CHALMERS

Development of a driving simulator for Chalmers Vera Team

Utveckling av körsimulator för Chalmers Vera Team

Bachelor thesis at Mechanical engineering program

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Front cover:
CAD render of the final mechanical design of the simulator

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Abstract

This report covers the development of a Stewart platform based driving simulator which is to be used by Chalmers Vera Team in the competition *Eco Marathon*. The aim is to aid the team in their strive to design and build the most fuel efficient vehicle possible by providing them with a valuable tool for driver practice and early testing of vehicle design parameters.

Based on analysis of existing technologies used in simulators a documented design process has led to a mechanical construction accompanied by a control system. Theoretical guidelines, design choices and advice on designing the control system are discussed in this report.

The simulator moves by using six independently controlled linear actuators in an arrangement known as a Stewart platform; allowing for motion in six degrees of freedom. Input to the control system is provided by the driver, interpreted by a vehicle model in Simulink and parsed to the control system using micro controllers.

The focus has been on utilizing the hardware to create a realistic and authentic environment for the driver, while refinement and verification of parameters in the vehicle model has not been part of the project.

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Abbreviations

NXT – A small computer device which control mechanical LEGO

UDP – User Datagram Protocol, a data transfer protocol

VESA – (Video Electronics Standards Association) a corporation that issues standards regarding physical connections as well as electronic communication between video displays and their surroundings and controllers.

1 Introduction

The following chapter describes the background of the project, its purpose and what it encompasses.

1.1 Background

Humanity’s need of transport has led to an immense consumption of fossil fuels; a consumption which may be greater than what our planet can handle. More fuel efficient vehicles in the transportation sector is a major piece in the green puzzle, but without proper driving their advanced technology may never be used to its full potential.

International mileage marathon competitions, such as *Shell Eco Marathon*, invite teams of upcoming engineering students to design vehicles with the sole purpose of covering as much distance as possible on every drop of fuel. *Chalmers Vera Team* is one of the world’s ten best teams in the gasoline class and is continuously exploring new ways to increase fuel efficiency. This project aims to aid them in that endeavor.

Racing disciplines, such as *Formula 1,* relies heavily on excessive amounts of testing. Simulators have therefore existed in this sector for a long time and are now making an entrance in the automotive industry; however, mainly for performance purposes. They are a great tool when testing different configurations and allows for instant feedback from the driver; a source of knowledge incomparable to any other data output.

By utilizing technology used in simulators to optimize fuel efficiency, this project aids *Chalmers Vera Team* in their work to achieve the most fuel efficient vehicle possible. This will act as a complement to their already advanced technology and offer the ability to develop and practice new driving techniques and strategies. It will also be a valuable tool when developing future vehicles, since it enables early testing of important parameters for systems such as engine and drive train.

1.2 Purpose

The project aims to assist the *Chalmers Vera Team* in accomplishing additional range in the mileage marathon competitions. This will be done by supplying the team with a real time vehicle motion simulator for additional driver training and virtual vehicle testing. The simulator will let the driver learn the layout of the track and practice driving strategies. The project will deliver an appealing and functional product at *Shell Eco-marathon* in Rotterdam 2014.

The simulator is also intended to be used for publicity and recruitment activities. These include demonstrations and test driving at exhibitions.

1.3 Task

Creating a realistic environment requires visual and physical authenticity. Leaning the driver, vehicle and monitors recreates the forces experienced when turning during real driving. To achieve maximum realism a real-time translation and rotation along all three axes based software simulation is needed. Apart from supplying information about forces, acting on the virtual vehicle, the software also renders the virtual environment. By visually immersing the driver in this virtual environment the simulator aims to create a close to real life driving experience.

To clarify and visualize the purpose and goal of the project, a list of tasks were derived:

- Design a motion platform
- Design an inner frame with satisfactory comfort
- Design screen suspension and opening mechanism for driver entrance
- Design and build a solution for the power unit needed for the actuators
- Control of the motion platform
- Design and control of the human user interface towards the simulator
- Manufacture the motion platform
- Manufacture the tube frame
- Manufacture the screen suspension opening mechanism
- Manufacture or buy power unit
- Plan and buy sound system

1.4 Boundaries

The project contains a great amount of designing, building and programming. Well defined limitations were therefore crucial to prevent the project from becoming overwhelming.

The project will therefore not cover:

- Graphical detail tweaks of the driving simulator environment
- Sound sampling from actual Vera vehicle
- G-force sampling of the real vehicle
- AI driven vehicles in the simulation software
- Possibility to use the platform with other vehicles than Vera
- Verification of the simulator representation of real driving experience

The list above includes details which would improve the driving experience, but cannot be implemented due to the limited time of this project.

2 Theory

The theory section gives an overview of the concepts, models and vocabulary used in the rest of the report.

2.1 Stewart platform

To be able to create the most realistic simulator possible, translation and rotation around each axis on a Cartesian coordinate system had to be made possible. This is usually referred to as six degrees of freedom (6 DOF) and allows the motion platform to simulate all possible forces that one would encounter whilst driving the real Vera vehicle. A platform able to perform 6 DOF movements is the hexapod movement platform, namely the Stewart platform *Figure 1*. It is the motion platform most commonly used in professional simulators such as those developed by *Cruden B.V* and *Moog Inc*. There are several other types of motion platform concepts, but they do not provide 6 DOF. Some concepts provide 2 DOF while others provide 4 DOF. As the project aimed for a realistic experience the Stewart platform was the only liable choice.

Figure 1: Stewart platform

One drawback of the Stewart platform is that the dynamics needed to control the movement of the platform is complicated, due to the need to control the six actuators in a synchronized manner. In the pre-study it was found that there was pre-written open source Simulink software for a Stewart platform that could be used in the project. This would save time and along with its common use it further strengthens the Stewart platform as an excellent choice for the project.

2.2 Terminology

To ease the reading of this report some terminology needs to be established. In the pictures below the components are annotated for easy recognition. *Figure 2* shows the main components of the simulator.

Figure 2: Simulator components

It is important to observe the difference between platform and Stewart platform. The whole structure will always be referred to as the Stewart platform and while only talking of the uppermost part of the Stewart platform it will always be referred to as the platform. The main parts of the Stewart platform can be seen in *Figure 3*.

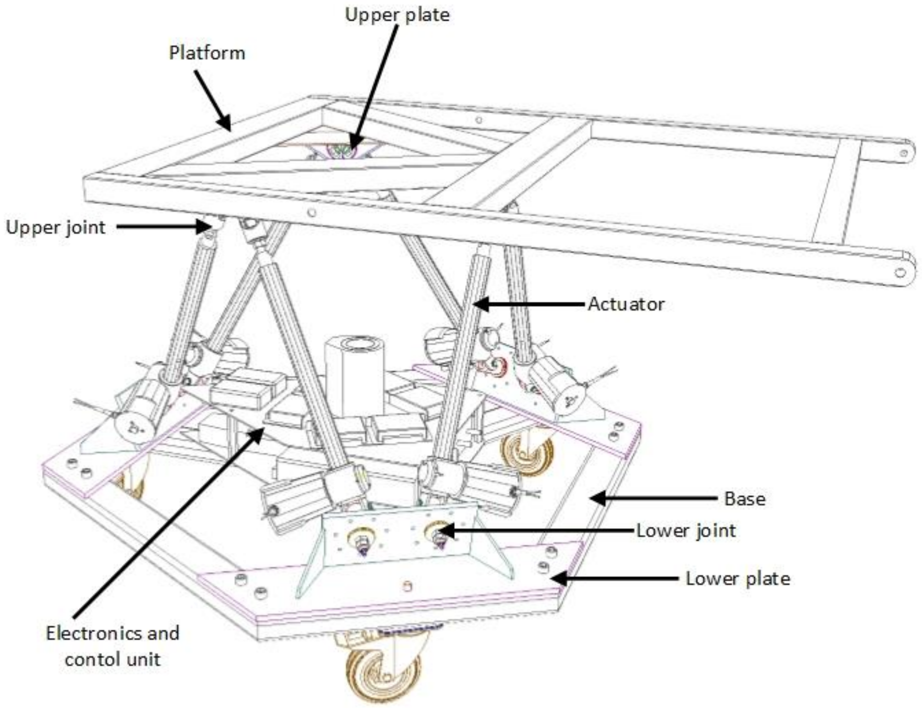

Figure 3: Annotation of Stewart platform components

In *Figure 3* the whole Stewart platform is shown. The base is the foundation of the Stewart platform and provides strength to the whole structure. There are plates mounted on the base in order to allow fastening of the actuators. The actuators are fastened to the plates via joints, allowing rotation. An actuator is a device able to create linear motion by rotating a ball screw with an electric motor. The synchronized extensions of the actuators are what create the movement of the platform. The platform is fastened to the actuators with another set of joints, connected to the upper plates which in turn are bolted onto the platform.

On the Stewart platform the top part is mounted with the purpose of replicating the experience of driving the Vera vehicle with regards to visual realism and driver environment.

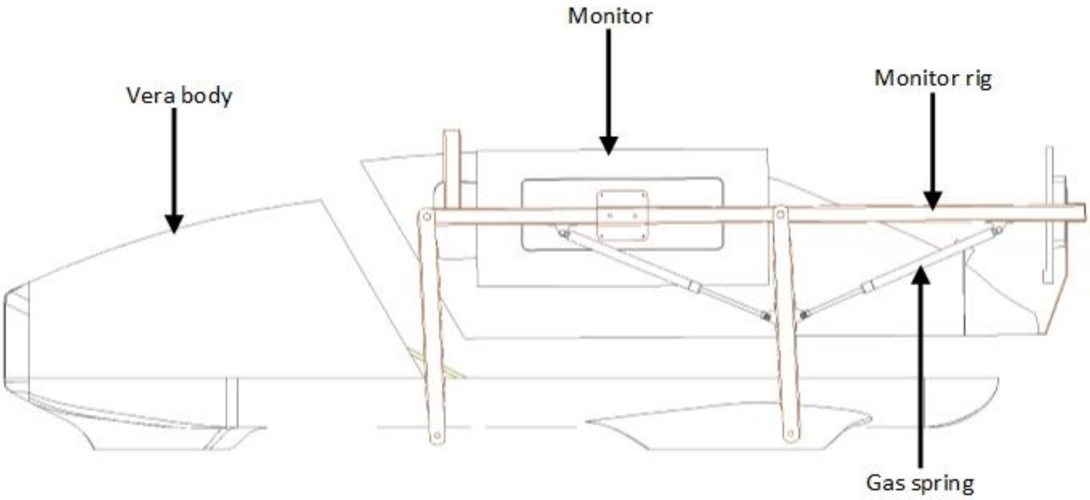

Figure 4: Annotation of Top part components

In *Figure 4* the top part of the simulator is shown. It consists of a copy of the Vera vehicle body which is fastened to the platform, surrounded by monitors displaying the simulated environment. To enable driver entrance and mounting of the monitors a frame structure called monitor rig is also fastened to the platform. This structure allows for smooth displacement of monitors and the cut off part of the body by a gas spring supported structure.

2.3 Pre-study

A pre-study was carried out to establish a base of knowledge regarding the design of a Stewart platform. It has quite a complex geometry as its function is to allow movement in six degrees of freedom. Due to the limited timespan of the project it was deemed virtually impossible to calculate optimal design, and therefore necessary to use results regarding this performed by others.

2.3.1 Literature study

Fichter (1986) was published in the journal of *Robotics Research* and has since been seen as one of the great pieces on Stewart platform design. This can be seen as both Gong (1992) and M.Raghaven (1993) among others refer to Fichter in their own work. Fichter's report is especially interesting as he takes a practical stand. He discusses how the actuators should be placed to allow maximum movement as well as the importance of the ratio between the base and the platform. One of his points is to place the nodal points of the actuators on the platform as close as possible to each other. This allows the actuators to form three triangles and therefore resembling a truss, granting the Stewart platform increased stability. Lastly Fichter provides a couple of examples on the change in range of motion due to different ratios between base, platform and actuator length.

Gong (1992) takes on were Fichter left off and discusses the design of a Stewart platform with the purpose of being used as a vehicle simulator at *MIT*. He points out the importance of considering the horizontal stiffness and not only range of motion when choosing the ratio between base and platform. By maximizing range of motion the design will have close to none horizontal stiffness, making the Stewart platform unstable. In the application of the Stewart platform as a vehicle simulator this is extra important as the loads need to be considered. Therefore Gong recommends sacrificing some range of motion to ensure the stability and safety of the simulator.

Kerr (1989) writes about the design of a Stewart platform in the use as a transducer and presents his own design and how he has chosen the ratios between base, platform, leg lengths and platform height. That is the information that has been of use in this project. His discussion regarding the use as a transducer has been of little importance as it does not really coincide with this project.

2.3.2 Mathematical formulas

In *MATLAB's Simulink* there is a pre made model of a Stewart platform (Mathworks, n.d.). This model contains the mathematical formulas needed to calculate the length of each leg of the Stewart platform from desired angles and translation. The length is calculated through several steps.

The first step is to create the rotational matrix R corresponding to the desired angles. This matrix is created by multiplying the rotational matrices around each of the three axes. From this the desired position of the top joint of each leg is calculated through (1), where TP is the original position of the top joint, TM is the translation movement.

$$DP = (R * TP) + TM \qquad (1)$$

From this the leg vector LV is calculated in (2), where BP is the position of the lower joint.

$$LV = DP - BP \qquad (2)$$

When the leg vector has been calculated the length of the leg is calculated by taking the square root of the sum of the element wise squared elements in the leg vector, (3).

$$Length = \sqrt{LV_x^2 + LV_y^2 + LV_z^2} \qquad (3)$$

These calculations are performed for each individual leg.

2.3.3 Observation of existing systems

To gather information and inspiration of how to design the Stewart platform a visit to *VTI* (*Statens väg- och transportforkningsinstitut*) was arranged. They have an advanced Stewart platform based vehicle simulator much like the one considered for this project; *Figure 5*.The simulator at *VTI* simulates cars in traffic and is used for scientific research on driver behavior in different traffic situations, with the goal of increased traffic safety.

Though the *VTI*-simulator is larger and more advanced, the design concept is basically the same as in this project. It was therefore of value to observe their design choices regarding their Stewart platform.

Figure 5: VTI Stewart platform

2.4 Result of pre-study

From Fichter's report it was concluded that a good way to place the actuators on the base and platform were as in *Figure 6*. On the base the actuators are placed in pairs distributed evenly on an imagined circle (to the left in *Figure 6*). The points of connection to the base are all located at an equal distance, radius, from the center point. On the platform the actuators are placed on a smaller circle, as seen to the right in *Figure 6*.

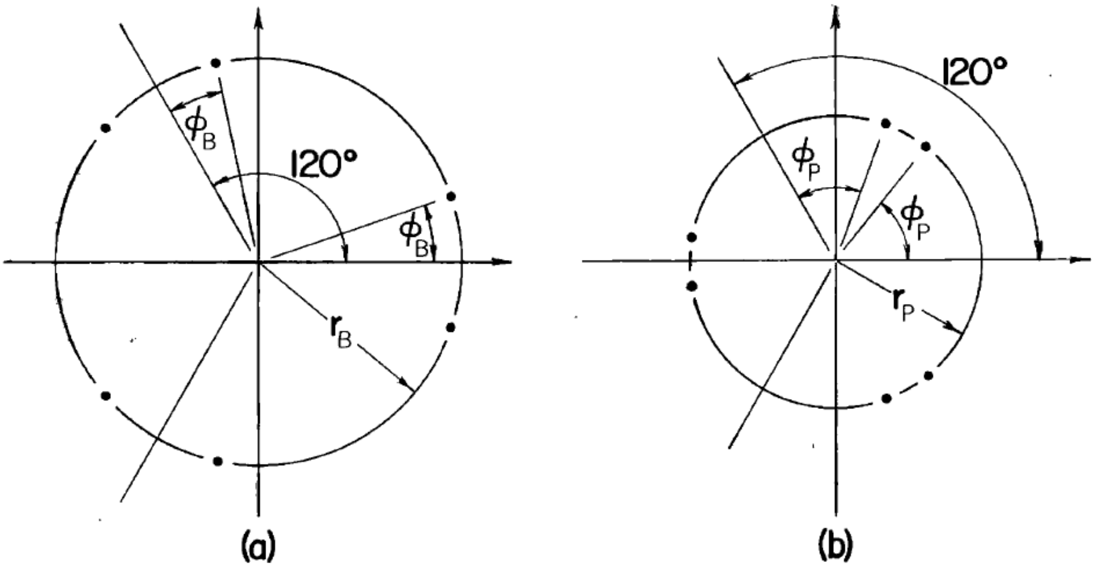

Figure 6: Nodal positioning of actuators (Fichter, 1986)

The angle between the fastening points on the platform is also smaller so that the extended axes of the actuators cross each other and create a triangle, see *Figure 7*. This ensures good strength in the structure.

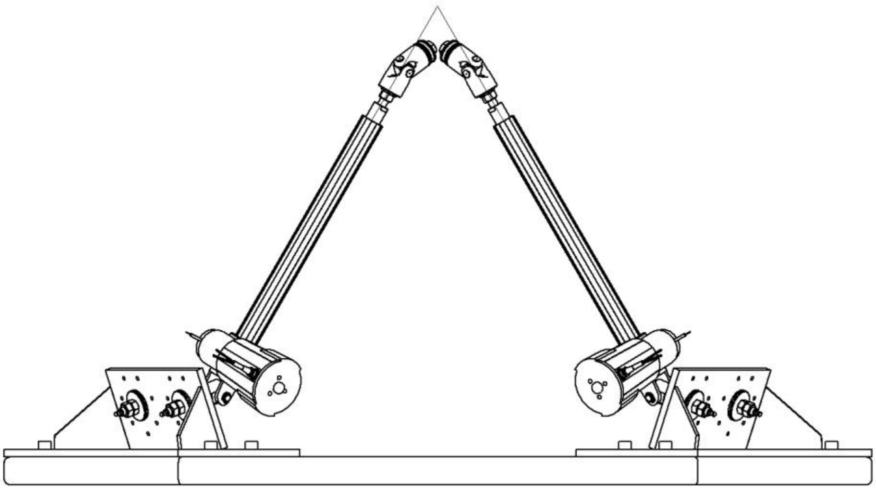

Figure 7: Intersection of actuators

The ratio between the radii of the base and platform, $r_B \& r_P$ are based on the suggestions of Kerr (1989). His suggestions were the following:

- Platform radius, $r_P = 1$
- Base radius, $r_B = 2$
- Leg length, $l = \frac{3}{\sqrt{2}}$

- Platform height, $h = \sqrt{1.5}$

This is to be considered as a somewhat middle way in design, allowing a satisfactory range of motion as well as stability in the horizontal plane. By increasing the radius of the platform the angle of the actuators can be decreased, allowing for an increase in range of motion. The disadvantage is that the horizontal stiffness decreases, making the Stewart platform weak when utilizing the furthermost of its range. This is illustrated by Gong (1992) in *Figure 8*.

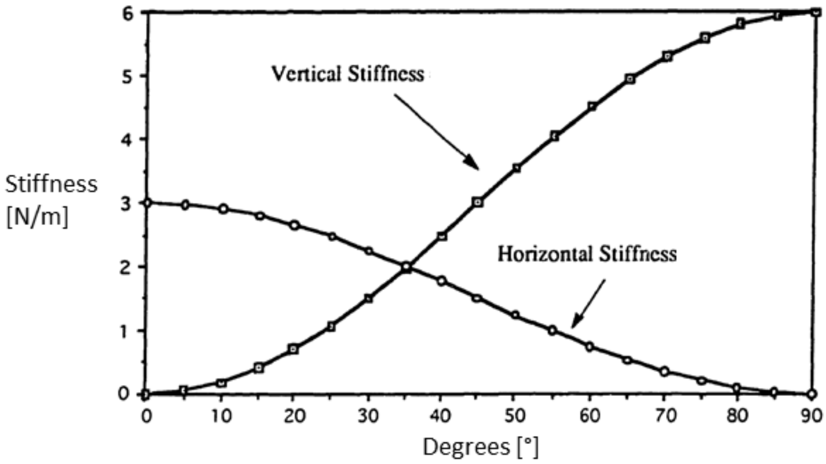

Figure 8: Structural stiffness (Gong, 1992)

As can be seen, designing the Stewart platform with too steep an angle will result in a device significantly stiffer in the vertical plane than in the horizontal. This may result in a floppy or weak behavior if the loads are too large during simulation.

3 Methodology

In the beginning of the project the main focus was to collect data and information that could be useful in understanding how the project should evolve. Analyzing which parts were of most importance would provide the right basis for the later parts of the project. A literature study of articles from scientific journals and master theses' was therefore performed in the early stage of the project. The study resulted in a choice of concept for the motion platform, being the Stewart platform, see *4 Concept*. The study then aimed to understand the basics of designing a Stewart platform, most notably things as the ratio between the base and platform diameter and the length of the actuators. A study of existing Stewart platforms in the Gothenburg area was also performed to act as guidelines in the development of the group's Stewart platform.

To utilize the diverging prior knowledge held by the group's members, each member has focused on their area of expertise. This also led to the project being split into two subprojects. These were designing and building of the physical simulator as one subproject with electronics and control systems being the other.

3.1 Computer Aided Design

The design of the physical platform was done using *Autodesk Inventor Professional 2014*, a CAD-software easy to learn and use. It also provides tools for rendering images and making drawings. A contributing factor in choosing *Inventor* over other software such as *Catia* or *Solid Works* was the fact that the members of the groups felt most at ease with Inventor due to prior experience and knowledge, therefore cutting the learning curve. Another positive factor is the availability of student licenses, allowing work with Inventor in school as well as on personal computers.

When designing a complex assembly containing lots of different components and with multiple people working simultaneously, it is important to have good discipline for handling revisions. With no structure there will most likely be confusion of what revisions to be used and it leaves no possibilities of going back to earlier assembly revisions. Often this means that parts or assemblies have to be reworked which is wasted time. To get a good structure a guideline (*Appendix B*) was set up regarding the naming of files and how they were to be sorted in folders. The simulator was divided into two major parts, the "Stewart Platform" and the "Top Part", given the numbers 1000 and 2000. The subassemblies and parts were named in a similar way. This system would make for easy identification of parts and easy recognition of what assembly they belonged in. Each part was also given a name, describing what kind of part it was, making it easier to navigate the system.

As can be seen in *Figure 9* the name of the previous folder was abbreviated to make it easier to read. An important feature of the system was to only place one assembly in each folder together with the parts in it. This ensured an easy to navigate folder structure.

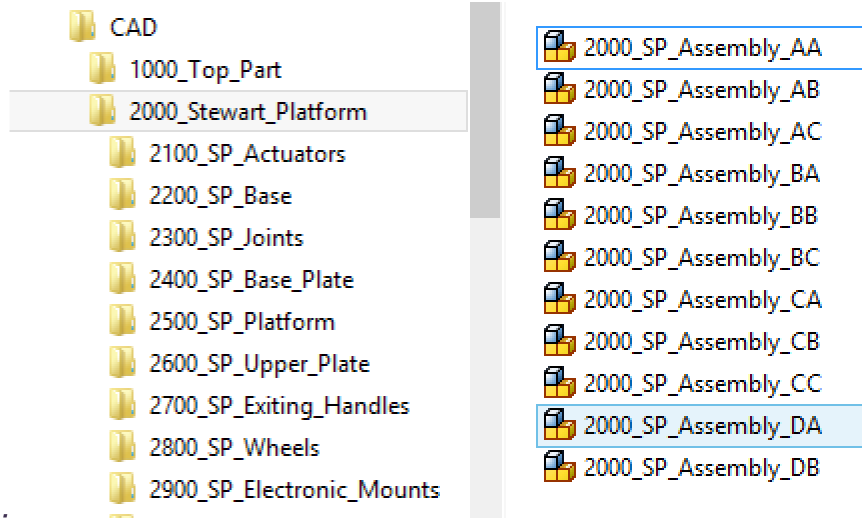

Figure 9: Folder structure

Every assembly and part was given a revision number in the form AA, AB, AC or BA. The second letter was changed when a small change on the part or the assembly has been made while the first letter was changed if a major design change was made. The first assembly of the Stewart platform was therefore named *2000_SP_Assembly_AA.*

To keep track of all changes made in different revisions a document containing information about every change was established. From this document it was possible to track changes made on different parts and also when and by whom each change was carried out.

3.2 Design phase

Each person was given responsibility for the design of a part of the simulator, corresponding to the sub-assemblies discussed in the previous chapter. The actual designing was then carried out individually while encompassing close communication. The parts and sub-assemblies were continually assembled and evaluated for clashes and mismatching dimensions. If any errors were encountered they were adjusted, and the process began again in an iterative manner. Design choices were discussed amongst the designers to ensure cross functionality and solid solutions.

3.3 Manufacturing process

After seven weeks of pre study and designing of parts the next phase of the project was initialized. All of the parts that had been designed were now supposed to be manufactured in the school workshop. The first step was to get hold of all of the material needed. From the careful planning a gap in the project was scheduled during the exam week during which the material and parts ordered could be shipped without affecting the timeframe of the project. Everything to be manufactured and purchased was listed in a document extracted from the main assembly of the CAD model. All parts had different attributes depending on if they were to be manufactured or purchased, this made for easy sorting of what to order.

This list was also used to provide an overview for the status of the manufacturing process. All parts were given three different states; *Not started*, *In progress* and *Completed*, depending on their current status. Each person was responsible for one part at a time; the most common were for the designer of a part to be the one responsible but there were exceptions to even out the workload. The responsible person then made drawings for his part and carried out the manufacturing, at some times aided by the other members when their knowledge of a machining process was superior.

The timeframe for this part of the project was seven weeks. With limited time to work in the workshop during school hours, the possibility to be in the workshop during evenings became a criterion in order to get enough time to complete the build.

3.4 Control system

The control of the platform started out as only a software simulation in *MATLAB's Simulink* and *SimMechanics* programs. Both of these programs contain a pre-made model of a Stewart platform which made them a good choice to decrease the workload. This was later implemented to work with a *LEGO NXT* in order to control a scale model, as seen in *Figure 10*, helping the group to get knowledge of how the final product would behave and how it would be controlled. Due to the limited time, this prototype was never used to its full potential.

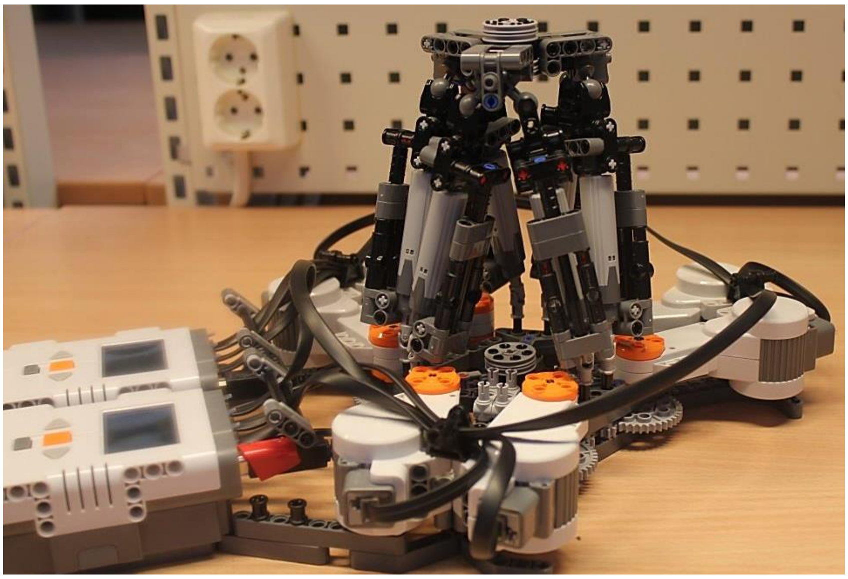

Figure 10: Lego NXT Model of Stewart platform

LEGO® MINDSTORMS® NXT (LEGO NXT) is a small, easily programmable computer, which has the ability to use basic sensors and motors. *LEGO NXT* is also compatible with *LEGO TECHNIC* meaning there were a vast amount of different parts available to use when making a model. Specifications for the electronic components of the simulator were determined by computer simulations based on logged data from previous races. These specifications were then used in order to find suitable products from suppliers.

4 Concept

This chapter provides detailed explanations and arguments regarding the design of all components used in the Stewart platform based vehicle simulator.

4.1 Top part

With a realistic experience as the primary goal; authenticity and immersion became the foundation upon which the design took place, as seen in *Figure 11*. To allow drivers of varying lengths to use the simulator, a certain amount of adjustability had to be added compared to the original design in the Vera vehicle. This had to be performed without adding excessive amounts of weight, since this would interfere with the responsiveness and stability of the simulator.

Figure 11: Top part

To create a familiar environment for the driver the design phase included gathering of measurement that were crucial to imitate the driver's posture used during an actual race. This ensures that reflexes developed in the simulator are applicable on the track as well.

4.1.1 Opening mechanism

To prevent functionality from interfering with aesthetic appeal a variety of solutions had to be considered. In Vera the body is split in two parts, where upper part has to be vertically lifted approximately one meter before it can be removed so that the driver can exit the vehicle. Giving the driver the ability to exit the simulator without assistance was considered to be an important feature and due to its weight and shape, lifting the entire upper part was not an option. The body was therefore split into three parts and the final design was based on minimizing movable weight and maximizing ease of access as can be seen in *Figure 12*.

Figure 12: Cutting of Body

Several solutions were considered when designing the mechanism that would move the upper part. It was determined that rotating it around an edge would either cause instability or an unappealing design. These solutions were therefore discarded.

Moving the upper part forward was considered to be the best option, but sliding it would be difficult since the body lacks straight edges. Using a parallelogram stood out as the best option since this ensured a stable design and provided mounting points for the body. The design was made out of aluminum profiles. This helped minimizing weight while maintaining stability.

Gas springs were then implemented to ensure a smooth experience when moving the upper part. Calculations with different springs were carried out and it was determined that four 150 N springs would provide the best experience.

4.1.2 Monitor mounting

Correct placement of the monitors is crucial to prevent nausea. The software will render the horizon in the middle of the screen and the vertical position of the monitors was therefore determined by measuring where the eye of the driver was located. The left and right monitor was placed so that they would cover as much of the driver's field of view as possible.

Determining the best position for the monitors is difficult in the design phase when the driver isn't yet able to test different configurations. The ability to perform adjustments was therefore ensured by adjustable mounts on the monitor rig. The monitors' built-in ability to use *VESA-mounts* was then used to attach them to the adjustable mounts on the monitor rig. *VESA-mounts* is a standard hole pattern used on many commercial monitors for easy mounting. The full rig with monitor mounting and opening mechanism can be seen in *Figure 13*.

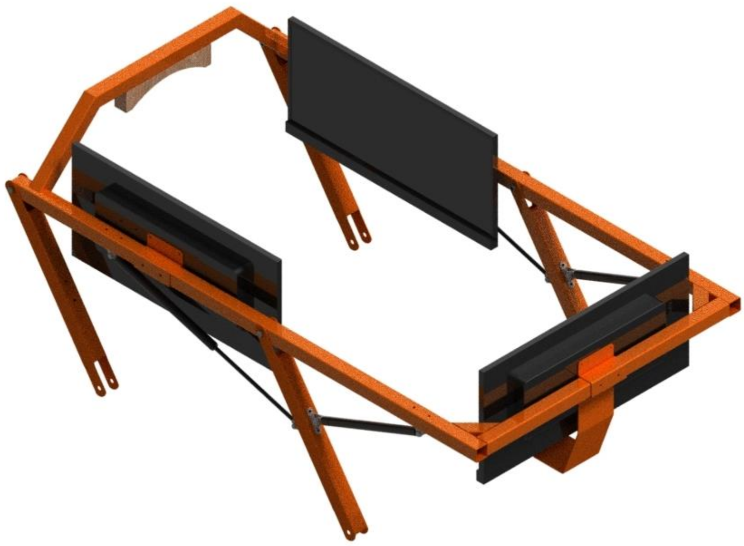

Figure 13: Opening mechanism & monitor mounting

4.1.3 Driver environment

The driver environment of the simulator differs in some ways compared to the driver environment of the actual Vera vehicle. An inner frame, which exists in the Vera vehicle, has been excluded from the simulator. This is mainly because the simulator body is not in need of as much stability and stiffness as the body of the Vera vehicle being driven on a real track, which is the frame's main purpose. Having no inner frame inside the simulator results in a beneficial weight loss and leaves more free space. The possibility to use that space for other purposes arises, such as making room for longer persons to use the simulator. This is desirable as one of the intended areas of use is publicity, in the way of demonstrating the simulator at exhibitions and during recruitment activities for *Chalmers*. Of course there is less realism without the inner frame, but the perks of not having one are predominant.

The seat is made of plywood with a coat of textile fabric stuffed with foam plastic. The seat itself is placed on aluminum profiles which allow it to glide in the driving direction, to make the seat adaptable for persons of different lengths. As can be seen in *Figure 14* it is also possible to adjust the angle of the lower and upper part of the back support. The lower part is supposed to support the larger part of the back, while the upper part supports the neck and head. This has an ergonomic favor as well as creating the possibility for drivers and technicians of the Vera team to experiment with the back seat while practicing, using the simulator, to find a better way to design the seat in an eventual next generation of the Vera vehicle.

There is a possibility to adjust the seat for approximately 20 cm in the driving direction. This is so that people of somewhat varying height will be able to fit into the seat of the simulator. The seat in the actual vehicle is built in a way which excludes drivers whose heights are above approximately 160 cm. Having a driver taller than that in the real vehicle will result in him or her having a bad posture and there are also regulations saying that there must be a certain space between the helmet and the upper part of the inner frame.

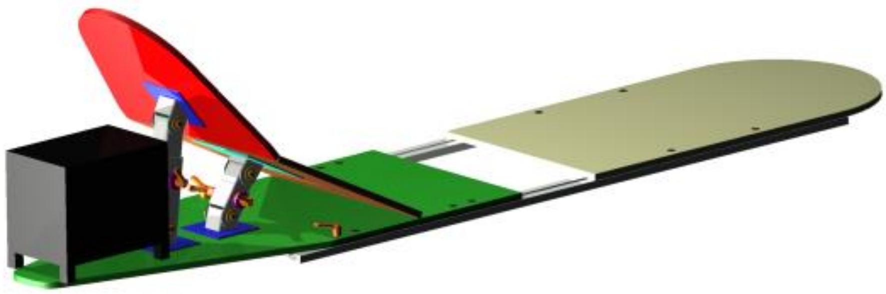

Figure 14: Drivers environment

4.1.4 Steering

With focus on recreating a familiar interface while keeping production time at a minimum, most of the components was modified bicycle parts. A *Logitech Formula RX* PC-steering wheel was provided to the project for which an adapter and a hub had to be designed in order to translate rotation of the handlebar to the PC-steering wheel.

The layout of the switches and buttons were copied from Vera, but with a few exceptions.

The left brake handle is, in Vera, used to stop with the rear wheel. The load is transferred to the front wheels when braking which makes locking up the rear wheel relatively easy. This can cause unnecessary tire wear and the driver is therefore instructed to primarily brake using only the front brakes.

Figure 15: Steering handle

When driving Vera, the driver cannot idle the engine. This could be a problem in the simulator and the left brake handle was therefore chosen to act as the throttle. The final steering assembly is shown in *Figure 15*.

4.1.5 Light prevention

A problem with some simulators is that the experience is often diminished because of exterior light reaching the driver. This leads to both distraction and a sense of unrealism that affects the driver and hinders the proper training that the simulator is supposed to provide. To counter this it was decided to block out the light with sheets wrapped around the monitors and sealed to the body of the vehicle, completely blocking out all excess light. This will ensure that the only light getting through the windows will be coming from the monitors and therefore maximizing the driving experience and the realism.

4.2 Stewart platform

In the following chapter the components of the Stewart platform are discussed; which factors that was of most importance on each component and how they were designed.

4.2.1 Base

One criterion that has been of great importance when designing is that the simulator should be transportable and functional at almost any place where sufficient electrical power is available. This means that the simulator would not be bolted to the ground in all arrangements. For the simulator to not risk tipping over when in use the weight distribution was of great importance. The goal was to get the center of gravity as low as possible. To be able to accomplish this with a fairly heavy top part, due to the driver being placed on it, the weight of the base needed to be high enough to compensate. This was done by using thick steel profiles for the base and lightweight aluminum profiles on the upper moving part. Also the base was made wide enough to remain stable thus the momentum created by the moving top part.

As can be seen in *Figure 16*, the base of the Stewart Platform is shaped as a hexagon. The reason for this is to utilize the immerse stability of a triangle while at the same time cutting down the size of the base. The size is desired to be kept down due to the requirement for the Stewart platform to be mobile so that it may accompany *Chalmers Vera Team* on competitions around the world.

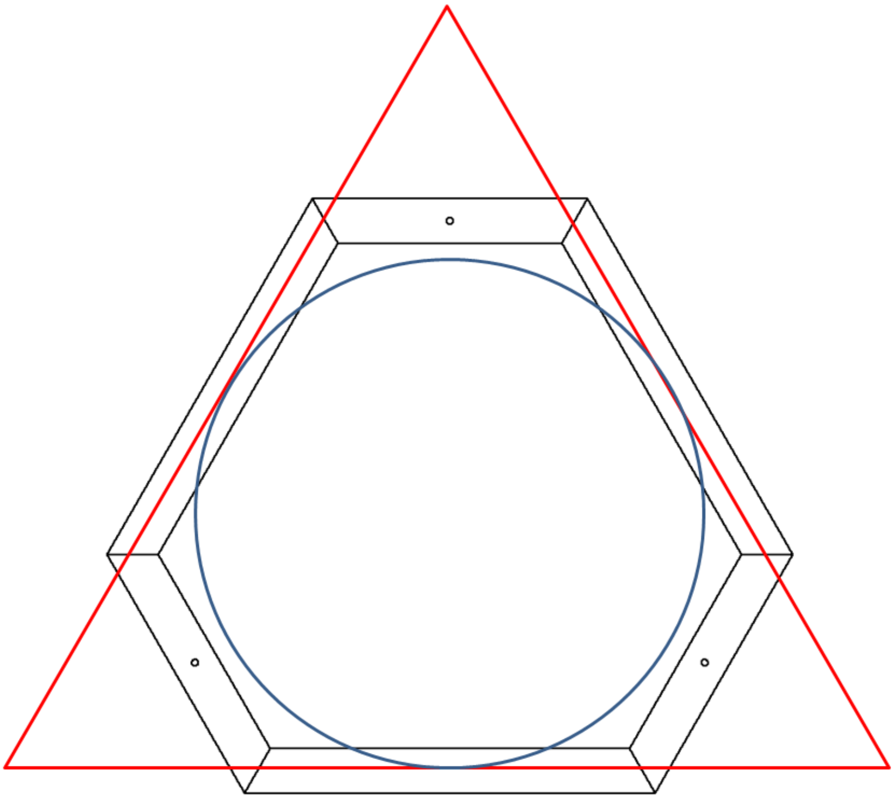

Figure 16: Design of the Base

The central geometry in the design of the base is a circle (see blue circle in *Figure 16*) with a diameter of 920 mm, related to the length of the actuators as described in the pre-study section. A triangle tangent this circle in three places (see red triangle in *Figure 16*) the form of the base was then drawn from the triangle.

The base is built using 80x40x4 mm steel profiles, welded together at their intersections. Profile dimensions were chosen larger than deemed necessary, therefore providing a safety factor against failure and breakdown. As the base is not moving during the simulations the extra weight and stiffness provided by this design choice is not negative, rather it provides extra stability to the whole Stewart platform as described earlier.

The base also features the possibility to mount three wheels which will make Stewart platform easily to maneuver during transport. The wheels are fastened to the base in the simple manner of lifting the platform up and inserting a tap mounted on top the wheels into designated holes.

4.2.2 Lower plates

Since the top part would be relatively heavy, it was decided to make the base larger than what Kerr (1989) recommended in order to get more stability. This meant that an adapter, named Lower plate, was needed to get the correct positioning of the actuators via the lower joints (see *Figure 17*). These lower plates were made of a 10 mm thick steel plate to obtain additional weight and stiffness to the base.

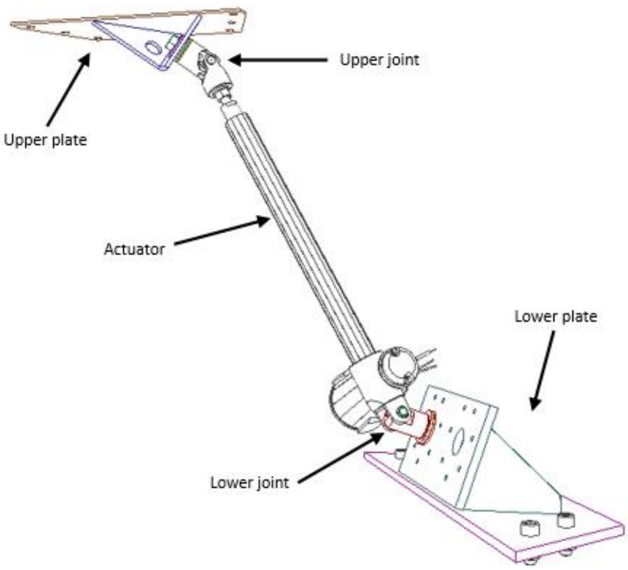

Figure 17: Joints of the Stewart platform

4.2.3 Joints

The joints are the links between the actuators, base and platform as seen in *Figure 17*. The purpose of the joints is to allow for independent movement of the platform relative to the base.

During design it had to be considered that the joints, both the ones on the base and those on the platform, needed to allow the platform to do a minimum 30 degree tilt without risking clashes between any of the components. Also they needed to be made so that they under no combination of movements would self-lock or allow the actuators to rotate and risk crushing the electric motors. Therefore the joints are not placed in line with the actuators but rather with an angle as can be seen in *Figure 17*.

The upper joint used, is a pre-bought universal joint *(Wiberger DIN808S18)* which allow for rotation and twisting in two directions. The joint is mounted to the upper plate much like the lower joint is mounted to the lower plate. The upper joint has thread adapters for mounting to the actuator and the upper plate as can be seen in *Figure 18*.

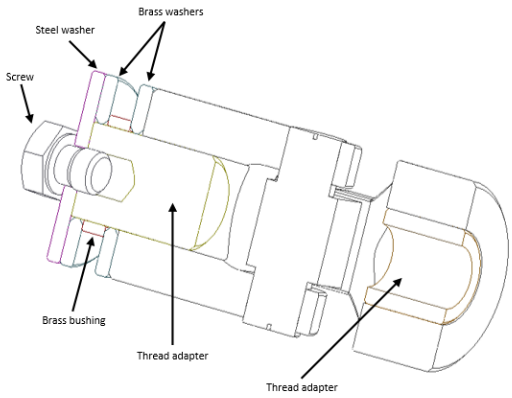

Figure 18: Annotated half section view of upper joint

The lower joint was manufactured during the project and is able to rotate in the lower plate. Between the plate and joint there are brass washers for lower rotating friction. The friction is further reduced with an internal lubrication system consisting of a set of holes which transport grease to the designated surfaces from the lubrication nipple, see *Figure 19*. To the left a hole with a thoroughgoing sprint can be observed. That part is where the actuator is fastened to the joint, the sprint locks them together.

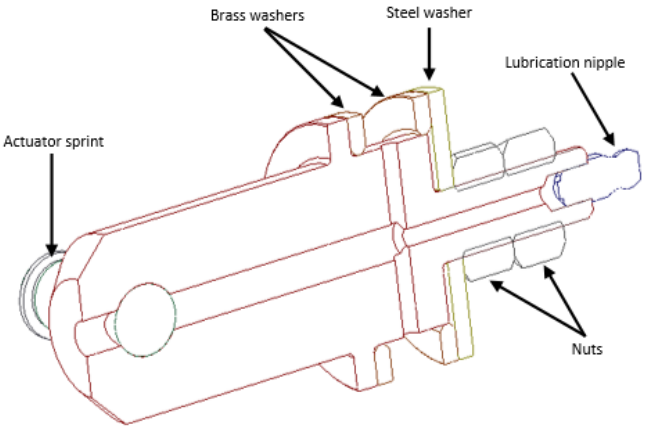

Figure 19: Annotated half section view of lower joint

4.2.4 Actuators

The actuators to be used for the project were *SKF CAT33H*, (SKF, 2010). These were suitable for the project since they had sufficient speed and force properties. But they had a drawback regarding the duty cycle capability; that is the relation between the actuator moving and being stationary. The actuators had a recommended duty cycle of 30 %; the calculated value during normal driving was 40 %. Though it was still chosen to use this actuators since the other alternatives were both too weak and slow or much more expensive. To lower the duty cycle regulations are set in the software so that the simulator would run below this duty cycle limit.

4.2.5 Platform

The design of the platform is geometrically different from the base as it features a rectangular geometry rather than the hexagonal one of the base, see *Figure 20*. This is due to the geometry of the Vera body which is very long and thin, the driver of the vehicle actually lies down whilst driving. The consequences of this are that the platform has to adopt the lengthy design to be able to support the vehicle body and the driver inside it while the simulator is running.

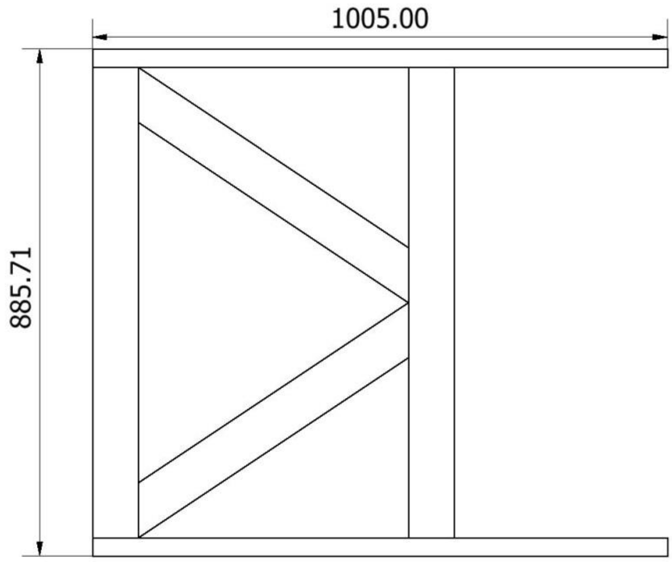

Figure 20: Platform design, [mm]

The platform stiffness and strength is increased by implementing a truss design inside its rectangular periphery. Aluminum profiles were used in order to get a stiff but still lightweight design. A lightweight platform was desirable, for the reasons mentioned in chapter *4.2.1 Base*.

4.2.6 Upper plates

To create an interface between the upper joints and the platform, upper plates made of steel were designed. These were bolted to the platform while the joints were attached in the same way as on the lower plates.

4.3 Control system

One of the major tasks in the creation of a Stewart platform was to develop a way of controlling the stroke of each actuator and thereby the movement of the platform. It was decided to utilize *MATLAB's Simulink* software as the primary program due to its capability of handling powerful mathematical calculations together with the ability to send and receive data in different ways allowing it to communicate with the different parts of the control system.

The control system, which can be seen in *Figure 21*, consists of five major parts:

- Master PC, renders graphics and takes input from the driver
- Physics PC, calculates the movement of the vehicle and regulates the actuator stroke
- *Arduino*, transmit the control signal from the Physics PC to the servo controllers and tracks the actuator stroke
- Servo controller, amplify and control the voltage and current to the actuators
- Linear Actuators, makes the platform move

The control loop starts with the input going from the driver to the Master PC. This information is retransmitted to the physics where all calculations take place. Some of the calculated data is then sent back to the Master PC to render the graphics while some is sent to an *Arduino* that retransmit the information to servo controllers that drives the actuators. The movement of the actuators are tracked by an *Arduino* and sent back to the physics computer, which regulates the position, so it matches the reference value.

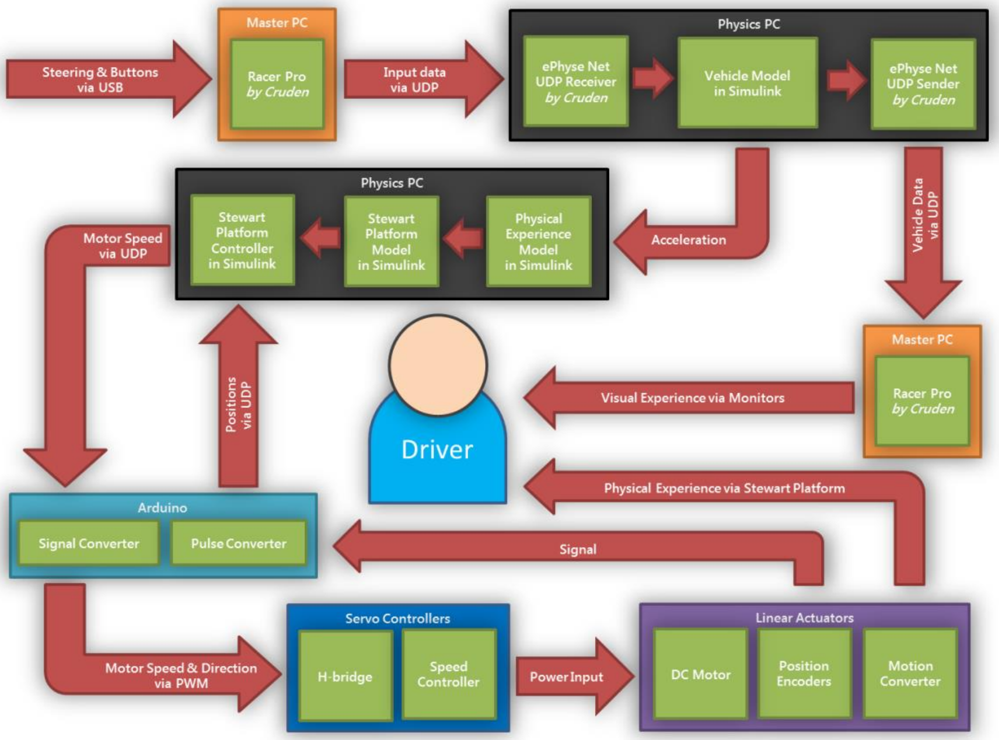

Figure 21: Control system overview

4.3.1 LEGO MINDSTORMS NXT

In the beginning the plan was to use Simulink's inbuilt ability to communicate with a *LEGO Mind storms NXT*. This was planned in order to do research in a transitional state of the project where it would control a miniature platform made of *LEGO*, before the real Stewart platform was built. This however created a lot of problems since in order to connect to a *NXT brick MATLAB 2012a* or a newer version has to be used. It is also problematic to connect multiple *NXTs* to *Simulink* since the communication with one of them has to be configured in the target hardware parameters of the configuration parameters.

This means that a model cannot communicate with two different *NXT's* even if they are contained in different sub-systems. The *NXT* also has a problem when more advanced models, like the premade Stewart platform model, are created in *Simulink*. When trying to compile these, the *NXT bricks* crash without any notice which ultimately leads to a crash of *Simulink* too. Due to all these problems the *LEGO* project was abandoned, since it had become a time-eater instead of a time-saver.

4.3.2 Calculations

The first part of controlling the legs of the platform is to calculate the length of each leg. *Simulink* has a pre made model of a Stewart platform which greatly decreased the amount of mathematical research that would have been needed if this was not the case. This model can be seen in *Appendix C*. From this model only the *"Leg Reference Trajectory"* block remains, the regulator was replaced by a discrete regulator and the *"Plant"* was replaced by the real platform. The *"Leg Reference Trajectory"* block was also slightly modified with different constants, like size, in order to fit the actual platform. The movement blocks in the pre made model were also replaced in order to be able to take in real-time G-forces from the physics model and convert these into angles. It also does a slight translation in order to compensate for the head of the driver not being in the center of the platform. This is important as a rotation around another point than the head are more likely to cause nausea (Johnson, 2005).

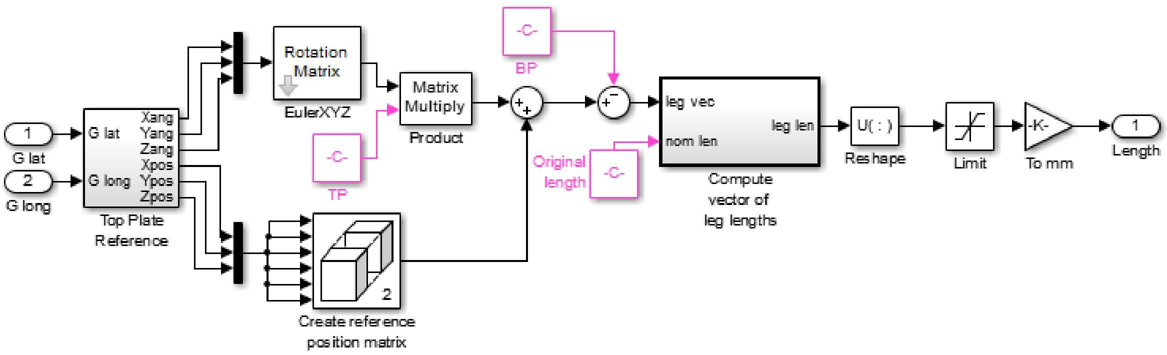

Figure 22: Leg reference trajectory block

In *Figure 22* the inside of the "*Leg Reference Trajectory"* block is shown, where on the left the desired angle and translation are created from the real-time G-forces, and on the right the six individual leg lengths is sent out of the block after being checked to be in an allowed range in order to avoid reaching the endpoints of the actuators.

4.3.3 Regulator

The regulation of the length of the actuators is done with a discrete PID-regulator that is implemented in *Simulink* on the physics PC, in the same model as the main program which also contains the model that calculates the length of the actuators from G-forces. The regulator is capable of regulating each of the platform's six actuators individually.

Due to the fact that it is the length of the actuators that is regulated, meaning that there is a built in integration in the system, only a P-regulator would be necessary. Due to the high inertia in the system it is hard to do adjustments with a small control signal that occurs with a small error in a P-regulator. Because of this an integrator was added to the regulator, since this will increase the amplitude of the control signal until the actuator moves to its desired position. This however creates a new problem when the actuator reaches the reference value, because the integrator has accumulated an error, meaning that the control signal will still be non-zero. This leads to the actuator wanting to continue on its current direction which can lead to a big overshoot that may create a lot of tension resulting in the simulator being damaged.

To counter this problem the accumulated error in the integrator part of the regulator is reset when the instantaneous error crosses zero. This leads to the control signal being set to zero the moment the reference value is reached, minimizing the overshoot. This also greatly decreases the settling time of the actuator due to the integrator immediately trying to get the actuator back to the reference value in case of an overshoot happening. Due to delays and inertia in the system the actuator does not stop immediately when the regulator tells it to stop, which still leads to an overshoot, but due to the reset of the integrator it is not as big as it would have been without it.

The derivative part of the regulator has been implemented because of the inertia in the system. This inertia means that the actuators have a hard time to start moving. This can be countered by applying a bigger control signal when a change in the reference value occurs. This is done by the derivative part that contributes to the control signal when the change in the error is significant.

The biggest problem with the regulation of the platform is the sampling times of both the measured values and the output of the control signal. Due to these sampling times being relatively long the risk of an overshoot and instability increase. To counter this, regulator parameters have to be decreased, which leads to an increased rise time of the system. This gives a bigger delay between the input from the driver and the feeling of G-forces affecting the driver.

4.3.4 Motor control unit

In order to allow the computer to communicate with the motors, it has been decided to use a couple of *Arduino* units that can communicate with a computer through a number of different connections. *Arduino* is also relatively easy to program and has a number of input and output channels that will be needed to drive and control the motors. The output channels are limited in the amount of voltage and current they can deliver as well as only being able to send out either 5 V or 0 V as a digital signal.

Because the motors run on 24 V and the signal from the *Arduino* maxes out at 5 V and with a limited current, the signal would have to be run through an amplifier. In order to allow the motors to run in both directions a two-quadrant converter has to be used. This converter can be placed either before or after the amplifier. There are numerous possible amplifiers available that have a built in two- or four-quadrant converter along with a couple of safety features, like current limit and temperature warning. These are commonly known as motor controller units (MCU). The reference value to a MCU can be represented through different types depending on which controller is used, for example; an analog reference between 0 and 5 V, a digital signal via USB or a pulse-width modulation (PWM).

A MCU only draws a small amount of power from the input signal meaning it will be able to use the signals from the *Arduino* as a reference. The power to the output of the controller comes from a separate power supply which will not damage the *Arduino*.

The motor controller needs to be able to deliver a peak current at least as high as the one in the motor specification. The controller also needs to be able to put out a continuous current that is high enough to satisfy the need of the motor, so that the controller do not get overheated, which is the main limiting factor. Due to the fact that the actuators seldom have to move at their full speed or with their maximum load, combined with the fact that the actuators spend most of the time in their default position it is reasonable to assume that the continuous current output only has to be rated at 5 A.

The position of the actuators can be tracked through an encoder. It works on the principle of Hall Effect in which they send out a pulse when the motor rotates a certain amount of degrees. These pulses can be counted, through which the distance traveled can be calculated. The encoder uses two channels with a slight offset between the pulses which can be used to decide the direction of rotation for the motor as well. Some motor controllers have a built in support for an encoder and such a controller is desirable but not necessary due to the fact that the encoder signals can be routed directly into an *Arduino* which can do the calculations.

4.3.5 Regulator/MCU interface

The interface between the regulator in *Simulink* on a computer and the MCU is done in two steps. The first is done via UDP between the *Simulink* and an *Arduino* and the second is simple digital signals from the *Arduino* to the MCU. Since the *Arduino* is only capable of receiving and sending UDP packets in the form of a maximum of 24 single bytes, both the amount of data as well as the values of the individual data has to be limited. Since the platform contains six actuators a maximum of four bytes can be used for each actuator. Although some of the data that is transmitted, such as the direction of each actuator, only has to be a zero or one which means that this data for all six actuators can be combined into a single byte leading to less data transmitted. In the used configuration 3 bytes are used to transfer the data. It was decided to not implement this because it would increase the amount of calculations and programming on the *Arduino*.

The signals between the *Arduino* and the MCU are two high/low signals that represent the direction and enable signal as well as one PWM signal which is the relative speed of the motors. To write a PWM signal from the Arduino a value between 0 and 255 is demanded which is the minimum and maximum value of a byte. This leads to the *Arduino* being able to just take each value it receives via UDP and simply resend it out to each actuator through the appropriate output port. All this contributes to minimize the amount of calculations on the *Arduino* enabling it to increase the data transfer rate.

The regulator sends out a signal ranging from -300 to 300, depending on which regulator parameters is being used, which represents the speed and direction that the actuator should move. In order to not send a negative number to the *Arduino* through UDP, which would need an extra byte being sent that can lead to misinterpretation of the number in the *Arduino*, the sign of the control signal is checked and sent over in its own dedicated byte. The enable signal to the MCU is set to high when the PWM value has reached a certain amplitude in order to not drive the motors with a very low current which would not be able to move the actuators anyway which would wear them down. Due to the fact that the MCU needs a PWM duty cycle between 10-90 % in order to not get an error, forcing a reset to be made, the output from the regulator has to be saturated to be between 25 and 230. This means that it is not possible to use a zero value on the PWM to tell the MCU not to send out any current to the motors. Instead this has to be done by setting the enable signal to low.

4.3.6 Encoder/Regulator interface

In order to be able to regulate the platform the actual positions have to be measured and transmitted to the regulator. This is done in three steps. First the signal from the encoder is being read by the encoder *Arduino*. One of the encoder signals is connected to a regular input and the other is connected to an interrupt port. The *Arduino* has a premade library for encoders that include all the code needed to count the number of pulses that has arrived from the encoder, as long as at least one of the encoder signals is connected to an interrupt pin. From the encoder *Arduino* the positions of all actuators are converted to bytes and transmitted serially at a predetermined interval to the main *Arduino*. From the main *Arduino* the actuator positions are transmitted to *Simulink* via UDP where it is converted back to millimeters so it can be used in the regulator.

The first reason an extra *Arduino* was used for the sole purpose of handling the encoders was because an *Arduino* only has a limited amount of interrupt pins, some of which would coincide with the pins needed for other purposes. The second reason is that every time a pulse comes to the interrupt pin the main program is paused while the interrupt is being handled and with six actuators moving at high speed the amount of interrupts might compromise the ability to execute the main program.

4.3.7 Power supply

In order to supply the actuator motors with energy from a 230 V socket, an electrical power conversion to 24 V is required. Since every actuator is rated at a maximum current of 9 A the total power needed to supply the actuators would be around 1300 W. This does not however include losses, in particularly the motor control units. However, due to the heat limitations in the actuators and the small movements needed, the motors will likely never work at full power simultaneously, which reduces the requirements of the power supply. These two facts lead to the decision that the power supply had to be able to supply at least 1300 W continuously. The power supply used in the simulator is able to deliver 1500 W and therefore meets the required need without any problems.

4.4 Vehicle model

Having an accurate computer model of the vehicle is crucial when aiming for associating a specific input with a corresponding output. While mass and some geometrical parameters were available for Vera, fundamental properties such as inertia and tire data were missing. This led to the use of approximations which then were analyzed by performing empirical tests. Since refinement of vehicle parameters were not part of the project, a model which could supply the necessary data to control the platform was considered to be sufficient.

4.4.1 Bicycle model

The vehicle model was based on a bicycle model to minimize the amount of necessary parameters. This is the simplest vehicle model, in the way that calculations are based upon having only two wheels, rigid suspension and only horizontal rotation and velocity. Effects of lateral and longitudinal load transfers were ignored to allow for easy testing of the model. The front wheels were then graphically extrapolated to the coordinates used in Vera.

4.4.2 Tire model

The lateral force acting on an object with the mass: m, moving with velocity: v_x, in a circle with radius:r, can be derived from the formula: $m * \frac{v_x^2}{r}$. The following data is used:

$Mass\ =\ 90\ kg$

$Maximumvelocity\ =\ 72\ km/h\ =\ 20\ m/s$

$Minimumturningradius\ =\ 8\ m$

This would theoretically allow for a maximum lateral force of 4500 N; equivalent to approximately 5 G. However, this is not possible due to the properties of the tires. The maximum amount of lateral force the tire can generate depends on several factors such as temperature and tire pressure. However, when used in a vehicle model the lateral force is easiest described as a function of what is known as the slip angle (see *Figure 23*); the angle between the direction of the wheel and its velocity vector: v_{tire}.

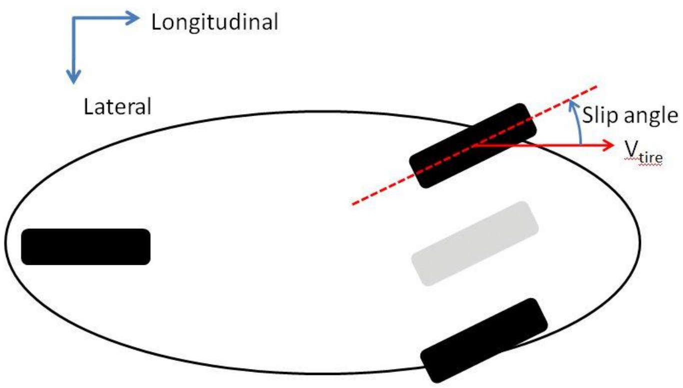

Figure 23: Vehicle model

Since accurate tire data was unavailable the tire model was empirically adjusted to reach a behavior that would equate to 1 G in the lateral direction. Verification of the tire model is recommended in future development since it has a big impact on the driving experience.

4.4.3 Engine model

A graph, *Figure 24*, of the correlation between output torque and the rotational velocity of the engine was supplied by the Vera team. This could then be used to determine the propelling force from which the negative forces of braking, drag resistance and rolling resistance was subtracted. In reality the resulting force is also limited by the tire slip, but due to the lack of data this was ignored.

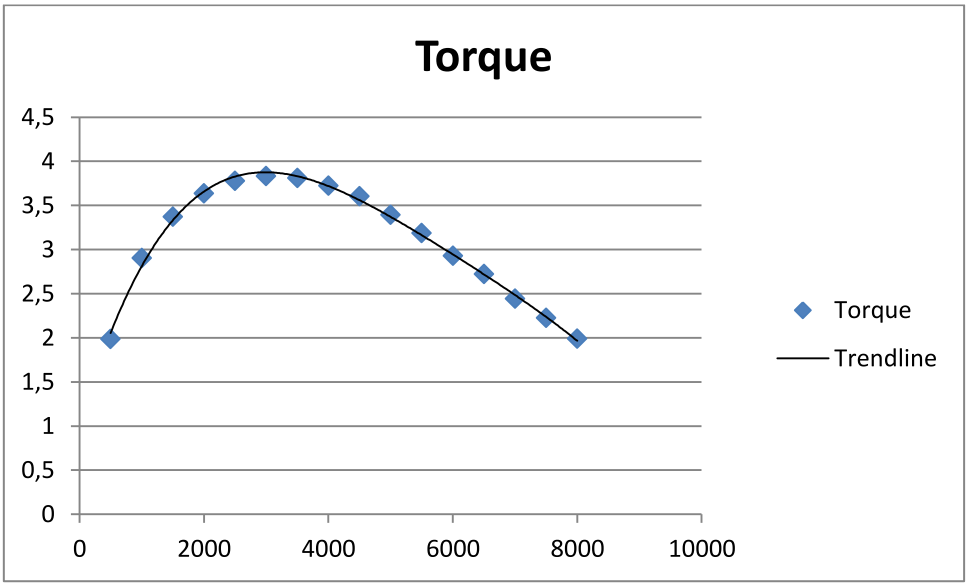

Figure 24: Engine Torque curve

Vera has a clutch, but only one gear. Implementing a fixed gear ratio in the model was easy, but the use of a clutch was ignored. The rotational velocity of the engine was therefore directly correlated to velocity of the vehicle.

When Vera is used during an actual race the engine is being turned on and off several times. This is a crucial part of the driving strategy and this functionality was therefore implemented in the model.

5 Final product

As the project goal states the aim was to let *Chalmers Vera Team* bring a functioning simulator to *Shell Eco Marathon* in Rotterdam in 2014, the final assembly took place on the 11th of May and the team left for Rotterdam the following day. The simulator is close to the concept although some parts such as the light prevention, due to time constraints, were not fully implemented. Even though the simulator is not complete it still fulfills its main goals and the remaining tasks mostly involve testing, tweaking and polishing.

Figure 25 displays a bird's eye view of the finished simulator, showing how the monitor rig which holds up the roof of the Vera body and the monitors.

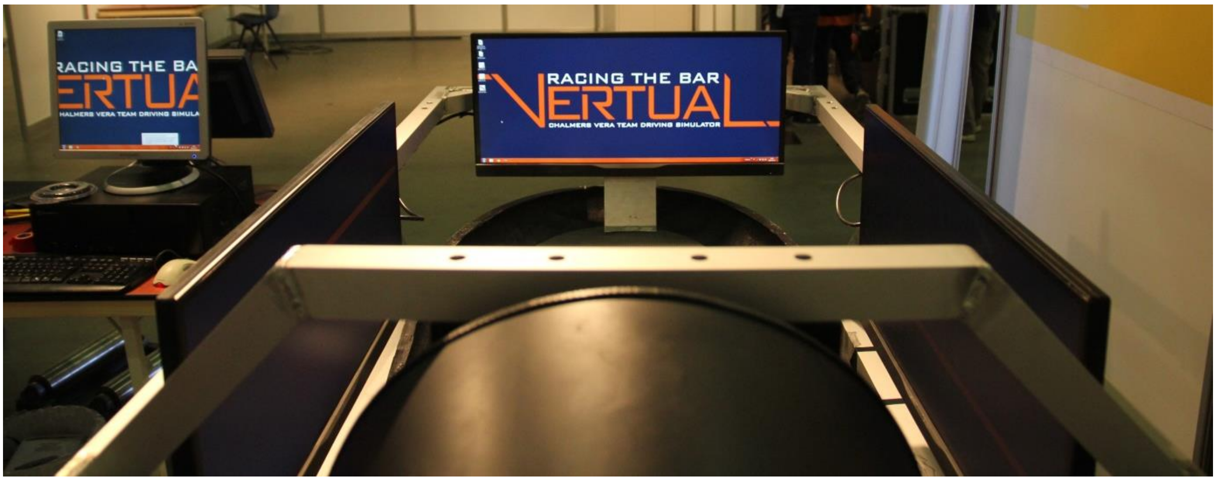

Figure 25: Birds eye view of the Simulator

Figure 26 displays the completed simulator, elevated to its highest point. The master computer, rendering the graphics and communicating with the other units, can be seen in front of the base. Also to be noted are the wheels of the platform, making it easier to move around as it is being displayed during the exhibition in Rotterdam in May 2014.

Figure 26: Simulator at the highest point

Figure 27 shows the assembled monitor rig, complete with gas springs in its final stage when powder coating had been applied. The top part has also been displaced backwards relative to the platform to improve stability since initial testing indicated a problem with load distribution on the actuators.

Figure 27: Monitor rig assembled and powder coated

6 Discussion and recommendations

The project has been a success in regards of fulfilling the goals. The final product is a working Stewart platform based vehicle simulator, giving both a physical and visual driving experience. There are still minor adjustments left to achieve the real life driving experience. However this is as expected as the boundaries of the project excluded fine tuning and verification.

6.1 Design adjustments

After being given the opportunity to bring the finished simulator to *Cruden B.V (Figure 28)*, a manufacturer of professional motion simulators, the group was given a substantial amount of feedback on how the design could be improved, both geometrically and in the control system. This chapter will discuss possible improvements as well as changes that have been made past design phase.

Figure 28: Visiting Cruden B.V during Shell Eco Marathon 2014

When planning, designing and manufacturing a rather complex product, one learns a lot along the way. Physical constraints are not always obvious during the design phase; therefore solutions to these minor problems have risen during the manufacturing of the simulator. This chapter discusses some of these solutions as well as possible improvements.

6.1.1 Top part

While manufacturing and building the top part, some modifications were made:

6.1.1.1 Adjustability of the seat

The original design of the seat adjustability consisted of two aluminum profiles attached to the two parts of the back support, sliding horizontally across the floor of the fiberglass body in two mounted aluminum profiles with incisions. At the early design stage it was unclear what kind of sound system would be installed, it later turned out to be a subwoofer included, which were decided to be placed inside the back of the Vera body as seen to the left in *Figure 29*. Therefore there had to be changes to the design of the seat adjustability to a more compact solution. The aluminum profiles supporting the backrest were made to slide vertically instead of horizontally, saving space needed to fit the subwoofer. A comparison between the two designs can be seen in Figure 29 with the old design to the right and the new one to the left.

Figure 29: Comparison of seat design

The current driver of the real Vera vehicle has given input regarding the seat design of the simulator. The posture when sitting in it is greatly improved and the ability to practice for longer periods of time using the simulator compared to driving the real Vera vehicle is highly presumable; though this has not been confirmed due to the fact that no testing of the finished product has been performed. The adjustability of the seat has filled its purpose as a 180 cm tall person can fit into the simulator as was desired.

6.1.1.2 Minimizing the inlet of light

As mentioned in the section Light prevention it is important to minimize the amount of exterior light reaching the driver during simulation. Throughout the project there have been thoughts of sealing off the light between the monitors and outer wall of the Vera body by the use of some kind of rubber sheets or latex coating. After more extensive consideration the material of choice changed to oilcloth because of the cost and flexibility advantages. However, this is still to be implemented on the simulator.

6.1.1.3 Seat comfort

The original plan was to make the seat comfortable enough to sit on during longer periods of time in order to be able to perform frequent long testing and training sessions. This was done not only by implementing a seat adjustability function but also to attach textile fabric stuffed with foam plastic on top of the plywood. This later evolved into only using a layer of foam plastic that was cut to fit the seat. Consensus was reached concerning this solution to be the best when taking aspects as time and function into account. In a further perspective a textile coating is still desired as the current solution carries with it the possibility of tearing if a driver accidently gets stuck on entry or exit. As this is merely a minor comfort issue it has not been deemed a priority during the project, which explains why this in essence simple task has not been completed.

6.1.2 Stewart platform

While manufacturing of the parts and assembling of the Stewart platform, a few modifications had to be made after the design lockdown to ensure a strong final product.

6.1.2.1 Preparation for bearing solution

While designing the Stewart platform there were some discussions about the attachment of the lower joints to the base. The two prevailing solutions were to either allow rotation by a roller bearing design or a design based on brass bushing. The design that was chosen was the one with brass bushing, due to its simplicity and easy implementation. It should be noted that the plates on the base have been prepared for the implementation of a bearing solution in the future if the current solution proves to be inadequate.

6.1.2.2 Lubrication of lower joints

As mentioned in *Preparation for bearing solution*, it was decided to use brass bushings to attach the joints. After the design lockdown concerns were raised regarding how to enhance the ability of lubricating the joints. By drilling a hole at the top and bottom surfaces of the lower joint, *Figure 19*, and attaching grease fitting at the threaded end of it, the possibility of lubricating both shafts with only one grease fitting emerges and increases the lifespan of the joint construction.

6.1.3 Control system

The mentioned problems with the *NXT* communication problems might have been solvable but due to time restraints for the project and the fact that the *NXT* part became more of a burden than a resource it was decided to put this part on hold. This was done after a couple of days without any progress when the focus had to be moved towards the other parts of the project.

6.1.4 Feedback from *Cruden B.V*

The position of the upper platform was determined in an early stage based on an approximation of where its center-of-gravity was to be located. This was done to even out the load on the actuators. While this allowed the design to rapidly evolve, the positioning should have been more thoroughly investigated. At this point the exact weight of the included components was not yet determined and the approximation was therefore not very accurate. The end result was that the responsiveness of the system was not as good as expected.

The ratio between the radiuses of the base and platform were chosen to maximize stability while still maintaining a sufficient range of motion. Based on the documentation found in the pre-study the design took shape based around the concept of tilting the driver to recreate the forces experienced when driving a real vehicle. When the finished product was brought to *Cruden B.V*, feedback was received which indicated that when working with the relatively low amount of lateral forces experienced in Vera, simply translating the platform in the horizontal plane may provide a more realistic experience for the driver.

Knowing this beforehand would have allowed for a different design strategy. The relatively small platform on which the body is mounted could have been larger when focusing on translating rather than tilting the driver. Furthermore this would have allowed the body to be mounted lower down, allowing for a more stable construction. This would also reduce the risk of nausea since the head would experience less rotation.

6.2 Planning

A time schedule for the project was done at an early stage in the process. It was changed many times throughout because of tasks taking a longer time than first estimated and long delivery times from suppliers.

6.2.1 Late deliveries

During the later manufacturing and building phases there were problems with receiving some of the ordered parts on time. This kind of problem arose with the actuators, the control units and the gas springs.

At the outset of the project six actuators left from other projects were supposed to be accessible. However, it was later realized that these actuators would not be sufficient neither in size nor in numbers which resulted in the decision that a search for new actuators from an external company would be initiated. This later resulted in *SKF* sponsoring the project with a full set of actuators, excluding the possible solution of modifying and repairing the first set of actuators provided. However due to the postponement of the decision and delivery of the actuators the time available to develop the control of the actuators was compromised.

The first company that was contacted to supply the control units was not able to deliver the desired parts on time. This caused decisions to be made and another supplier was found that luckily could deliver the parts significantly faster than first alternative.

The supplier of the gas springs was located in Denmark which resulted in longer delivery time than expected. This was due to the time it took for the payment to be transferred across borders. This led to the gas springs not being delivered in time before the first real demonstration of the simulator and had to be added afterwards. This problem could easily have been avoided by doing better research and placing the order earlier.

6.2.2 Time-consuming manufacturing

Some of the project members have spent an extensive share of the allocated project time on manufacturing various parts in a workshop. A relatively large portion of the parts manufactured there could probably have been purchased from an external supplier. With a larger budget and a more extensive lack of time this could be a good idea. However, one of the reasons with this project was to successfully produce parts on our own, since it has an educational purpose. Some of the group members had experience of machining in workshops and also had access to the proper machines making this possible.

6.3 Future development

The biggest room for improvement of the simulator in the future is in the software and communication areas. Even though a lot of work has already been put into these, the never ending development of computers and especially microcontrollers will mean that within a year it will be possible to upgrade those parts. This will lead to faster calculations but particularly this will allow faster communication which at the moment is the weakest point in the software.

To improve the performance of the simulator there will have to be work done in the areas which were excluded from the project, like sound and real handling performance of the vehicle. There are also improvements to be made with fine tuning the different parameters in the regulator and the microcontrollers. These parameters will most probably be decided by endless amount of testing and tuning and they can always be a little bit better.

In order to be able to fully utilize the simulator for developing driving strategies, extra software functions, such as fuel usage, has to be implemented.

Although the simulator can be used, the knowledge of how to operate it has not yet been transferred to the current and future members of *Chalmers Vera Team*. This can be done using a combination of tutoring and a user manual including an *Error database* that contains; what can go wrong, why it does and how to fix it.

All of these software tweaks are relatively cheap, but it mostly just demands a lot of hard work and patience in order to optimize it step by step.

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Appendix A: Requirement specification

Chalmers	Dokumenttyp	Kravspecifikation				
	Projekt:	Simulator - Chalmers Vera-team				
Utfärdare: Kandidatgrupp		Skapad: 2014-02-16				
		Modifierad:		Vikt: 1 lägst, 5 högst		

	Kriterier		Målvärde	K/Ö	Vikt (1-5)	Verifieringsmetod	Referens (kravställare)
	Funktion						
		Simulera körning av Chalmers Vera					
1.	Prestanda						
	1.1	G-krafter	Återges simulerade G-krafter på uppemot 0.5G	K		funktionstest	Kandidatgrupp
	1.2	G-krafter	Återges simulerade G-krafter på uppemot 0.7G	Ö		funktionstest	Kandidatgrupp
	1.3	Aktuatorrörelse	Ställdon med maxhastighet på 90 mm/sek	K		funktionstest	Kandidatgrupp
	1.4	Aktuatorrörelse	Ställdon med maxhastighet på 113 mm/sek	Ö		funktionstest	Kandidatgrupp
	1.5	Nätaggregat	Kunna drivas på trefas	K			Kandidatgrupp
	1.6	Nätaggregat	Kunna drivas på enfas	Ö			Kandidatgrupp
	1.7	Aktuatorkraft	Dynamisk last 900N	K			Kandidatgrupp
	1.8	Aktuatorkraft	Dynamisk last 1200N	Ö			Kandidatgrupp
2.	Ergonomi						
	2.1	Säte	Möjliggöra förskjutning på 20cm	K			Kandidatgrupp
	2.2	Ryggstöd	Justering på ±15° från Vera-sätet	K			Kandidatgrupp
	2.3	Nackstöd	Justering på ±20° från Vera-sätet	K			Kandidatgrupp
	2.4	Ratt	Möjliggöra förskjutning 10-15cm	K			Kandidatgrupp
	2.5	Placering av rotationscentrum	Minimera illamående vid användning	K			Kandidatgrupp
	2.6	Öppningsmekanism	Hanterbar av en person	Ö			Kandidatgrupp
	2.7	Bekvämt säte	Möjliggöra längre träningspass	Ö			
3.	Livslängd						
	3.1	Robust konstruktion	Minimera friktionsslitage av delar	Ö			Kandidatgrupp
4.	Underhåll						
	4.1	Logisk konstruktion	Främja justerbara konstruktioner	Ö			Kandidatgrupp
	4.2	Logisk konstruktion	I största möjliga mån utnyttja modulära komponenter	Ö			Kandidatgrupp
5	Tillverkningskostnad						
	5.1	Kostnad	Inom budget + ev. Sponsring ?*****	K			Kandidatgrupp
6	Användarvänlighet						
	6.1	Uppstart/Avstängning	Skall kunna ske inuti simulatorn	K			Kandidatgrupp
	6.2	Sätesjustering	Kan utföras sittandes i simulatorn	Ö			Kandidatgrupp
7	Storlek****			Ö			
	7.1	Höjdbegränsning	Stewartplattform + Glasfiberskal (nedfällt läge)	Ö/K			Kandidatgrupp
	7.2	Breddbegränsning	Stewartplattform/Monitor-ställning	Ö/K			Kandidatgrupp
	7.3	Längdbegränsning	Glasfiberskal	Ö/K			Kandidatgrupp
	7.4	Inuti	Plats för 188.5 cm lång person	Ö/K			Kandidatgrupp
8	Vikt						
	8.1	Vikt	Maxvikt på?	K			Kandidatgrupp
	8.2	Vikt	Minimera vikten	Ö			Kandidatgrupp
9	Estetik						
	9.1	Skal	Efterlikna Vera-bilen	K			Kandidatgrupp
	9.2	Utseende insidan	Efterlikna Vera-bilen	K			Kandidatgrupp
	9.3	Primärt färgschema utsidan	Svart och Orange	Ö/K			Kandidatgrupp
	9.4	Utseende	Estetiskt tilltalande				Kandidatgrupp
10	Material						
	10.1	Skal	Glasfiber	K			Kandidatgrupp
	10.2	Innerram	Aluminium	K			Kandidatgrupp
	10.3	Stewartplattform	Stål och aluminium	K			Kandidatgrupp
	10.4	Stödram förskärmar	Aluminium	K			Kandidatgrupp
11	Säkerhet						
	11.1	Nödstopp	Åtkomligt för förare och utifrån	K		Test	
12	Tidsschema						
	12.1	Färdig simulator	2014 05 10	K		Uppföljning	

Appendix B: Guidelines for folder structure

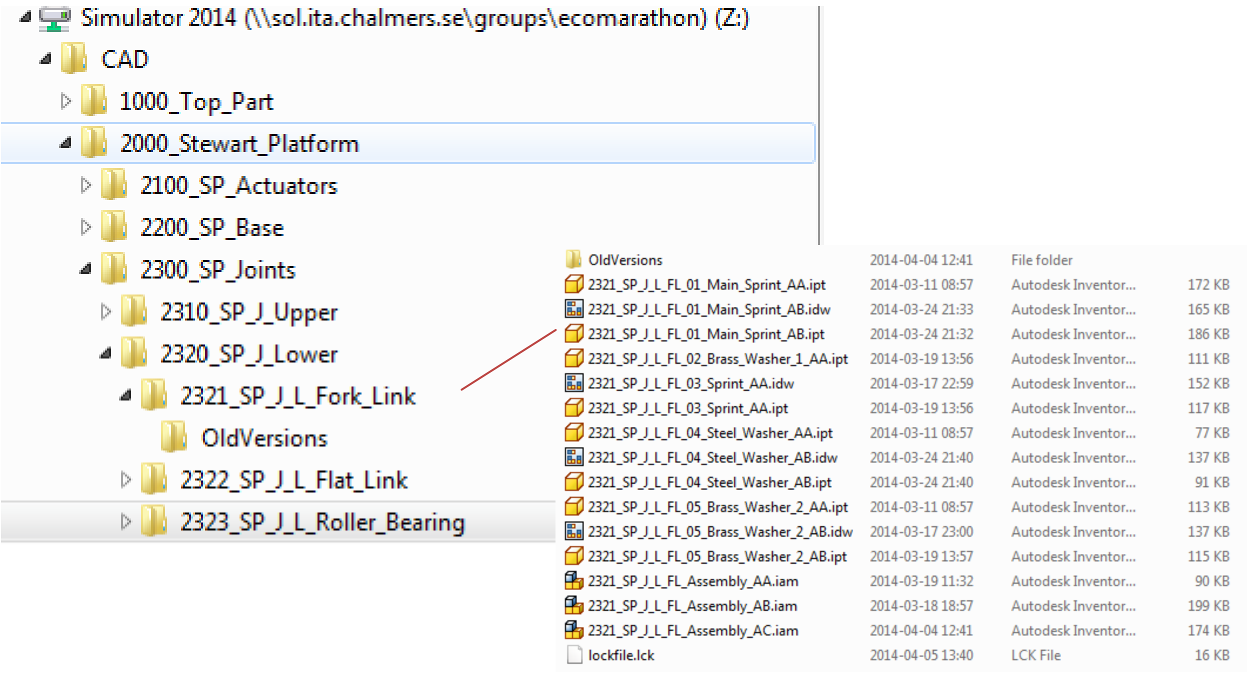
Folder and file structure for Vera Simulator Project

This document is a guide for how files and folder are to be structured in the Vera Simulator Project.

The file is always to me named with abbreviation of the parent folders with additional; ”_01_Part_AA” where ”AA” is the revision number, ”01” is the part number and ”part” is the English name of the part. The revision number is to be changed when a new revision of a part is made; the old revision is saved to enable backtracking of parts. A small change of a part, such as a change of a hole diameter, requires for a change of the second letter of the revision number, e.g. AA → AB. For a major concept change the first letter is to be changed, e.g. AA → BA.

An assembly does not have a part number. They are to have an ending resembling ”_Assembly_AA”. Assemblies are to be put in the top level in a folder with the same name.

Picture below gives a visual explanation:



Appendix C: MATLABs Stewart platform model