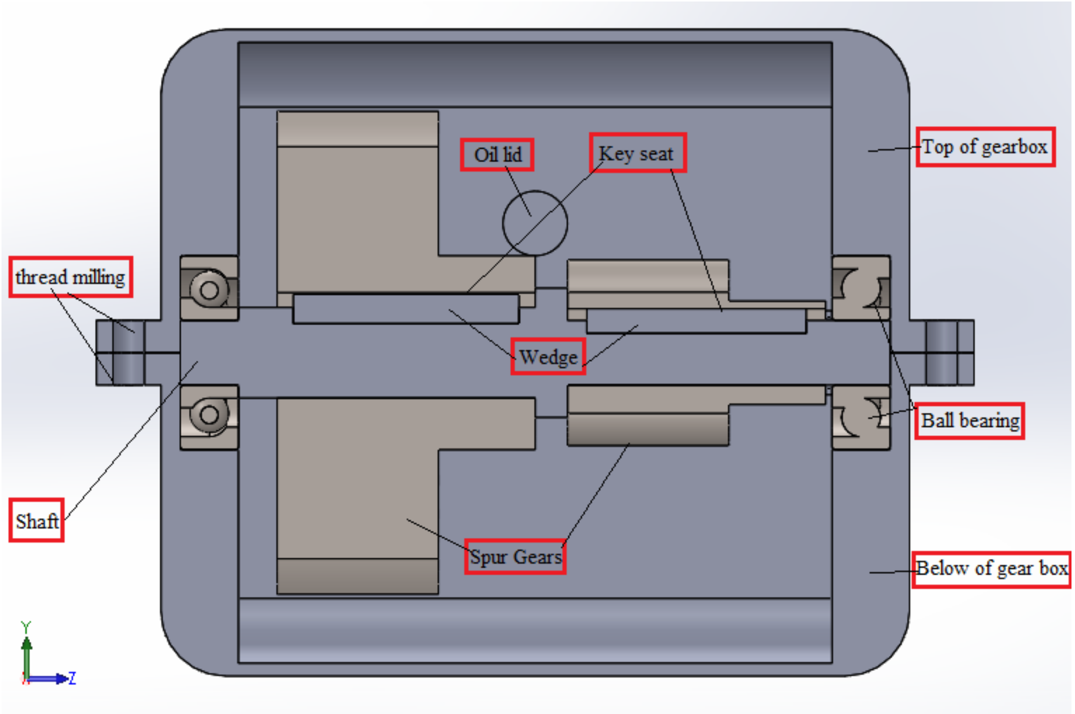

Figure 4.7. The components of gearbox for shaft of rear wheel

Table 4. Description of components

Name of part	Number	Features (dim.)
Spur Gears	4	DIN 8187 M25 FW:25 Z:10,10,28,31
Sprocket Gear	2	DIN 8187, 06B-1
Chain	1	DIN 8187, 12B-1
shaft	2	L:110,
Ball-bearing	6	7200BEP Bearing Size 10x30x9 mm Angular contact ball bearing
Oil lids	2	1 cm diameter
O-ring	2	Inner diameter:10mm diameter thickness:1
Bolt and nut	8	M6

4.4. Rotating of assistant motor (M5)

After power calculation, desired torque is obtained as 370,64 Nm (see power calculation) and motor is selected 28Nm (see motor selection). Thus If it is assumed that perfect conditions are provided herewith power could be transferred perfectly and we would merely have needed 370,64/28= 13,234 ratio. However, we do not have these conditions, we should choose an efficient power transfer. We could take it as μ=0,9 between two gears. Thus, (370,64/28) / 0,9 = 14,708 ratio

Now, this step number stage should be decided. As it seen 1:14,708 ratio is really high to transfer only in one or two stages. Therefore, the number of stage could be taken as 3 and now ratio change again as; (370,64/28) / (0,9 x 0,9 x 0,9) = 18,158 ratio

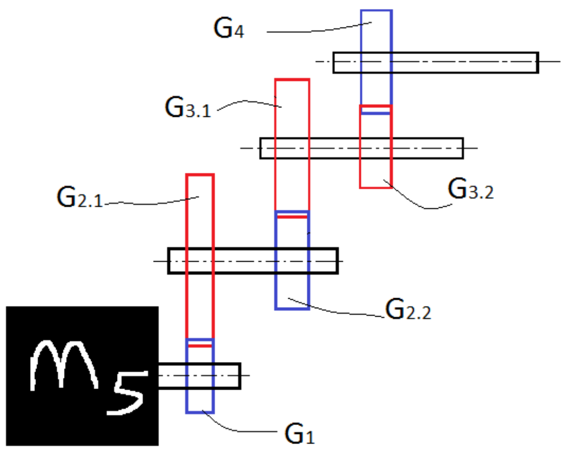

Figure 4.8. Schematic of spur gears gearbox of rotating rear wheel

Moment and revolution per minute of G_3 are orderly 370.64 Nm and 6 s^{-1}.

$$w_4 = \frac{2\,x\,\pi\,x\,N_3}{60}$$

$$w_4 = \frac{2\,x\,\pi\,x\,6}{60}$$

w_4 = *0,628 rad/s*

Moment and revolution per minute of $G_{3.2}$ shall be as it shown below;

Firstly, the distance between the centre of the shaft of assistant-tracks and ground 150 mm and so maximum outside diameter of the gear should be 90 mm and $i_1 = 2{,}8$ **[table of DIN 867]**

$i = i_1 \, x \, i_2 \, x \, i_3$

If we choose $i_2 = 2{,}6$

$18.158 = 2{,}8 \, x \, 2{,}6 \, x \, i_3$

$I_3 = 2{,}4942$ so we can choose it as $i_3 = 2{,}5$

$M_{3.2} \, x \, Z_4 \text{ x } 0{,}9 = M_4 \, x \, Z_{3.2}$

$M_{3.2} \text{ x } 28 \text{ x } 0.9 = 370{,}64 \text{ x } 10$

$M_{3.2} = 147{,}08$ Nm

$N_{3.2} \, x \, Z_{2.2} = N_3 \, x \, Z_3$

$N_{3.2} \text{ x } 10 = 3{,}6 \text{ x } 28$

$N_{3.2} = 10{,}08 \text{ s}^{-1}$

$$w_{3.2} = \frac{2 \, x \, \pi \, x \, N_{3.2}}{60}$$

$$w_{3.2} = \frac{2 \, x \, \pi \, x \, 10{,}08}{60}$$

$w_{3.2} = 1{,}055 \, rad/s$

Number teeth and revolution per minute of $G_{2.2}$ shall be as it shown below;

$I_2 = Z_{3.1} / Z_{2.2}$

$Z_{3.1} = 2{,}6 \text{ x } 10$

$\underline{Z_{3.1} = 26}$

$N_{2.2} \, x \, Z_{2.2} = N_{3.1} \, x \, Z_{3.1}$

$N_{2.2} \text{ x } 10 = 10{,}08 \text{ x } 26$

$\underline{N_{2.2} = 26{,}208\ s^{-1}}$

$W_{2.2} = \frac{2\ x\ \pi\ x\ N_{2.2}}{60}$

$W_{2.2} = \frac{2\ x\ \pi\ x\ 26{,}208}{60}$

$W_{2.2} = 2{,}743\ rad/s$

Number teeth and revolution per minute of G_1 shall be as it shown below;

$I_3 = Z_{2.1} / Z_1$

$Z_{2.1} = 2.5 \text{ x } 10$

$\underline{Z_{2.1} = 25}$

$N_1\ x\ Z_1 = N_{2.1}\ x\ Z_{2.1}$

$N_1 \text{ x } 10 = 26{,}208 \text{ x } 25$

$\underline{N_1 = 65{,}52\ s^{-1}}$

$W_1 = \frac{2\ x\ \pi\ x\ N_1}{60}$

$W_1 = \frac{2\ x\ \pi\ x\ 65{,}52}{60}$

$W_1 = 6{,}858\ rad/s$

4.4.1. Control of Strength power transmission between G4 and G3.2

$P_{3.2} = M_{3.2}\ x\ w_{3.2}$

$P_{3.2} = 147{,}08\ x\ 1{,}055$

$P_{3.2} = 155{,}169$

$Fs_{3.2} = \frac{P \times 60{,}000}{\pi \times M \times Z \times N} \, x \ C_s$

$Fs_{3.2} = \frac{155{,}169 \times 60000}{3.14 \times 3 \times 10 \times 10{,}08} \, x \ 1.25$

$Fs_{3.2}$ =12256,15 N

$F_t = \sigma_s$ x b x J x M

F_t =462 x 39 x 0,228 x 3

F_t = 12324,3 N

$F_{t\text{-}max} = F_t$ x C_V

$V = \frac{\pi \ x \ M \ x \ Z \ x \ N}{60{,}000}$

$C_V = \frac{3}{3 + V_t}$

$V_t = \frac{3{,}14 \ x \ 3 \ x \ 10 \ x \ 10{,}08}{60{,}000}$

V_t = 0,0158 m/s

$C_V = \frac{3}{3 + 0{,}0158}$

C_V = 0,995

$F_{t\text{-}max}$ = 12324,3 x 0,995

$F_{t\text{-}max}$ = 12256,15 N

$Fs \leq F_{t\text{-}max}$

12256,15 $\leq$ *12259,63* so strength of gears which $G_{3.2}$ and G_4 are secure.

4.4.2. Control of Strength power transmission between $G_{2.2}$ and $G_{3.1}$

$M_{2.2} \ x \ Z_{3.1}$ x 0.9 = $M_{3.1} \ x \ Z_{2.2}$

$M_{2.2}$ x 26 x 0.9 = 147,08 x 10

$M_{2.2}$ = 62,855 Nm

$P_{2.2}$ =62.855 *x 2.743*

$P_{2.2}$ = 172,41 W

$F_{S2.2} = \frac{P \times 60000}{\pi \times M \times Z \times N} x$ C_s

$F_{2.21} = \frac{172,41 \ \times 60000}{3,14 \times 3 \times 10 \times 26,208} x \ 1.25$

$F_{S2.2}$ =5237,7 N

$F_t = \sigma_s$ x b x J x M

F_t =462 x 30 x 0,228 x 3

F_t = 9480,24 N

$F_{t\text{-max}} = F_t$ x C_V

$V = \frac{\pi \ x \ M \ x \ Z \ x \ N}{60000}$

$C_V = \frac{3}{3+ V_t}$

$V_t = \frac{3,14 \ x \ 3 \ x \ 10 \ x \ 26,208}{60000}$

V_t = 0,0411 m/s

$C_V = \frac{3}{3+ 0,0411}$

C_V = 0,9865

$F_{t\text{-max}}$ = 9480,24 x 0,9865

$F_{t\text{-max}}$ =*9351,97* N

$Fs \leq F_{t\text{-max}}$

$5237,7 \leq$ *9351,97* so strength of gears which $G_{2.2}$ and $G_{3.1}$ are secure.

4.4.3. Control of Strength power transmission between G_1 and $G_{2.1}$

$M_1 \ x \ Z_{2.1}$ x 0,9 = $M_{2.1} \ x \ Z_1$

M_1 x 25 x 0,9 = 62,855 x 10

M_1 = 27,936 Nm

P_1 =27,936 *x 6,858*

P_{21} = *191,585* W

$F_{S1} = \frac{P \times 60000}{\pi \times M \times Z \times N} x$ C_s

$F_{S1} = \frac{191,585 \ \times 60000}{3,14 \times 3 \times 10 \times 65,52} x \ 1.25$

F_{S1} =2328,1 N

F_t =σ_s x b x J x M

F_t =462 x 30 x 0,228 x 3

F_t = 9480,24 N

$F_{t\text{-}max}$ = F_t x C_V

$V = \frac{\pi \ x \ M \ x \ Z \ x \ N}{60000}$

$C_V = \frac{3}{3 + V_t}$

$V_t = \frac{3,14 \ x \ 3 \ x \ 10 \ x \ 65,52}{60000}$

V_t = 0,1029 m/s

$C_V = \frac{3}{3 + 0,1029}$

C_V = 0,967

$F_{t\text{-}max}$ = 9480,24 x 0,967

$F_{t\text{-}max} = 9165{,}95$ N

$Fs \leq F_{t\text{-}max}$

$2328{,}1 \leq 9165{,}95$ so strength of gears which $G_{2.1}$ and G_1 are secure.

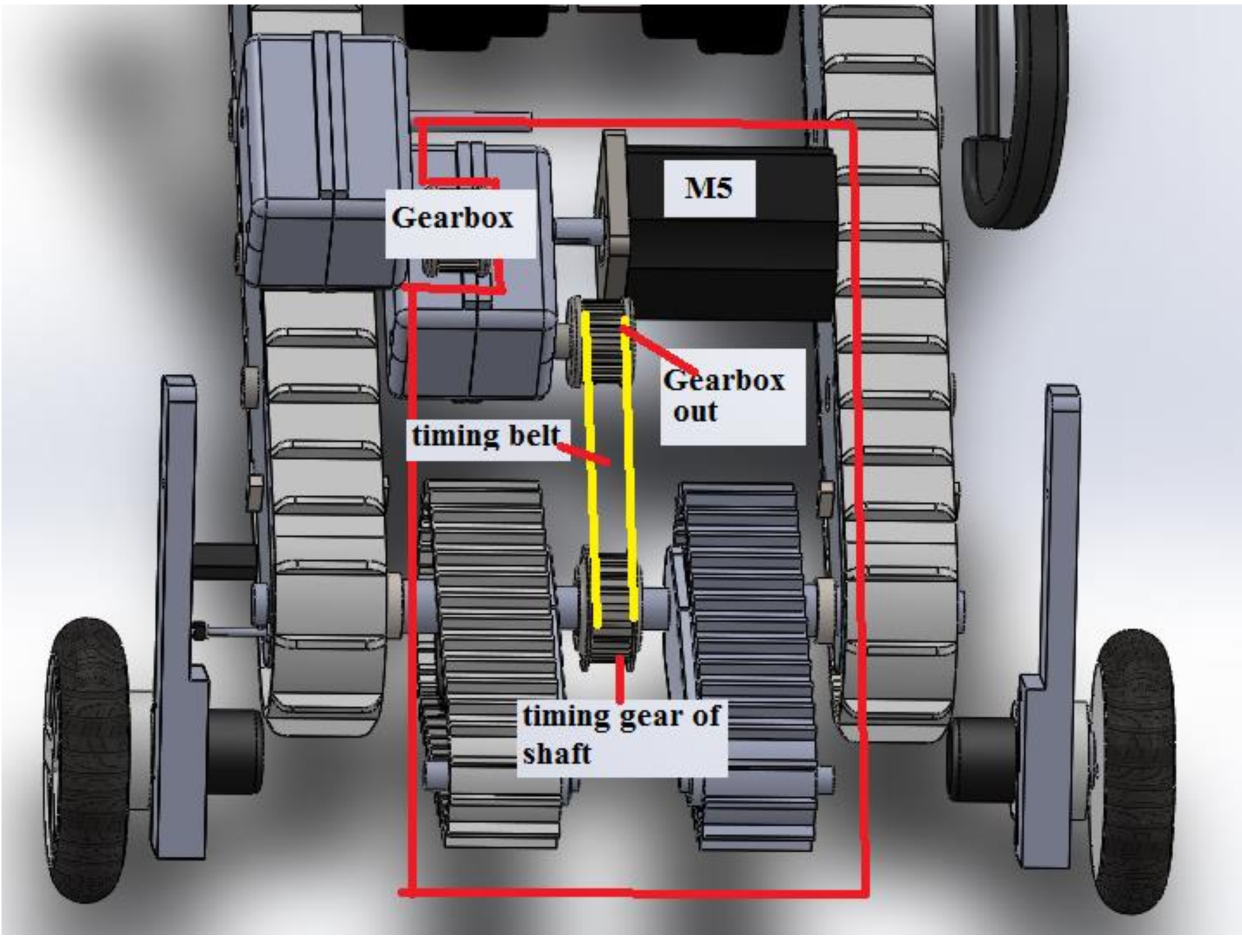

Figure 4.9. Illustrated of gearbox of rotating rear wheel

4.5. Summary

In this chapter, motors connected to the mechanism, the result of calculation in chapter 4, it is understood that the vehicle requires quite high torque and motors which can provide this torque, is quite big and heavy, however, mass and limited space such kind of factor that need to be overcome. Thus, one for lifting up the rear wheels and one for assistant tracks, two gearboxes designed using gear from DIN 867.

5. CONTROL SYTEM

5.1. Defining I/Os

Table 5. I/Os

Inputs	Outputs
limit switches	screen
angle sensor (ADXL and (gyroscope)	electromagets
joystick and push-buttons	relay
speed controller (pwm)	motors (M1, M2, M3, M4, M5, M6 LA1 and LA2)

5.2. Single board industrial PC

Freescale i.MX6 single-board computer is selected. As it is seen at table xx, there are 6 motors, 5 of them DC motors and which each of them has different characteristic and it will be needed to control speed and acceleration. Furthermore, when the vehicle on stairs, the chair is lifted up by signal an angle sensor or gyroscope. Freescale i.MX6 is capable to do that. It has integrated ADXL sensor, gyroscope and there are 3 PWMs. It has digital pins besides analog pins which allows to easily connect a joystick that we will need to control main tracks motor and in this case, the vehicle gains one more talent, to climb spiral stairs.

Figure 5.1. Freescale i.MX6 single-board pc

The features of Freescale i.MX6 single-board pc are illustrated at fig 6.2.

FEATURES

Processor	NXP **i.MX6SX SoloX** Processor, Single core Cortex®-A9 @ 1GHz + Cortex®-M4 core @ 227MHz
Max Cores	1 + 1
Memory	32-bit DDR3L memory soldered on-board, up to 1GB
Graphics	Integrated Graphics Vivante GC400T, 2D and 3D HW accelerator OpenGL ES 2.0, OpenGL ES 1.1, OpenVG 1.1 supported
Video Interfaces	Single Channel 18- / 24- bit LVDS connector + Touch Screen (I2C signals) 24-bit Parallel RGB Connector Video ADC input (PAL and NTSC formats supported)
Video Resolution	LVDS: up to 1366x768 @60Hz, 24bpp RGB: up to 1920x1080p @60Hz, 24bpp
Mass Storage	16MB NOR Quad-SPI Flash soldered on-board eMMC soldered on-board, up to 8GB µSD Card slot
Networking	Up to two Fast Ethernet RJ-45 connectors WiFi (802.11 b / g / n) +BT LE combo module + antenna on-board
USB	1 x USB 2.0 OTG port 3 x USB 2.0 Host ports on standard Type-A socket 1 x USB 2.0 Host port on internal pin header
Audio	I2S Audio interface on programmable pin header S / PDIF interface (In and Out) on programmable pin header
Serial Ports	1 x CAN Port with CAN transceiver on dedicated connector, optional 1 x CAN Port reconfigurable as GPIO 3 x UARTS on programmable pin header (optionally available with RS-232 or RS-485 interface)
Other Interfaces	2 x I2C dedicated connectors (one reserved for Touch Screen) 6 analog inputs for A / D Conversion Programmable (*) expansion pin header connector, able to offer: • Up to 26 GPIO • SPI interface • SPDIF Audio interface • I2S Audio interface • CAN interface (TTL level) • 3 x PWM • 2 x I2C • 3 x UARTs (TTL, RS-232 or RS-485 interface) (*) Please note that some of these interfaces are factory options, other configurations are made via SW using the pin multiplexing possibilities of the i.MX6SX processor.
Integrated Sensors	Optional 9-Axis Motion Sensors (Accelerometer, Magnetometer and Digital Gyroscope)
Power Supply	+12V_{DC} nominal voltage Optional additional embedded Low Power RTC
Operating System	Android Linux
Operating Temperature*	0°C ÷ +60°C (Commercial version)
Dimensions	89.5 x 87 mm (3.52" x 3.43")

*Measured at any point of the heatspreader/heatsink during any and all times (including start-up). Actual temperature will widely depend on application, enclosure and/or environment. Upon customer to consider specific cooling solutions for the final system.

Figure 5.2. The features of Freescale i.MX6 single-board pc

Inputs and outputs of Freescale i.MX6 single-board pc are illustrated at fig 6.3.

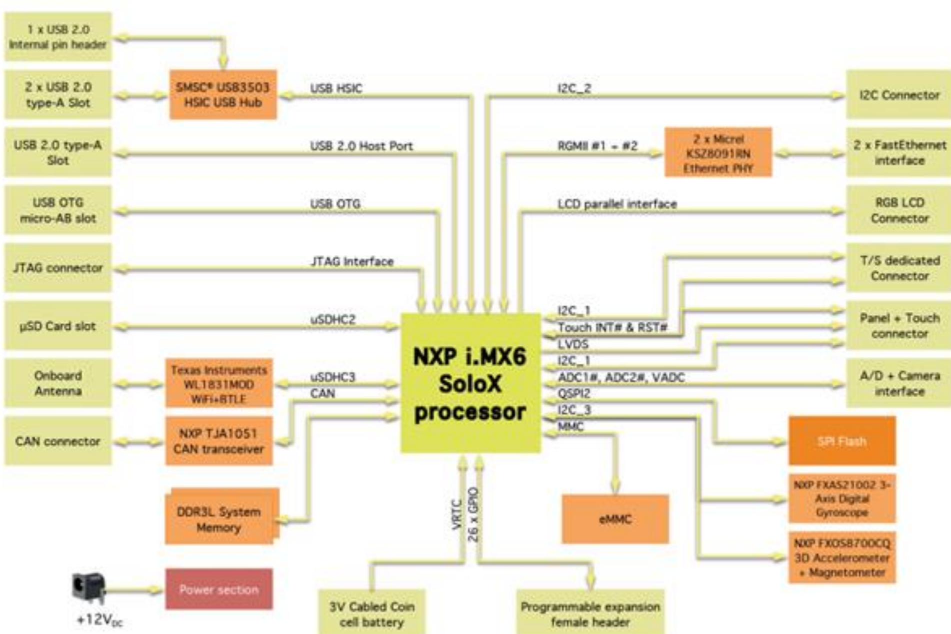

Figure 5.3. Inputs and outputs of Freescale i.MX6 single-board pc

5.3. Linear actuators for balancing the chair

The linear actuators are used to balance the chair in real time when the wheelchair is lifting the stairs. This is done to keep the user balanced by pushing or pulling one side of the chair based on the feedback of the angle data provided from the IMU sensor on the single board computer (SBC) fixed under the moving chair. **(Fig. 6.4.)**

The linear motors comprise of two DC motors connected to their controller. **(Fig. 6.5.)** The controller will drive the motors depending on the SBC.

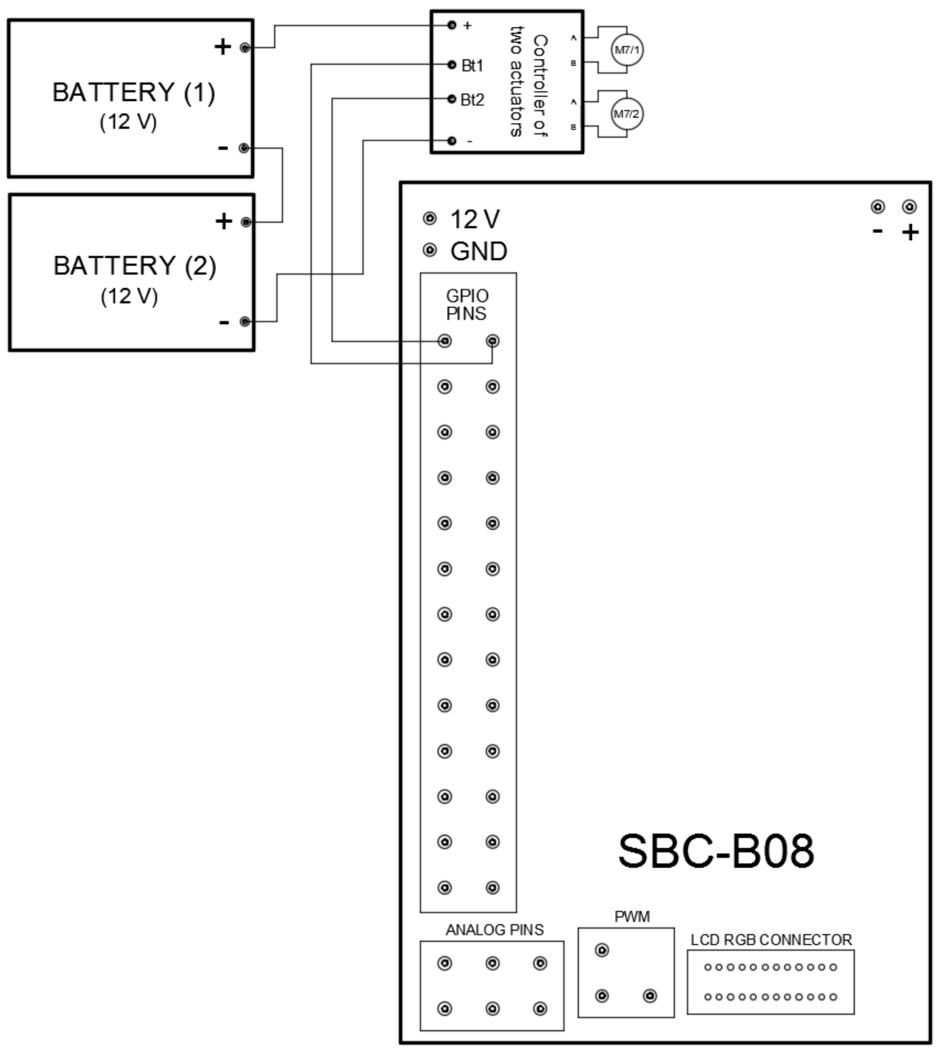

Figure 5.4. The circuit diagram of the linear actuators

Figure 5.5. Linear actuators and the controller

5.4. Stepper motor for rotating the assistant track shaft

The stepper motor of the shaft makes possible to rotate the in two directions, and this is done by using a Leadshine DM556 digital stepper driver. The driver inputs consist of the power pin ACC for supplying self-work, the grounding pin GND, the power input (+) pin for delivering battery power source to the stepper motor (M5), and the three inputs PUL for pulse control, DIR for direction and EN for enabling the driver, all three inputs are connected and controlled by SBC GPIO pins.

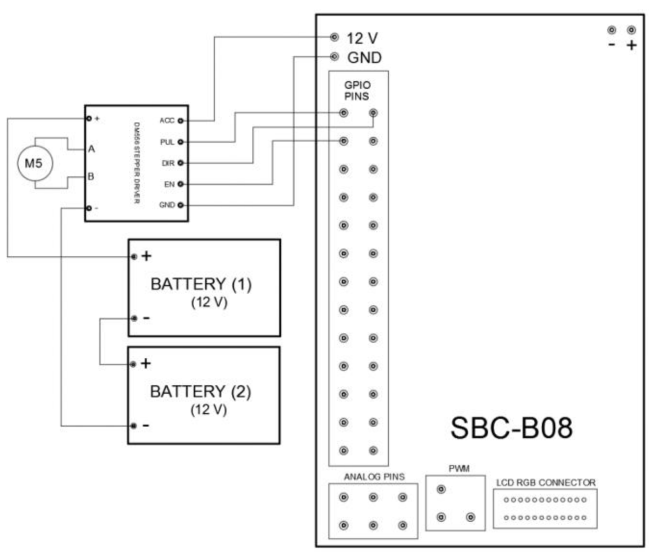

Figure 5.6. Stepper circuit diagram with the SBC

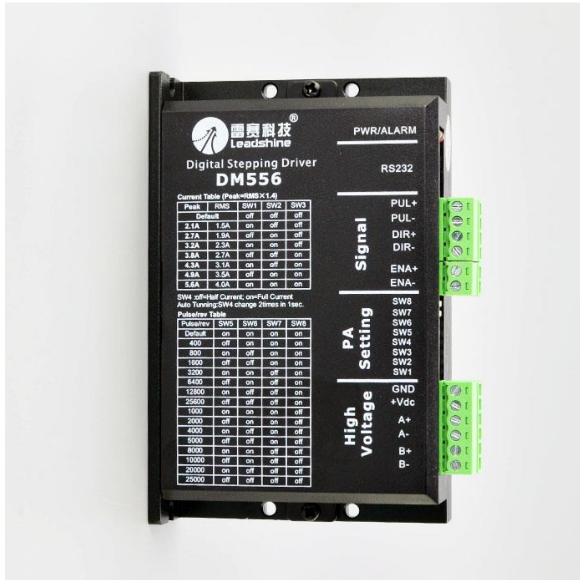

Figure 5.7. Driver of the stepper motor

The connection between stepper motor and its driver is shown below in figure 6.9.

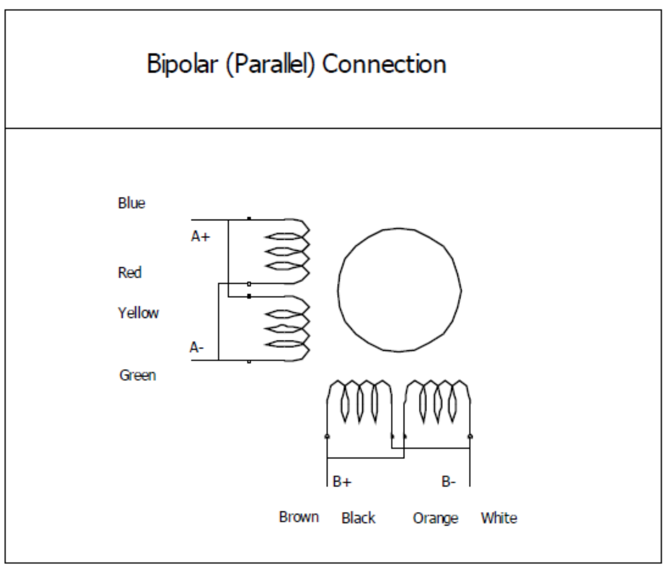

Figure 5.8. Stepper motor connection

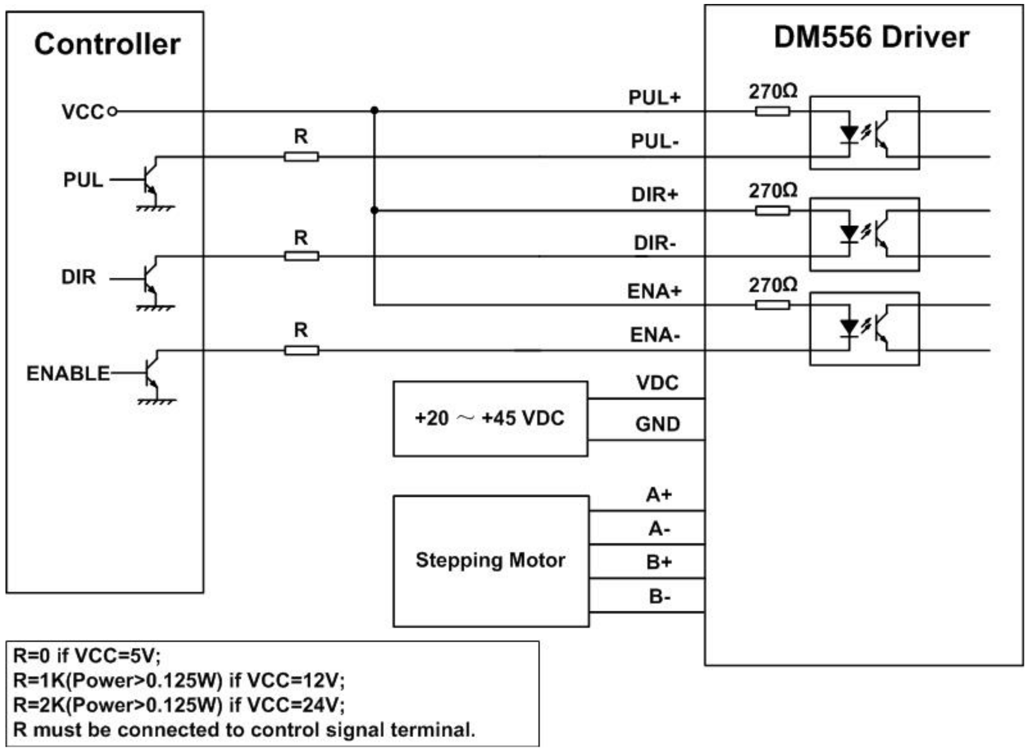

Figure 5.9. The schematic of stepper motor driver

5.5. The rear wheel's rotation shaft

The DC motor used to rotate the rear wheel's shaft is controlled by SBC using a relay in between two forward/backward the direction of the motor. The SBC is able to activate the direction of the motor by activating I1 or I2 inputs.

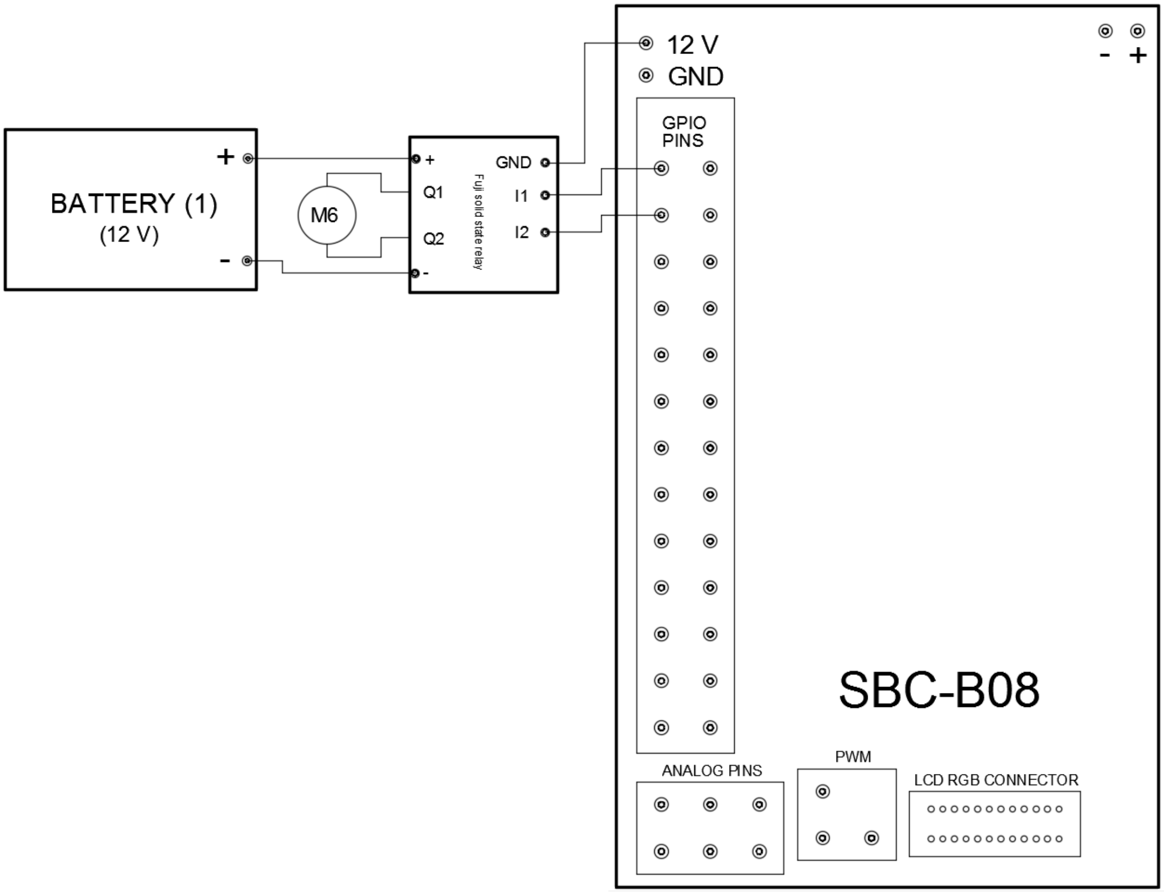

Figure 5.10. Circuit diagram of the DC motor with the relay and SBC

Figure 5.11. Relay used for the application

Figure 5.12. PN00113-6 12V DC motor of the rear wheel's shaft

5.6. The Joystick

The joystick will be used to control the track active motors when the wheelchair is lifting the stairs. The use of the joystick will give the wheelchair the possibility to manoeuvre during the lifting stairs by turning left and right and also forward and backward position by means of the SBC. **(Fig. 6.4.)**

The joystick is comprised with four outputs x, -x, y, -y, power input VCC and ground GND. The 'x' output corresponds to moving the motor forward, and '-x' backwards, the 'y' will turn off the right track motor and '-y' will turn off the left track motor. **(Fig. 6.15) (Fig. 6.16.)**

On the joystick panel are also three push buttons. The 'Push button (1)' function will be to prepare the wheelchair for the lifting stairs mode, the 'Push button (2)' function is to prepare it for normal movement mode and the 'Push button (3)' for lift the wheelchair for gain height mode. Each push-button has an LED which is turned on once the button is pushed. All the three function modes are executed by means of SBC control access to the required hardware.

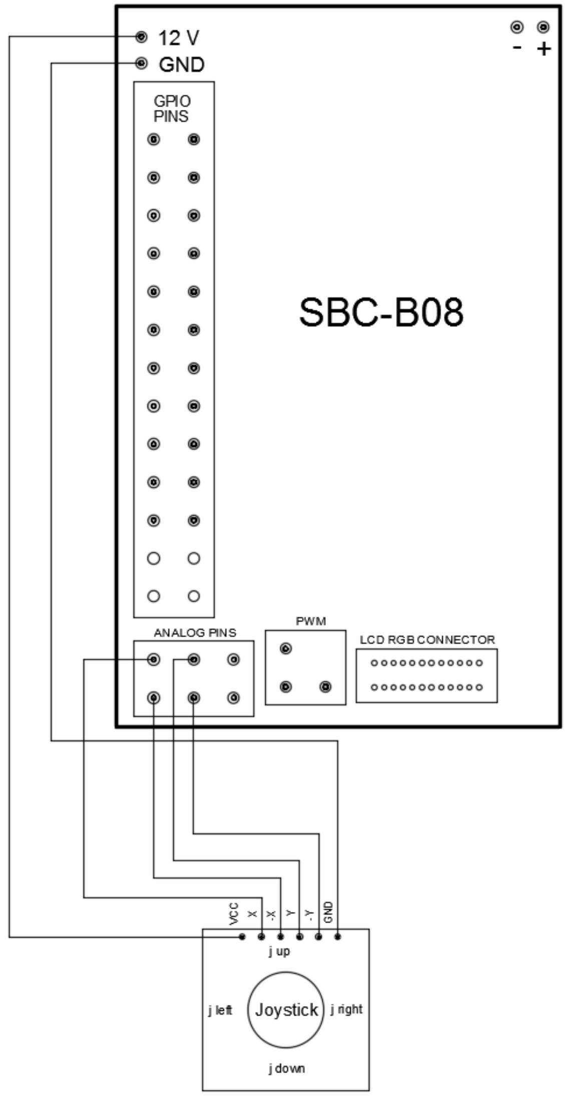

Figure 5.13. The schematic connection of the Joystick with the SBC

Figure 5.14. PN00113, one of the 12V DC motors of the main track

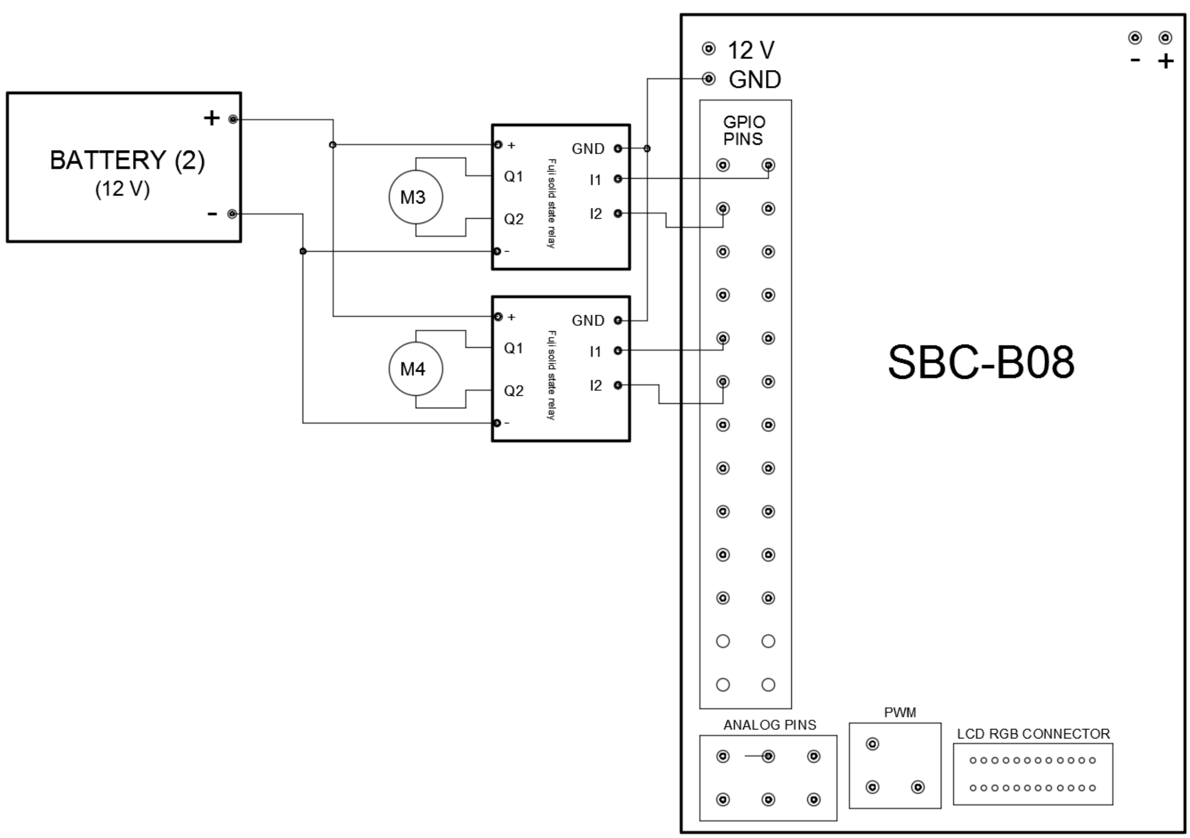

Figure 5.15. The schematic of main tracks' motors

In figure 6.15, the circuit diagram of the left and right main-track DC motors connected with relays and the SBC

Figure 5.16. The Joystick that controls the main track, the three work-mode push-buttons

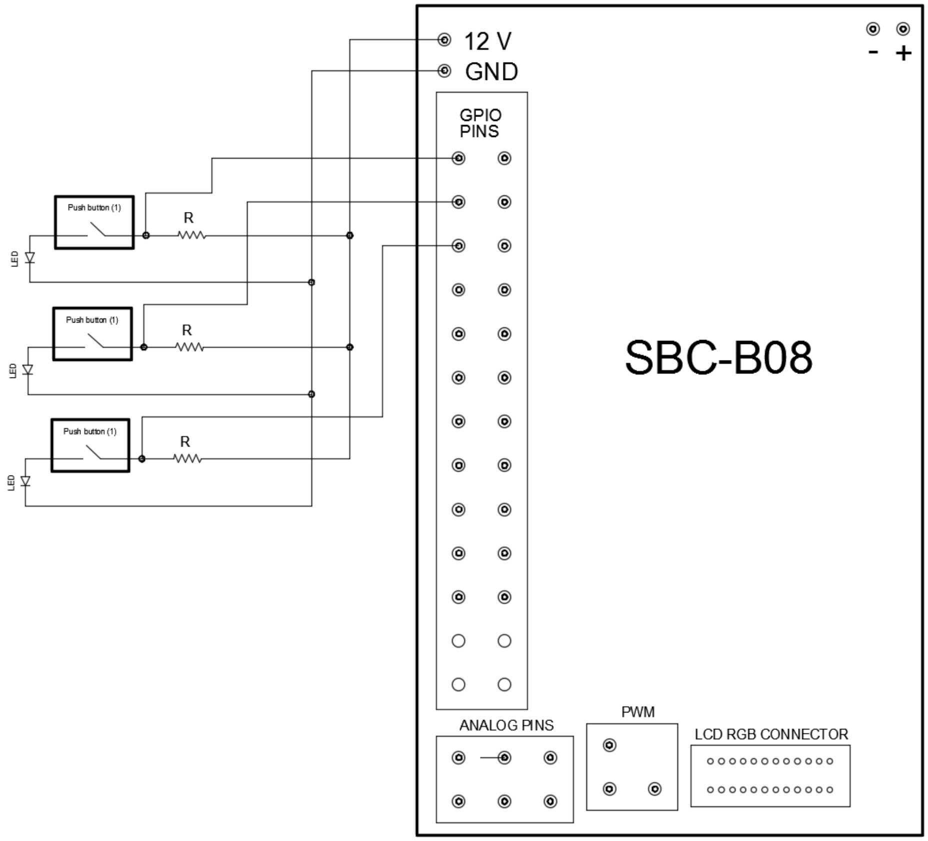

Figure 5.17. The schematic connection of the push-buttons with the SBC

5.7. The electromagnet mechanism

The electromagnets are used to keep the mechanical movement fixed. The rotation of the track shaft needs to be fixed at a specific point. Also the rear wheel's shaft needs to rotate in a specific degree and electromagnets are used to limit the movement.

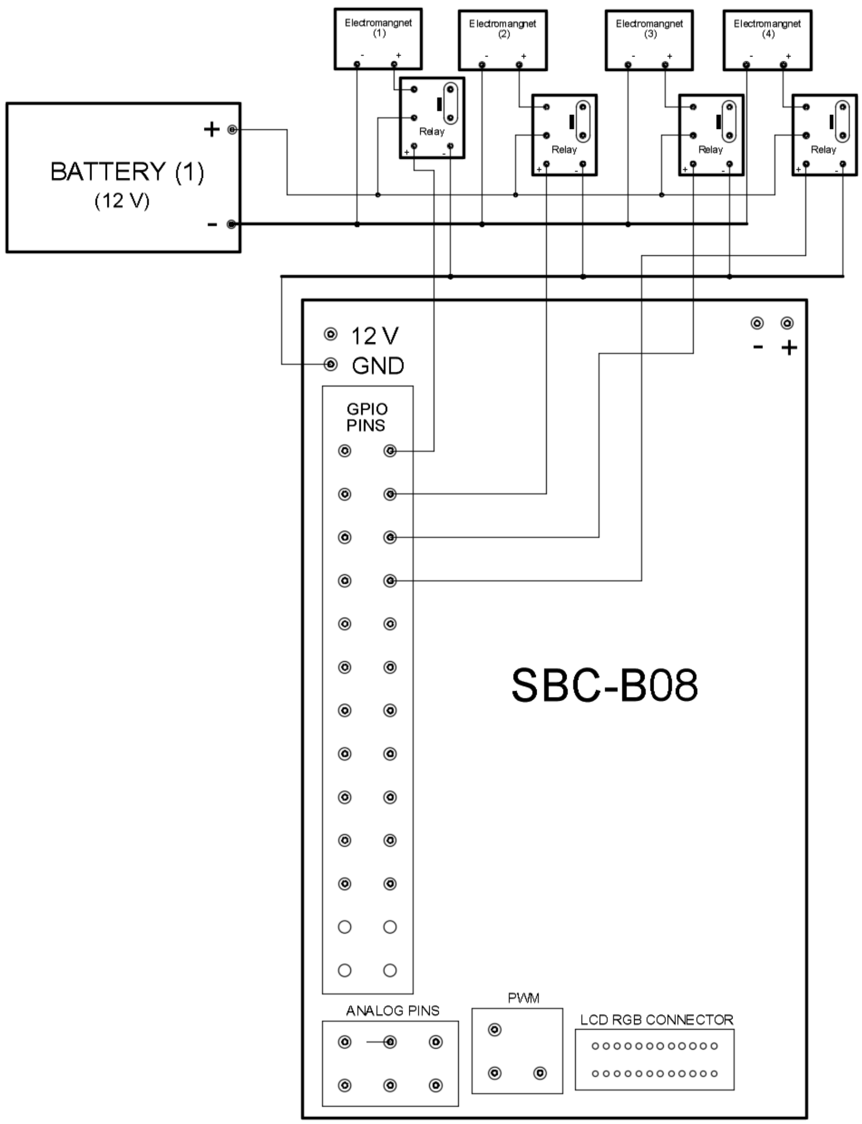

Figure 5.18. The circuit diagram of the electromagnets and SBC

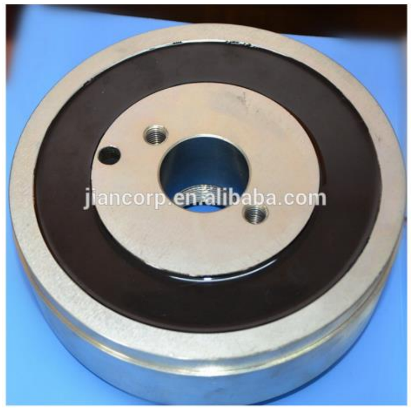

Figure 5.19. The round holding electromagnet

5.8. Limit switches for movement restriction

The limit switches are used to limit our movement of the shaft rotation of the rear wheels and the shaft rotation of the assistant track. All together we are using four limit-switches which will be powered from the controller.

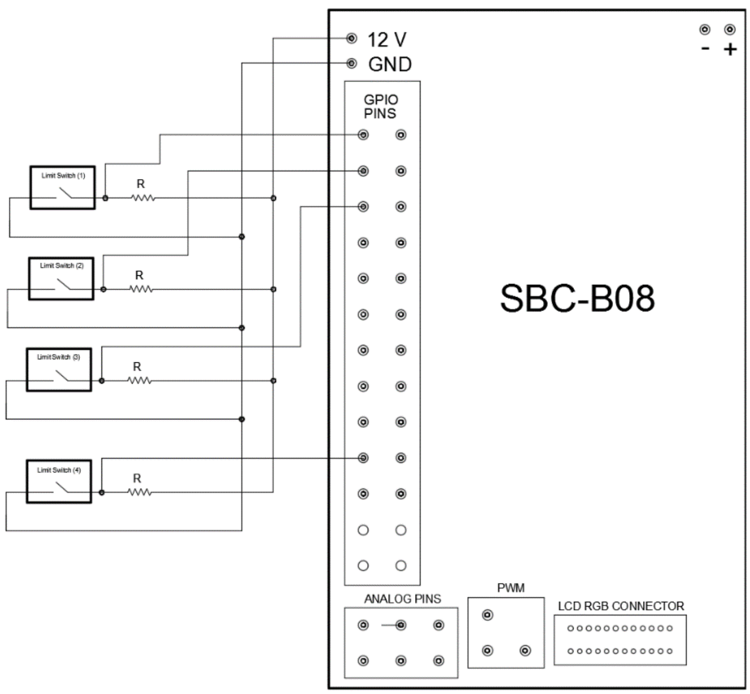

Figure 5.20. Circuit diagram of the limit-switches and SBC

5.9. LCD RGB Screen

The screen will be connected to the 24 bit RGB, parallel connector of the SBC, which suits perfectly with our selected LCD screen.

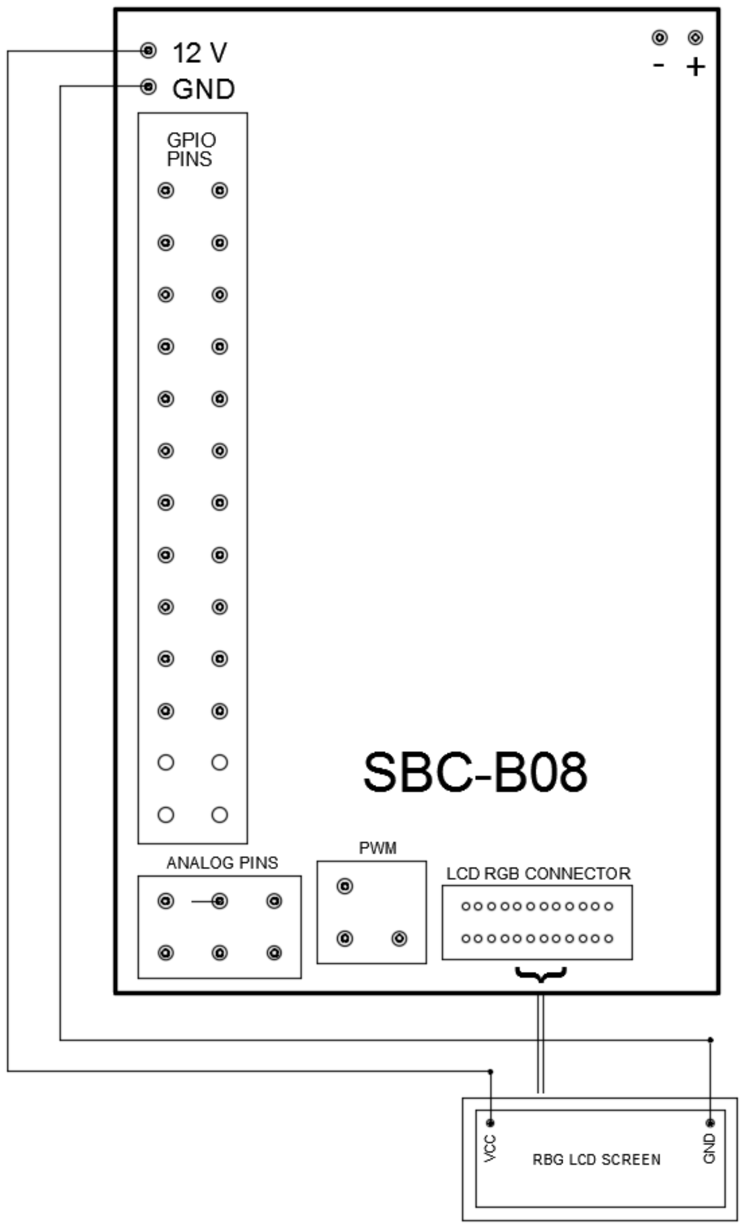

Figure 5.21. Circuit diagram connection of LCD screen and SBC

Figure 5.22. TFT LCD Display

5.10. Summary

Briefly, joystick, push-buttons, limit switches, are used as input apart from single board PC with integrated sensors. The push buttons are used for changing position of the vehicle. As it has been mentioned before, the vehicle has a combine system. It can convert to a tracked vehicle to climb, descend stairs or move quite inclined roads, a powered wheelchair to go indoors or outdoors or it become a lifter to reach a height or get eye level. The switch sensors are using especially for DC motors to get a feedback to learn system reach to the initial or last positions. Motors, linear actuators, the screen are electromagnets using as outputs. The screen is used to create an easy interface and following current situation easily. And electromagnets are used to lock the rear wheel or the chair on initial or last position.

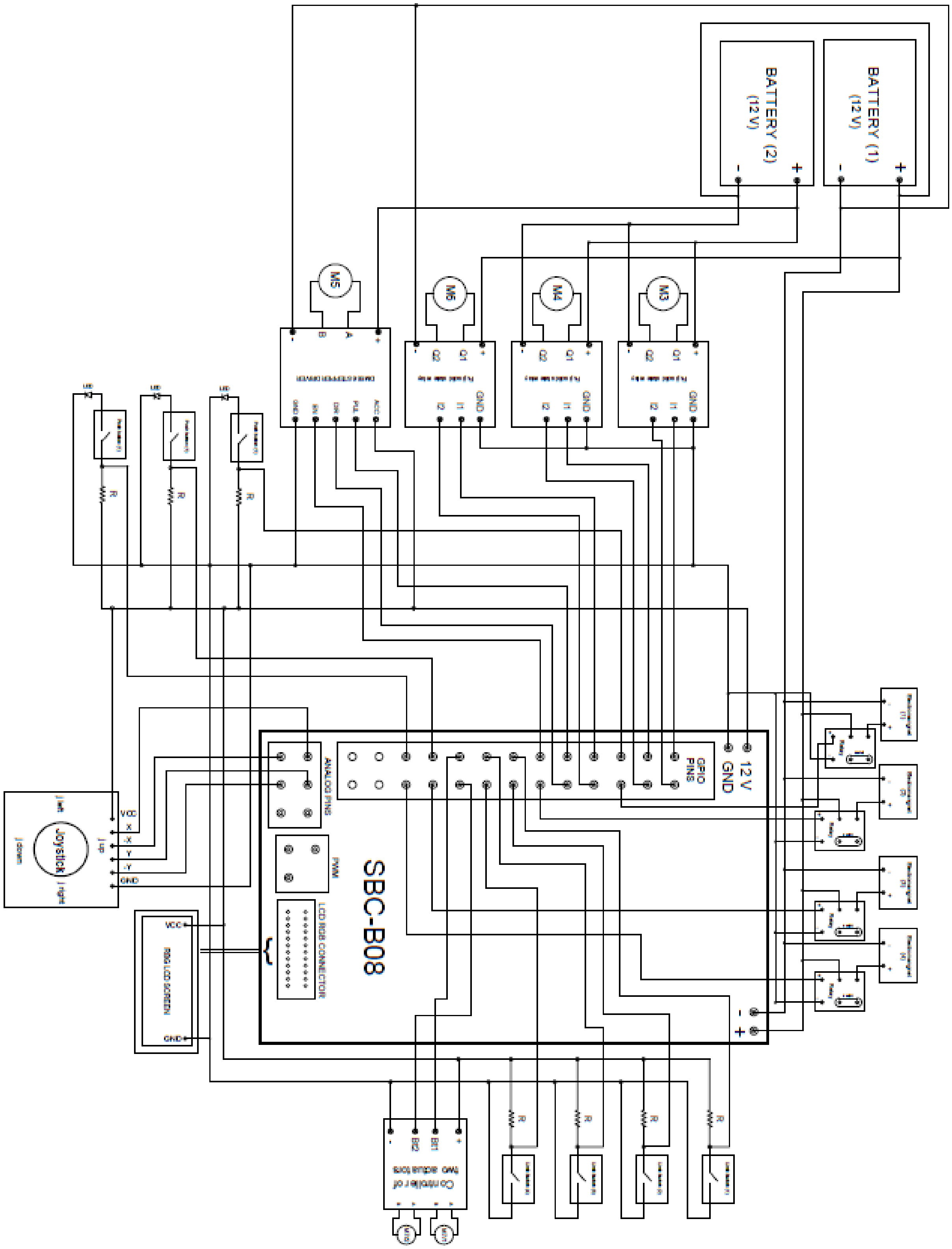

Figure 5.23. The schematic of control system

6. SUMMARY

First of all, worth mentioning that this study is the sample of borderless study, which is still open for further improvements. Despite the efforts and research studies in the area of handicap technology for years, however, implementation of researches has been taking a long time. Nevertheless, in particular, due to very rapid growth in technology and a remarkable increase in manufacturing, recent studies enable to deliver those accumulations to the needy people.

Stairs are the biggest problems of disabled people and even of wheelchair users. Easy and convenient climbing up and going down stairs highly will facilitate their lives. So far, manufacturing companies have produced portable tracked vehicles, special wheeled vehicles which can climb stairs. These tools are vital developments to facilitate the lives of the disabled. However, the most important point is that disabled people should freely stand-alone at social environment.

After deeply research of academic papers and analyses of products which exist in the market, various shortcomings have been identified. Some of the foremost deficiency is that the most of current vehicles on the market cannot climb high stair steps and do not allow to climb the spiral staircase. In addition, there is a restriction on the weight of the user. Furthermore, the absence of a common standard of ladder height is the one of the greatest barriers.

The new design was made by taking into account the studies, researches, current gaps and challenges which are mentioned above. Furthermore, Robots which have been developed especially for the more advanced defence industry, have been the main inspiration for the design of this study.

According to design of the chair, vehicle has a tracked system. Apart from the two main tracks, the vehicle has also two assistants which connected two main tracks. Any kind of stairs with different angles are made possible to climb with the help of these assistant tracks. By keeping main track's width larger, surface area increases. At the same time, when climbing up, track's number of contacts with the corner of stairs aimed to be increased. In this way, by increasing the frictional forces, vehicle was targeted safely climb even at the steepest angle and a higher step stair. The seat can be lifted up through linear actuators. Thus, the stairs with every angle, the seat remains in a horizontal position. Therefore, users are always ensured to climb safely to stairs and safely go down from the stairs. Apart from stairs, rear wheels of the vehicle move by chassis on the straight road while the front wheels move through the wheels connected to the seat. Therefore, while going on the straight road, compared to stairs, this causes the wheels to be exposed less friction force and in this way less energy consumed and wheels move much faster. Due to a combined system, when climbing stairs up, vehicle demonstrates very cautious and safe characteristics and at the straight road, vehicle shows characteristics of a normal battery wheelchair. Moreover, due to help tracks and Linear Actuators, vehicle comes to the lifted up position and reaches the user's eye level. Thus, in case user needs to get something from a shelf or higher floor, the system provides him this opportunity. With a simple interface makes it possible for anyone to easily use.

Therewithal, due to high prices of similar vehicles, during the design of vehicle, we have worked as possible as sensitive in order to come up with a cost efficient vehicle. Especially, we preferred standardized, ease order, low cost elements, and minimized use of elements which needed for special designs.

Safety is our priority. Power calculation, selection of power transmission elements, and balance calculations are taken into account and then the vehicle has been made based on the worst case scenario.

A new model of designing of mechanism which more functionality, more secure and has high stability, is developed to meet requirements of disabled people. In order to do this work is desired that to improve and to broaden the living conditions of people with disabilities.

The vehicle is unobservant in a social environment; makes easy life of the users, the most important matter the vehicle is an engineering design example that provides disabled people going outside lonely, overcoming obstacles and “their own obstacles”.

KOKKUVÕTE

Esiteks väärib äramärkimist, et käesoleva töö puhul on tegu käsiteldava valdkonna piire kompiva uuringuga, mis on avatud edasisele arutelule. Vaatamata aastatepikkustele invatehnoloogiaalastele uuringutele ja jõupingutustele on uurimistulemuste kasutuselevõtmine olnud aeganõudev. Tänu kiiresti arenevale tehnoloogiale ja tootmisprotsessidele on siiski lootust toimetada uuringute viljad erivajadustega inimesteni.

Trepiastmed on üks suurimaid takistusi liikumisraskustega inimeste jaoks ja eriti ratastoolikasutajatele. Mugav ning kerge liikumine mööda treppe parandab nende elukvaliteeti märkimisväärselt. Käesoleva ajani on tootjad toonud turule portatiivseid roomikliikureid, spetsiaalsete ratastega seadmeid, mis suudavad ületada trepiastmeid. Nende tootmine on olnud vajalikuks edasiminekuks erivajadustega inimeste elukvaliteedi parandamise teel. Kõige olulisem argument on siiski see, et puuetega inimestele peaks olema antud võimalus saada iseseisvalt hakkama sotsiaalses elukeskkonnas.

Pärast põhjalikku teadusuuringute läbivaatamist ning turul saadaolevate toodete analüüsimist selgusid mitmed puudujäägid. Üks olulisemaid on asjaolu, et suurem osa saadaolevatest liikuritest ei ole võimelised liikuma mööda kõrgemaid trepiastmeid ning ei ole kasutatavad spiraaltreppidel. Lisaks on seadmetel ka piirangud kasutaja kaalule. Üks suurimaid takistusi on aga trepiastmete mõõtmete ühtse standardi puudumine.

Võttes arvesse erinevaid uuringuid, uurimistöid ning ülalpool mainitud puudujääke ja probleeme, valmis uue liikuri kavand. Spetsiaalselt kaitsetööstuse jaoks arendatud robotid on olnud käesoleva magistritöö peamiseks inspiratsiooniallikaks.

Liikuri kavand näeb ette roomiksüsteemi. Peale kahe pearoomiku on liikuril ka kaks abiroomikut, mis on kinnituvad pearoomikute külge. Erinevate kaldenurkadega trepid on liigeldavad tänu neile abiroomikutele. Roomikute laiuse tõttu on nende pindala suurem. Mööda treppi ülespoole liikudes suureneb seega ka roomikute kokkupuutepind trepiastmetega. Sel viisil, tänu suurenenud hõõrdepinnale, saab liikur turvaliselt liikuda mööda järsema nurgaga treppe ja kõrgemaid trepiastmeid. Iste muudab trepist liikumise ajal oma positsiooni tänu lineaarsetele aktuaatoritele. Nende abiga jääb iste horisontaalasendisse erinevate nurkade all treppi mööda liikudes. Trepilt lahkudes võtavad tagumised rattad ning istme külge kinnitatud esirattad liikuri enda kanda.

Seetõttu väheneb siledal pinnal liikudes hõõrdetakistus ning liikumisele kulub vähem energiat ning saavutatakse suurem kiirus. Sel viisil kombineeritud süsteemi tõttu on liikuril trepist üles väga turvaline ning siledal teel käitub liikur samaväärselt tavalise elektrimootoriga liikuva ratastooliga. Tänu abiratastele ja lineaarsetele aktuaatoritele on võimalik istet kergitada kõrguseni, kus on võimalik hoida otsest silmsidet teiste inimestega. Kui aga kasutaja peaks vajama mõnda eset riiulilt või kõrgemalt pinnalt, on tal võimalik selleni ulatuda liikuri abiga. Lihtne ehitus muudab seadme kõigile kergesti kasutatavaks.

Sarnaste liikurite kõrgete hindade tõttu üritasime kavandamisfaasi jooksul luua võimalikul kuluefektiivse liikuri. Eelistasime kasutada võimalikult palju standardseid, kergesti ning soodsalt valmistatavaid detaile ja võimalikult vähe komponente, mis nõuaksid erilahendusi.

Turvalisus on meie prioriteet. Tugevusarvutused, jõuülekande detailide valik ja tasakaaluarvutused on kavandamisel arvesse võetud ning liikur on valmistatud silmas pidades halvimat võimalikku stsenaariumit.

Tegu on uue kavandiga, mis on funktsionaalsem, turvalisem ja stabiilsem ning arendatud arvestades puuetega inimeste vajadusi.

Liikur on sotsiaalses keskkonnas silmatorkamatu, teeb selle kasutaja elu kergemaks ja mis kõige tähtsam, aitab puuetega inimestel ületada nii füüsilisi kui ka vaimseid takistusi teekondadel, mis avardavad nende suhtlemisvõimalusi välismaailmaga.

REFERENCES

1. Website of crutch.com [WWW] http://www.crutch.com/history_of_crutches.htm (15.03.2016)
2. Stockwell, Walter E. "Forearm crutch." U.S. Patent No. 5,555,904. 17 Sep. 1996. APA
3. Website of abilitytools [WWW] https://abilitytools.org/blog/history-of-the-wheelchair/ (20.03.2016)
4. Yoneda, Kan, Shigeo Hirose, and Yusuke Ota. Stair Climbing Robots and High-grip Crawler. INTECH Open Access Publisher, 2010. (79)

5. McLaurin, Colin A., and Peter Axelson. "Future developments--Wheelchair standards: An overview." Journal of rehabilitation research and development (1990): 100

6. Website of engelsiz urunler [WWW] http://www.engelsizurunler.com.tr/ust_faydali_bilgiler.html (20.03.2016)

7. Website of learn easy [WWW] http://www.learneasy.info/MDME/modules/7758D_Machine_Design/gears/gears.pdf (25.03.2016)

8. Yoneda, Kan, Shigeo Hirose, and Yusuke Ota. Stair Climbing Robots and High-grip Crawler. INTECH Open Access Publisher, 2010. (89)

9. Website of mkbattery [WWW] http://www.mkbattery.com/documents/2774MK_HME_guide_0609.pdf (11.04.2016)

10. Website of engineers edge [WWW] http://www.engineersedge.com/calculators/gearmotor_move/gear-motor-inertia.htm (08.03.2016)