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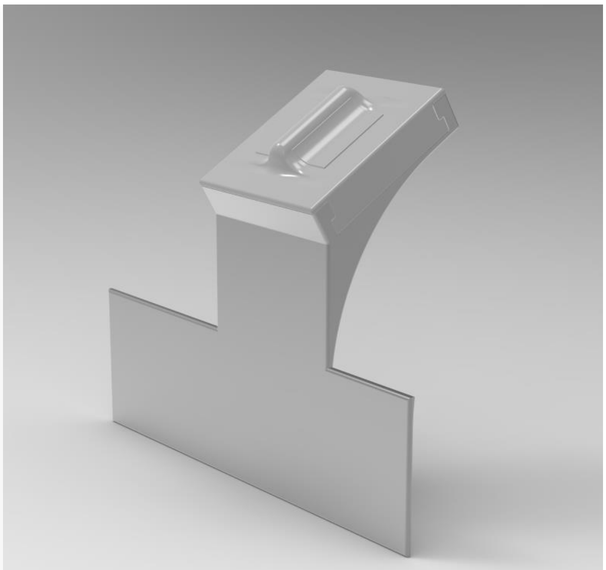

Bluetooth remote control for Volvo Construction Equipment and Volvo Penta

Bachelor thesis in mechanical engineering

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Cover: renderings of final concepts, see page 52

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Abstract

The purpose of this project is to develop a remote control for Volvo Co-Pilot, to increase the safety for the operator by enabling operation of the system without raising the hands from the steering device. Volvo Co-Pilot is a state-of-the-art touch screen tablet, which by using on-board machine data and high-precision sensors makes it easier to complete tasks, such as digging a trench for an excavator or loading a truck with material for a wheel loader.

To enable operation directly from the steering device this project aims to develop a bracket and a remote control for Volvo Co-Pilot, which can be fitted onto the steering devices for the excavator, wheel loader and dumper.

An excavator is a construction vehicle designed to dig out earth with its bucket and can either be four wheeled or equipped with crawlers, a wheel loader is a four wheeled machine equipped with a front mounted bucket, mainly used to load loose materials and a dumper is a six wheeled machine designed to carry bulk material.

The remote control will be optional for the operator, which means that the remote control has to be suitable for retrofitting. Since the remote control can be used in different vehicles with different applications, the needed functions will vary, therefore the operators should be able to define the functions of the remote control by themselves.

The project started with a research of ergonomics, Volvo Co-Pilot and patents that could be used as inspiration for this product. Which followed by idea generation, concept generation and elimination of concepts that did not meet the requirements, were not realizable or clearly worse than other.

The concepts that had passed the eliminations were made into clay models. These models were brought to the clients for test to narrow down the number of concepts to one concept for each steering device. The design of the remaining concepts were then completed in CAD, the CAD models were then 3D printed to enable more tests with the clients.

This project resulted in one bracket each for one excavator joystick, two joysticks for the wheel loader and the dumper steering wheel and in one mutual remote control, which were all displayed on the cover of this report.

Keywords: Remote control, Bracket, Excavator, Wheel loader, Dumper, Volvo Co-Pilot

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Tobias F. Fridh and Ida E. Wikman, Gothenburg 2020

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1 Introduction

This chapter will define the purpose and aim of the project.

1.1 Background

CPAC Systems, located in Mölndal, is a company completely owned by AB Volvo. AB Volvo offers financing, service and manufactures construction equipment, buses, trucks and power solutions for industry and marine applications. AB Volvo has several subsidiaries such as Volvo Trucks, Volvo Construction Equipment, Volvo Buses and Volvo Penta etc. AB Volvo was founded 1927 and currently have factories in 18 countries with headquarter located in Gothenburg (AB Volvo, 2020).

The work CPAC systems do is mostly for Volvo Construction Equipment and Volvo Penta. CPAC's focus lies on the control systems for the vehicles and vessels and have created systems like Volvo Co-Pilot to streamline the construction work and a smart steering device that will enable auto docking for vessels.

Now CPAC needs help to develop a remote control for the Co-Pilot in excavators, wheel loaders and dumpers. An excavator is a construction vehicle designed to dig out earth with its bucket and can either be four wheeled or equipped with crawlers, a wheel loader is a four wheeled machine equipped with a front mounted bucket, mainly used to load loose materials and a dumper is a six wheeled machine designed to carry bulk material.

Volvo Co-Pilot is a state-of-the-art touch screen tablet that drives four different Volvo Assist platforms (Load Assist, Compact Assist (not included in the project), Haul Assist and Dig Assist), that with on-board machine data and high-precision sensors makes it easier for the operator to complete tasks, such as digging a trench for an excavator or loading a truck with material for a wheel loader.

The operator can easily and intuitively configure projects with just a few prints by selecting the desired job parameters. The operator can then monitor the job's progress and feel safe, with messages on the screen telling you when pre-set parameters are reached.

CPAC Systems now wants to improve the safety even more by developing a remote control for Volvo Construction Equipment and Volvo Penta which may be mounted on the steering wheel and joystick on the construction equipment as well as on boats. The remote will increase safety when operating the machine as you can control some of the often used functions of the Co-pilot without raising the hands from the steering wheel or joystick. This will make the operators work easier and more comfortable.

CPAC Systems wants this project to be the start of a longer development and see this project as a way to define customer needs and to see how such a solution of a remote control can look like, with focus on the bracket.

1.2 Purpose

The purpose of this project is to develop a remote control for the Co-Pilot system and to increase the safety for the operator of the vehicle, by enabling operation of the system without raising the hands from the steering wheel or joystick. For the operator to be able to operate the Co-pilot without letting go of the steering device, the remote control will be attached to the steering wheel/joystick. Since the Co-Pilot is used in different construction vehicles the bracket needs to be adjusted for all the steering devices.

This remote control will be optional for the operator, which means that the remote control has to be suitable for retrofitting on the steering device. Since the remote control can be used in different vehicles with different applications, the needed functions of the remote control will vary. Therefore, the operators should be able to define the functions of the remote control by themselves.

1.3 Delimitations

This project is limited to:

1. The mechanics of the remote control, i.e. no electronics will be processed
2. The study will stop at a prototype of the remote control and bracket
3. The focus of the attachment will be for Volvo Construction Equipment, marine in second hand
4. The Volvo Construction Equipment is limited to excavator, wheel loader and dumper

1.4 Clarification of the issue

This project will process the following problems:

1. How is the Co-Pilot operated today?
2. What functions should be included on the remote control?
3. Which is the best design and position of the remote control, regarding ergonomics?
4. How should the remote control be attached to the steering wheel or joystick?
5. Is the attachment the same for all the steering devices or should it be different solutions for each one?

2 Theoretical references

To get a deeper understanding of the project this chapter identify the theory of the Co-Pilot, the steering wheels and joysticks that the remote control may be attached to. It also discuss some ergonomics and existing patents of mountings.

2.1 Co-Pilot

The subchapter about Co-Pilot will discuss the function and operation of the system.

2.1.1 What is Co-Pilot?

Co-Pilot is a state-of-the-art touchscreen tablet that powers four different Volvo Assist platforms. The platforms are Load Assist, Compact Assist (not included in the project), Haul Assist and Dig Assist. Using real-time data Volvo Co-Pilot can monitor progress, increase safety and optimize productivity. All data about the Co-Pilot is retrieved from AB Volvo (2020).

2.1.1.1 Load Assist

Load Assist is the Volvo Assist platform for wheel loaders. A wheel loader is a four wheeled machine equipped with a front mounted bucket, mainly used to load loose materials (see figure 1).

Figure 1 - Wheel-loader02 (MathKnight, 2006)

Load Assist is an application to optimize the load cycles, by using its functions on-board weighing and operator coaching.

On-board weighing is a system that allows the operator to measure the bucket load on the go, the operator is also able to receive the work order directly to the Co-Pilot and can with this function keep track of the total amount loaded on the truck, which eliminates any interruptions in the workflow. If the maximum bucket load is exceeded an alert will pop up in this application.

Operator coaching helps the operator to understand when and how to use the different functions of the wheel loader, to deliver optimum fuel efficiency and reduced machine wear. This is done by notifications that offer a real-time guidance on how to best operate the machine.

2.1.1.2 Haul Assist

Haul Assist is the Volvo Assist platform for the dumper. A dumper is a six wheeled machine, designed to carry bulk material (see figure 2).

Figure 2 - Volvo A30D dumper (Martinlenes, 2006)

Haul Assist monitors the amount of material moved and shows useful real-time data on the productivity of the hauler. This will make sure that the hauler shifts the optimal load and reduces fuel consumption.

2.1.1.3 Dig Assist

Dig Assist is the Volvo Assist platform for the excavator. An excavator is a construction vehicle designed to dig out earth with its bucket, e.g. to create a hole or a trench. The excavator can either be four wheeled or equipped with crawlers. Figure 3 displays one model of excavators with crawlers.

Figure 3 - Volvo Kettenbagger EC290B 3 (btr, 2007)

Dig Assist is an excavating tool and by using predefined limits and GNSS, it will maximize the machine productivity.

The 2D function of Dig Assist uses real-time data to show when the target depth or slope levels have been met, which increases the safety as a manual check no longer is needed.

Another function of Dig Assist is the in-field design, which uses satellite navigation to ensure a centimeter-accuracy for excavation. The in-field design allows the operator to define 3D shapes on the tablet, so that no surveyors is needed to mark out the excavation site. If the site is more complex a 3D design can be downloaded from an external source.

Dig assist also contains an on-board weighing to keep track of the bucket's load and the total amount unloaded in a pre-defined truck.

2.1.2 How is Co-Pilot operated today?

The Co-pilot is today operated by a touchscreen tablet. From the homepage in the different applications the operator can open several menus and select various functions. By doing so the operator has to let go of the joystick or steering wheel and make an interruption in the work process.

Figures 4 - 6 displays the interface of the three different Volvo Assist Platforms. On the display you can see surveillance of the chosen parameters, those parameters are set by using the menus on the right side of the screen. In the menu at the bottom of the screen the operator can set which job he/she is working on and what vehicle is used during project.

Figure 4 - Dig Assist

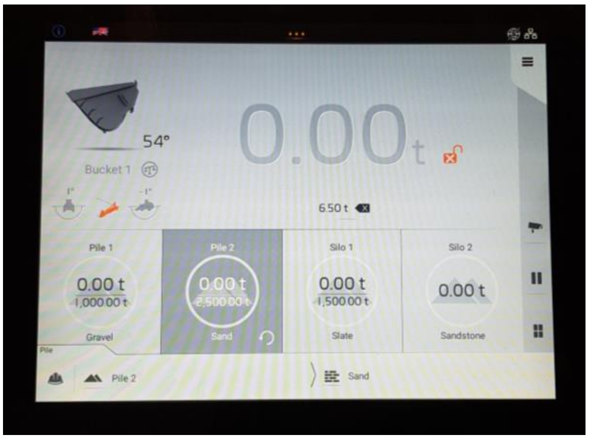

Figure 5 - Load Assist

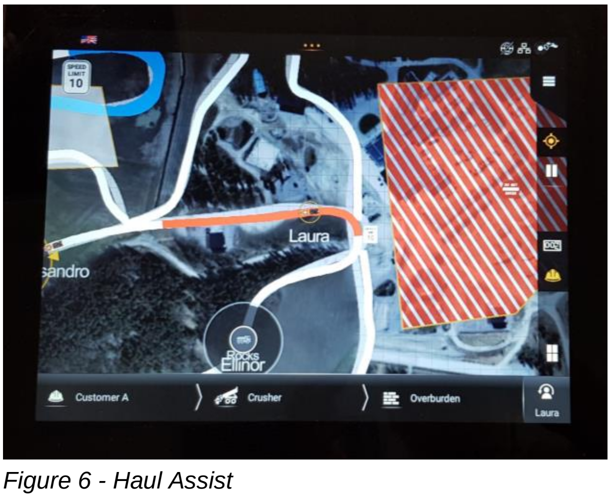

Figure 6 - Haul Assist

2.2 Steering devices used in Volvo CE vehicles

Volvo haulers are operated by a steering wheel. Volvo loaders are maneuvered with either a steering wheel or a joystick (called CDC steering) and its bucket is operated by a joystick, either by one joystick (called single lever) or three little levers (from now on called multi lever in this report). The excavators are operated by two joysticks called L8, although some models comes with a steering wheel that can be used to maneuver the machine.

The different steering devices are shown in figure 7-17. The front of a joystick is the side facing the operator.

Figure 7 - Steering wheel dumper

Figure 8 - Steering wheel, wheel loader

Figure 9 - Single lever front

Figure 10 - Single lever backside

Figure 11 - Multi lever front

Figure 12 - Multi lever backside

Figure 13 - Steering devices, wheel loader

Figure 14 - Joysticks, excavator

Figure 15 - Joystick L8 backside

 

Figure 16 - Left joystick L8 front   *Figure 17 - Right joystick L8 front*

2.3 Existing mounting solutions

There are already a few different solutions for attachment that can be used to mount a remote control on both steering wheels and joysticks. The following patents were useful as inspiration for the brainstorming process in this project and were retrieved from Espacenet Patent search (2020). The key words used were *joystick attachment* and *mounting clamp*, no filters or classifications were used.

2.3.1 Joystick attachment

Diccion, A.R. (2009) Joystick attachment US2009139360A is a clamp put around the bottom of the joystick, with a lever up along the side. The lever contains the complementary buttons for the joystick (see figure 18).

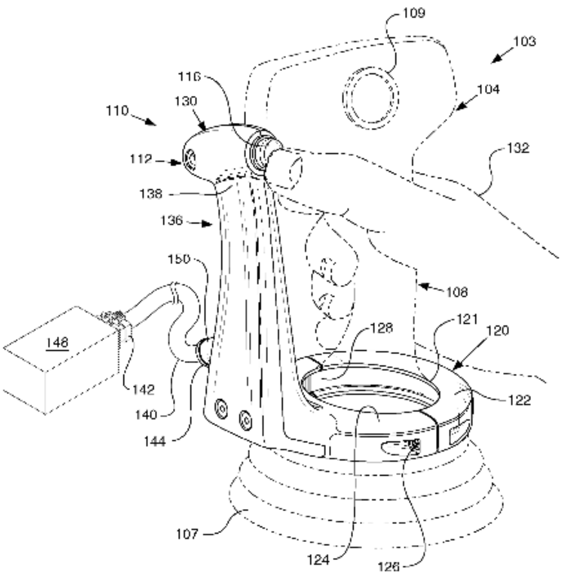

Figure 18 - US2009139360A1 JOYSTICK ATTACHMENT by Diccion (2009)

2.3.2 Mounting clamp

Sullivan, K.A. (2009) Mounting clamp US2009321588A is illustrated in figure 19. The clamp's purpose is to retain construction components within the mounting clamp, it does not use any threaded fasteners.

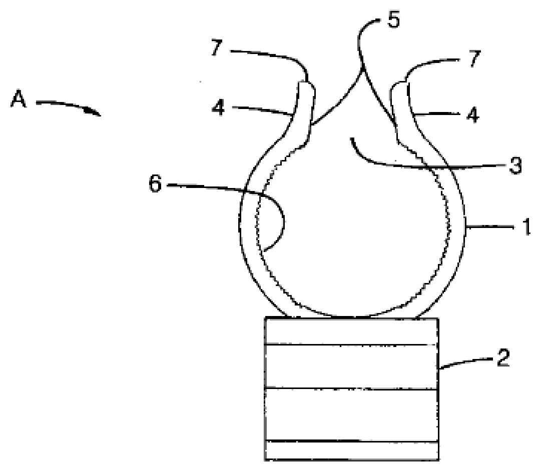

Figure 19 - US2009321588A1 Mounting clamp by Sullivan (2009)

2.3.3 Mounting bracket

Liljevik, T. (2001) Mounting bracket US6283425B1 consist of two halves with a recess for the object it is being attached to (see figure 20). The two halves are then assembled with screws and nuts to clamp the intermediate object.

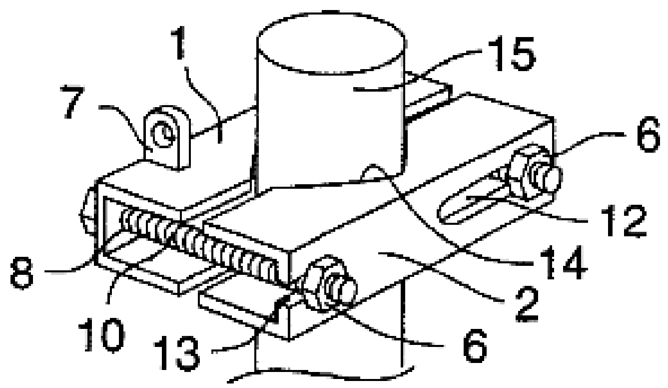

Figure 20 - US6283425B1 Mounting bracket by Liljevik (2001)

2.3.4 Clamp

Chen, J., Jin, J., Liu, S., Wang, N. & Zhao, H. (2019) Clamp (CN209431033U), figure 21, is a ring put around an object and then tightened with a screw to adjust the diameter to the object it is being attached to.

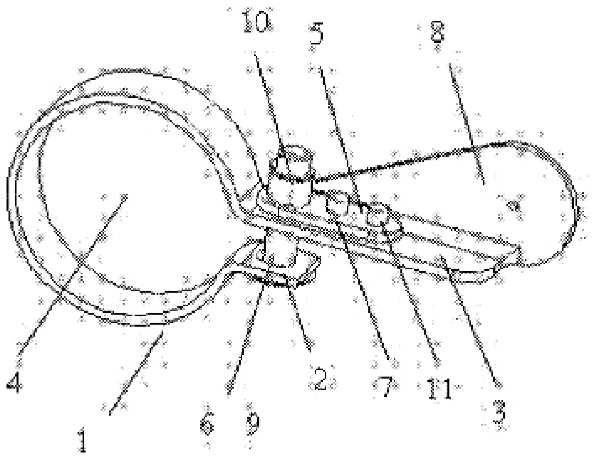

Figure 21 - CN209431033U Clamp by Chen, Jin, Liu, Wang & Zhao (2019)

2.3.5 Hydraulic line mounting clamp

Eckart, D.D. & Keddie L.D. (2001) Hydraulic line mounting clamp US2001051072A is a clamp that consist of two clamping parts, one upper and one lower, which has jaw portions that defines a receiving area for the hydraulic line. The two parts are joined together i one end by a hinge structure. On the opposite side there is coaxially aligned bores for mounting bolt through the upper and lower clamping parts (see figure 22).

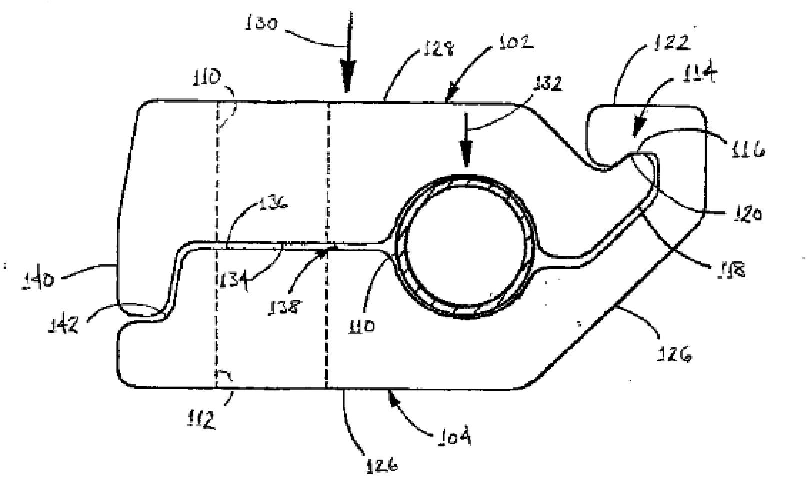

Figure 22 - US2001051072A1 Hydraulic line mounting clamp by Eckart & Keddie (2001)

2.3.6 Mounting clamp for coupling scopes to mounting rails of firearms

In figure 23 you can see Karagias, T. (2011) Mounting clamps for coupling scopes to mounting rails of firearms US2011271578A1. This clamp consists of a ring cap and ring base that are unite via a joint. The other end of the ring cap can be attached and released via a screw.

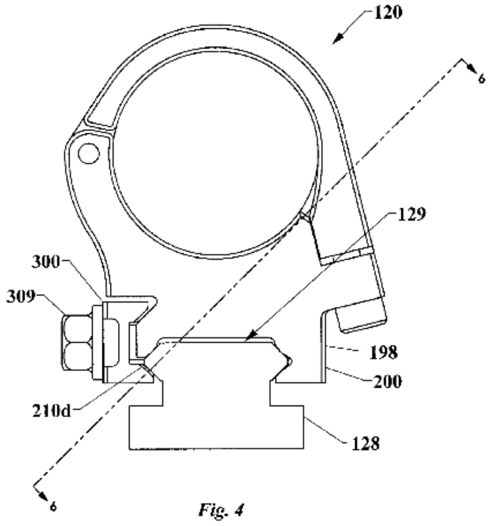

Figure 23 - US2011271578A1 MOUNTING CLAMPS FOR COUPLING SCOPES TO MOUNTING RAILS OF FIREARMS

2.4 Electronics

A PCB (printed circuit board*)* is a plate made of insulating material that includes electric wires. The plate is constructed by alternating layers of the insulation material with wires of a conductive material, often copper. This creates a conductive trace within the plate (se figure 24), to which electronic components can be added by soldering (see figure 25). Thus, a PCB is used instead of connecting all electronics by individual wires to prevent entanglement and to organize the electronics in a more systematic way (Altium Limited 2020).

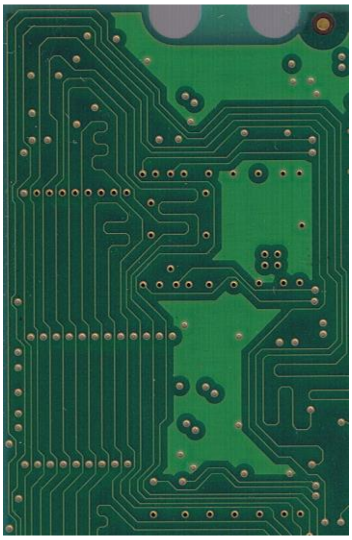

Figure 24 - Pcb (Humanoc, 2010)

Figure 25 - SEG DVD 430 - Printed circuit board-4276 (Raimond Spekking, 2016)

2.5 Ergonomics

The word ergonomics comes from the Greek *ergos* (work) and *nomos* (natural law) and is the science of people doing a job and how it is done, which tools and equipment they use, the places they work in and psychosocial aspect of the environment. The purpose of ergonomics is to achieve the best possible match of the user and the product that are being designed in the context of the task that is to be done. Ergonomics is the science of fitting the product to the user and the job to the worker.

Table 1 lists the most common ergonomics fallacies and providers some important points for what one should work to avoid, i.e. fallacy 2 is very common in student project due to insufficient understanding of the anthropometrics, the measurement of the human body (Pheasant & Haslegrave, 1996).

Table 1 - Common Fallacies according to Pheasant & Haslegrave (1996)

The Five Fundamental Fallacies	
1	This design is satisfactory for me - it will, therefore, be satisfactory for everybody else
2	This design is satisfactory for the average person - it will, therefore, be satisfactory for everybody else
3	The variability of human beings is so great that it cannot possibly be catered for any design - but since people are wonderfully adaptable, it doesn't matter anyway
4	Ergonomics is expensive, and since products are actually puchased on appearance and styling, ergonomic considerations may conveniently be ignored
5	Ergonomics is an excellent idea. I always design things with ergonomics in mind - but I do it intuitively and rely on my common sense so I don't need tables of data or emperical studies

2.5.1 Ergonomics and normal distribution

It is empirically shown that most anthropometric variables confirm to the normal distribution. The normal distribution curve has a characteristic bell-like shape and needs only two parameters to be drawn up, the mean and the standard deviation. The mean indicates were the distribution is located and the standard deviation tells the width of the curve, how much it varies from the mean. The mean and the standard deviation are normally estimated from a sample drawn from the population.

If the mean and standard deviation is known it is easy to calculate the value (Xp) for the pth percentile (%ile), with the formula Xp = m + z * SD. Where m is the mean, SD the standard deviation and z is a tabled value specific for the %ile. In general p% of the population measures a value smaller than the pth %ile, e.g. 40% of the population is shorter than the person on the 40th %ile.

The normal curve only applies to one specific population and it is therefore important to identify the user population as the mean and standard deviation may differ from others, e.g. the height of the world's population differs from the population of Sweden.

As the limits of the normal deviation curve theoretically goes to the infinity it is hard to know where to set the design limits. But a commonly used limit, that many times have been proven “good enough”, is to design for the span between the 5th and the 95th %ile. That covers the middle 90% of the population and may be considered okay as long as it just means a mild discomfort for the extreme users and not a severe risk of injury. (Pheasant & Haslegrave, 1996)

2.5.2 Ergonomics of the hand

If the operator is exposed to frequently occurring loads it can lead to injuries, similar to those injuries that occurs when the load is sudden and severe transient. A usual condition is different kinds of inflammation in tendons. (Hägg, Ericson & Odenrick, 2008)

To minimize the risks for injuries high repetition of a motion, extreme angles should be avoided. A comfortable wrist motions lies within 10 degrees flexion and 10 degrees extension.

The data in figures 26 - 27 and table 2 defines the different motions of the wrist, the different parts of the hand and the normal distribution of their amplitudes (Pheasant & Haslegrave, 1996).

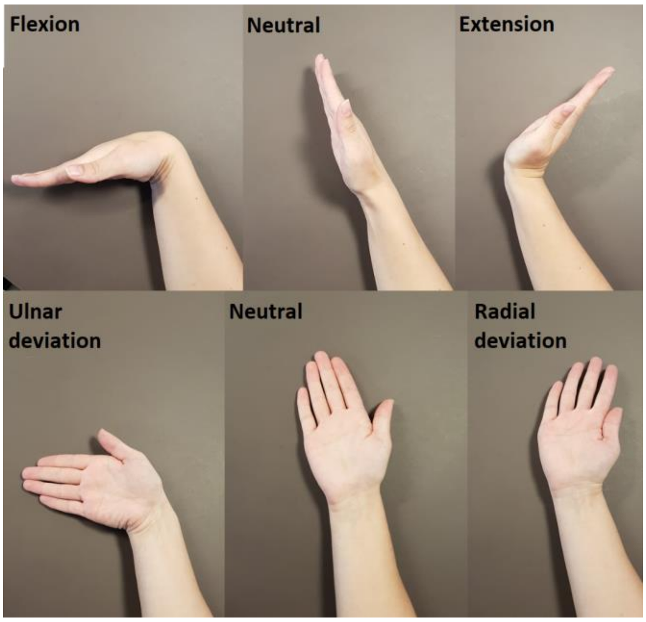

Figure 26 - Motions of the wrist

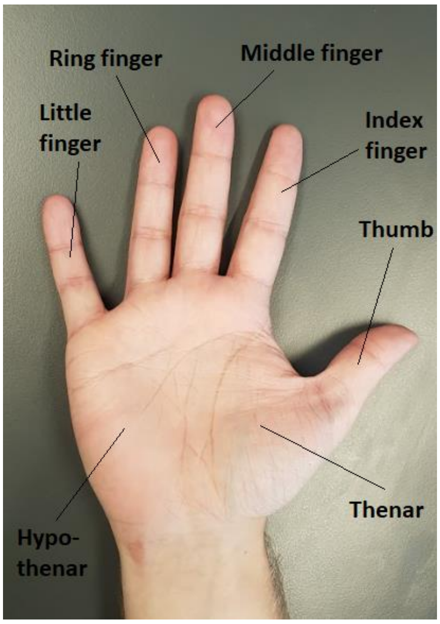

Figure 27 - Parts of the hand

Table 2 - Motions of the wrist in degrees

Motions of the Hand				
Motion	**5th %ile**	**50th %ile**	**95th %ile**	**SD**
Extension	78	99	120	13
Flexion	70	90	110	12
Pronation	37	77	117	24
Supination	77	113	149	22
Radial deviation	12	27	42	9
Ulnar deviation	35	47	59	7

Humans vary in size and to develop a user-friendly product these variations must be considered, table 3 lists the size of the different parts of the hands. The data in the table is retrieved from Pheasant & Haslegrave (1996).

Tabel 3 - Dimensions of the hand

Dimensions of the Hand								
Dimension (mm)	**Men**				**Women**			
	5th %ile	**50th %ile**	**95th %ile**	**SD**	**5th %ile**	**50th %ile**	**95th %ile**	**SD**
Hand length	173	189	205	10	159	174	189	9
Palm length	98	107	116	6	89	97	105	5
Thumb Length	44	51	58	4	40	47	53	4
Index finger length	64	72	79	5	60	67	74	4
Middle finger length	76	83	90	5	69	77	84	5
Ring finger length	65	72	80	4	59	66	73	4
Little finger length	48	55	63	4	43	50	57	4
Thumb breadth (IPJ)	20	23	26	2	17	19	21	2
Index finger breadth (PIPJ)	19	21	23	1	16	18	20	1
Hand breadth (metacarpal)	78	87	95	5	69	76	83	4
Hand breadth (across thumb)	97	105	114	5	84	92	99	5
Hand breadth (minimum)*	71	81	91	6	63	71	79	5
Maximum grip diametre**	45	52	59	4	43	48	53	3
Maximum spread	178	206	234	17	165	190	215	15
Minimum functional spread***	122	142	162	12	109	127	145	11
Minimum square access****	57	67	77	6	51	59	66	5

IPJ is the interphalangeal joint, i.e. the articulation between the two segments of the thumb

PIPJ is the proximal interphalangleal joint, i.e. the finger articulation nearest to the hand

*As for dimension "Hand breadth (metacarpal)", except that the palm is contracted to make it as narrow as possible

**Measured by sliding the hand down a graduated cone until only the thumb and middle fingre touched

***Measured by gripping a flat wooden wedge with the tip end segments of the thumb and ring finger

****The side of the smallest equal-sided aperture through which the hand will pass

3 Methodology

This chapter presents the methodology of the different stages of the project.

3.1 Information gathering

The initial data needed for the project (i.e. information on Co-Pilot and useful existing solutions) was collected by meeting colleagues, watching informational YouTube videos and searching patents in the database Espacenet.

This subchapter process details of the information gathering from coworkers and our work process during the project.

3.1.1 Customers' needs

Since this product will not be necessary until the new updates of Co-Pilot are on the market, there was no use asking todays clients what functions they would have wanted on such a product. This meant that our search for customers' needs only involved asking the developers of each application of what they thought would be necessary.

These interviews were conducted semi-structural. Meaning that question sheets were made in preparations for the interviews, but the exact structure of these sheets were not followed during the interviews. The interviews were planned this way to enable a more natural flow in the conversation. (Patel & Davidson, 1994)

3.1.2 Electronics

The PCB for the remote control needs to consist of a battery, a Bluetooth chip with an antenna, a processor and parts for the control functions of the remote. The size of the included electronics had to be known to be able to create the mechanics of the remote control, to give an idea of the minimal possible size. This information was obtained by asking the electronics department at CPAC Systems.

Since the Bluetooth sends signals over 2,4 GHz radio frequency, materials such as metal and bulletproof glass should be avoided for the remote control due to its negative impact of the Bluetooth performance (Apple Inc, 2020).

The Electronics department also assisted with the battery capacity needed for operation of the remote control.

3.2 Defining requirements and objectives

The specification was based on the function requirements given by CPAC Systems and were then expanded by adding the objectives and requirements the project group thought was necessary. In the specification the requirements were marked with R and the objectives with O. Each requirement is measurable and will be verified, therefore the verification methods were listed next to each requirement in the specification. The objectives were ranked on a scale from 1 to 5, where 5 is the most important to be fulfilled.

3.3 Idea generation

This subchapter describes the process of how the project proceeded from the specification to having a concept of how the product could look like to solve the problem in the best way possible.

3.3.1 Function analysis

The product was broken down into functions and sub functions, in purpose to make the idea generation easier, since it is easier to find solutions for the sub functions and combine these into a complete product than to the whole complex product at once.

The function analysis was created by analyzing what functions were needed to fulfill the requirements and objectives in the specification. Each function was then branched out into smaller functions, called sub functions, which together make up the main function.

In addition to the main function are the support functions. The support functions are not needed for the product to fulfill the main function but are secondary functions that makes the product better. Just as with the main function the support functions were divided into sub functions.

The function analysis was built as a table where the main function was listed at its top and then the sub functions below, followed by the support functions with their sub functions. Each sub function was marked with R or O, depending on if it is a requirement or an objective (Johannesson, Persson & Pettersson, 2013).

3.3.2 Brainstorming

Brainstorming is a creative method for idea generation which is used in group. The group will produce as many ideas as possible without asses and criticize any of them. In this process quantity comes before quality.

There are four ground rules for brainstorming that should be followed in order to get a satisfying result of the exercise. The ground rules are:

1. Criticism is not allowed: do not give any comments on the ideas, neither positive nor negative
2. Aim at quantity: high quantity increases the chance that some of the ideas are really good
3. Go outside the box: a crazy idea with some modification can be an excellent solution for the problem
4. Combine ideas: complete solutions can emerge when ideas are combined

(Johannesson et al., 2013)

The brainstorming was performed in two stages, first the project group brainstormed on their own and then a second brainstorming was performed along with the mechanical engineers at CPAC Systems.

3.3.3 Literature method

This is a very common method and easy to use. The method is about searching for solutions to similar problems. You can either systematically search for how they solved their problem, or you can search information on a more unstructured way just to get inspiration. The information can be found in non-fiction books, patents, product catalogs and internet.

In this this project the literature method was used to search for patents of existing attachment solutions (see subchapter 2.3) and to see how small remotes look today (Johannesson et al., 2013).

3.3.4 Concepts

The sub solutions generated in the brainstorming were then inserted in a morphological matrix to get all the possible solutions. The functions were listed in the first column and the different solutions were then listed after each function, on the same row as the function that they satisfied. Concepts were produced by combining one solution for one function with each solution of the other functions (Johannesson et al., 2013).

To begin narrowing down the number of possible concepts a first elimination of the sub functions was performed, before the concepts were generated. This was achieved by first eliminate all sub solutions which did not meet following criteria:

- Solving the problem
- Fulfill all the requirements from the specification
- Can be realized
- Suitable for the company´s collection of products
- Is advantageous in the perspective of ergonomics, safety and environmental

(Johannesson et al., 2013)

The insufficient solutions were marked red in the morphological matrix, to indicate that they were no longer possible to use for this project.

The next step to narrow down the number of concepts was to eliminate the sub solutions that evidently did not meet the objectives as well as the others. These solutions were market orange in the morphological matrix, to indicate that they no longer were possible to create concepts out of.

Since the remote control must be the same for all the vehicles, while the bracket can vary between the different models, the remote control and bracket were separated from each other for the concept generation and elimination.

3.4 Evaluation

This subchapter will describe the process of evaluation and how the best solution for the remote control and bracket was found.

3.4.1 Pugh matrix

A Pugh matrix was used to rank the concepts from the morphological matrix. This was done by listing the objectives from the specification in the first column and the remaining concepts in the first row. One concept was selected as a reference, which means that all the other concepts will be judged on how well they fulfill the objectives compared to the datum.

Here the concepts only measures if they are better, worse or equally good as the reference and not by how much better or worse they are. This is marked in the matrix by (+), (-) or 0 respectively, were the concept (not the reference) and function crosses each other.

The result of a Pugh matrix depends on the reference. To ensure that the ranking of the concepts actually was correct, another Pugh matrix was performed (Johannesson et al., 2013).

The results from the first and second Pugh matrix were then compared, and all the concepts ranked in the bottom half in both matrices were eliminated. The limit was set to be in the middle because the outcome of the second matrix was not the same as for the first, and if the concept were ranked in the bottom half in both matrices it is clearly worse than the other concepts.

3.4.2 Further elimination

The remaining concepts were then compared in the aspect of how they could be positioned on the steering device. The concepts were shown for colleagues at CPAC systems to visualize where the different concepts could be positioned for the different steering devices. The concepts with a great weakness that made the concept clearly worse than the others were eliminated.

3.5 3D model

To visualize the resulting concept CAD models and prototypes were made, this subchapter discusses the process of the manufacturing of these models.

3.5.1 Clay and cardboard model

To be able to visualize the different concepts, simple models were made in clay and cardboard. These models enabled tests of different placements for each steering device. The range of reach were explored with these models so it would fit the 5-95th %ile.

The users of the construction vehicles at CPAC were asked of their opinion of the different models. They were not to choose which concept they liked the most, just give their thoughts of advantages and disadvantages for each concept.

3.5.2 CAD

The design was completed in the CAD program Creo Parametric 3.0. One 3D model was created for each steering device. An assembly was then created in which the bracket was mounted onto the steering device, to make sure there were not any interferences and that the bracket could be mounted in the right position.

The measurements for the steering devices came from a CAD model of the L8 joystick, an old CAD model of the single lever (with small differences from today's single lever) and from the actual steering wheel mounted in the dumper and console for the multi lever.

3.5.3 Prototype

The CAD models were printed to enable tests of the different solutions. During the tests the clients were able to try out the placement of the remote control and give feedback on their thoughts on reach and ergonomics. The ergonomics were investigated by one person with hands close to the 5th %ile and another test person with hands close to the 95th %ile, among others in between.

4 Results

In this chapter are the results of the project presented.

4.1 Information Gathering

In this subchapter are the information gathered from the customer survey and the minimal size of the electronics within the remote control presented.

4.1.1 Customers' needs

To understand what the company wanted from this project the person responsible for each application on Volvo Co-pilot (Load Assist, Haul Assist and Dig Assist) were asked what functions they wanted to see on the remote and if they had any ideas for its placement.

The L8 joystick already contains a lot of buttons, which have different functions depending of the selected preset. To make the surveillance of the ongoing digging project easier CPAC needs a way to minimize the numbers of presets and a way to change set values within the Co-Pilot.

The dumper does not need a lot interaction with the system as it is today, but a new update of the software will make it possible for the operator to map areas and set for example a maximum speed limit for the area, which would need more interaction between the operator and the Co-Pilot. Based on this the company sees a need of an easier way to change the camera view (based on the todays application) and to map an area (for the new update).

The application for wheel loaders is in need of a solution that allows the operator to accept and cancel the notifications in the Co-Pilot.

4.1.2 Electronics

The PCB, including a Bluetooth chip and the other needed electronics, takes up a space of 30 x 30 millimeters with a height of four millimeters.

To run the remote and to keep it running for 2000 keystrokes a CR2032 battery had to be added. It can either be put underneath the PCB and only add five millimeters to the height or at the top of the PCB or add 20 x 20 millimeters to the area and one millimeter to the height.

Each button on the remote will add 5 x 5 millimeters to the PCB and each scroll will add an area equal to its physical size to the PCB.

4.2 Defining requirements and objectives

The specification based on the function requirements from CPAC Systems and the supplements from the project groups is shown in table 4. The requirements are marked with R and the objectives with O. The objectives are ranked on a scale 1 (not important) to 5 (very important).

Table 4 - Specification

	Specification Remote Control and Bracket					
	Criteria	**Target value**	**R/O**	**Significance**	**Verification method**	**Reference**
1.	**Functions**					
1.1	Flexible attachment to steering device		R		Test	Cpac Systems
	- Joystick excavator, 1 version					
	- Joystick loader, 2 versions					
	- Steering wheel loader, excavator and dumper					
1.2	Sutable for retrofittning		R		Test	Cpac Systems
1.3	Attachment for remote control		R		Test	Cpac Systems
1.4	Bloutooth interaction with Co-Pilot		R		Test	Cpac Systems
1.5	Control of Co-Pilot functions from the remote control	>=2 functions	R		Test	Cpac Systems
1.6	One attachment suitable for all steering devices		O	1		
1.7	Ease of use		O	4		Project Group
2.	**Performance**					
2.1	Water and dust resistant	IP65	R		Test	Cpac Systems
2.2	No movement in joints when the remote control is operated		R		Test	Project Group
2.3	Minimize dislocation after impact (shockproof)		O	5		Project Group
2.4	Minimize risk of accidental operation		O	4		Project Group
3.	**Maintenance**					
3.1	Battery life	>2000 keystrokes	R		Calculations	Cpac Systems
3.2	Minimize steps for battery change		O	3		Project Group
3.3	Minimize the number of steps to attach the bracket		O	1		Project Group
3.4	Minimize the number of steps to attach the remote controll		O	3		Project Group
4.	**Size**					
4.1	Big enough to enclose the circuitboard		R		Test	Project Group
4.2	Minimize the outer volume		O	4		Project Group
5.	**Mass**					
5.1	Minimize mass		O	3		
6.	**Material**					
6.1	Sustain usage temperature	-40ºC < t < 100ºC	R		Tables	Project Group
6.2	Salt water resistant		R		Tables	Cpac Systems
6.3	Recyclable material		R		Tables	Project Group
6.4	Minimize the number of different materials		O	2		Project Group
7.	**Ergonomics**					
7.1	No sharp edges		R		Test	Project Group
7.2	No interference with the grip		R		Test	Project Group
7.3	Enable an ergonomic position of the remote control for 95% of the population		O	5		Project Group
7.4	Button tactile similar to the already existing bottons on joystick		O	2		Project Group
8.	**Production**					
8.1	Be able to be assembled		R		Test	Cpac Systems
9.	**Aesthetics**					
9.1	Adress the target audience		O	2		Project group

4.3 Idea generation

This subchapter accounts for results of the idea generation.

4.3.1 Function analysis

The function analysis that followed from the specification is shown in table 5. Every function is divided into subfunctions, which are marked with R for requirement or O for objectives. Each function is also marked with what type of function it is, i.e. MF for main function, SF for support function and SubF for sub function.

Table 5 - Function analysis of the remote control and bracket

Function analysis		
Remote Control and Bracket		
MF/SF/SubF	**R/O**	**Function**
MF		**Control Volvo Co-pilot from steering device**
SubF	R	Offer control functions
		- External components for interaction with Co-Pilot
		- Provide space for internal components
	R	Offer attachment on steering device suitable for retrofitting
		- Offer attachement of bracket
SubF		- Offer attachement of remote control
SF		**Possess ergonomics**
SubF	R	Offer ergonomic grip
		- Space between buttons/scroll
		- Maximum grip diameter
		- Hand size
		- No sharp edges
SubF	O	Facilitate operation of buttons
SF		**Attract target audience**
SubF	O	Express quality
SubF	O	Express ergonomics
SubF	O	Be aesthetically pleasing
SubF	O	Allow ease of use
SF		**Facilitate maintenance**
SubF	R	Offer the electronics protection from the enviroment
SubF	O	Facilitate attachment and detachment of the remote control
SubF	O	Facillitate battery change

4.3.2 Brainstorming

The brainstorming was performed in two stages. The first stage was a brainstorm within the project group, which was followed by a brainstorming performed together with colleagues at CPAC system to get other ideas from people with much more experience.

The second brainstorming were performed with four CPAC employees and the project group. The brainstorming started with a presentation of the project and the functions that were to be solved. First the CPAC employees got to brainstorm as a group for control functions for the remote control during 10 minutes and then the project group showed what they come up with at their brainstorming to see if any ideas could be combined or generate some new ideas. When the ideas for *offer control functions* stopped coming, the CPAC employees were asked to brainstorm for *offer attachment on steering device suitable for retrofitting* for 15 minutes. Which was followed with a presentation of the project group's ideas for the attachment to explore the possibility to combine different ideas and to see if any new ideas came up. The whole session lasted for about an hour.

The brainstorming resulted in table 6 and 7. Each solution is explained in in the subchapters 4.4.2.1 and 4.4.2.2.

Table 6 - The results of the brainstorming for attachments

Brainstorming	
Offer attachment to steering device	
Attachment remote control	**Attachment steering device**
Velcro	Velcro + Plate
Tape	Tape + Plate
Glue	Glue + plate
Screws	Two halves joined with screws
Remote control with threads	Elastic clamp
Remote control with resilient sprint	Elastic clamp locked with screw
Ball joint	Plate and rubber band
Twisting lock	Two halves joined with one screw and one hinge
Sprawling wedges	Resilient clamp
Rails with locking sprint	Two halves joined with one joint and one snap lock
Elastic clamp	Two halves joint with one joint and one screw
Resilient clamp	
Permanent on the attachment for steering device	

Table 7 - Results of the brainstorming for interaction

Brainstorming
Interaction with Co-Pilot
Joystick (Presets)
Touch (Presets)
Buttons
- Button with presets
- Buttons for navigation in menues
Scroll (Presets)
Voice control
Joystick + buttons (Navigation in menu)
Scroll + buttons (Navigation in menu)
Optical (Navigation in menu)
Optical + buttons (Navigation in menu)
Trckball + buttons (Navigation in menu)
Trackball (Navigation in menu)

4.3.2.1 Attachment remote control

In figures 28 - 38 are all the solutions for the attachment of the remote control illustrated and above the figures are short descriptions of each solution listed.

The solutions for attachment of the remote control are:

- Velcro/Tape/Glue (figure 28): Here the remote control is attached into a frame, for extra stability, by either glue, double sided tape or Velcro.
- Screws (figure 29): The remote control is attached into the supporting frame with one screw in each corner.
- Remote control with threads (figure 30): The remote control is equipped with threads so that the control itself can be screwed into the supporting frame.
- Remote control with resilient sprint (figure 31): The remote control is equipped with, at least, two resilient sprints that are pushed in when the control is to be attached. The sprints then spring out into two holes when it is placed in the frame, which will keep it in place.
- Ball joint (figure 32): The remote control is fitted on a ball joint.

- Twisting lock (figure 33): The remote control is fitted in a bowl for support and to attach the remote control it is twisted 90 degrees.
- Sprawling wedges (figure 34): The remote control is fitted with sprawling wedges that are pushed together when the control is to be attached. When the remote control is placed in the supporting frame the wedges springs out and the barbs at the top of the wedges locks it into position.
- Rails with a locking sprint (figure 35): The remote control is equipped with rails that are fitted into the bracket and then the remote control can slide into place.
- Elastic clamp (figure 36): The remote control is placed in the gap of the elastic clamp
- Resilient clamp (figure 37): The supportive frame is equipped with a resilient lever that is bent opened before attaching the remote. When the lever is released it will keep the remote control in place.
- Permanent on the attachment for the steering device (figure 38): The Remote control is a permanent part of the attachment for the steering device.

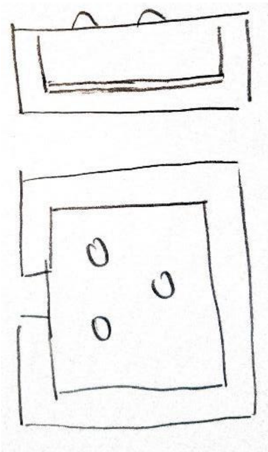

Figure 28 - Tape/Velcro/Glue

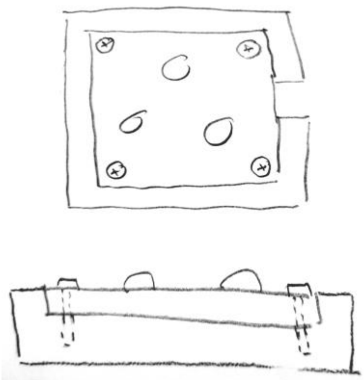

Figure 29 - Screws

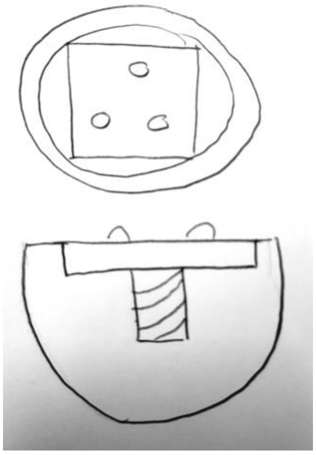

Figure 30 - control with threads

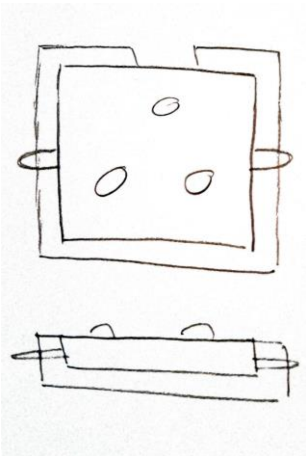

Figure 31 - Resilient sprint

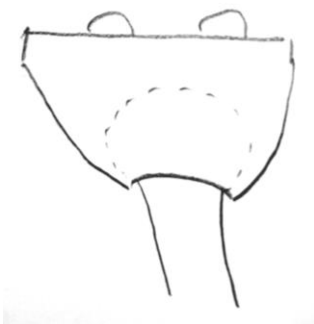

Figure 32 - Ball joint

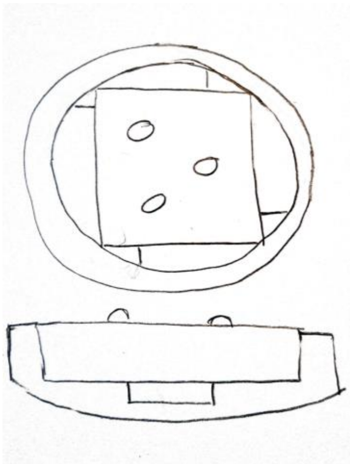

Figure 33 - Twisting lock

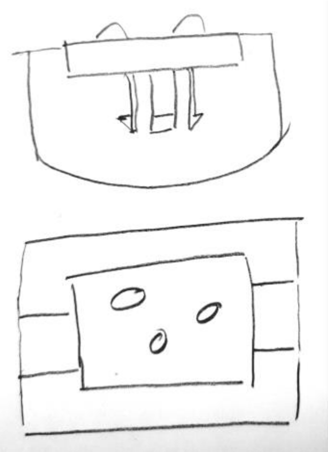

Figure 34 - Sprawling wedges

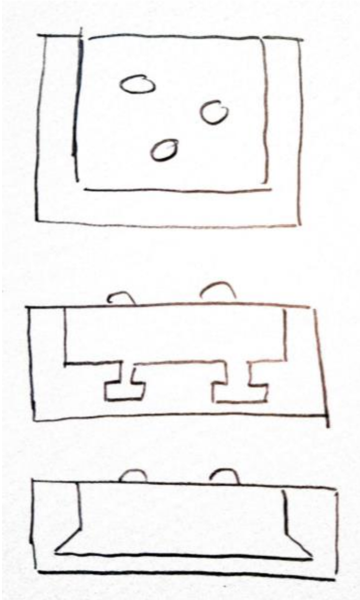

Figure 35 - Two alternatives for rails

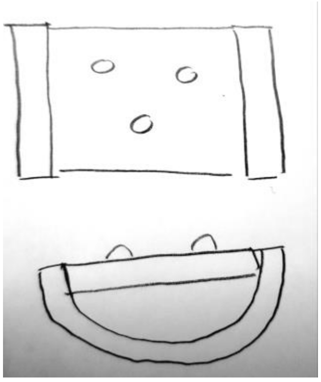

Figure 36 - Elastic clamp

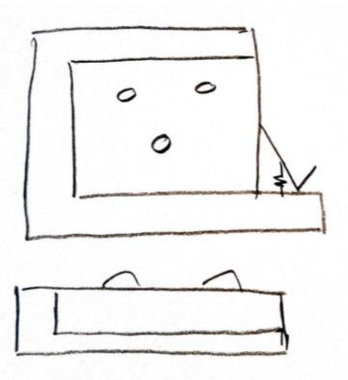

Figure 37 - Resilient Clamp

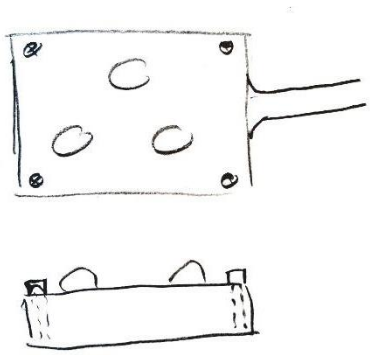

Figure 38 - Permanent attachment

4.3.2.2 Attachment to steering device

In figures 39 - 47 are all the solutions for the attachment to the steering device illustrated and above the figures are short descriptions of each solution listed.

The solutions for attachment to the steering device are:

- Velcro/Tape/Glue + Plate (figure 39): This solution includes a plate shaped after the joystick/steering wheel on one side while the opposite side contains an attachment for the remote control. The plate is attached to the joystick/steering wheel by either glue, tape or Velcro.
- Two halves joined with screws (figure 40): The two halves are fitted around the joystick or the spoke of the steering wheel and are then attached to each other by two screws.
- Elastic clamp (figure 41): The attachment for the steering device is dimensioned for elastic deformation so that the clamp can be pressed around the steering device.
- Elastic clamp locked with screws (figure 42): uses the same clamp as in figure 39 but the ends of the clamp are then locked together by a screw, to decrease the risk of accidental removal.

- Plate and rubber bands (figure 43): The plate is shaped to fit the joystick/steering wheel on one side and enables attachment of the remote control on another, the plate is attached to the steering device with rubber bands.
- Two halves joined with one screw and one hinge (figure 44): Two halves are put around the steering device and joined together by a hinge in one end and by a screw in the other end.
- Resilient clamp (figure 45): The resilient clamp consists of two halves joined by a spring-loaded joint that will press the ends together when no outer force acts on the clamp.
- Two halves joined with one joint and one snap lock (figure 46): The two halves are put around the steering device and are joined together by one joint in one end and by a snap lock in the other end.
- Two halves joined with one joint and one screw (figure 47): Two halves put around the steering device, joined together by a joint in one end and by a screw in the other end.

Figure 39 - Tape/Velcro/Glue

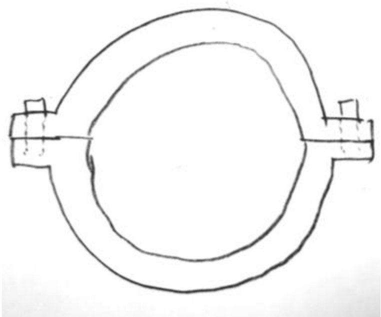

Figure 40 - Two halves and screws

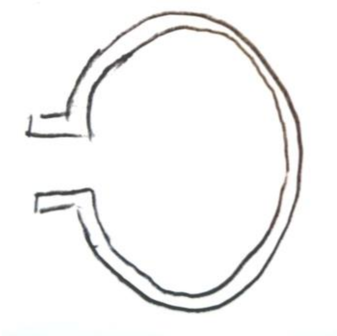

Figure 41 - Elastic clamp

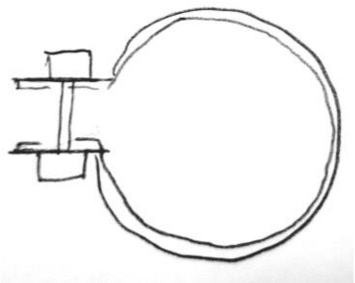

Figure 42 - Elastic clamp locked with screw

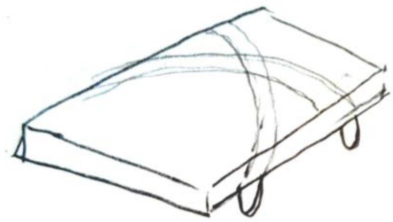

Figure 43 - plate and rubber band

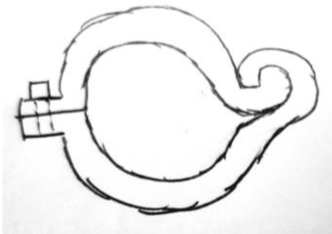

Figure 44 - Two halves, one screw and one hinge

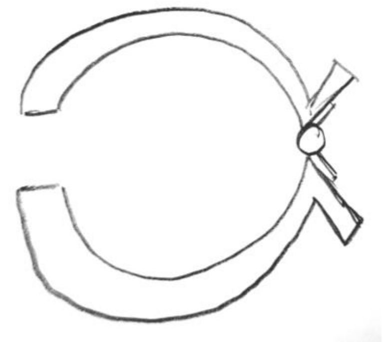

Figure 45 - Resilient clamp

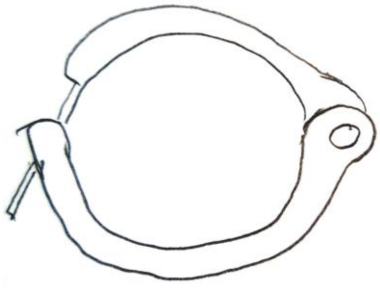

Figure 46 - Two halves, one joint and one snap lock

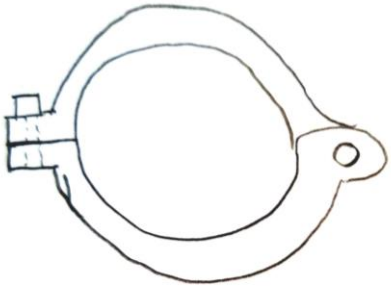

Figure 47 - Two halves, one joint an one screw

4.3.3 Concept generation

Due to the fact that the remote control has to be the same for all vehicles, while the bracket can differ from one vehicle to another, two morphological matrices were created, one for the remote control and another for the attachment. Meaning that the concepts for the attachment and the remote control were created and evaluated separately.

4.3.3.1 Concepts attachments

The ideas that came out of the brainstorming were put into the morphological matrix (see table 8). Each solution to a sub function is listed in the same column. The solutions for each sub function are then combined and creates a concept.

Before putting the sub solutions together into concepts, the solutions marked red in the morphological matrices were eliminated due to an insufficient fulfillment of the requirements for any of the three vehicles. The following sub solutions were eliminated:

- Attachment to steering device
  - Velcro - Does not meet the temperature requirement
- Attachment remote control
  - Ball joint - possible movement during operation

Another elimination that was performed, before creating concepts, were to eliminate the solutions clearly worse than the others. The concepts eliminated in this step were marked orange in the matrices, to indicate that they no longer can be used in a concept. The following solutions were eliminated for all the three vehicles:

- Attachment to steering device
  - Elastic clamp - Not shockproof
  - Resilient clamp - Not shockproof
  - Glue + plate - Same function as *Tape + plate* but messier to attach and cannot be used right away due to hardening
  - Two halves joint with one screw and one hinge - Same function as *Two halves joint with one screw and one joint* but depends on the operator to fit the halves right to each other when the joint holds them in the right place automatically
  - Sprawling wedges - Same function as Resilient sprint, but more sensitive for an inaccurate mounting
  - Rubber band + plate - Not shockproof
- Attachment remote control
  - Screws - small parts that easily can be lost at a battery change, requires tools for battery change
  - Elastic clamp - Similar to *Resilient clamp* but needs a higher force to remove the remote control
  - Remote control with threads - Same principle as *Twisting lock* but takes up more space

Since there were no additional sub solution eliminated for any specific steering device, only one morphological matrix was necessary for the brackets (see table 8). From the morphological matrix the concepts were created by combining one (white) sub solution for Offer *attachment of bracket* with one (white) sub solution for *Offer attachment of remote control.* After combining these in every possible way there were 30 concepts created and these are presented in table 9.

Table 8 - Morphological matrix: Attachment Excavator, Wheel Loader and Dumper

Morphological Matrix							
Attachment Excavator, Wheel Loader and Dumper							
Function	**Solution**						
Offer attacement of bracket	Velcro + Plate	Tape + Plate	Glue + plate	Two halves joined with screws	Elastic clamp	Elastic clamp locked with screw	Plate and rubber band
	Two halves joined with one screw and one hinge	Resilient clamp	Two halves joined with one joint and one snap lock	Two halves joint with one joint and one screw			
Offer attacement of remote control	Velcro	Tape	Glue	Screws	Remote control with threads	Remote control with resilient sprint	Ball joint
	Twisting lock	Sprawling wedges	Rails with locking sprint	Elastic clamp	Resilient clamp	Permanent on the attachment for steering device	

(pink)	Sub solution eliminated due to unsuffisient fulfillment of requirements
(beige)	Sub solution eliminated because it is clearly worse than the others

Table 9 - Concepts

Concepts		
Attachment Excavator, Wheel Loader and Dumper		
Concept	**Solution**	
	Attachment Steering Device	**Attachment Remote Control**
1	Tape + Plate	Remote control with resilient sprint
2	Tape + Plate	Twisting lock
3	Tape + Plate	Rails with locking sprint
4	Tape + Plate	Resilient clamp
5	Tape + Plate	Permanent on the attachment for steering device
6	Tape + Plate	Tape
7	Two halves joined with screws	Remote control with resilient sprint
8	Two halves joined with screws	Twisting lock
9	Two halves joined with screws	Rails with locking sprint
10	Two halves joined with screws	Resilient clamp
11	Two halves joined with screws	Permanent on the attachment for steering device
12	Two halves joined with screws	Tape
13	Elastic clamp locked with screw	Remote control with resilient sprint
14	Elastic clamp locked with screw	Twisting lock
15	Elastic clamp locked with screw	Rails with locking sprint
16	Elastic clamp locked with screw	Resilient clamp
17	Elastic clamp locked with screw	Permanent on the attachment for steering device
18	Elastic clamp locked with screw	Tape
19	Two halves joined with one joint and one snap lock	Remote control with resilient sprint
20	Two halves joined with one joint and one snap lock	Twisting lock
21	Two halves joined with one joint and one snap lock	Rails with locking sprint
22	Two halves joined with one joint and one snap lock	Resilient clamp
23	Two halves joined with one joint and one snap lock	Permanent on the attachment for steering device
24	Two halves joined with one joint and one snap lock	Tape
25	Two halves joint with one joint and one screw	Remote control with resilient sprint
26	Two halves joint with one joint and one screw	Twisting lock
27	Two halves joint with one joint and one screw	Rails with locking sprint
28	Two halves joint with one joint and one screw	Resilient clamp
29	Two halves joint with one joint and one screw	Permanent on the attachment for steering device
30	Two halves joint with one joint and one screw	Tape

4.3.3.2 Concepts remote control

The ideas that came out of the brainstorming were put into the morphological matrix, table 10. Each solution to a sub function is listed in the same column. Since the remote control only has one function, the morphological matrix just functions as a list of what the possible solutions are.

Just as for the attachment the solutions with insufficient fulfillment of the requirements for the remote control were eliminated and marked red in the morphological matrix. The eliminated solutions were:

- Control function
  - Voice control - Cannot be realized due to high noise level within the cabin

The second elimination aimed to eliminate the solutions clearly worse than the others, based on the fulfillment of the objectives. By doing so the following solutions were eliminated and marked orange in the morphological matrix:

- Control function
  - Joystick - High risk of accidental movement
  - Touch - High risk of accidental movement
  - Optical control - High risk of accidental movement
  - Trackball - Needs a mouse symbol (that does not exist today) on the screen to know where on the screen the operator is, while the scrolls can tab between menus just by a click
  - Twist and press - Needs two fingers to be operated and so the operator has to let go of the steering device

All solutions for control function except for the ones consisting of buttons and/or scrolls were eliminated. The remaining concepts can be formed in a way that lets the operator to interact with the Co-Pilot either by using presets or by navigating in menus.

Table 10 - Sub solutions remote control

Sub Solutions
Interaction with Co-Pilot
Joystick (Presets)
Touch (Presets)
Buttons
- Button with presets
- Buttons for navigation in menues
Scroll (Presets)
Voice control
Joystick + buttons (Navigation in menu)
Scroll + buttons (Navigation in menu or presets)
Optical (Navigation in menu)
Optical + buttons (Navigation in menu)
Trckball + buttons (Navigation in menu)
Trackball (Navigation in menu)

Red	Sub solution eliminated due to unsuffisient fulfillment of requirements
Orange	Sub solution eliminated because it is clearly worse than the others

Table 11 - Concepts

Concepts	
Remote control	
Concept	**Solution**
	Control Function
R1	Button (Presets)
R2	Buttons (Navigation in menues)
R3	Scroll (Presets)
R4	Scroll + buttons (Navigation in menu)

4.4 Evaluation

The results of the elimination process is presented in this subchapter.

4.4.1 Pugh matrix

All concepts from the morphological matrix were put into a Pugh matrix where the concepts were compared to a chosen reference. The objectives that could not be evaluated, due to their dependence of the position and shape of the remote control (which will be decided when the worst attachment concepts are eliminated and the remaining concepts are furthered developed and integrated with a remote control), were marked red in the matrix.

In a Pugh matrix the concepts only measures if they are better, worse or equally good as the reference and not by how much better or worse they are. This is marked in the matrix by (+), (-) or 0 respectively, were the concept (not the reference) and function crosses each other. In the end a sum is calculated for each concept, based on how many (+) (representing +1) and (-) (representing -1) it was assigned. Then the concepts were ranked according to their sum, the concept with the highest sum is ranked 1 and the concept with the second highest sum is ranked 2 and so on (Johannesson et al., 2013).

The result of a Pugh matrix depends on the reference. To ensure that the ranking of the concepts actually was correct, another Pugh matrix was performed with the highest ranked concept from the first matrix as reference.

The results from the Pugh matrices are displayed in table 12 and 13, in the first matrix was concept 1 reference and in the second matrix was it concept 29.

Table 12 - Pugh matrix 1

Pugh Matrix																														
Attachment Excavator, Wheel loader and Dumper																														
Objective	**Concept**																													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Ease of use	REFERENCE																													
Minimize dislocation after impact (Schokproof)		-	0	-	+	0	0	-	0	-	+	0	-	-	-	-	-	-	-	-	-	-	-	-	0	-	0	-	+	0
Minimise risk of accedental operation																														
Minimize steps for battery change		0	0	0	+	-	0	0	0	0	+	-	0	0	0	0	+	-	0	0	0	0	+	-	0	0	0	0	+	-
Minimize the number of steps to attach the bracket		0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
Minimize the number of steps to attach the remote controll		-	0	-	+	-	0	-	0	-	+	-	0	-	0	-	+	-	0	-	0	-	+	-	0	-	0	-	+	-
Minimize volyme		-	0	-	+	0	0	-	0	-	+	0	+	0	+	-	+	+	-	-	-	-	+	-	0	-	0	-	+	0
Minimaize number of materials																														
Enable a ergonomimc position of the remote control for 95% of the population																														
Button tacltile simiular to the already existing bottons on joystick																														
Express quality		+	+	-	+	-	+	+	+	-	+	0	-	-	-	-	0	-	-	-	-	-	0	-	+	+	+	-	+	0
Express ergonomic																														
Be aesthetical pleasing		0	+	-	0	+	0	-	0	-	0	0	-	-	-	-	0	-	0	0	0	-	0	0	0	0	+	-	0	+
Sum +		1	2	0	5	1	1	1	1	0	5	0	1	0	1	0	3	1	0	0	0	0	3	0	1	1	2	0	5	1
Sum -		3	0	5	0	3	1	5	1	6	1	3	4	5	4	5	2	6	3	4	3	5	1	5	0	3	0	5	0	2
Total	0	−2	2	−5	5	−2	0	−4	0	−6	4	−3	−3	−5	−3	−5	1	−5	−3	−4	−3	−5	2	−5	1	−2	2	−5	5	−1
Ranking	**5**	**7**	**3**	**10**	**1**	**7**	**5**	**9**	**5**	**11**	**2**	**8**	**8**	**10**	**8**	**10**	**4**	**10**	**8**	**9**	**8**	**10**	**3**	**10**	**4**	**7**	**3**	**10**	**1**	**6**

Table 13 - Pugh matrix 2

Pugh Matrix																														
Attachment Excavator, Wheel loader and Dumper																														
Objective																														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Ease of use																														
Minimize dislocation after impact (Schokproof)	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-		-
Minimise risk of accedental operation																														
Minimize steps for battery change	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-		-
Minimize the number of steps to attach the bracket	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	REFERENCE	0
Minimize the number of steps to attach the remote controll	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-	0	-	-	-	-	-		-
Minimize volyme	-	-	-	-	0	-	-	-	-	-	0	-	0	-	0	0	+	0	-	-	-	-	-	-	-	-	-	-		-
Minimaize number of materials																														
Enable a ergonomimc position of the remote control for 95% of the population																														
Button tacltile simiular to the already existing bottons on joystick																														
Express quality	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
Express ergonomic																														
Be aesthetical pleasing	0	0	+	-	0	+	0	0	+	-	0	+	-	-	0	-	-	0	0	0	+	-	0	+	0	0	+	-		+
Sum +	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0		1
Sum -	5	5	5	6	1	5	6	6	6	7	2	6	6	7	5	6	3	5	5	5	5	6	2	5	5	5	5	6		5
Total	−5	−5	−4	−6	−1	−4	−6	−6	−5	−7	−2	−5	−6	−7	−5	−6	−2	−5	−5	−5	−4	−6	−2	−4	−5	−5	−4	−6	0	−4
Ranking	**5**	**5**	**4**	**6**	**2**	**4**	**6**	**6**	**5**	**7**	**3**	**5**	**6**	**7**	**5**	**6**	**3**	**5**	**5**	**5**	**4**	**6**	**3**	**4**	**5**	**5**	**4**	**6**	**1**	**4**

After comparing the two matrices it is evident that the result shifted a bit depending on the reference. This means that a concept's exact ranking cannot be determined. However, a concept ranked in the bottom half in both matrices is clearly not performing as well as the other concepts and is therefore eliminated from the process. This means that concepts 4, 8, 10, 12, 13, 14, 15, 16, 18, 19, 20, 22 and 28 are eliminated.

The concepts that went on to the next step in the process of the elimination are listed in table 13.

Table 13- Remaining concepts of Pugh matrix for Excavator, Wheel loader and Dumper

Remaining Concepts		
Attachment Excavator, Wheel Loader and Dumper		
Concept	Solution	
	Attachment Steering Device	Attachment Remote Control
1	Tape + Plate	Remote control with resilient sprint
2	Tape + Plate	Twisting lock
3	Tape + Plate	Rails with locking sprint
5	Tape + Plate	Permanent on the attachment for steering device
6	Tape + Plate	Tape
7	Two halves joined with screws	Remote control with resilient sprint
9	Two halves joined with screws	Rails with locking sprint
11	Two halves joined with screws	Permanent on the attachment for steering device
17	Elastic clamp locked with screw	Permanent on the attachment for steering device
21	Two halves joined with one joint and one snap lock	Rails with locking sprint
23	Two halves joined with one joint and one snap lock	Permanent on the attachment for steering device
24	Two halves joined with one joint and one snap lock	Tape
25	Two halves joint with one joint and one screw	Remote control with resilient sprint
26	Two halves joint with one joint and one screw	Twisting lock
27	Two halves joint with one joint and one screw	Rails with locking sprint
29	Two halves joint with one joint and one screw	Permanent on the attachment for steering device
30	Two halves joint with one joint and one screw	Tape

4.4.2 Further elimination

The personnel at CPAC with experience of driving this sort of vehicles were asked where they thought the concepts could be placed on the different steering devices. These are the conclusions drawn from the investigation:

- The single lever cannot be clamped in any way - A clamp on the handle of the joystick would interfere with the grip and there is no where it can be attached underneath the handle due to the gaiter.
- The steering wheel for the wheel loader is not suited for an attachment for the remote control - The direction of the steering wheel is reset after turning the vehicle off and on again, this means that the position that the steering wheel had when the wheel loader was turned off is the new position for steering straight forward.
- The remote control cannot be fitted onto the multi levers - Some operators of a wheel loader equipped with multi levers maneuver the vehicle by either resting the hand on the levers and only touching the top of the levers or by a bigger movements that include pushing the levers forward or backward by using the levers whole area. Due to the second operator style there is not possible to place the remote on the levers.
- The remote should not be attached to the outer ring of the steering wheel - The operators will be able to change position of the hands without interference.
- It is possible to attach the remote control to the steering wheel of dumpers - This steering wheel always has the same position for steering straight forward.
- It is possible to attach the bracket to the L8 joystick by clamping the bottom of the handle - The bottom of the handle is equipped with a metal plate which can be accessed for retrofitting of the remote control.

Based on these conclusions the following concepts were eliminated for all vehicles:

- Concept 11, 17, 23 and 29 (all concepts with a permanent attachment of the remote control combined with any kind of clamp) - The joysticks of the wheel loader are not suitable for any sort of clamp and since the remote control needs to be the same for all vehicles a permanent solution of the remote control combined with a clamp is no longer possible for any vehicle.

Based on these conclusions the following concepts were eliminated for the wheel loader:

- Concept 7, 9, 21 24, 25, 26, 27 and 30 (all concepts with a clamp function) - The joysticks of the wheel loader are not suitable for any sort of clamp and the steering wheel is not suitable for any attachment of the remote control.

To narrow down the number of concepts even more, they were compared to each other and the concepts evidently worse were eliminated. The following concepts were eliminated for all vehicles:

- Concepts 6, 24 and 30 - These concepts all have tape as an attachment of the remote control. The tape solution would obstruct the battery change, since the whole backside of the remote control is permanently attached to the bracket. The battery change would then be carried out by unscrewing the top of the remote control, instead of just opening a snap hatch.
- Concepts 2 and 26 - These concepts all have a twisting lock as an attachment of the remote control. The twisting lock consist of either a circular remote with threads on the bottom or on the sides which will be fitted into the bracket and makes it either thicker or wider than for the solutions with rails or resilient sprint. Even if the remote control is a quadrangle the bracket needs to be wider to make it possible to twist the remote control.

The bracket for twisting lock is eliminated due to it requires more volume than rails and resilient sprint.

- Concepts 1 and 25 - Both concepts have the same solution for the attachment of the remote control, *remote control with resilient sprint.* For this solution to be as shockproof as rails with locking sprint the frame needs to be very tight around the remote control which makes it harder to mount the remote control into the frame.
- Concept 21 (two halves joint with one joint and one snap lock, rails with locking sprint) - The snap lock cannot be as hard tightened as the concepts with screws, which makes the bracket more unstable than the other concepts.
- Concepts 7 and 9 - These concepts all have two halves joined with screws as a steering device attachment. This solution is more difficult to attach then the solution with two halves joined with one joint and one screw, where one end of the halves always is in the right position and automatically fits the other ends into the right position. While for concepts 7 and 9 the two halves must be fitted to each other and held in right position while the operator tightens the screws.
- Concept 5 (Tape + plate and permanent attachment of remote control) - The plate would have to be shaped after the geometry it is taped onto and since the different steering devices all have very different shapes it is not possible to find a solution that fits all

The remaining concepts are listed in table 14-16.

Table 14 - Remaining concepts for the excavator attachment

Remaining Concepts		
Attachment Excavator		
Concept	Solution	
	Attachment Steering Device	Attachment Remote Control
3	Tape + Plate	Rails with locking sprint
27	Two halves joint with one joint and one screw	Rails with locking sprint

Table 15 - Remaining concepts for the wheel loader attachment

Remaining Concepts		
Attachment Wheel loader		
Concept	Solution	
	Attachment Steering Device	Attachment Remote Control
3	Tape + Plate	Rails with locking sprint

Table 16 - Remaining concepts for the dumper attachment

Remaining Concepts		
Attachment Dumper		
Concept	Solution	
	Attachment Steering Device	Attachment Remote Control
3	Tape + Plate	Rails with locking sprint
27	Two halves joint with one joint and one screw	Rails with locking sprint

4.4.3 Defining concepts for further investigation

The remaining concepts are described and developed into a complete idea, with both a bracket and remote control.

4.4.3.1 Concept 3

Concept 3 is a plate that on one side is formed for the specific steering device it will be attached to, this side is then taped against the steering device. The other side is equipped with an attachment for the remote control, consisting of a frame with rails. To attach the remote control, it is slid into the rails and then locked with a resilient sprint on one of the sides (figure 48-49).

Concept 3 is possible for all the different steering devices (L8, Single lever, multi lever and dumper steering wheel), but there will be different solutions for different vehicles because the plates is specifically formed for the steering devices it will be attached to.

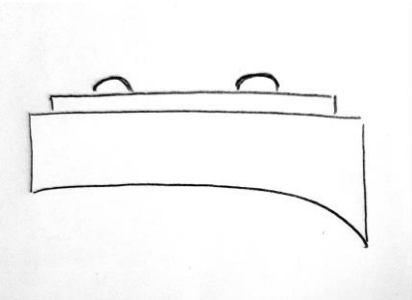

Figure 48 - plate for single lever

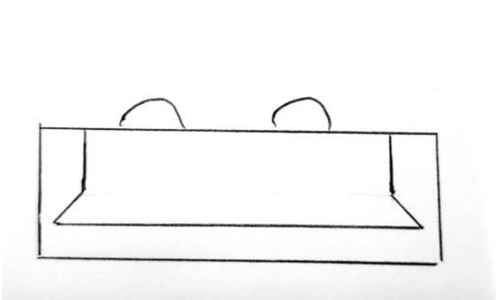

Figure 49 - remote control attachment, rails

4.4.3.3 Concept 27

Concept 27 consist of a clamp (two halves joint by one screw and one joint, see figure 50) which is attached around the bottom of the joystick, for the excavator (see figure 51). From the clamp a lever goes up to the appropriate height for the remote control. The end of the lever is equipped with an attachment for the remote control, consisting of a frame with rails. To attach the remote control, it is slid into the rails and then locked with a resilient sprint on one of the sides (see figure 52).

For the dumper the clamp is put around one of the spokes and is equipped with an attachment for the remote control (see figure 53).

This solution is only possible for the excavator and dumper.

Figure 50 - Two halves, one joint and one screw

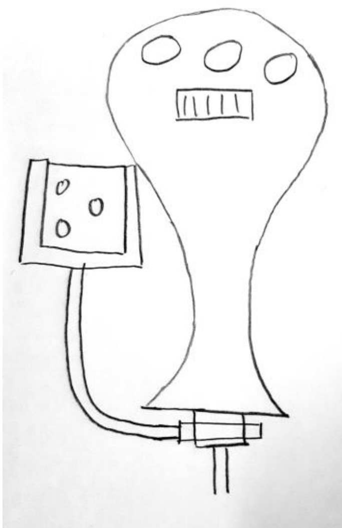

Figure 51 - Excavator joystick

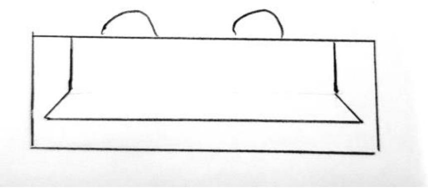

Figure 52 - Remote control attachment

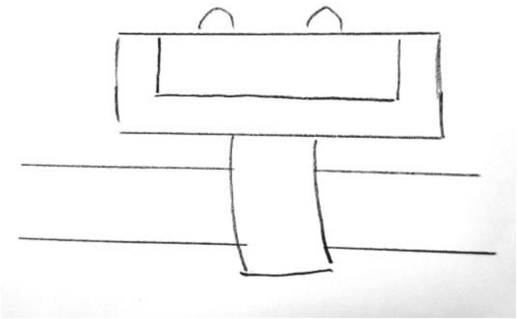

Figure 53 - Steering wheel dumper

4.5 Clay and cardboard models

The remaining concepts were further developed and in this chapter the models representing each concept is demonstrated.

4.5.1 Concept 3 - Excavator, L8

The tape concepts for the L8 joystick can only be fitted at the top of the handle, due to already existing buttons on the joystick. The concept can look like figures 54, where a frame is mounted directly onto the joystick and then the remote control is attached with rails.

If this concept is used the operator would have to loosen the grip and move the wrist in an ulnar motion to reach the keys (see figure 55). The remote control is operated with the thumb, but since it is placed in such far distance from the normal grip the scrolling motion does not come naturally.

Figure 54 - Concept 3 attached to the L8 joystick

Figure 55 - Hand position when operating the remote control

4.5.2 Concept 27- Excavator, L8

Concept 27 for the L8 Joystick can look like figure 56, where the bracket is attached at the bottom of the handle and a lever goes up to an appropriate height for the remote control. The remote control is attached by sliding it into a frame with rails.

When using concept 27 for L8 joystick, the grip can be maintained during the operation of the remote control, which is conducted by the middle finger and ring finger (see figure 57 - 58). Scrolls is not suitable for this concept since the scrolling motion do not come natural for those fingers.

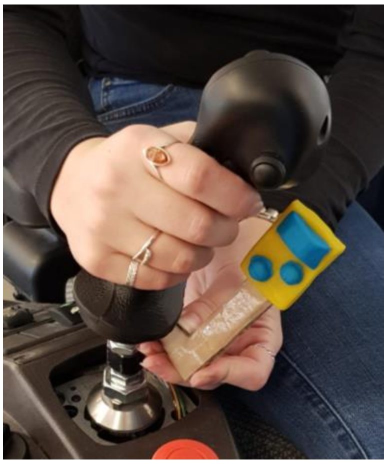

Figure 56 - Concept 27 attached to the L8 joystick

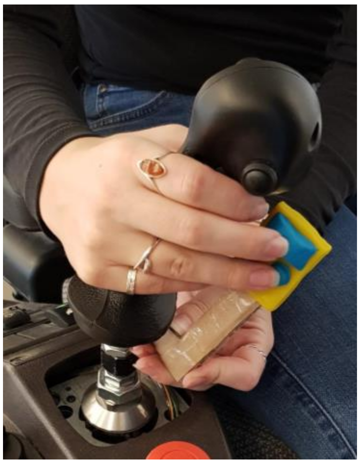

Figure 57 - Hand position when operating the remote control from the side

Figure 58 - Hand position when operating the remote control from the back

4.5.3 Concept 3, version 1 - Wheel loader, single lever

Version 1 of concept 3 consists of a plate attached to the single lever with tape. The plate forms a support for the thenar to make the handle more ergonomic. From the plate a lever goes out in front of the joystick to enable a suitable position of the remote control, which is attached by sliding into a frame with rails (see figure 59 – 60).

The remote control is operated by the index finger and middle finger (see figure 61) and the grip can be maintained during the operation. Scrolls are not suitable for this concept since the scrolling motion do not come natural for those fingers.

Figure 59 - Concept 3 attached to single lever, seen from the side

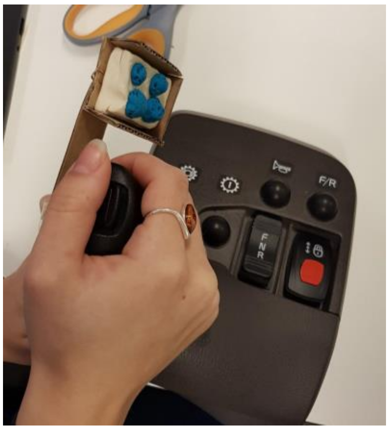

Figure 60 - Concept 3 attached to single lever, seen from above

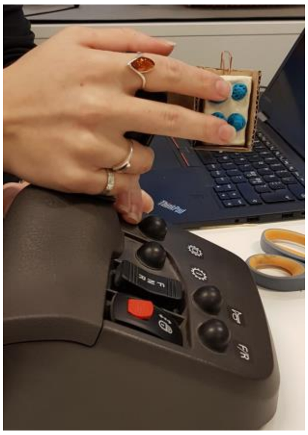

Figure 61 - Hand position when operating the remote control

4.5.4 Concept 3, version 2 - Wheel loader, single lever

Version 2 of concept 3 for the single lever is attached to the console behind the joystick (see figure 62). The plate is attached to the console with tape and the frame for the remote control is angled towards the operator for a more ergonomic operation. The remote control is attached to the frame by sliding it into rails.

The remote control is operated by the index finger, middle finger or ring finger (see figure 63) to reach the keys the hand must be moved from the original position (see figure 64). Scrolls are not suitable for this concept since the scrolling motion do not come natural for those fingers.

Figure 62 - Concept 3 attached to the console behind of the single lever

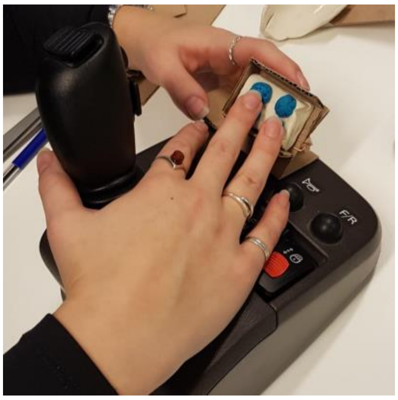

Figure 63 - Hand position when operating the remote control

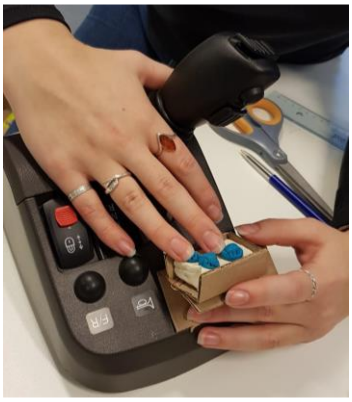

Figure 64 - Concept 3 attached seen obliquely from above

4.5.5 Concept 3, version 1 - Wheel loader, multi lever

The plate in concept 3 version 1 for the wheel loader with multi levers will be mounted with tape in the back of the console (see figure 65). The plate will go up over the console and bend away from the console where the bracket for the remote control will be mounted (see figure 66). Figure 67 and 68 show the distance between the remote control and the fingers when the hand rests on the levers. The space between the bracket for the remote control and the fingers when the levers are fully forward is displayed in figure 69.

The remote control is operated by index finger, middle finger or ring finger. The hand can be kept on the levers during the operation, although a small adjustment of the hand position may be required depending on the size of the hand. Scrolls are not suitable for this concept since the scrolling motion do not come natural for those fingers.

Figure 65 - The plate attached to the console

Figure 66 - Display position of the remote control

Figure 67 - Distance between fingers and levers in neutral position

Figure 68 - Fingers operating the remote control

Figure 69 - Distance between fingers and levers, when in forward position

4.5.6 Concept 3, version 2 - Wheel loader, multi lever

In version 2 of concept 3 the plate with the bracket for the remote control is located in the left front corner of the console, as shown in figure 70 and 71. Since the levers are located on the operator's right side of the console, the remote control is positioned on the left side of the console for enable the thumb to operate the remote control.

When operating the remote control, the hand must be flexed (see figure 72) or the whole arm has to be moved (see figure 73) to reach the buttons. Even though the operator uses the thumb to press the keys it is not suitable with scrolls due to the highly flexed position of the wrist, if scrolls are used the operator will have to move the whole arm to be able to use the remote control.

Figure 70 - The placement of the remote control

Figure 71 - Hand position when levers are in neutral

Figure 72 - Reaching for the remote control while keeping the hand on the levers

Figure 73 - Reaching for the remote control after moving the arm backwards

4.5.7 Concept 3 - Dumper, steering wheel

Concept 3 for the dumper consist of a plate with a bracket for the remote control that can be taped directly onto one of the spokes (see figure 74).

The operation of the remote control, when placed as in figure 74, is conducted by the thump, no flexion or extension of the wrist is required. In this solution it is possible with scrolls since it is operated by the thumb when the hand is close to its natural position.

Figure 74 - The placement of the remote control

4.5.8 Concept 27 - Dumper, steering wheel

In this concept the bracket is attached to one of the spokes. The frame for attachment for the remote control is located on top of the spoke (see figure 75). The remote control builds on the height, but it can still be operated by the thumb with a natural hand position.

In this solution it is possible to use scrolls since it is operated by the thumb and no extension or flexion of the wrist is required.

Figure 75 - The remote control placed on top of the stoke

4.5.9 Evaluation of the models

In this subchapter all the models will be evaluated and then eliminated until only one concept for each vehicle remains.

4.5.9.1 Remote control

A conclusion from the models, which were in common for all the steering devices, is that no scrolls will be used, since the remote control will be the same for all the vehicles and scrolls are only suitable for the dumper.

The models also led to the decision to only include two buttons on the remote control, even though it was desired more for the excavator. This decision was based on the fact that the remote control will be located where the operator cannot see the buttons for the single lever, which makes it harder to differ the buttons from each other. Also, the Dumper and the wheel loader only needed two buttons, which makes it optimal for two out of three.

4.5.9.2 Excavator - L8

The benefit of using the tape solution is that the buttons are visible for the operator and that it is not as easy to get stuck in on the way in and out of the cabin. The downside of the concept is that the operator must let go of the joystick and put the wrist in an ulnar deviation in order to reach the remote control. This cannot be avoided because this is the only position that is not interfering with the ergonomic shape or already existing buttons of the joystick.

The lever on the other hand enables the operator to keep the original grip and just reach out with the middle and ring finger to operate the remote control, but in this concept the buttons are not visible and the lever is easier to get stuck in, however if the lever is put on the right joystick it minimizes the risk of accidentally getting stuck in the remote control, since the door into the cabin is located to the left of the operator. To help the operator to know which button is which the different keys can be formed into different shapes.

The purpose of this project is to make is easier for the operator to operate the Co-Pilot and the big downside with the tape solution is that it makes it much harder to access the keys, to which nothing can be made. While the downsides for the concept with a lever can be improved with smart design. Since the objective to enable an ergonomic grip is the most important, the tape concept is eliminated.

4.5.9.3 Wheel loader - Single lever

The benefit with version 1 of concept 3 is that it offers an ergonomic support for the thenar and at the same time puts the remote control within reach from the normal grip of the joystick without interfering the grip. One disadvantage of the concept is that the operator cannot see the buttons which make it difficult to know which button is which. This can be solved by smart design of the remote control that allows the operator to feel difference between the different buttons. Another downside is that bracket is easy to hit accidentally when getting in or out of the machine.

The benefit for version 2 is that the bracket and the remote control have a more protected placement, which makes it hard to accidental hit in comparison with version 1. The downside with version 2 is that the operator needs to let go of the joystick to be able to operate the remote control.

The big advantage of the ergonomic grip is the support if offers to the operator’s thenar and that the operator can reach the remote control without releasing the joystick. The risk of tearing the bracket of the joystick is a bit higher than the plate behind the joystick, but with a high strength tape the risk of it happening should not be that big. With this in mind, the plate version 2 of concept 3 is eliminated.

4.5.9.4 Wheel loader - Multi lever

The plate located behind the levers (version 1) is easy to reach from the normal operating position, for most people it would only require an extension of the index, middle or ring finger and for those with really short fingers a small movement of the arm. Its placement would not be in a risk area for accidental operation of the remote control or to get stuck and tear of the bracket.

Version 2 includes a plate located in front of the joystick on the left side of the console, this puts the remote control in an area that easily could be hit by clothing or anything that sticks out of the pocket. This means that the risk of accidentally pressing any button and to tear the bracket of the console is higher for version 2 than version 1. The operation angle for the hand is not ideal in this version either, since for everyone with an average hand size or smaller would have to flex the wrist or move the arm to reach the remote control.

From the above mention arguments for each version of concept 3 it is clear that version 2 is not as good as version 1 and is therefore eliminated.

4.5.9.5 Dumper - Steering wheel

The tape solution (concept 3) for the steering wheel is small and only changes the surface of the upper side of the steering wheel. Another advantage for the tape solution is that it does not need any tools to be attached, however once the bracket is attached it cannot be removed without leaving a mark and if removed it needs a new tape to be reattached.

The clamping solution (concept 27) add on volume all around the spoke when it is assembled on and needs a screwdriver to be assembled, but on the plus side the clamp can be attached and removed multiple times and does not leave as distinct mark as the tape.

Concept 3 is eliminated due to there were an objective that the bracket should not leave any marks.

4.6 CAD model

The remote control will be the same for all the vehicles and therefore is the frame, in which the remote control is attached, the same for all the different steering devices as well.

The CAD models, created in Creo Parametric 3.0, are presented in the following subchapters.

4.6.1 Remote control

The remote control consists of 8 parts, (from the bottom to the top in figure 76) the battery hatch, the bottom hatch, the PCB, the mainframe with rails, the rubber mat, two buttons and the top. Figures 77 and 78 shows the remote control assembled.

The bottom hatch and battery hatch are held in place with screws, while the rubber mat and the top are glued onto the mainframe. The PCB is clamped between the bottom hatch and the mainframe and the buttons are clamped between the top and the rubber mat.

The rubber mat and rubber lists placed between the bottom hatch and the mainframe and between the battery hatch and bottom hatch will make the remote control water and dust resistant.

The top is designed with a barrier between the buttons to make it easier for the operator to identify the buttons, since the operator cannot see the buttons when the remote control is attached to the single lever or L8 joystick she/he would have to identify the buttons by feel.

Figure 79 illustrates the frame that the remote control will be attached to, this is the part that will be the same for all the brackets. The remote control is slid into the frame on rails and is kept in place by a resilient sprint. In figure 80 the remote control is attached to the frame.

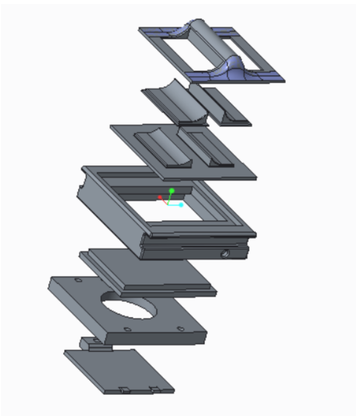

Figure 76 - Parts of the remote control

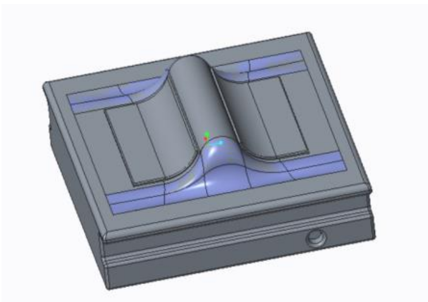

Figure 77 - The remote control from above

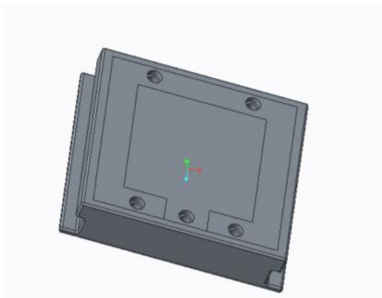

Figure 78 - The remote control from below

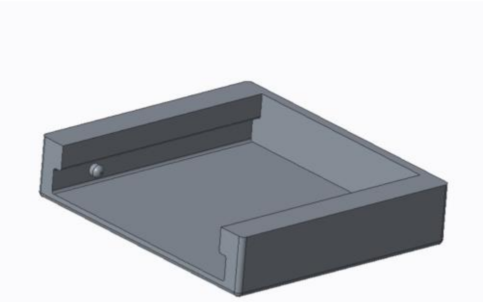

Figure 79 - Frame for attachment of the remote control

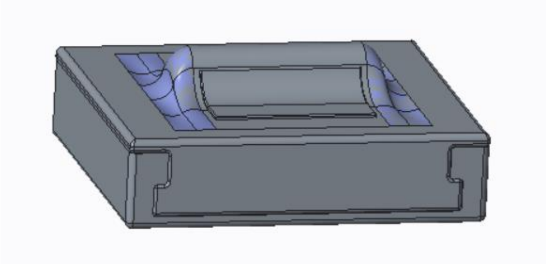

Figure 80 - The remote control attached to the frame

4.6.2 Excavator - L8

The bracket for the L8 joystick is clamped around a metal plate below the handle, where the gaiter normally is attached. When the bracket is mounted there is no longer room for the gaiter to be attached at the same place, therefore is the bracket equipped with a plate just below where the metal plate would be, for the gaiter to be attached to.

The bracket consists of two parts one half that positions the remote control and the other half for the clamping function. The two halves are joined by a screw in one end and a joint in the other end (see figure 81 and 83).

Figure 82 and 84 displays the bracket mounted onto the L8 joystick.

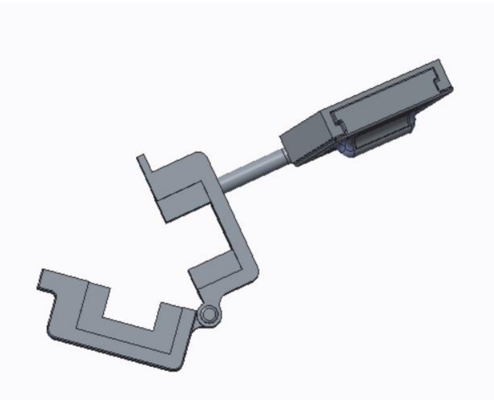

Figure 81 - Bracket for the L8 joystick seen from above

Figure 82 - Bracket mounted on the L8 joystick seen from above

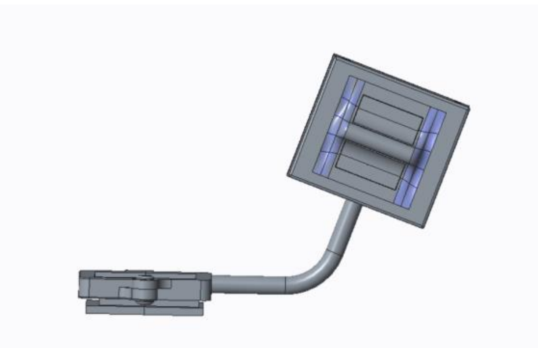

Figure 83 - Bracket for the L8 joystick seen from the right

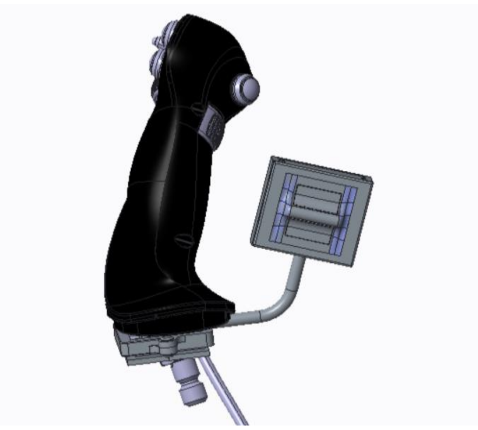

Figure 84 - Bracket mounted on the L8 joystick seen from the right

4.6.3 Wheel loader - Single lever

The single lever bracket (figures 86 and 88) is an ergonomic support for the thenar and will be taped onto the joystick. From the ergonomic support a lever extends out in front of the single lever and holds the frame for the remote control on an appropriate distance to enable easy interactions with the Co-Pilot.

The remote single lever is shown mounted on the single lever in figures 85 and 87.

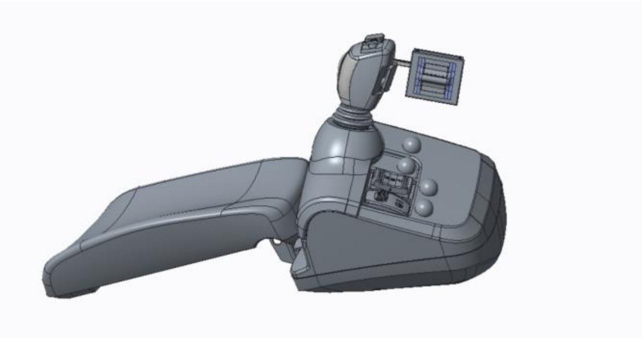

Figure 85 - Bracket mounted on the single lever seen from the right

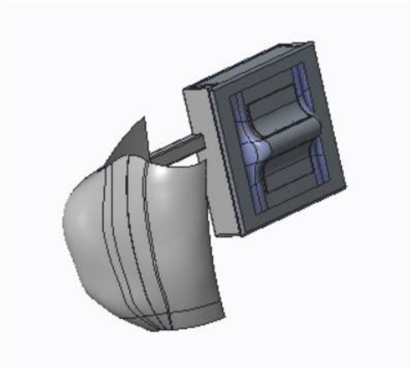

Figure 86 - Single lever bracket seen from right rear

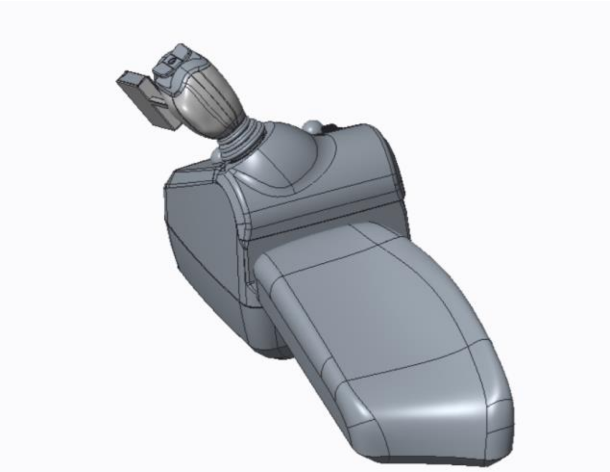

Figure 87 - Bracket mounted on single lever seen from the rear

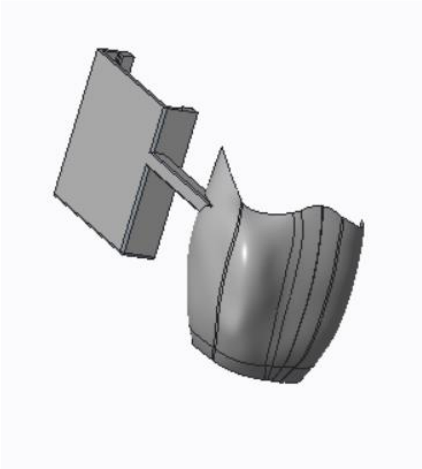

Figure 88 - Single lever bracket seen from the left rear

4.6.4 Wheel loader - Multi lever

The big rectangular plate on the bottom of the bracket (see figure 89) is taped onto the console. The frame for the remote control is then held by the bracket on a height similar to where the hand is at rest on top of the multi lever. The angle of the remote control (see figure 90) enables a more natural pushing motion then if it would have been in the same direction as the rectangular plate.

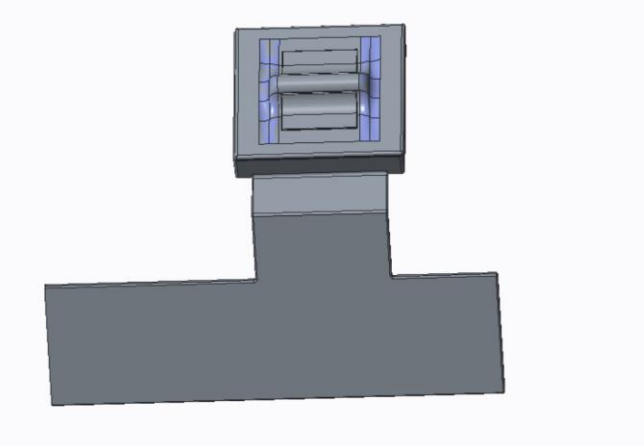

Figure 89 - Bracket for multi lever

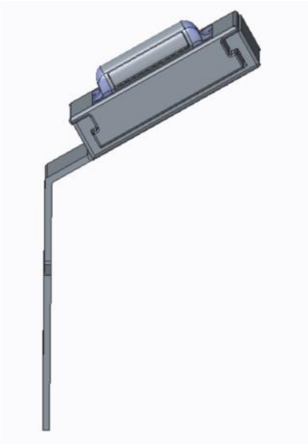

Figure 90 - Bracket for multi lever seen from the right

4.6.5 Dumper - Steering wheel

The bracket for the dumper is clamped around one of the spokes. The bracket consists of two parts (see figure 91), the top half that contains the frame for the remote control and the bottom half for the clamping function. The two halves are joined by screws in one end and a joint in the other end.

The spokes are wider at the center of the steering wheel, therefore the bracket will only be able to be attached at the end of spoke, close to the outer ring of the steering wheel (see figure 92 and 93).

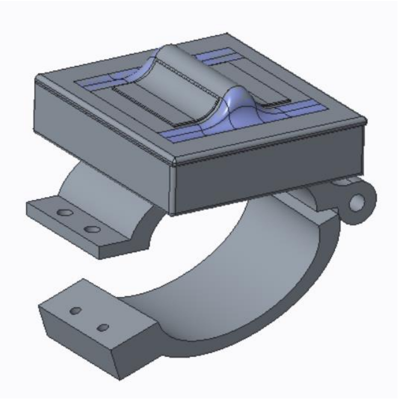

Figure 91 - Bracket for the dumper

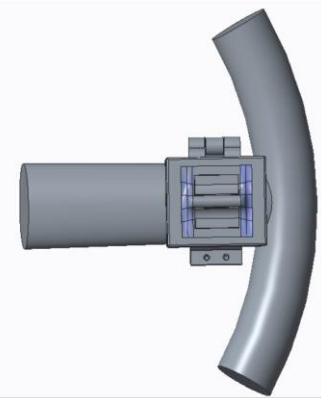

Figure 92 - Bracket mounted on the steering wheel seen from above

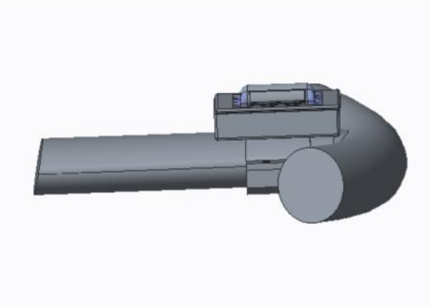

Figure 93 - Bracket mounted on the steering wheel seen from the side

4.7 Prototype

This subchapter handles the evaluation of the prototypes. The prototypes were 3D-printed from the CAD drawings in plastic.

The clients were asked to test the brackets and remote control assembled on the steering devices, to see if a person with experience of driving these vehicles had any other opinions then the project group.

4.7.1 Excavator - L8

The prototype for the L8 joystick were not able to be completely assembled onto the joystick, due to a nut on the metal plate, but it was close enough to perform tests of the prototype.

The users liked the overall placement of the remote control (see figure 94-95) and the design with a bar between the buttons of the remote control, this made the remote control easy to operate. They would however like to place the remote control a bit higher up to be able to operate the control with the index finger and middle finger, instead of middle finger and ring finger (see figure 96).

Figure 94 - Bracket mounted onto L8 joystick

Figure 95 - Space between hand bracket when mounted

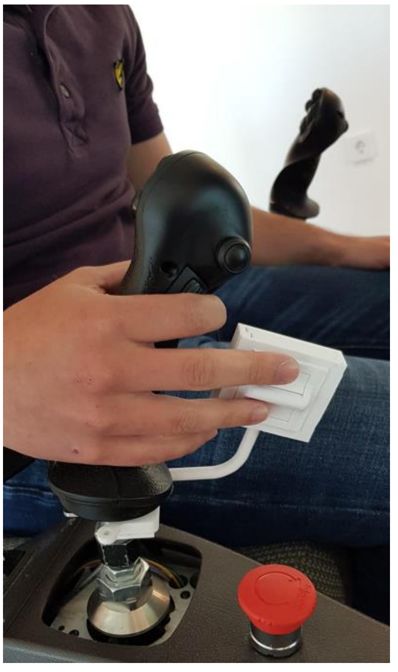

Figure 96 - Hand position during operation of the remote control when mounted

4.7.2 Wheel loader - Single lever

The bracket for the single lever got an overall good review, the grip and the left/right placement of the remote control passed without any remarks, but the distance between the joystick and the remote control were too big to reach the buttons (see figure 97) and the lever that holds the frame in place were in the way for a person with long fingers.

Figure 98 shows the support for the thenar and in figure 99 the position of the hand during operation of the joystick is shown.

Figure 97 - Hand position during operation of the remote control

Figure 98 - The support for the thenar

Figure 99 - Hand position during operation of the joystick

4.7.3 Wheel loader - Multi lever

The bracket attached to the console were experienced too far away from the multi levers by the users (see figure 100 - 101). Therefore, another prototype was created, where the remote control is places closer to the levers (see figure 102 - 105). The second prototype were proven better in the client’s tests since it was easier to reach.

There were split opinions on however the separating barrier between the buttons were in the making it hard to find the buttons fast or if it did not affect the operation.

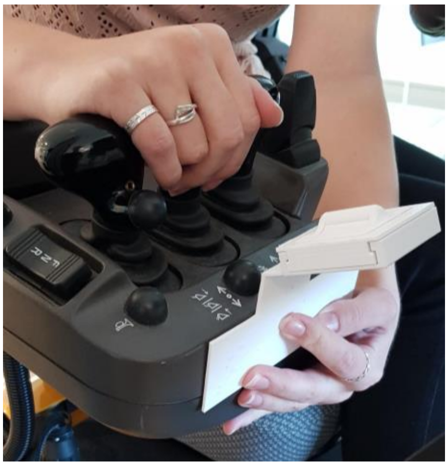

Figure 100 - Space between hand and bracket when resting on the levers

Figure 101 - Space between hand and remote control when reaching for the buttons

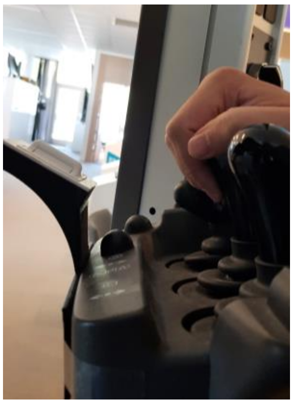

Figure 102 - Levers in neutral

Figure 103 - Reaching for remote control

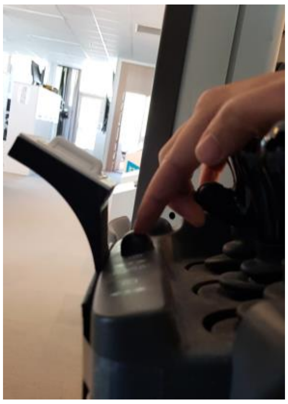

Figure 104 - Reaching for button on the console

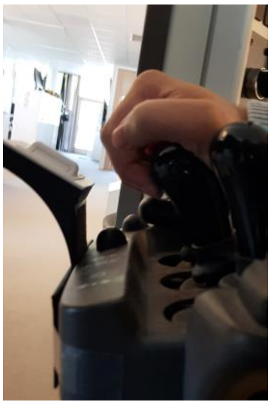

Figure 105 - Levers pushed fully forward

4.7.4 Dumper - Steering wheel

When attached to the dumper steering wheel the barrier between the buttons become more of an obstacle than a help and making it hard to reach the top button. The placement on the spoke forces the operator to have a lower grip on the steering wheel than the normal (10 to 2) grip to be able to operate the remote control (see figure 106-107).

To enable a higher grip a new prototype was made, where the remote control was placed slightly above the spoke (see figure 108-109). This prototype was more appreciated by the clients than the first one (where the remote control where placed on the spoke), but the barrier were still a problem.

Figure 106 - grip on the steering wheel

Figure 107 - grip when operating the remote control

Figure 108 - grip while maneuver the Dumper

Figure 109 - grip while operating the remote control

5 Discussion

Each requirement in the specification were supposed to be tested to make sure they were met, but since the project ended with a 3D printed prototype of the mechanical parts all requirements could not be tested. For example, no requirements of the electronics could be tested and since the 3D prints all were made in plastic the “No movement in joints when the remote control is operated” requirement were not tested. But since this only is the start of a longer project the project group considers this acceptable, as these tests will be performed on the final product.

The tests of the prototype were not tested by all the clients involved in the project due to COVID -19 and changed working hours, but the tests that were made are still believed to point in the right direction and can be used to evaluate the prototypes.

When the placement of the remote control on the L8 joystick were investigated, it become clear that it cannot be placed any higher up without interfering with the already existing buttons on the joystick or being placed out of reach. The joystick is equipped with buttons for the middle finger and ring finger, which means that the operator already is used to use these fingers to operate buttons and that it would not be a problem for the operator to use these fingers for the remote control as well. The ergonomic aspect of the L8 bracket were investigated during the tests through one test person with hands close to the 5th %ile and a second test person with hands close to the 95th %ile. The bracket worked for both persons. As for the persons outside these boundaries, it can be discussed whether the bracket should it be adjustable, so each person could have the optimal fit for their hands, or not. This would mean that it would be more parts to produce and actions would have to be taken to maintain rigidity, which would make the product more expensive. The question is of an adjustable bracket increase the value of the product enough to cover the increased price. To answer this an analysis of the production and customers interest in the product must be performed.

Another discussion point on the L8 bracket is that the company wanted to control more than two functions from the remote control. Since the excavator has two joysticks a second bracket could be made for the left joystick to double the number of buttons. But the left joystick is placed right by the door, which means that there is a high risk for the operator to get stuck in the bracket on his or her way in and out of the cabin, so maybe this is not a good idea or the lever could be detachable so the operator could remove the protrusion part of the bracket and attach it again when seated.

The remote control was experienced to be too far away from the single lever and the normal grip for the joystick. That problem could be solved by providing the bracket with an adjustable lever, so each operator could set the distance suitable for their own hand. Another opinion for the single lever bracket was that the lever holding the frame, in which the remote control is attached, were in the way for the grip for operators with long fingers. This could be solved by forming the lever into an arc to create more space for the index finger. The ergonomic support for the thenar was approximated by the project group just to create a picture of what the idea for the ergonomic part aimed to do, but to truly create an ergonomic support a more thorough study of the hand is required. With other words, the design of the single lever bracket needs further development but is a good first prototype of how a bracket for the single lever could look like.

One of the operator styles for the wheel loader multi lever (where the operator rests the hand on top of the levers), would require the operator to move the hand regardless of the placement of the remote control. The other operator style (where the operator uses the whole lever) could make it possible for the operator to keep the hand on the levers and still reach the remote control, if the hand is big enough. The placement cannot be adjusted for smaller hands, since a position closer to the levers than the second prototype would complicate the access of buttons on the console and possibly interfere with the levers when they are in forward position. But since this is such a small maneuver and since it is not performed that often, it is still okay in an ergonomic standpoint.

As for the dumper, the second prototype solved the problems of the prototype placed on top of the spoke and allowed the normal (10 to 2) grip. This means that the only notes left on the solution for the dumper were the design of the remote control.

The remote control is the same for all the different brackets, which in this case means that it is not optimal for all steering devices. The design with a barrier between the buttons were great for the single lever and the excavator, i.e. where the operator could not see the remote control the barrier helped the operator to identify the buttons. But for the dumper steering wheel the barrier was an obstacle the operator had to reach past to reach one of the buttons. The project group suggestion to solve this is to either keep working with the surface design of the remote control to see if there is a solution that works for all the steering devices or to create one remote control for each steering device and sell all the brackets separately along with the belonging remote control, instead of selling all the parts in one big package (e.g. sell the L8 bracket along with one remote control and the dumper bracket with another remote control instead of selling one remote control along with all the brackets).

6 Conclusion

This project processed the following problems:

6. How is the Co-Pilot operated today?
7. What functions should be included on the remote control?
8. Which is the best design and position of the remote control, regarding ergonomics?
9. How should the remote control be attached to the steering wheel or joystick?
10. Is the attachment the same for all the steering devices or should it be different solutions for each one?

The Co-Pilot is today operated by a touch screen tablet placed in front of the operator in the cabin, which meant that the operators had to make an interruption in their work to interact with the system.

To make the work process more effective CPAC now wanted to add a remote control on the steering device with a few functions each for the different vehicles. The excavator has a lot of different presets and they wanted a way to decrease the number of presets and a way to change set values, the wheel loader needed a way to accept and cancel the notifications from Co-Pilot and the dumper was in need for a fast way to change the camera view and to map areas. Since the remote control will be the same for all vehicles the buttons on the remote control will be programmable, which means that the operators can choose what functions they want on their own remote control.

The best placement for the L8 and single lever brackets were on the back of the joystick, the bracket were attached onto the handle, so the remote control followed its movements. The best placement of the multi lever were on the console behind the levers and for the dumper on the spoke of the steering wheel. Since they all were placed on different places and the geometry of which it was attached to varied from one steering device to another, the bracket got one design for each joystick/steering wheel.

The final design of the remote control was with two buttons separated by a barrier, to make it easier for the operator to find and identify the buttons. The remote control is attached to the bracket by being slid on rails into a supporting frame on the bracket (see figure 110), the remote control is then locked in place by a resilient sprint.

The L8 bracket was designed to clamp around a metal plate located just underneath the handle of the joystick, where the gaiter usually is attached. From the clamp a lever goes up on the backside of the joystick to hold the remote control in an appropriate position (see figure 111). When the bracket is attached to the joystick the gaiter can no longer be attached around the metal plate, therefore were the clamping part of the bracket equipped with a plate where the gaiter could be attached instead, just a bit further down from where it usually is.

The bracket for the single lever were designed with an ergonomic support for the thenar (the thumb part of the palm), from which a lever protrudes to place the remote control in the right position (see figure 112). The bracket is attached to the joystick with tape.

The multi lever bracket (see figure 113) is a plate taped onto the console and holds the remote control in the right position, close to the levers and in the same height as the top of the levers.

The final design of the dumper bracket is a clamp around one of the spokes and the frame for the remote control is placed on the side of the spoke to enable a more natural position of the hand (see figure 114).

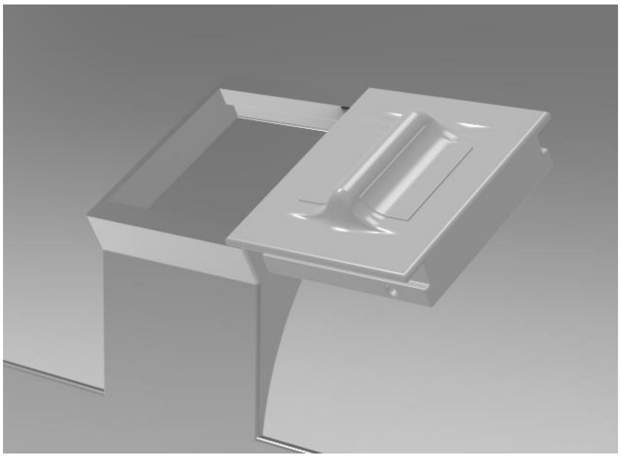

Figure 110 - Attachment remote control

Figure 111 - Final design of L8 bracket

Figure 112 - Example of single lever bracket

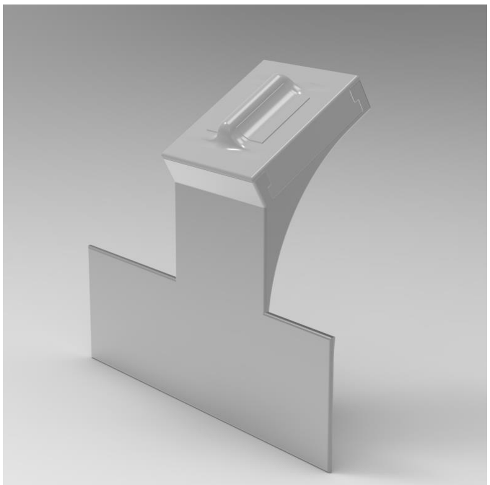

Figure 113 - Final design of multi lever bracket

Figure 114 - Final design dumper bracket

7 Further work

Since this project is the start of a longer development more work is to be done to produce a complete product. What is left to do before this becomes a complete product is selection of material, set dimensions based on material and strain and to develop the electrical parts of the remote control.

A more thorough study for the thenar support of the single lever bracket is required to make it fit the hand perfectly. Another idea that came up during the tests (that can be investigated) were to include the control functions of the remote control into the ergonomic support. Which mean that the control functions will be operated by the thumb, to maintain the ergonomics of the bracket stricter requirements for the size of the electronics is to be set.

Since the vehicles (that the remote control will be mounted in) is shaking a lot, an investigation of the possibility to charge the battery with energy from these vibrations should be done to improve the product, since it would eliminate the battery change.

Further work should include a more detailed study for the design of the top of the remote control so the final design would be easy to use in all vehicles, at the same time as the operator easily can distinguish the different control functions.

Work can be done on the bracket for the L8 joystick as well, to investigate if a second bracket should be attached on the joystick on the operators left side. Further work can also include the possibility to make the bracket adjustable, which means that the operators can set the height and angle of the remote control by themselves.

8 References

1. AB Volvo. (2020). CONSTRUCTION EQUIPMENT NORTH AMERICA: Productivity Services. Retrieved January the 22nd, from https://www.volvoce.com/united-states/en-us/services/volvo-services/productivity-services/
2. AB Volvo. (2020). THIS IS WHO WE ARE: About Volvo Group. Retrieved May the 20th, from https://www.volvogroup.com/en-en/about-us.html
3. Altium Limited. (2020). WHAT IS A PRINTED CIRCUIT BOARD? MAKE CIRCUITS BY CONNECTING COMPONENTS. Retrieved February the 3rd, from https://www.altium.com/solution/what-is-a-pcb
4. Apple Inc. (2020). Lös wifi- och Bluetooth-problem som orsakas av trådlösa störningar. Retrieved May the 20th, from https://support.apple.com/sv-se/HT201542
5. Hägg, G.M., Ericson, M. & Odenrick, P. (2008). Arbete och teknik på människans villkor: Fysisk miljö, fysisk belastning. Stockholm: Prevent.
6. Patel, P. & Davidson B. (1994). Forskningsmetodikens grunder: Att planera, genomföra och rapportera en undersökning. Lund: Studentlitteratur.
7. Pheasant, S. & Haslegrave C.M. (1996). Bodyspace: Anthropometry, Ergonomics and the Design of Work. Retrieved from https://www-taylorfrancis-com.proxy.lib.chalmers.se/books/9781315375212
8. Johannesson, H., Persson, J-G & Pettersson, D. (2013) Produktutveckling: Effektiva metoder för konstruktion och design. Stockholm, Liber
9. MathKnight (2006). File:Wheel-loader02.jpg [Electronic picture]. Retrieved May the 20th, from https://commons.wikimedia.org/wiki/File:Wheel-loader02.jpg
10. btr (2007). File:Volvo Kettenbagger EC290B 3.jpg [Electronic picture]. Retrieved MAy the 20th, from https://commons.wikimedia.org/wiki/File:Volvo_Kettenbagger_EC290B_3.jpg
11. Martinlenes (2006). File:Volvo A30D dumper.jpg [Electronic picture]. Retrieved May the 20th, from https://commons.wikimedia.org/wiki/File:Volvo_A30D_dumper.jpg
12. Raimond Spekking (2016). File:SEG DVD 430 - Printed circuit board-4276.jpg [Electronic picture]. Retrieved May the 20th, from https://commons.wikimedia.org/wiki/File:SEG_DVD_430_-_Printed_circuit_board-4276.jpg
13. Humanoc (2010). File:Pcb.jpg [Electronic picture]. Retrieved May the 20th, from https://commons.wikimedia.org/wiki/File:Pcb.jpg
14. Sullivan, K.A., (2009). Mounting clamp (US2009321588A1). U.S Patent and trademark office. https://worldwide.espacenet.com/patent/search/family/041446237/publication/US2009321588A1?q=mounting%20clamp
15. Liljevik, T. (2001). Mounting bracket (US6283425B1). U.S Patent and trademark office. https://worldwide.espacenet.com/patent/search/family/020410380/publication/US6283425B1?q=mounting%20clamp
16. Chen, J., Jin, J., Liu, S., Wang, N. & Zhao, H. (2019). Clamp (CN209431033U). The State Intellectual Property Office of The People´s Republic of China, SIPO. https://worldwide.espacenet.com/patent/search/family/067971509/publication/CN209431033U?q=mounting%20clamp
17. Eckart, D.D. & Keddie L.D. (2001). Hydraulic line mounting clamp (US2001051072A1). U.S Patent and trademark office.

https://worldwide.espacenet.com/patent/search/family/026893377/publication/US2001051072A1?q=mounting%20clamp

18. Karagias, T. (2011). Mounting clamps for coupling scopes to mounting rails of firearms (US2011271578A1). U.S Patent and trademark office. https://worldwide.espacenet.com/patent/search/family/044900962/publication/US2011271578A1?q=mounting%20clamp
19. Diccion, A.R. (2009). Joystick attachment (US2009139360A1). U.S Patent and trademark office. https://worldwide.espacenet.com/patent/search/family/040674418/publication/US2009139360A1?q=attachment%20joystick

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