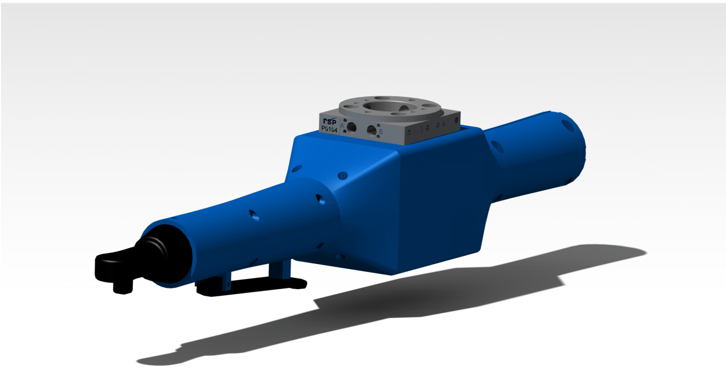


Design of a collaborative tool

Design of a generic tool for mounting/demounting of rotational design elements for use by robots and humans

Lovisa Almér
Glen Bales
Hugo Göthberg

Alexander Hocken
Apoorva Mathur
Alexandra Wickham
James Wychock

Department of Electrical Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

Department of Mechanical Engineering
PENNSYLVANIA STATE UNIVERSITY
Pennsylvania, U.S.A 2018

Contents

Executive Summary

The goal of this project was to redesign a functional prototype of a collaborative tool that could be used by humans and robots for mounting and dismounting rotational design elements in Volvo's truck manufacturing process. Collaborative robots are frequently being used in industries today because they eliminate some of the environmental and spatial dangers traditional robots encounter, allowing humans to work alongside these robots in the same space. This not only increases efficiency and production capability within a manufacturing process, but also reduces labor costs and creates a safer work environment for the human. This project was a continuation of a project from 2017, where Penn State (PSU) and Chalmers University students collaborated again to improve the previous tool created for Volvo. This project aimed to improve the previous collaborative tool by reducing the overall product weight, redesigning the shape to allow for the use of senors, minimizing the force applied for counter torque, reducing the overall cost, and making the tool more ergonomically efficient for human use.

In the Alpha phase of the project, the team worked with Volvo to compile a detailed list of customer needs and translated those needs to target engineering specifications for our final product. A Needs-Metrics-Matrix was then used to ensure that our designs concepts were meeting all of our customer needs and that those needs were accounted for within those engineering specifications. After analyzing our requirements and design concepts, the team collaborated to narrow down our design ideas into a few feasible concepts using a Pugh Matrix. In the Beta phase of the project, the team refined the final design by updating the target engineering specifications based on Volvo's feedback. This included incorporating the robot attachment not only on the top of the tool but also on the perpendicular face. Due to time constraints, the team also chose to take a gearbox and motor solution from an existing tool and fit it in the prototype. Overall, the Beta prototype grew upon the Alpha concept by changing the design of the handles and the placement of electronics inside the tool. The final steps for the project included integrating the battery, testing the electronic parts within the tool, and perfecting the physical components of the tool.

Over the past four months, the team was able to produce a functioning prototype that would allow for the mounting and dismounting of screws and bolts on an assembly line. The final tool consisted of a front and back handle, a middle compartment, a Milwaukee 3/8 ratchet tool, three 18650 batteries, and two mock robot connections. The design featured a horizontal body, as compared to a vertical body in the previous tool, which allowed the team to incorporate a front and back handle for the operator, leading to a more stable support structure for the operator. The team also added rubber grips to add comfort to the handles. This overall analysis and design of the handles targeted the operator comfort concern of the sponsor. The horizontal structure also allowed more connection points for the robot, making it easier for the robot to use the tool in multiple directions. The tool lost a great deal of surface area compared to the previous tool by condensing the drive system and battery to the handles, limiting the electrical components to the central compartment. This reduced the weight of the tool to less than 5 pounds. Overall, the redesign was extremely successful with targeting the principal concerns of the sponsor.

1 Introduction

This project is based upon the hypothesis that collaborative robots (co-robots) and humans working on the same task in manufacturing process will improve adaptability and efficiency in assembly demand. The project was a continuation of previous project where a collaborative tool was designed, but aimed to improve the tool by making it more ergonomically and economically efficient, as well as increase its capability. By doing so, the team further explored the idea that optimal human and robot collaboration could be achieved to enhance Volvo's manufacturing process by using this type of tool to mount and dismount screws into a part.

1.1 Background

Today, industries use both humans and robots to assemble products, but mostly in separate environments (Tsarouchi, Matthaiakis, Makris, & Chryssolouris, 2016). This is due to the fact that robots and humans require a different level of flexibility and adaptability when it comes to the environment needed to successfully complete a task. The goal of a collaborative tool is to solve this issue, and create a tool that doesn't replace the human but complements the operator's capabilities and relieves them of difficult tasks. This allows for a work space where both humans and robots can work simultaneously on the same task. There are many benefits for this type of collaboration in a manufacturing setting, including maximum flexibility in production volume and reduced risk for human operators (KUKA, 2017). When production demand is low, a human workforce can be working the assembly line and when the production demand is high the robots can be utilized to work together with human workers to facilitate a more efficient flow in the system. By doing so, the company would not have to hire temporary staff when demand for a product becomes high or allow workers to be idle when demand is low. They can instead do a one time investment of x-number of co-robots and thus more quickly adapt to differences in demand (*Meeting with sponsor*, 2018).

With human-robot collaboration revolutionizing industrial production, many companies are quickly adopting these tools into their manufacturing processes. Volvo Group Truck Technology (VGTT) is a company seeking to redesign a collaborative tool used by both humans and collaborative robots that performs mounting and dismounting operations in their truck manufacturing process. This project will specifically focus on developing a tool used for the mounting and dismounting of screws and bolts, and will produce the same result as a traditional torque wrench but with increased adaptability, speed, and efficiency. Instead of the user controlling the speed and duration while performing the operation, the user, either human or robot, will position the tool on the bolt and then let the tool complete the mounting procedure.

Volvo prides itself in being one of the world's leading manufacturers of trucks and other transportation equipment, but in order to achieve this goal their manufacturing processes need to produce high quality products. By combining the learning ability and flexibility of humans with the technological advantages of modern robots, the redesign of this collaborative tool will make it easier for Volvo to keep track of the quality of products being produced, and ensure proper assembly throughout their process. Overall, this project aligns with Volvo's core vision of being the most desired and successful transport solution provider in the world, while working to achieve maximum efficiency within their manufacturing process.

If implemented successfully, the development of this type of tool can save Volvo time, money and resources compared to their current human-run manufacturing process. In addition to improving Volvo's manufacturing process, this project was chosen from a technical perspective because it is a complex engineering challenge to construct a tool that satisfies ergonomic standards for human workers, while at the same time utilizing the strength, precision, and stamina of a robot.

1.2 Initial Problem Statement

The purpose of this project is to construct and redesign a tool that is lighter, smaller and more ergonomically efficient than the previous constructed prototype.

1.3 Previous tool

The previous tool created was a battery operated, working prototype of a collaborative tool drafted in CAD and 3D printed in PLA plastic. The tool had three main parts, the tool body that contained most of the electronics and the drive system, a detachable head, and two handles. To accomplish this, an impact wrench was reversed engineered and ergonomically redesigned so that it could be connected to an interface and used by the robot, but also detachable to be used by the human. The tool communicated with an overhead system via Wi-FI connection using a Robot Operating System (ROS) and a Raspbery Pie microprocessor. The Raspbery Pi micro-processor worked with ROS by allowing the overhead system to communicate with the tool for various controls such as how many impulses to apply to a bolt, when to move on to the next bolt, and when a bolt has been entered incorrectly. The final prototype was able to bolt screws in 5 seconds, and took 10 seconds to pick up a new bolt and begin the process again. The prototype reached a speed of 800 rpm, and was able able to reach a torque of 160 Nm. The accuracy requirement of $\pm 10\%$ on torque was not met because of the choice of the drive system, which resulted in a lack of space for torque and tightened angle sensors. One of the biggest future recommendations for this project was how to best manufacture the tool on a mass scale, and to explore different material options for the final 3D printed prototype. Overall, the tool successfully met the main customer requirements, was ergonomically designed for both robot and human use, and was able to produce the necessary torque to achieve the needed mounting and dismounting operations for use in Volvo's truck manufacturing processes.

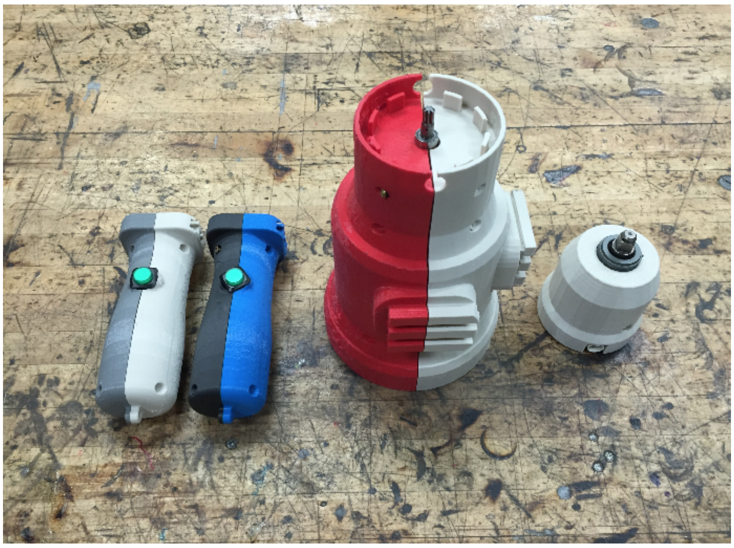


Figure 2: Previous Tool - 3D printed prototype

1.4 Objectives

The previous prototype outlined the basic customer needs, goals, and purpose of the project. In this project, the team will leverage the research, designs, and basic specifications of the previous prototype to create a more efficient and elegant design of the collaborative tool. After analyzing the previous project and gathering customer needs from Volvo, the main objectives and delimitations of the project can be seen below. These objectives and delimitations will describe the primary focus of the tool, but other detailed engineering specifications of the tool will be described in Chapter 6.

Main Objectives:

- Generate a tool for both humans and co-robots to utilize.
- Create a functional prototype that can produce >40 Nm to screw in bolts.
- Allocate space in tool for sensors, such as camera and accelerometer.
- Achieve a low weight (<2.5kg) without sacrificing structural integrity.
- Produce an optimized design proposal for a light and rigid body based on a finite element analyses.

Delimitations

The project will not:

- include functionality for sensors.
- include working software functionality for between co-robot and prototype.

- give exact speed for fastening bolts.

The objectives of this project were created by working with Volvo to figure out what is feasible to accomplish within the given time frame while also fulfilling the requirements of the tool. The team also analyzed the past team's objectives to understand where the project needed to continue in order to be successful. The reason why the project will not include the above mentioned delimitations is because the team only has one member, of 7, that has experience coding and implementing sensors. There is still other code implementation needed that will take a long time in relation to the projects duration. It was therefore deemed that the best result from this project would come from focusing on and refining the parts of the product that matched the teams main competences, which are mechanical and industrial engineering.

1.4.1 Scope of work and limitations

The project started 15/01-2018 and will conclude 25/05-2018. Due to other classes running in parallel during this project, the amount of time dedicated per week by each member will be limited to approximately:

- Chalmers: 20 hours per week per person
- Penn State University: 15 hours per week per person

Both groups have access to, and will utilize, the following software and programming language to aid in the completion of this project:

- Microsoft Office
- Catia v5 (CAD)
- SolidWorks (CAD)
- Latex
- Google Drive
- Box
- ROS

1.5 Budget

For this project, the group in total does not have a set limitation for the budget. The budget depends on the progress of the work and what the team deems is necessary to purchase in consultation with a supervisor. However, the purchasing process differs for each

University. For Chalmers, a purchase is approved if the supervisor deems it is necessary. For PSU, the students are reimbursed for purchases relevant to the project through the University.

The budget analysis, show in Table 1, outlines the costs of the items purchased throughout the project life. Most of the parts for the prototype came from the Milwaukee M12 tool (Seen in Figure 31). Throughout the project life, Chalmers and Penn State predetermined which group purchased certain components or parts for the prototype, and worked together to create the final tool.

Table 1: Total cost

Material	**Quantity**	**Cost**
Milwaukee M12™ Cordless 3/8" 12-Volt Lithium-Ion	1	$99
Milwaukee Cordless Tool Battery	1	$33
Arduino Microcontroller	1	$20
Potentiometer	1	$9
Cords and connectors	1	$38
Charger for battery	1	$40
3D printing parts	1	$275

Additionally, by the help of a scholorship from the foundation *Herbert & Karin Jacobssons Stiftelse* the Chalmers students had the opportunity to visit Penn State in April. The trip took place the week of April 8th through the 14th. This trip enabled the students to meet, develop and build the prototype together and improve the group dynamic.

2 Team and Project Management

Once the scope of the project was set, a detailed project management schedule was generated. Due to the strict deadline of the final prototype, the project was divided into an Alpha, Beta, and Gamma phase to break down each project stage. The Alpha phase outlined the project objectives, team and project management schedule, concept generation and selection, customer needs assessment, relevant patents and existing products, and target engineering specifications. A final Alpha prototype was then created in CAD, and presented to the sponsor to ensure the project direction and vision aligned with the customer's original specifications and goals. The Beta phase marked the midpoint of the project's life, and outlined what had changed since the Alpha phase of the project. The Beta phase went into further detail about the final concept selection and prototype, as well as analyzed performance predictions and tests for our selected design. The Gamma phase represented the final phase of the project, and concluded in a physical, 3D printed prototype of our design that will be delivered to Volvo.

This chapter will outline the methods the team used to deliver a final, working prototype by the end of the project. This chapter will also outline how the project was tracked to ensure our deliverables were being met, as well as our risk and safety plan which reduced the chance of failure.

2.1 Project Management

To properly track and manage the project an extensive Gantt chart was formulated, where all the delivereables and sub deliverables of the project where specified (see appendix A). This included milestones for the project, stages of prototype design and responsibilities. Each task was assigned to a point person on the team who tracked the progress of that task. The Gantt chart allowed the team to understand the future steps of the project and have a clear view of what needed to get done. Detailed in Section 2.2 are major milestones that had to be accomplished within each iteration of the product in order for the product to be successful.

2.2 Methods

During the project life, different stages were outlined in order to stay on track for the delivery of a finished, final prototype. The process started with background research and a concept generation phase, and concluded with testing and constructing the tool.

Background Research: As previously stated, the first step in this project was to do background research about the subject. This began with conducting research in human-robot collaboration as well as reading the Gamma report from last year's project. The information gained from this report was how much last year's group had accomplished regarding electronics and exterior design of the tool, as well as areas to improve upon for this redesigned tool. After initial research was performed, an external search was made to gain information about existing tools, patents and reports related to the subject of human-robot collaboration. This information was then used in the concept generating phase.

Concept Generation: The first stage of the concept generation phase was conducted by brain storming concepts based on shape, leverage for counter torque and battery placement solutions. Next, a decision on the initial concept was made by comparing all design ideas in a Pugh matrix. The results of the Pugh Matrix gave the team a single design to move forward with and implement. The concept generation phase concluded with the construction of a CAD-model of our chosen design.

CAD and Analysis: After the first concept generation stage was completed, an initial draft of the Alpha prototype was created based on a structural outline of the main body of the tool using CAD software. A basic FEA analysis was then completed on this first CAD draft. Further into the project, the design process consisted of refining the mounting tool, creating space for the sensors, implementing solutions for reducing the power train, as well as focusing on increasing the ergonomic efficiency of the tool. Throughout each iteration of the tool design, multiply FEA analyses were conducted in order to improve the concept. The design process concluded with a final prototype 3D printed in order to give a more accurate analysis of the functionality of the tool.

3D-Printing: Two 3D printed prototypes were created in the late stages of the project in order to give the sponsor a more visual representation of the developed concept. The final prototype concluded with the assembly of a main 3D print model of our CAD design with electronics and power train incorporated into the body.

Electronics: The internal electronics of the tool were decided based on what was used for last year's final prototype. These electronics were then researched to develop further knowledge of their capabilities and functionalities. Additionally, a careful review of last year's code was conducted in order to decide whether it could be implemented into our design. After these steps were completed, brainstorming was performed regarding ways to possibly add additions to the code and improvements if possible.

2.3 Risk Plan and Safety

There is a risk plan identified for this project in order to understand the areas where there is room for failure. The plan allows the team to foresee the chance of the identified risks, the actions that can be taken in order to further minimize the chance of the risks, and the fall back plan in the case of a failure.

In the table below, the team has identified six principal risk the group feels will most likely hinder the success of this project. Three of the risks are high risk items, the others are low to moderate showing that the likelihood and impact of the risk combined are within the team's reach. The three that are high risk are placed there because the likelihood of them occurring is much higher than the other three. Due to the team's limited time it is possible that the group are unable to create a product that meets all of the customers needs, which would lead to a wastage of time, money and valuable resources. However, the team would be less likely to hand over a product that would be dangerous or cause extreme failures because of the amount of importance the team is placing on safety and the testing of the product itself. As far as loss in competitive edge, the team will still be providing useful information for Volvo to continue their research regardless of whether the product is successful or not.

Risk	Level	Actions To Minimize	Fall Back Strategy
Waste the company's time	High	Stick to Gantt Chart, Work Ahead of Schedule	Work with sponsor to understand what components are most crucial for the team to finish and focus on that
Waste the company and the school's money	High	Keep and itemized list of everything purchased and prioritize items needed	Finance parts that are necessary to produce the final prototype
Wasting resources provided by the school and the sponsor	High	Create a list of essential resources and what their purpose is for the project	Find resources on our own that will fit in our budget and fulfill sponsor needs
Product causes injuries to operators	Moderate	Test all prototypes thoroughly	Investigate cause of injury and either redesign manufacturing process or redesign tool to eliminate future injury
Product has a high failure rate during production	Moderate	Test all prototypes thoroughly	Investigate cause of failure and either redesign manufacturing process or redesign tool to eliminate future failures
Sponsor loses competitve edge in their field	Low	Generate meaningful prototypes and experiments to fulfill customer needs	Provide useful data to help move research forward in the future in order to help others complete the product

Figure 3: Risk Management Table

2.4 Communication and Coordination with Sponsor

The primary form of communication with the sponsor at Volvo was conducted via email. There was one person from Chalmers and one from PSU, Hugo Göthberg and Alexandra Wickham, who were responsible for sending updates and questions to the Sponsor at Volvo. A weekly update on how the project was developing was uploaded to the cloud service Box, where the sponsor was included.

There was also some key occasions where the project group was in more direct contact with the Sponsor. These occasions are stated below:

- 25/01-2018, Conference call with Per-Lage Götvall (Sponsor gave information on the project and what Volvo wants to get out of the project)
- 01/03-2018, Project proposal presentation
- 20/03-2018, Mid term presentation

- 24/04-2018, Final project presentation (Penn State)
- 25/05/-2018 Final project presentation (Chalmers)

2.5 Timeline

A plan was made to ensure that all project deliverables were met on time, within budget, and satisfying our customer needs. In the first phase of the project, the team compiled and weighed customer needs, finalized the engineering specifications needed in the tool, researched existing products and relevant patents, generated a risk management plan and created design concepts for our final prototype. The next phases of this project included:

Alpha Prototype:

- Alpha FEM Analysis
- Cost Analysis of Tool

Beta Prototype:

- Concept Refinement
- Focus on Powertrain and control systems
- Second Tier CAD Model and FEM Analysis
- Second Tier Small Scale 3D Model
- Cost and Failure Analysis

Gamma Prototype:

- Create a functional prototype including:
- Refined CAD Model
- Full Scale 3D Printed Prototype
- Full Analysis of Cost and Failures

The team has created a Gantt Chart in this format to be consistent in the iterations of the design process which can be seen in Appendix A. After solidifying the specifications and needs in the first phase of the project, the team is able to focus on creating a refined design. The research done in the first phase of the project also gives the team a clearer view of what is feasible in terms of design. The patent search allowed the team to eliminate any ideas that would be an infringement of intellectual property.This project is both a challenging and cooperative effort between both sides of the team to create a successful prototype.

2.6 Project Deadlines

Task	Due Date
Alpha CAD Model	2/9/18
Alpha FEM analysis	2/16/18
Beta CAD Model	3/19/18
Beta FEM Analysis	3/19/18
Beta Prototype	3/18/18
Final CAD Model	4/10/18
Final FEM Analysis	4/10/18
Final Prototype	4/14/18

Figure 4: Gantt Table Due Dates

The table above shows major deadlines in terms of finishing the first, second, and final tiers of prototyping. The Gantt chart has laid out different steps in order to reach each milestone successfully. The group has assigned specific tasks to each member in order to stay informed of our progress on any given component of the project. The Gantt chart is a helpful tool for the team to plan ahead in terms of starting various parts of the project, ordering parts, doing design work and building different components.Since our group is larger, there are at least one support member on each task to help with completion of the work. The group is working hard to keep up communication in order to ensure success of the project.

3 Customer Needs Assessment

The following section specifies the customer needs for the project. It also specifies what need that should be focused most on via the use of an AHP (Analytic Hierarchy Process) matrix Pairwise Comparison Chart.

3.1 Gathering Customer Input

After several meetings and emails with our sponsor at Volvo, a number of customer needs where generated. The initial customer needs focused on essentials of the product such as maximum torque required, specific dimensions, and the co-robot that would be used in conjunction with the tool. After the basic specifications were understood, the team asked for more detail on metrics that would help make the tool safer and easier to use. These metrics included maximum weight of the tool, additional use of sensors, and optimal shaping for ease of use. Through this two tier communication, the team discovered that the sponsor actually wanted the weight of the tool to be a fundamental need to be fulfilled. To understand the feasibility of each need, the group then performed background research on how other basic hand drills compared to the customer specifications gathered. Finally, the customer needs were then paired with engineering metrics or specifications that the team could use to measure and quantify the prototype's performance. Listed below are the customer needs summarized as factors to optimize.

List of factors to optimize:

- Reduce size
- Reduce weight
- Type of sensors and its usage
- Minimize force applied for counter torque
- Optimize structure integrity of prototype
- Reduce cost
- Increase compatibility

3.2 Weighing of Customer Needs

Since it was crucial that this project fulfilled the outlined customer needs, a weighing process called The Analytic Hierarchy Process (AHP) was utilized (*The Analytic Hierarchy Process*, 2018). The Figure 5b, below, explains the relative importance between criteria that was measured according to a numerical scale. Figure 5a, below, shows the distribution of the important factors to optimize relative to the final prototype.

	Reduce size	Reduze Weight	Type of sensors and its usage	Minimize force applied for counter torque	Optimize structure integrity on prototype	Cost	Factor of Compatibilty	Total	Weighting
Reduce size	1.00	0.90	1.00	7.00	5.00	2.00	0.66	14.90	32.2%
Reduze Weight	1.11	1.00	5.00	7.00	5.00	1.66	1.25	19.11	41.3%
Type of sensors and its usage	1.00	0.20	1.00	3.00	1.00	2.00	0.77	6.20	13.4%
Minimize force applied for counter torque	0.14	0.14	0.33	1.00	0.90	2.50	0.33	2.52	5.4%
Optimize structure integrity on prototype	0.20	0.20	1.00	1.11	1.00	1.25	0.66	3.51	7.6%
Cost	0.50	0.60	0.50	0.40	0.80	1.00	0.25	2.80	6.1%
Factor of Compatibility	1.50	0.80	1.30	3.00	1.50	4.00	1.00	8.10	17.5%

(a) Table of weighing

Value of a_{jk}	***Interpretation***
1	*j* and *k* are equally important
3	*j* is slightly more important than *k*
5	*j* is more important than *k*
7	*j* is strongly more important than *k*
9	*j* is absolutely more important than *k*

(b) Table of relative scores

Figure 5: AHP on customer needs

In Figure 5a the total distribution of the weighing can be seen. As shown, the primary customer needs is on the weight of the tool, at about 40%. Reducing the weight of the tool is critical because the workers need to be able to handle the tool during a work shift of at least eight hours. The size of the tool is another critical factor, weighing in around 30% of the total customer needs. Additionally, the tool needs to have the right dimensions to be able to fit in small areas while performing mounting and dismounting operations. Overall, since size and weight are 70% of the combined customer needs, that is where the main focus of the project will be.

The next point of focus is the sensors within the tool. The sensors are important for the robot to be able to use the tool correctly, and accurately sense when the tool needs to perform a mounting or dismounting operation. The analysis in the AHP showed that the sensors comprised of approximately 13% of customer needs. Compared to the other criteria, the counter torque and structural integrity were not as important for the customer, but the team felt that these needs were dis-proportionally low compared to the sensors in this matrix. Therefore focus will also be on fulfilling these needs.

In addition to understanding what needs were most critical for the success of the tool, it was also important to outline what needs were not as critical. Volvo wanted the team to be aware of the cost of the tool itself, but understand it is not a huge concern for this project. In regards to cost, the main goal is to reduce the cost when possible. Increasing the compatibility of the tool is more important to the sponsor since the tool needs to accommodate both co-robot and human.

In conclusion, the focus for this project was not going to be on the sensors, counter torque or the structure integrity, but rather making the tool smaller, lighter and more ergonomically efficient. The customer's main objective was to gain useful conceptual ideas and unique solutions that could be shared and developed more extensively by the research and development team at Volvo.

4 Social and Ethical Aspects

There are central ethical principles that should be considered while doing an ethical analysis. This includes harm to participants, lack of informed consent, invasion of privacy and deception (Bryman & Bell, 2015). The ethical principle that has been most relevant for this project is harm to participant. Other ethics and legal considerations that have been relevant for this project include data management and copyright, but also potential beneficial outcomes of this project.

In order to complete this project without ethical dilemmas, regarding the ethical value of data management, it is important to share files and information associated with the project in a safe and secretively way. Due to the fact that Volvo Group owns the project it is important to follow the guidelines that are given associated with how to transfer and share files, particularly when it comes to handle files with digital models. During the course of the project, the group will work to minimize the risk of this being a dilemma. In order to do so, secret files will be handled with care and only shared in an approved file-sharing system called Box. These files will only be shared with Volvo Group, the project members, supervisors and examiners.

Another aspect to consider is the ownership of the outcome from this project, where the built prototype belongs to Volvo Group, since Volvo Group owns the project. In beginning of the project a contract between the project group and Volvo Group have been written to underline the ownership of this project. During and after the project, the response is to handle information with care and transmit the prototype to the contact at Volvo Group Truck Technology. When doing so, there will not be an issue regarding the ethical value of copyright.

In terms of the ethical problematic regarding the likely outcome, it is important to develop a product that will not affect the user negatively, in form of not causing injuries or to break apart. This is also ergonomically related, where the aim is not to cause direct harm in a physical way for the user. When developing this product, the group will use all the knowledge within the group and also reflect and analyze the concepts in order to make the product strong and safe to use.

There is also benefits with the outcome of this project concerning developing relationships and collaborations between parties. Volvo-related facilities could possibly in the future use the same tool as used in Volvo factories, since the tool could be used by both robots and humans and this could possibly make the facilities feel closer to Volvo in the long run.

Another benefit with this project is that industry development is being promoted, since the elaboration of autonomous and manual work and the collaborative work between these two. This is not something that the project members actively have to work to achieve as the project's aim is to make a collaborative tool. Although, it is still a positive outcome from this project.

After analyzing the ethical problematics that can be associated with this project the conclusion is that there is more to gain, then not, to start the project.

5 Review of Existing Technologies

An external search was required for this project in order to find the most current Human Robot Collaboration (HRC) tools used in the market, to ensure that the tool concept will not infringe on any patents, and to gain a better understanding of HRC in the workplace.

The team found that there are no current existing HRC tools available on the market that meet the scope of the project. For this reason, the search was narrowed down to torque wrenches that are not robot collaborative. This search allowed the team to gauge the cost of torque wrenches varying in cost and capabilities, and allowed the team to gain a better understanding of how large certain components will be within the project's design. Next, an extensive patent search was conducted in order to determine which aspects of the project's design will be new and which have already been explored in the past. Finally, this section will begin with the team's final focus of the search, which was geared towards research articles discussing some key ideas behind human-robot interactions. This provides the team with an understanding behind what people in the industry are concerned about and working towards in the human robot interaction field.

5.1 Research Articles

This section of the report states the articles that have been valuable for this project. Each article has also been summarized shortly in this section.

The first article whose title is *Simplifying Robot Tools by Taking Advantage of Sensor Integration in Human Collaboration Robots* (Gerbers, Mücke, Dietrich, & Dröder, 2016) presents a way to develop simplified HRC tools in order to ensure profitability in small scale operations. Arguments of the article are among others that automatic screwdriving systems can have a reduced cost by omitting force based sensor technology and instead use the integrated sensors of the robot. The author of the article also provides suggestions towards the safety components of the design. Some of these design suggestions are stated in the list below:

- No sharp, pointed, cutting edges or rough surfaces have to be in the contact area
- No surface load is allowed that exceeds the limits specified for the maximum total force and surface pressure
- The work space has to be designed in such a way that the operator is able to avoid clamping situations

The article ends by suggesting that further work is needed to provide a more extensive basis for a rapid development process of HRC workplaces. Specifically, a library of algorithms for HRC applications needs to be developed, and design catalogs and guidelines for HRC tools have to be elaborated. Since this project also have as a long term aim to develop integrated sensor to the tool an issue is how to develop this tool in a cost effective way. This is of extra importance since the author of the presented article states that it is more economical to use the robots integrated sensors, due to that argument there should be a another study in topic that evaluates if it is possible to use integrated sensors in a more cost effective way. It is of importance since the project's aim is to use integrated sensors.

The second article that was valuable for this project is *Cooperation of human and machines in assembly lines* (J.Krüger, T.K.Lien, & A.Verl, 2009). This research article also discusses the growing demand for smaller, more adaptable and flexible batch sizes in assembly lines. They argue that a robot assisted/human guided assembly has significant advantages over full blown automation for this reason. The article proceeds to mention various ways in which humans and robots may coexist in the workplace.

One key point of the article is that humans and robots each offer their own strengths in the assembly line, and an optimized collaborative workstation should make the most out of each. While a robot naturally has high productivity without breaks or fatigue, a high programming effort is necessary for handling complex assemblies. Humans on the other hand have great senso-motoric abilities for complex assemblies but low productivity. The author states that one way to design the assembly process is to have robots performing simple tasks upstream, and humans performing complex, varied tasks downstream to give the assembled products their individual features.

In a workplace sharing system configuration, either the robot is performing an assembly task while the human performs a handling task, or the human is performing an assembly task while the robot performs a handling task. This interaction is severely limited by the avoidance of collisions. If the distance between robot and human is too close, the robot must slow down, halting the assembly process. If a joint handle and assembly operation between human and robot needs to occur, the robot must interact on a level which is much greater than just collision avoidance. A way to do this is to designate the robot into two modes: work and cooperation. While the robot is out of the worker's reach it is in work mode. Here the robot may move at maximum speed and perform task freely. However, once the robot is within the worker's vicinity, it is in cooperation mode. Here the operator may move and adjust the robot in a way to help the operator's assembly tasks.

This article is of importance since the project is built on the idea that an assembly process can be enhanced by combining the workforce of both operator and robot. A relevant problem to address is how to develop the tool so it is developed to perform both type of tasks, both the robot's tasks and the operator's tasks. Although this article does not provide a suggestion in important design elements for a combined tool, it still highlights the importance of the the projects aim, to generate a tool for both humans and co-robots to utilize.

The last article that where of importance is *Whose job is it anyway? a study of human-robot interaction in a collaborative task* (Hinds, Roberts, & Jones, 2004). This article discusses a 3x3 experiment which details how workers respond to robotic workers depending on robot appearance, along with robot status to the human. In the experiment, robots were either humanoid, human-like, or machine like, and the robot's status was either subordinate, peer, or supervisor. As humans and robots are expected to increasingly share the workspace in the future, the study aims to answer questions such as: Will people trust robots to perform operations that the robots are capable of without oversight? What aspects of the design of the robot will affect the way people and robots work together?

The experiment results revealed a few key findings. For one, the data suggests that participants felt more responsible when interacting with a machine-like subordinate robot. The authors argue that knowing this is useful as it is important for workers to feel the full weight of responsibility in a task, as mishaps are decreased when workers explore more options, and they are more diligent to finding a solution. On the other hand, a humanoid robot is preferred when responsibility for the worker should be decreased. The authors hypothesize that as the worker can share a greater identity to a humanoid robot, they are more likely to be accepting of tasks presented by the robot.

For a continuation of this project this article would be important when developing the programming of the tool. It is important since the tool can be used by a robot in a combined work environment. A question that one can reflect on is how the programming of the tool should be made so the robot uses it a smart way when collaborating with a human operator.

5.2 Patents

An important part of the project were to look into what patents already exists. The following section describes the patents that were explored in our external research and take a deeper look into each one's applications and relevance to the project. Figure 6 shows an overall table of the relevant patents for this project, all which are granted.

	Number	Name	Comment
Patent 1	US12280678	System for controlling the position and orientation of an object in dependence on received forces and torques from a user	Sensors
Patent 2	US6876173B2	Battery adapter for a cordless power tool system and related method	Battery
Patent 3	US7235940B2	Torque limiting device for an electric motor	Drive System

Figure 6: Patent Comparison Matrix

The first patent that was looked into is titled *System for controlling the position and orientation of an object in dependence on received forces and torques from a user* (*U.S. Patent No. US20090259412A1*, 10/15/2009). This patent focuses on the 6 degree-of-freedom sensor which is used to communicate with the robot at which angle the tool is performing its task. The patent author argues that existing sensors are not capable of measuring the counter torque produced in most assembly situations, which leads to errors. In the patent, the data processing unit includes an algorithm which converts the output signals from the sensor into drive commands for the joint drives of the robot, and adjusts the system of coordinates of the hand-grip sensor unit to the system of coordinates of movements of an actuator on an end-link of the robot. However, the patent author argues that a handle may be difficult to use as it could collide with other objects in the workstation. This patent is relevant to the project since the aim were to incorporating sensors in the tool. The same problem this patent aims to solve is also relevant to this project, and that is to deal with counter torque.

The next patent is *Battery adapter for a cordless power tool system and related method* (*U.S. Patent No. US6876173B2*, 04/05/2005). This patent focuses on the rechargeable battery aspect of the team's product. Specifically, it focuses on an adapter for electrically connecting a battery pack to an electrical apparatus such as a cordless power tool or a charger. A rechargeable battery is especially important for the project's design as a corded power supply will limit the robot's mobility in using the tool. While our idea of a detachable rechargeable battery is consistent with that of the patent, the design presented in the patent is inconsistent with our concept model.

The last patent that were looked into is *Torque Limiting Device for an Electric Motor* (*U.S. Patent No. US7235940B2*, 06/26/2007). This patent focuses on the power-train aspect of the product. It is a device that can monitor, detect, and adjust the speed and torque of an electric motor. This can be applied to a variety of basic hand tools and smaller collaborative tools such as the one used in the team's. This system uses a nominal value setting to adjust the torque. It also has a control and regulating device that sets the current to a maximum value set by the nominal value setting. Finally, it has a rotary speed detecting device that allows it to check the speed of the motor value and adjust it if need be. All valuable features to this project.

5.3 Existing Products

This section of the report states the existing tools on the market that have been useful when researching and developing the prototype of this project. Table 2 provides a brief description of the existing products that the team researched followed is a more complete explanation of each product.

Table 2: Product Comparison Matrix

	Company	Torque (Nm)	Battery	Cost	Comment
Product 1	Milwaukee	47 (Nm)	12 V	$99	Compact and cheep
Product 2	Ingersoll Rand	78 (Nm)	20 V	$194	Parts are appropriate size
Product 3	Atlas Copco	15-70 (Nm)	16 V	$560	Quality and expensive torque range
Product 4	Bosch	110 (Nm)	12 V	$350	Lightweight

The first existing torque wrench the team researches was M12™ Cordless 3/8" Lithium-Ion Torque Angle Wrench shown in figure 7. This wrench not only provides the user with feedback with green, yellow, and red lights, it also has the same voltage and torque that is required from the sponsor. This would be an ideal wrench to disassemble as it contains most specifications our team needs, but does not have a way to connect to a robot.

Figure 7: M12™ Cordless 3/8" Lithium-Ion

The next product researched was Ingersoll Rand's R3130 3/8 Inch cordless Ratchet shown in figure 8. This torque wrench reaches a torque of 78 Nm which is well above our 40 Nm requirement. While it's design is in no way suitable for robot interaction, the components within appear to be the correct size. The drive system does not appear to take much space and the small rechargeable battery allows for great portability, and more room for the sensors.

Figure 8: Ingersoll Rand's R3130 3/8 Inch cordless Ratchet

The following nutrunner Tensor SB ETV SB63-50-10-B shown in figure 9 is made by Atlas Copco and is suitable for a wide range of applications. This tool is userfriendly and has a high quality in tightening, operator mobility and longlasting durability. It has adjustable torque range from 15-70 Nm and a torque accuracy on ± 5%. It connects through Bluetooth and has a long lasting Li-Io 16 V battery. Operator feedback is provided by LEDs, which are visible through 360 degrees.

Figure 9: Atlas Copco Tensor SB ETV SB63-50-10-B

The last tool that were looked into is the Bosch GDR 12V-110 Professional shown in figure 10. It is a small and light nutunner with a longer runtime due to a 12V, 2.5 Ah battery pack. It has a 2-stage PowerControl to prevent overtightening of small screws and has a maximum torque of 110 Nm. It has a 3 ring LED light to give feedback to the operator that are visible through 360 degrees.

Figure 10: GDR 12V-110 Professional

The team researched existing products in order to get a better understanding of what is already on the market and what specifications that the existing products had. It was also an important research for gathering design ideas and understanding how it could be possible to reduce the size of the tool which was developed last year.

6 Engineering Specifications

To properly establish what the tool must achieve an engineering specification was made. The list is a more detailed and elaborate description of customer needs, from Chapter 3, in combination with the specifications from similar products presented in Chapter 5.

6.1 Establishing Target Specifications

The table below represents the targets that have to be met as specified by the sponsor (*Meeting with sponsor*, 2018). These specifications are a combination of specifications from the sponsor and engineering specifications from the previous project. It specifies all the thresholds that needs to be passed, the accuracy needed for the sensors and the features that need to be present.

Function	Metric
Structural	
Take load from produced torque without fatigue	>40Nm*length, from toolhead to counterforce
Elastic deformation under maximum work load	<2%
Resistance to cracking when dropped 1.5m	High
Powertrain	
Maximun torque produced	>40Nm
Variable threading speed	0RPM < x < 400 RPM (enough to thread M18 bolt in <5seconds)
Battery capacity	Be able to mount 8 M18 bolts, 10 second in between, 50 times per 8h, evenly spread over the day (with charging)
Battery voltage	>=12v
Rechargable battery	Charge time
Lifecycle battery	1000charge cycles
Control system	
Processing	Enough to handle in data, communication with robot and calculate output
In data	Enough to get telemetry from sensors and robot/operator
Output	High enough frequency to control threading speed and torque within +-10% of specified value
Communication with robot	Enough bandwidth for information and such a low latency that stability issues for controlsystem do not occour
Monitor bolt threading	Destinguish between correctly entered and incorrectly entered bolt
Sensors	
6-axis angle position	Measure angle of tool within +-2deg
Depth perception	Perceive depth of object within +-2cm
Object detection	Detect nescessary object with 98% accuracy
Tourque measurement	Measure tourque applied within +-2Nm
Battery monitor	Measure amount of cycles and individual cell voltage
Threading angle	Measure correct threading angle within +-2deg
Threading speed	Measure threading speed within +-2deg/sec
Ergonomics human operator	
Forces required for countertorque under maximum load	Low enough so that operator won't risk fatigue injuries in joints or muscles
Weight Tool	<2.5kg
Grip size	Fit both male and female hands
Communication with operator	As clear and simple feedback as possible for operator in terms of positioning and when task is complete.
Exchangable batteries	Low amount of actions to replace
Modularity and exchangeable parts	Easily upgradable/exhangeable parts

Figure 11: Engineering specifications

Below is a short description of what each sub-category aims to achieve.

Structural: These requirements are set to ensure that the tool will be able to handle the forces applied on the tool and eventual droppage.

Powertrain: This subsection is compiled of specifications to ensure that the power producing part of the tool can thread bolts tight and fast enough. It also specifies the requirements set on the battery in terms of lifespan, capacity and charge time.

Control system: Requirements regarding handling of sensor data, communication between operator (human and robot) and controlling of powertrain are defined here. The metrics here are vague because this project will not focus on how to properly implement each function in this subsection, just ensure that the control system has enough processing power and communication bandwidth.

Sensors: Specifies the data and a rough estimate of the accuracy needed. Further investigation on the accuracy required and which sensors are needed will be conducted in the Beta and Gamma stages of the project.

Ergonomics human operator: These specifications are to ensure that the cognitive and physical ergonomic properties of the tool are good enough to compete with other similar products.

6.2 Relating Specifications to Customer Needs

The list above, shown in figure 11, is an extensive description of which functions have to be in the final product. Since the project is in its Alpha phase it is therefore more suitable to have fewer specifications to take into account when generating and comparing concepts. The focus in this stage of the project is to decide the general shape of the product and basic layout, such as handles for leverage and where the tool bit is placed. Placement of battery and location for main electronics has also been taken into consideration. Later stages in the project will utilize the complete engineering specification as previously shown in figure 11 to further develop the chosen concept.

A customer Needs Metric Matrix was therefore produced, where the relevant engineering specifications were chosen and ranked in relation to one another (see figure 12). Each need was ranked based on how important it was for the customer. The scale was 1 (not important), 3 (fairly important) and 5 (very important). These results will show which needs should be prioritized when deciding on a concept and is of great importance since it is not possible to maximize all the metrics. Based on the results the following needs where focused on during the generation of our concepts.

Needs	Metrics	Load from Produced Torque	Elastic Deformation	Resistance to cracking	Maximum torque	Variable threading speed	Battery voltage	Battery capacity	Charge Time	Lifecycle of battery	Measure of tool angle	Distance of Perception	Object Detection Accuracy Percentage	Force required for countertorque under max load	Weight of tool	Grip Size	Compatibility
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Lightweight (5)	1														5		
Powerful (5)	2	5			5	5	5										
Compatibility (3)	3																3
Product Cost (1)	4																
Ease of Use (3)	5		3	3													
Ergonomics (5)	6													5	5	5	
Size (3)	7														3		
Durability (3)	8		3	3													
Safety (5)	9													5	5	5	
Functionality (5)	10							3	3	3	5	5	5				
		5	6	6	5	5	5	3	3	3	5	5	5	10	18	10	3

Figure 12: Needs Metrics Matrix

7 Concept Generation and Selection

The previous chapters have introduced the project, its logistics and the goals and specifications that need to be achieved. This chapter will take that information and use it to further clarify the problem, generate concepts and finally chose a concept to work on in more detail.

7.1 Problem Clarification

Based on the problem description in chapter 1 a black box model was made to get a general understanding on how the system, that is the tool, should work. It specifies what comes into the system, what the system produces and is divided into three categories: energy, material and information.

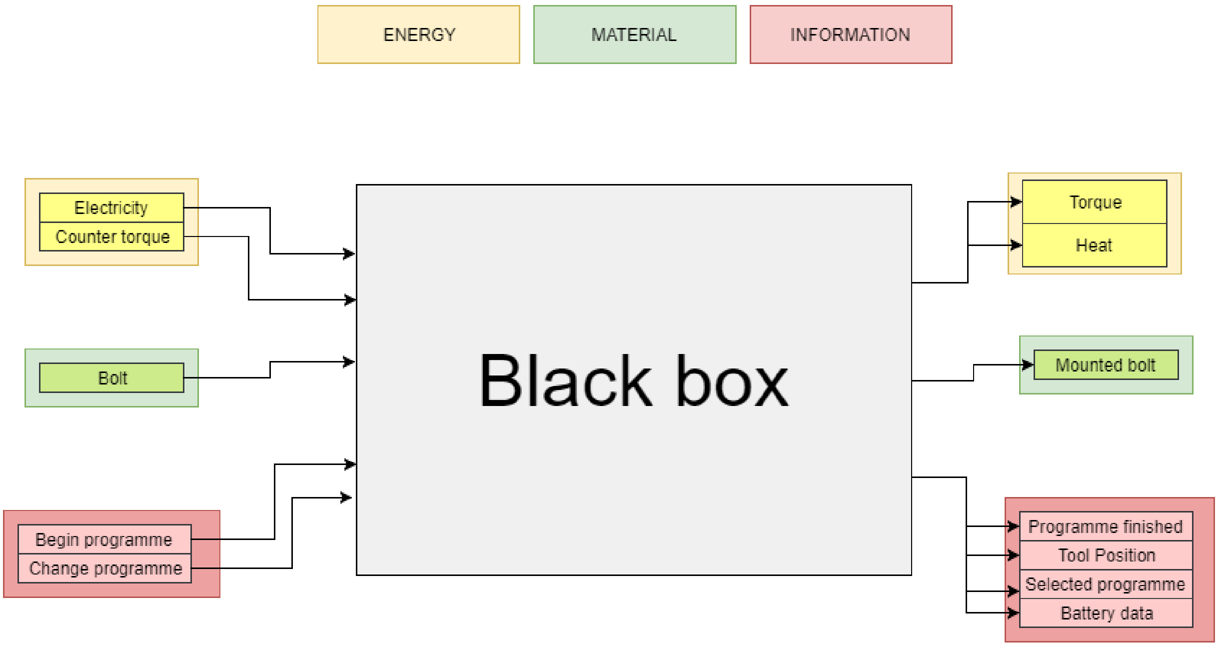


Figure 13: Black Box Diagram

To get an even more detailed understanding of how the tool works a sub-function diagram was made (shown below). It is a continuation of the black box diagram and describes the sub-functions that produce the output results shown in the black box model. This is a crucial part of the problem clarification since these sub-functions will dictate how the tool will work, thus also mandating which components that will be used. The model produced here only shows the general sub-functions, since each sub-function can be seen as its own black box model with in-data, out-data and subsequently has its own sub-functions. Later stages in this project will deconstruct and further specify some of these sub-functions. Mainly "Motor gets power", "Amount of bolt threading measuring" and "Tool position checking".

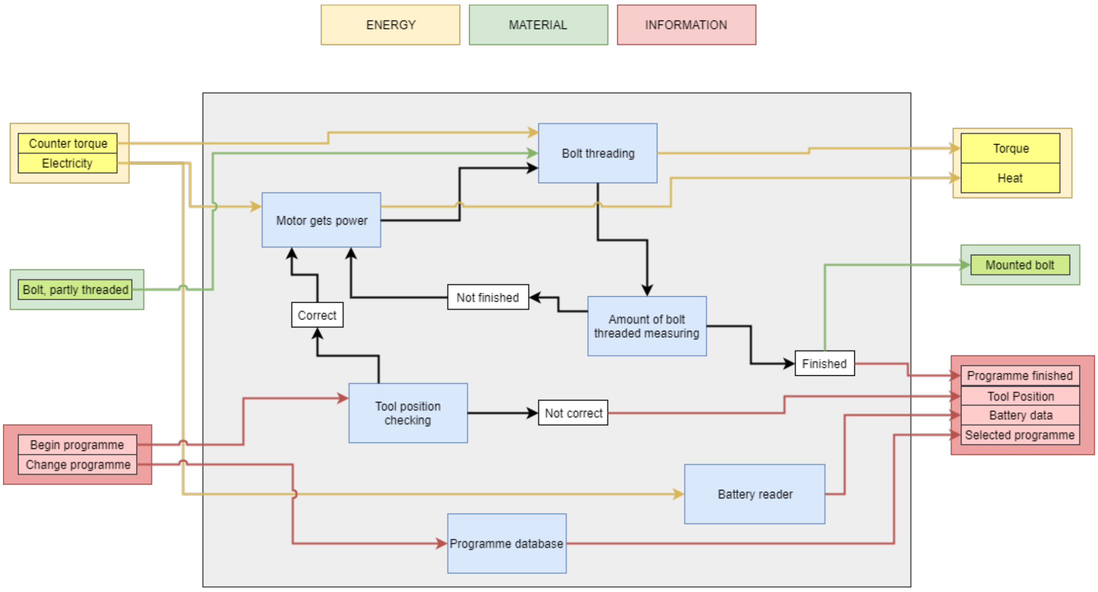


Figure 14: Sub Function Diagram

7.2 Concept Generation

Since this project is focused on the redesign and optimization of a previous tool created, concept generation started by analyzing the previous team's prototype and design. During this process, it was important to analyze the specific areas of where the previous team was successful, where their customer needs were not met, and how to leverage their concepts to create a more optimal design. The current customer needs were then outlined and target engineering specifications were created to ensure our design could satisfy those needs. Once the target engineering specifications were set, the team started brainstorming alternative design ideas. For this project, it was important to establish our engineering specifications before the concept generation phase because an important customer need of the project is to redesign the size and shape of the tool within a given specification. This ensured that each concept generated satisfied our main purpose of the project. Even though the geometry of this tool is completely different than the previous tool, it was still important to analyze the previous team's design to ensure that it would be possible for all of the electronics and components to fit into our design. In this section of the report, a short description of each concept generation is explained, as well as the benefits and limitations of each design.

7.2.1 Concept 1

Concept 1 provides a compact design with simple geometry. This concept gives optimal leverage to the operator by providing two short handles for ease of use rather than long handles. By doing so, the concept provides a shallow reach for the operator. One limitation of this concept is the inconvenient attachment location to the robot. When mounting and dismounting bolts, the operator will have a difficult time seeing the work space around the circular body which could limit their overall accuracy and precision of the operation. This concept will only be feasible with an integrated camera to aid the eyes of the operator. (See Figure 15)

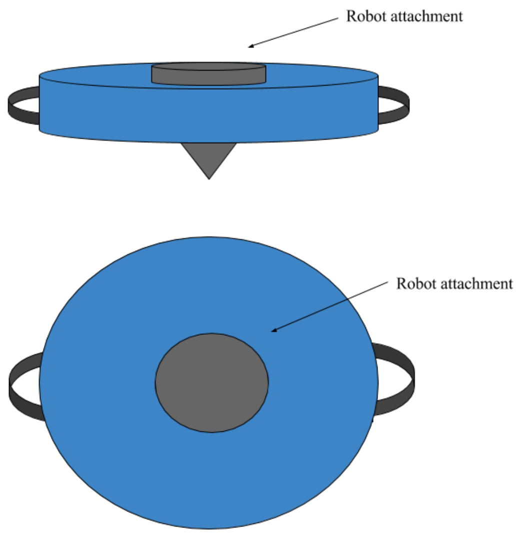


Figure 15: Design Concept 1

7.2.2 Concept 2

Concept 2 is based on an existing power tool commonly used in assembly lines at Volvo cars in Gothenburg (*Hugo Göthberg's working experience*, 2018). This concept yields great leverage for the operator, as well as an ergonomic and compact design. One limitation, however, is placing the robot attachment at the center of the tool hinders the robots reach when mounting and dismounting certain bolts. Additionally, finding a location for the battery may be challenge with this concept due to its narrow geometry. (See Figure 16)

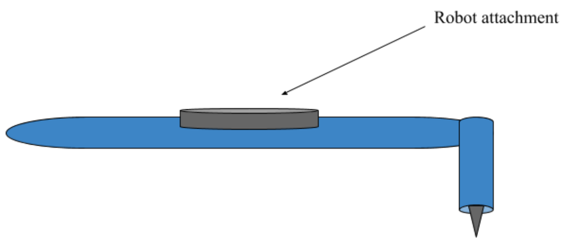


Figure 16: Design Concept 2

7.2.3 Concept 3

Concept 3 is also based on an existing power tool commonly used in assembly lines at Volvo cars in Gothenburg (*Hugo Göthberg's working experience*, 2018). This is the same basic geometry as Concept 2, but the robot attachment is in the rear of the tool as opposed to the center. Again, this concept provides great leverage for the operator, as well as an ergonomic and compact design, but in turn will be hard to fit the battery. Additionally, this design might cause a high load on the tool when the robot uses it due to the high leverage. (See Figure 17)

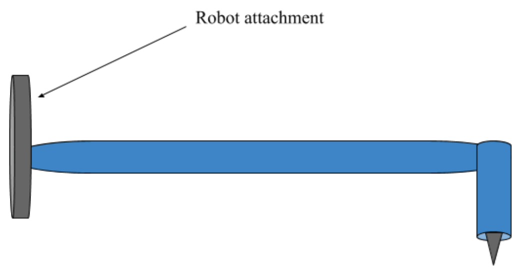


Figure 17: Design Concept 3

7.2.4 Concept 4

Concept 4 is based off of last years project, but aims to be smaller, lighter, and more of a traditional screw driver design. This concept provides a compact and intuitive use for the operator. One limitation, is that it does not have the leverage as seen in other concepts. Additionally, the diagonal design of the handles will make it hard for the operator to see around the drill when mounting and dismounting bolts. Because of this, this design will need a camera to aid operation. (See Figure 18)

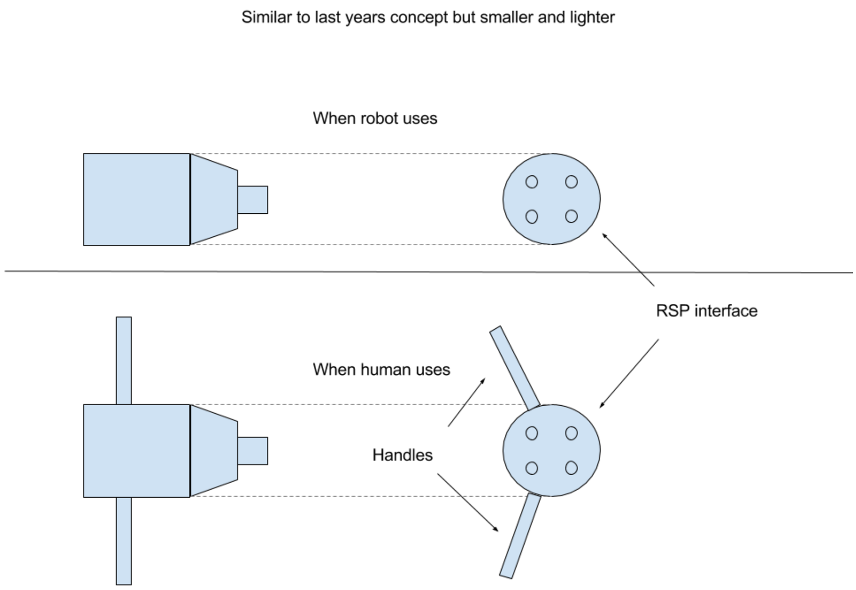


Figure 18: Design Concept 4

7.2.5 Concept 5

Concept 5 is similar in shape to Concept 4 but the main body is split into two different modules: one for the motor/electronics and one for the battery and handles. When the robot uses the tool in this design, only the motor and electronics module will be used with power sourced from the robot itself. When humans use it, the battery and handles module are attached. Additionally, this design offers a longer battery life due to the power from the source when robot uses the tool, as well as a compact design and good leverage for the operator. In turn, since this concept does not use the standard robot it may be difficult or impractical to design. Also, similar the last concept, it will be hard to reach specific bolts and hard for the operator to see around the tool. (See Figure 19)

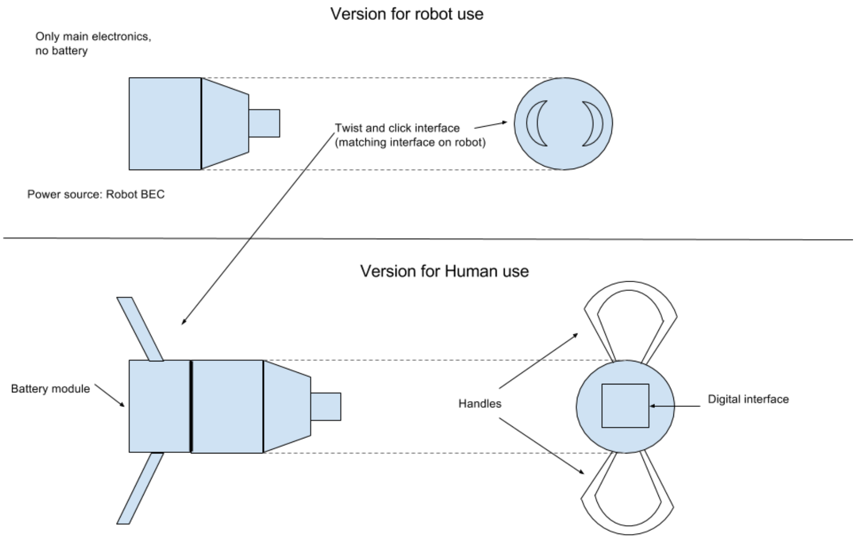


Figure 19: Design Concept 5

7.2.6 Concept 6

Concept 6 is the same basic design as Concept 5 but with different handles. This design is not as ergonomically efficient as others, but is intuitive as the handles are designed to be similar to any power tool on the market. (See Figure 20)

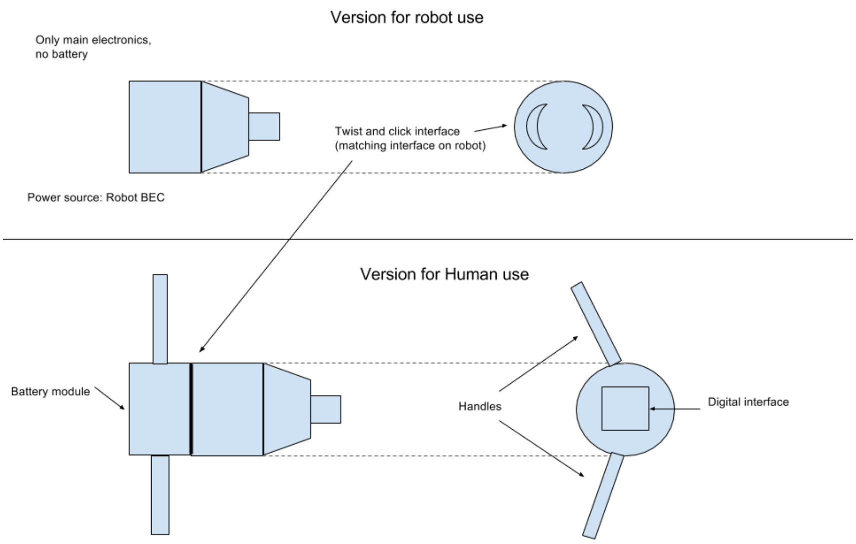


Figure 20: Design Concept 6

7.2.7 Concept 7

Concept 7 has the same basic shape as Concept 2 and 3, as well as the same division of main body as concept 5 and 6, but smaller. This concept provides great leverage for the operator, as well as an ergonomically efficient and compact design. This concept also saves battery life, but most importantly has short leverage, yielding lower structural load on the cylinder. One limitation would be that this concept does not have the typical robot connector used in most designs and may be a slightly more complex design to produce for a final 3D printed prototype. (See Figure 21)

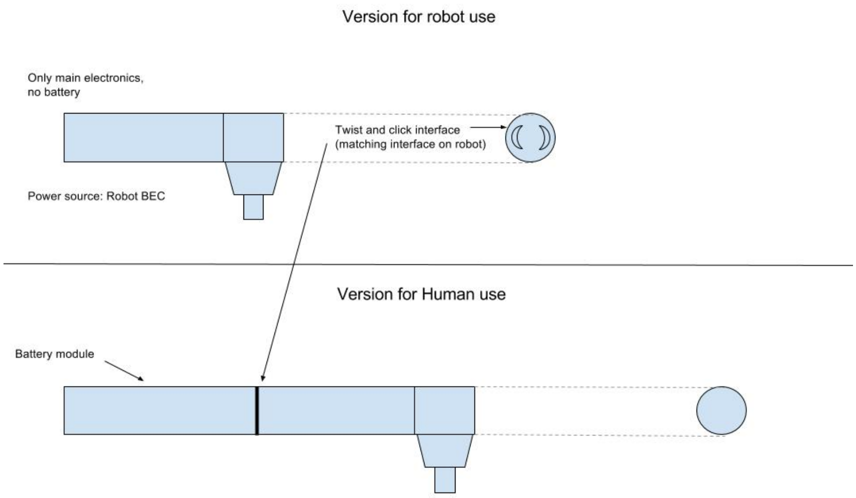


Figure 21: Design Concept 7

7.3 Decision Making

During the concept selection four of the best concepts where weighted through a Pugh selection matrix. The criteria used to weight the concepts were selected based of off the engineering specifications given by Volvo. Not only does the Pugh matrix show the most optimized concept, but it can also show key factors you may have overlooked while brainstorming. To simplify this matrix, we chose four generalized concepts to begin weighting. We generalized the alternative concepts because we felt some concepts were very similar, in turn producing many duplicate ratings. Another reason was that the only differences between some concepts were battery placement and different handles styles. Concept 1 was renamed "Hand-Drill". Concepts 2 and 3 were combined and renamed "Tube-Drill". Concepts 4 and 5 were combined and renamed as "Vertical Drill". Lastly, concept 7 was renamed "Multi-Component Drill". Based of this matrix, we generated a "multi-component tube drill" CAD model, shown below in figure 21.

Pugh Selection Matrix					
	Baseline(Last Year)	Hand-Drill	Tube-Drill	Vertical Drill	Multi-Component Drill
Criteria	**Rating (1-10)**	**1**	**2**	**3**	**4**
Lightweight	8	0	1.00	-1	1
Powerful	4	1	0.00	1	1
Compatibility	7	-1	0.00	-1	1
Product Cost	3	0	0.00	0	0
Ease of Use	7	0	1.00	0	1
Ergonomics	7	1	1.00	-1	1
Size	6	1	0.00	-1	0
Durability	4	0	0.00	1	0
Safety	4	1	1.00	-1	1
Functionality	9	-1	1.00	0	1
Sum of Positives		4	5	2	7
Sum of Negatives		2	0	5	0
Sum of Sames		4	5	3	3
Weighted Sum of Positives		21	35	8	46
Weighted Sum of Negatives		-16	0	-32	0

Figure 22: Pugh Matrix

The team believes the chosen concept meets all of the customer needs. Even though the concept design is more complex, it is needed to produce the most optimized finished product. This concept provides an ergonomic and intuitive design, ample space for internal electronics and supports great leverage for the operator. Also it should be noted that this design proves safer than the other concepts because the operator can easily see around the tool. Having a complete or almost complete view of the work space will in turn cut down the amount of times the operator needs to adjust his/her view of the bolt mounting process. This will assure complete focus on the more dangerous part of this process.

7.4 Chosen Concept and Preliminary FEA Study

Figure 23 below is a more elaborate CAD-model of the chosen concept. It has two grips for steering the tool and creating leverage for human operators. There is also a thicker middle section to accommodate the needed electronics. The battery module was moved to the back in this model, but a further study of what the battery module should look like, based on the FEA analyses and co-robot compatibility, will be performed for the Beta prototype.

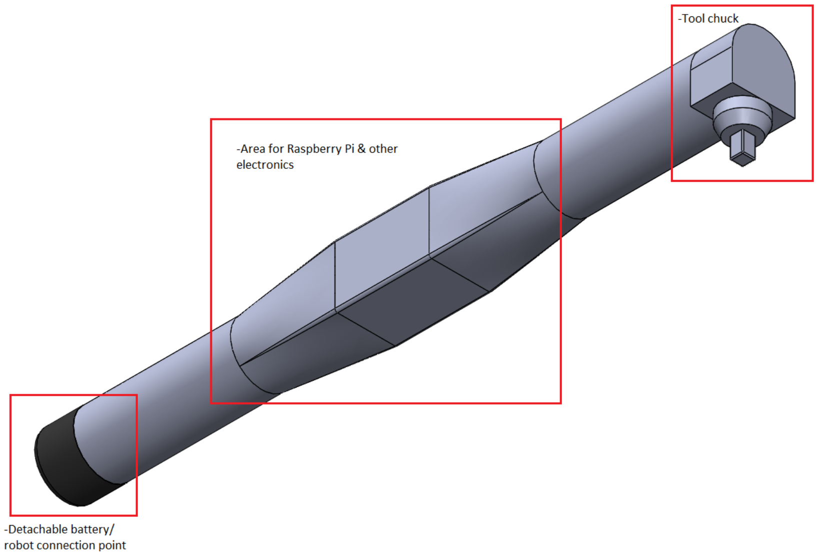


Figure 23: Multi-Component Tubular Concept

In Figure 24 below, an FEA study was performed on the chosen concept. An FEA study helps with visualizing where to move forward with the beta prototyping stages of the project. Having an idea where the maximum stresses occur indicates where the tool needs to be strengthened. From the study, most of the stresses are occurring on the outer edges of the model. Having this information saves time compared to doing hand calculations and countless preliminary guess and check work.

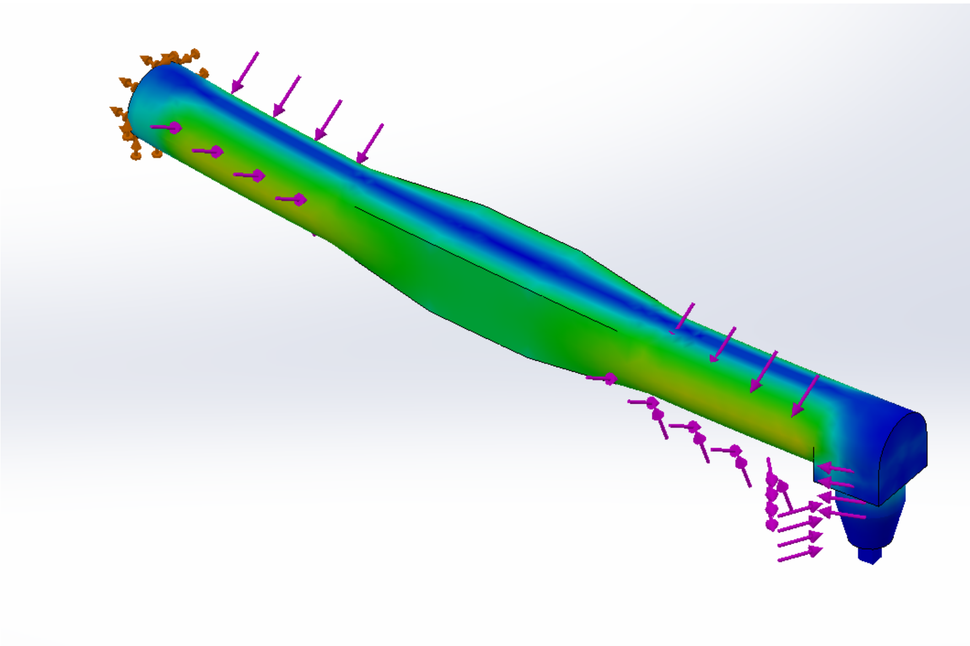


Figure 24: FEA Study

To further refine the study a Iso Clipping view of the tool was generated. The iso clipping tool in Solidworks simulation is very useful as it helps pin point specific stresses. Boundries were set to determine where the upper bound stresses are occurring. In figure 25, the maximum stress are occurring around the outer edges of the two hand grips. This shows what needs to be optimized in the Beta prototype, to ultimately lower these stresses and in turn lower the amount of displacement cause by torque. Further investigation will be into thickening the inner walls of the grips or possibly adding some sort of internal supports to the grips.

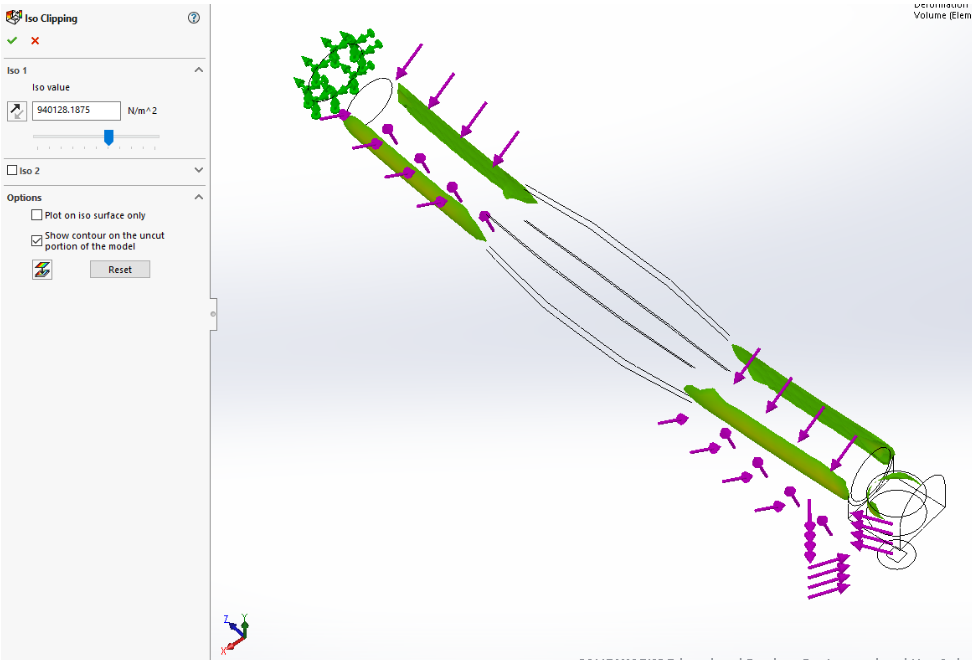


Figure 25: Iso Clipping Study View

8 Alpha Prototype

In the Alpha phase of the project, the team made a draft design from the final concept. It is a simple design based on Volvo's requests and teams' vision. Upon completion of a preliminary CAD-model, the tool was tested in a VR environment in order to get a sense of the tool's size. When the concept size was decided, the Alpha prototype was made with additive manufacturing. The printed prototype was then able to provide an even better sense of the tool's size.

8.1 CAD rendering

The first CAD rendering is shown in figure 26. The drawing shows the middle section of the tool, where the main electronics will be placed, and the back handle where the batteries will be placed.

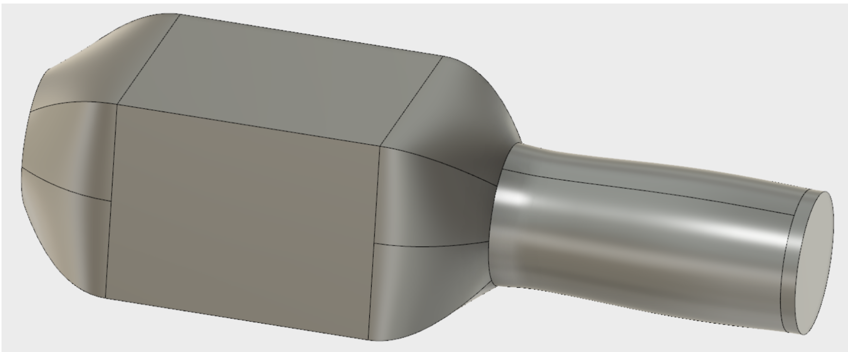


Figure 26: First CAD rendering

8.1.1 VR environment

All of the digitally constructed work was done in a CAD-program, see chapter 9.4 to later be 3D printed into a physical shape. 3D printing is a cheap way to get a physical prototype, but big parts can take over 24 hours to print, making small iterative changes based on the 3D print slow. An alternative method for evaluating general shape and size of the prototype was therefore devised. One solution was to use VR-goggles, in this case a HTC Vive, so that the user could look at the tool as if it was a one to one scale of the physical object in a virtual environment. This can be see in Figure 28, below. Basic interaction was also possible, such as manipulating object with a controller to move it around and inspect it from different angles.

Figure 27: VR Enviroment

The analysis of the tool gave a good indication of the tools general size and the size of each component. It became apparent that the middle section of the tool was large and that the rear handle was on the wider side, making it difficult to use. The results weren't as useful as holding a physical version of the model, but provided a sense of scale to see the disproportionate dimensions so that changes could be made and then 3D printed for further evaluation.

8.2 Assembly and 3D printing compatibility

Several goals were set for the first stage of 3D printing. This included evaluating if the middle section of the tool could house all the electronics, seeing if the tool itself could be made smaller, seeing if the assembly solutions where adequate, and determining if the handle could fit the battery while still being ergonomically efficient.

Results from initial 3D print:

- The middle section can fit all the main electronics but some modifications to the Speed controller will have to be made for it to fit
- Rear handle was a bit to wide to have a perfect grip (see Figure 29) , but with the batteries being used it can't get any smaller.
- The Assembly solution was effective. Both middle section and rear handle where rigid and the connection between allowed for almost no play. Eventually however, material needs to be added in order to strengthen the tool and prevent cracking.
- 3D-printing in ABS-plastic can warp components and this needs to be taken into account when designing parts in the future.

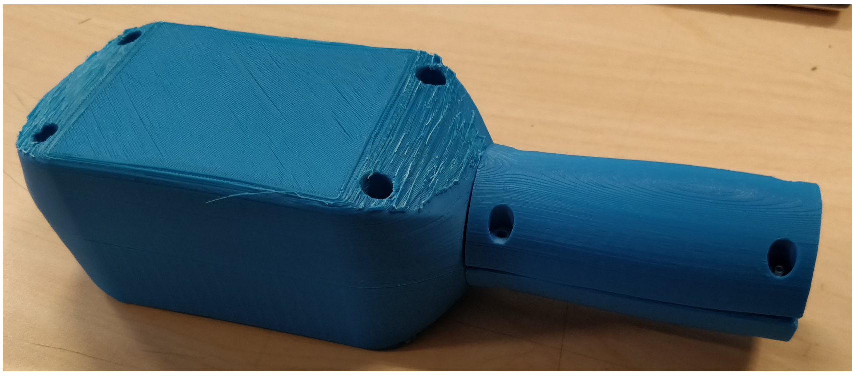


Figure 28: Middle section and rear handle

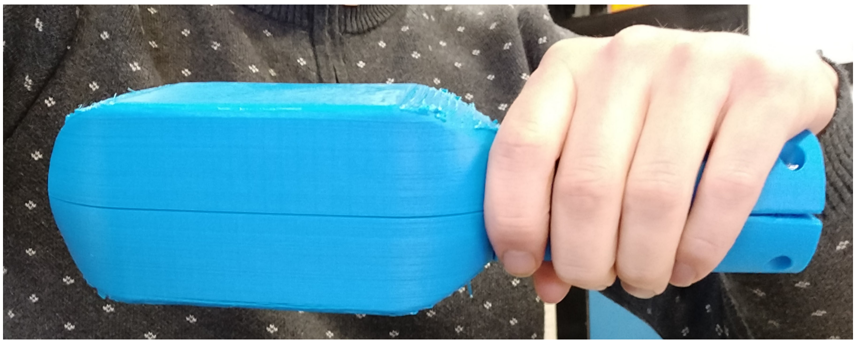


Figure 29: Grip on the rear handle

8.3 Testing prototype

Testing of the Alpha prototype was simple and mostly based on the sense of how it felt holding it. As shown in figure 29 the rear handle is quite wide which could make it hard for a small hand to hold the tool. This is something that was kept in consideration while the team continued to improve the tool for the Beta and Final prototype.

Testing of the prototype was valuable to understand the size of the tool. The design felt good enough and the team was happy with the first prototype and will continue to refine this design in the next two phases of the project.

9 Beta Prototype

In the Beta phase of the project, the team refined the final design by updating our target engineering specifications based on Volvo's feedback. This included incorporating the robot attachment not only on the top of the tool but also on the perpendicular face. Due to time constraints, the team also chose to take a gearbox and motor solution from an existing tool and fit it in the prototype. Overall, the Beta prototype grew upon the Alpha concept by changing the design of the handles and the placement of electronics inside the tool. The next steps for this project included integrating the battery, testing the electronic parts within the tool, and perfecting the physical components of the tool.

9.1 Functionality

After the Alpha prototype was presented to the sponsor, feedback was given that the positioning of the robot attachment had to be able to be on the top or on the bottom of the tool. Three solutions to this problem were generated:

- Mount the attachment directly to the main body with bolts, with mounting patterns on top and bottom. This is a mechanically simple design and keeps a low profile but it takes a little longer to change the position of the attachment.
- Use a "guidance rail" mounted to the attachment and the top and bottom middle section of the body (see Appendix B). Changing the position is relatively fast and mechanically simple but the profile of the tool becomes higher.
- Same mounting solution as the first concept but with a different approach to switching the position of the robot attachment. This is solved by partly detaching the first half of the tool, rotate it 180 degrees and attach it with a click mechanism. This solution has the fastest swap time since it doesn't require the robot attachment to detach from the middle section, but instead just rotate 180 degrees. The issue with this solution is that it is technically difficult to realize and has a complex mechanical solution that requires tight tolerances and thus becomes more expensive to manufacture.

These concepts where then evaluated based on the use case scenario described below:
The positioning of the robot attachment will depend on which assembly station it is used and will, in most cases, not switch between stations on a regular basis. This means that the robot attachment does not need a quick swapping solution, only the possibility of changing the attachment position. The emphasis was therefore chosen to be on mechanical robustness and a low profile.

Based on the two emphases mentioned above, the first concept was deemed to be the best alternative. The second concept had a higher profile and an extra mechanical mounting point compared to the first concept. Concept three had the same low profile as concept one but with several extra mechanical mounting points for it to be able to rotate. The extra mechanical mounting points/solutions increases the chance of breaking when used or dropped and should therefore be minimized.

9.2 Physical prototype

The physical prototype is constructed by three parts, a front, a middle and a back, seen in figure 30.

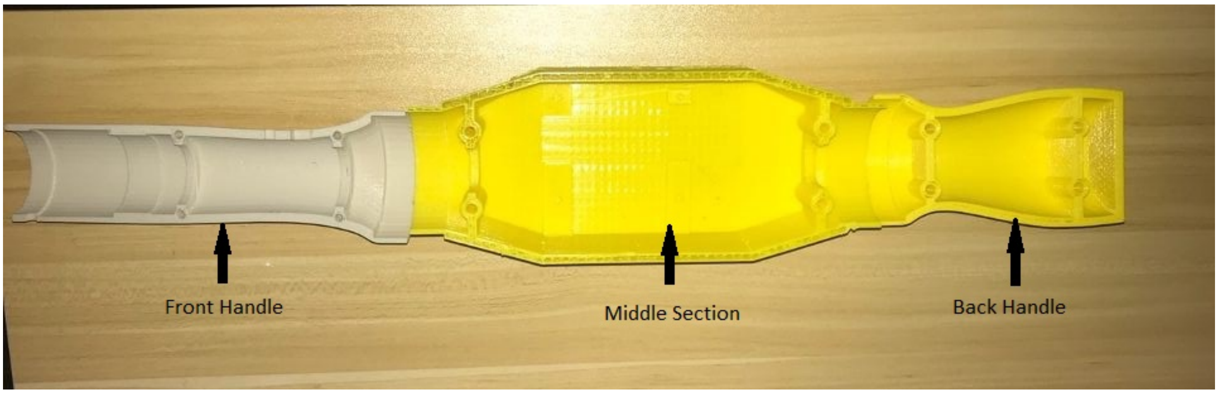


Figure 30: 3D Printed Concept

9.2.1 Front Handle

The front section will contain the drive system which is made up of the trigger, motor, chuck, and speed controller, all of which connect to the processor in the middle. Parts for the drive system were acquired by purchasing an existing electric torque wrench. After weighing the pros and cons of several options, the team finalized their decision on the Milwaukee M12 Cordless 3/8" Ratchet due to the fact that it had a torque range within our requirement, and was within our price range. Upon disassembly of the tool, measurements were taken of the critical components. With these measurements, the team was able to model the front of the prototype such that it would house all components correctly. The trigger however, was not modeled in this phase of development.

The trigger was not modeled as originally planned since the original idea was to include it in the back handle. The team then realized that this would lead to complications as the back handle is to be removable. The trigger will require careful deliberation in the next design phase as ergonomics will play a large role in how it will be incorporated.

9.2.2 Middle Section

The middle component will house the processor, the sensors, and will also serve as the gateway to the robot system. Originally, only one RSP connector was required, but due to the nature of the design, our sponsor noted that two connectors could be used. These will be placed perpendicular to each other on the top and side of the middle section allowing for certain versatility when operating with the robot as assembly can be performed horizontally or vertically. Most aspects of this section will be given attention during the last phase of the project.

9.2.3 Back Handle

Special attention was required in designing the back component as the operator will experience the most counter-torque from this location. It is important to keep in mind however, that power tools at Volvo's facilities hang from their workstations, significantly lowering the burden on the operator. The team developed several ideas for how to create an ergonomic handle, including mixtures of grooved and flat designs.

A big concern for the team about the possibility of a grooved design was that different operators possess different hand sizes which would ultimately provide discomfort for certain people. A simply flat design however, would also be uncomfortable to operate after several hours of use. For this reason, the team finalized on a flat handle design with a soft grip placed around it. Refining the back handle will be a part of the development for the gamma prototype since exact battery measurements needed to be taken before advancing to refining the back handle.

A customer need for the final design was that the battery should be easily rechargeable. The selected concept allowed for this possibility when the battery was placed inside of the back handle. This was beneficial because while the tool was in use by the robot, the handle could be removed for charging without causing disruption to it's function since the robot attachment lies in the middle. One concern was that fitting a 12V battery may require the handle to be thicker and less ergonomic than desired, but the team tackled this issue when the Chalmers students visited Penn State.

9.3 Electronics and powertrain

Since the project spanned four months, the choice was made to buy an existing power tool and take its gearbox and motor solution and put it in a new body. The tool that was chosen was the Milwaukee M12™ Cordless 3/8" 12-Volt Lithium-Ion (the tool can be seen in Figure 31 and its specifications in Table 3). This tool was chosen for its relatively low price and due to the fact that it fulfills the requirements for the torque and socket wrench size. Two of Volvo's requirements for the prototype were that it should have a standard socket connector size of 3/8" or 1/2" and that the minimum torque was 40 Nm. The tool also appeared to be easy to disassemble, allowing us to demount it and take out the existing parts for further use in the group's prototype.

Table 3: Tool Specifications Table

Length	27.3 cm
Width (Head)	1.9 cm
Weight	0.9 kg
Voltage	12V
Power Source	Cordless
Battery System	M12
Peak Torque	47 Nm
No Load Speed	0-250 RPM

Figure 31: Milwaukee M12™ Cordless 3/8" 12-Volt Lithium-Ion

9.4 CAD rendering

The CAD-renderings was updated after the Alpha prototype was completed in order to include the changes that were made design wise for the Beta prototype.

In figure 32 the refined CAD-rendering is shown that visualizes the outside body of the tool. In this figure the three different parts of the tool are shown.

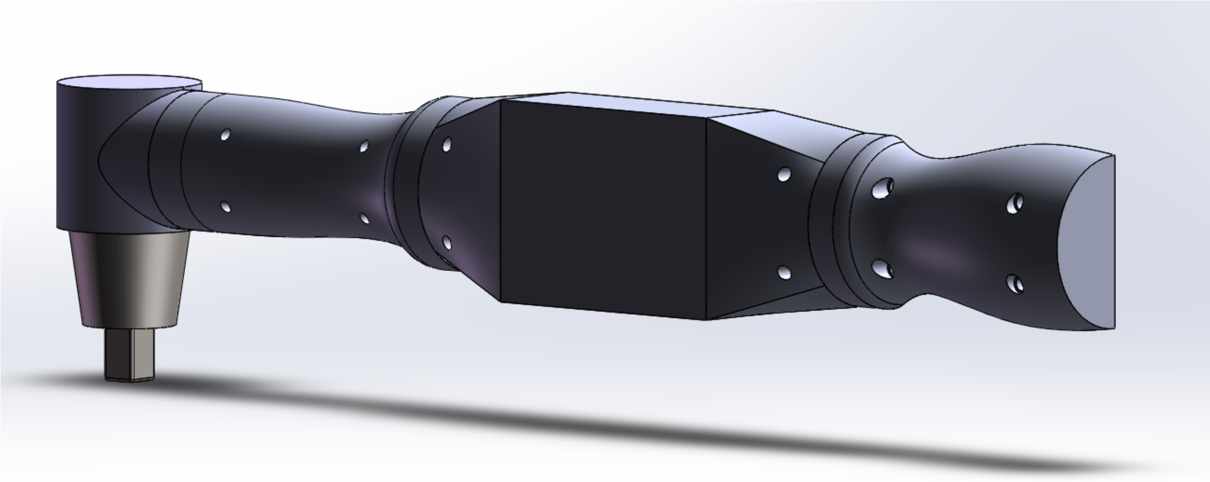


Figure 32: Design Concept

In figure 33 the inside of the tool is shown. As the figure visualizes the design shows a lap joint between the three different parts of the tool. Also showing is the screw joints between the other half of the tool.

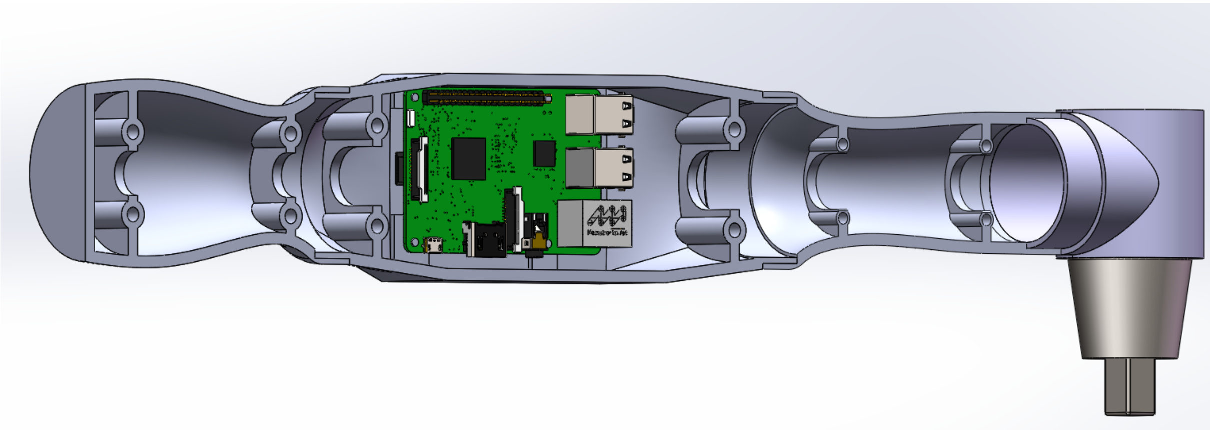


Figure 33: Design Concept

9.5 Assembly and 3D printing compatibility

One of the biggest changes from the alpha prototype is that the beta-prototype needs to be designed to be 3D printed and then assembled with the components inside, specifically the drive system. The easiest way to solve this would be to horizontally cut the tool in half and just add holes so that it can be screwed together, in a clam-shell assembly. The issue is that the 3D printers being used can't print such a large part. A solution to this problem was to divide the tool into three modules: Rear-section, middle-section, front-section. All the modules will use the same solution to assemble individually where the module is horizontally cut in half and four screw holes are added to each half so that four screws can fasten together the two halves (Needs pictures/references to pictures). To connect the three modules together three alternatives where devised:

- Have four mounting holes on each of the modules and fasten them with screws, the same way as fastening each individual module(show picture of this concept). This is a simple and robust approach that isn't that sensitive to the varying tolerances of 3D printing in ABS plastic. The drawback though is that it is not possible to detach the modules from each other without removing all 12 bolts holding together the module halves.
- Use a bayonet coupling between the modules(Do we need a picture?). This is a common solution to quickly attach or detach two parts. The drawback of this solution is that it needs fairly consistent and tight tolerances to function properly and that it is a bit harder to implement than the first solution.
- Connect the modules using threads, one male and one female. This approach also enables fast assembly/disassembly and is a well documented method. The issue is the same as in the second solution, it requires tight tolerances for a robust connection.

These three concepts have different pros and cons. Choosing which one of the solutions that is the best will fall down to deciding which of the following aspects are most important for the prototype: Structural integrity, time to develop, assembly/disassembly time. Due to the time constraint for this project the time to developed and structural integrity where prioritized. This resulted in that the solution with four mounting holes on each part that where bolted together was chosen. The drawback with this approach is that the assembly and disassembly time is longer. For a prototype this is fine but for a production model another mounting method should be explored.

9.6 Testing prototype

In order to get a greater understanding of the tool the team so far had designed an ergonomic testing was made. The ergonomic testing began with a comprehensive review of Michael Patkin's Checklist of Handle Design that was created by the Royal Adelaide Hospital in Sydney, Australia for the Department of Surgery. This checklist highlighted main components that were important for this project to consider when designing and testing the handles. The premiere decision was to understand which handle grip would be the most effective, Patkin walks through five different types of grips depending on the use of the tool. For this project the most applicable grip was the Power Grip. This grip utilizes the whole hand to hold the handle so it reassembles a fist. The team chose this grip because the operators should not be placing pressure on any phalanges or part of the hand. After picking the type of grip that was most suited, the next step was to get users to test the tool based on various testing parameters from Patkin's checklist. These parameters were among others: have an indicator to show the main pressure points in the handle, does the handle work in the expected way, have user tests, does the handle feel secure, does it look right, and is it comfortable? The rest of the section will show some of the user testing and talk more about the ergonomic design.

In the begin of the project the sponsor requested that one of our priorities should be to make sure that the tool that is created will be able to be comfortably when using by the operators on the shop floor. The previous tool was designed vertically with a trigger handle on the bottom. This was not sufficient for the operator because there was not much force on the handle from the tool component and made it too heavy for the operator to handle. Therefore, this design was converted to a horizontal layout to allow for a front and back handle that would connect to the drive train system in the middle. This would make it easier for the operator to handle the tool since they have two different areas with which they can secure the tool in their hands.

In order to ensure that the tool would truly be ergonomically friendly the shapes used for the handles were curved in the design. This fits with the more natural form of a human hand. However, the team wanted to make sure that they had more data to back up the design they had chosen and therefore as stated above a small group tried the basic 3D printed version of the handle. These subjects all had different size hands which allowed the team to get a wide variety of opinions on the design. The key feedback received was very positive with comments on the material and the width of the handle. Subjects suggested that the handle should have a softer more bouncy grip for their fingers especially. The other key suggestion was to try and reduce the width and/or thickness to make the handle slightly smaller and easier to hold. Figure 34 shows the 3D-printed prototype when being hold by a user.

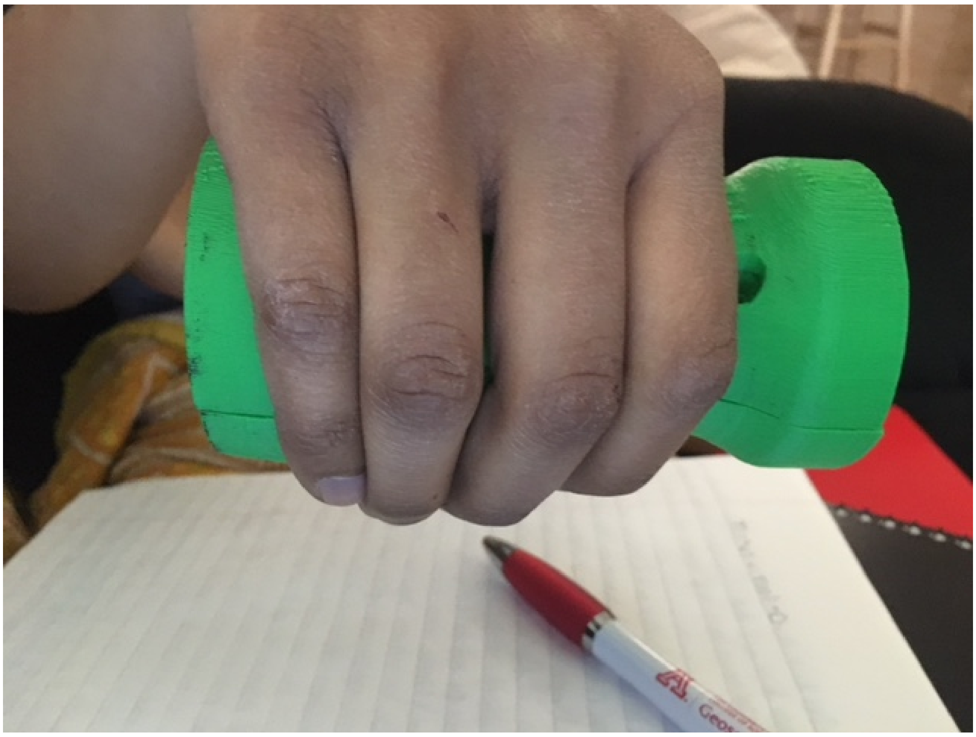


Figure 34: User Study

Both of these suggestions were looked into by the team. For the first suggestion, the team did research on several other types of handles currently seen on sports equipment and other hand tools. The common denominators between all these handles was the fact that most handles were grooved in some way, whether that be deeper finger grooves, or shallow rectangular or diagonal grooves to just separate the finger. The other commonality was that all the handles were wrapped in a rubber like material in order to make the handle more cushioned. The team is planning now to apply very shallow grooves/indentations to the design and also print high pressure areas of the handle with a special rubber available in the 3D printers in the Learning Factory at Penn State. As far as reducing the overall size of the handle and making it smaller, the team is confident that the dimensions will decrease once the the battery component are finalized. The battery component will be placed in the back handle and once that is done and those measurements are finalized the team can edit the specifications for the handle and make it smaller. For future work, the team will be doing some more trials with subjects using the softer grip and trying to pinpoint the exact locations for their placement according to the feedback they receive.

9.7 Conclusions

The main focus moving forward was to design exact mounting solutions for the electronics inside the tool, 3D print the entire tool body, make sure the body is strong enough and assemble the prototype. Deciding which attachment solution between the modules will also be a key feature to decide and implement. The middle section and the rear handle are basically completed but the front module will need some work and several iterations to successfully integrate the existing motor and gearbox in the front module. This will be a challenge since there where no CAD-models or drawings with measurements for the Milwaukee tool, there will likely have to be several iterations before a good design is produced.

Another big concern was how to control the electronics. The initial idea was to use the same components as last year I.E a Raspberry Pi 3 and a digital positioning speed controller, so that the amperage, threading speed and amount of threading can can be monitored. This will not be possibly due to problems with software and the amount of time it have taken to fix it. The team also had a problem with the actual computer that ROS was installed on and the problems had let to that the computer hosting the software is now not usable. A possibility is to use the speed controller that comes with the Milwaukee tool and with that replace both the Raspberry Pi and the other speed controller. Another decision regarding the control of the motor is where to put the trigger. This will also have to be further explored based on what is most ergonomically correct and what is possible with the current design.

10 Gamma Prototype

The gamma prototype is a continuation of the beta prototype with some alterations. From the beta prototype the team learned that a next step in the process would be to focus on the electronics of the tool, to decide what attachment solution between the modules would be good and how to finalize the front module in order to integrate the existing motor and gearbox. The beta prototype phase also included a group of people testing the ergonomics of the tool and a suggestion was to develop a good rubber grip for the next prototype.

Therefore the next phase of the project consisted of making minor alterations to the prototype in order to make it a functioning tool. To increase the structural integrity, the fastenings connecting the three parts have been changed in the gamma prototype. The new design consists of a bolt connection to ensure that the structure can handle the counter-torque from the tool. Along with this, a rubber grip was designed and implemented into the rear handle in order to improve the tool's usability as requested from the ergonomic testings during the beta prototype phase.

During the beta phase there was also problems with controlling the electronics and therefor the team decided to focus some during this phase on what type of sensors that could be integrated into a future tool. Another solution that was developed during this phase was the solution for the trigger. The new solution consists of a lever so that the operator could easily start the tool when using it.

This section of the report will detail the above changes that the team have made during the gamma phase. The physical prototype has not been majorly changed since the Beta prototype. It still consists, after a few design changes, of three parts. A front handle, a middle section and a back handle. Figure 35 shows the gamma prototype as a whole.

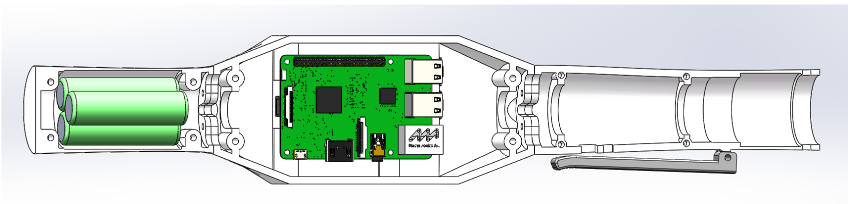


Figure 35: A CAD rendering showing the three sections of the tool.

10.1 Fastenings

A main difference from the Beta prototype that can be seen in both figure 35 and figure 36 are the connections between the three parts. In order to make the prototype more robust, a bolt connection was added to the design. The Beta prototype had only lap joints keeping the sections together and with this improved design, the tool is more resistant to force and counter torque.

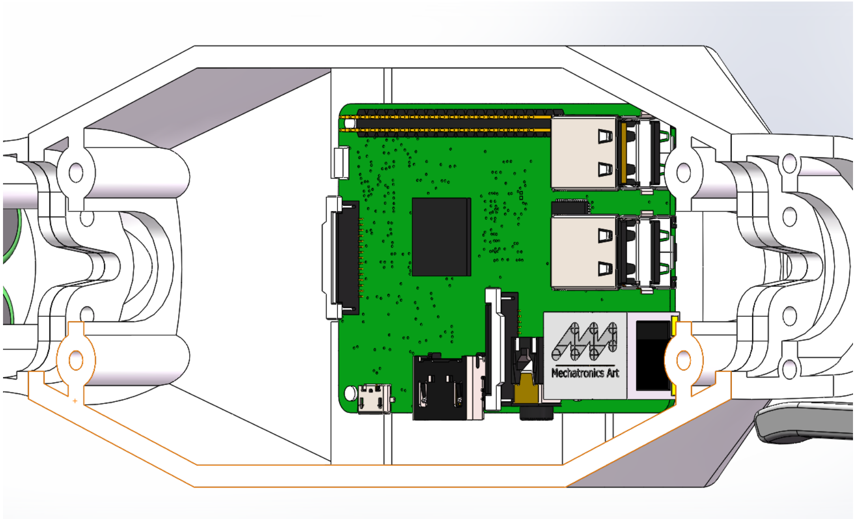


Figure 36: A CAD rendering showing the middle section.

Also shown in the figure 36 above is the amount of space available for other components. This space was intentionally designed into the tool in order to house electronics and sensors which has as purpose to communicate with the robot. This is not anymore a part of this project, but if in a future project there are an aim to develop the tool's electronics the space would not be a constraint.

10.2 Rubber Grip

The back handle of the tool was designed to be able to hold the batteries that are needed for the tool to function. As visualized in figure 37, this section was improved from the beta prototype by making the design of the part more efficient than before. This means leaving little leftover room to housing the batteries.

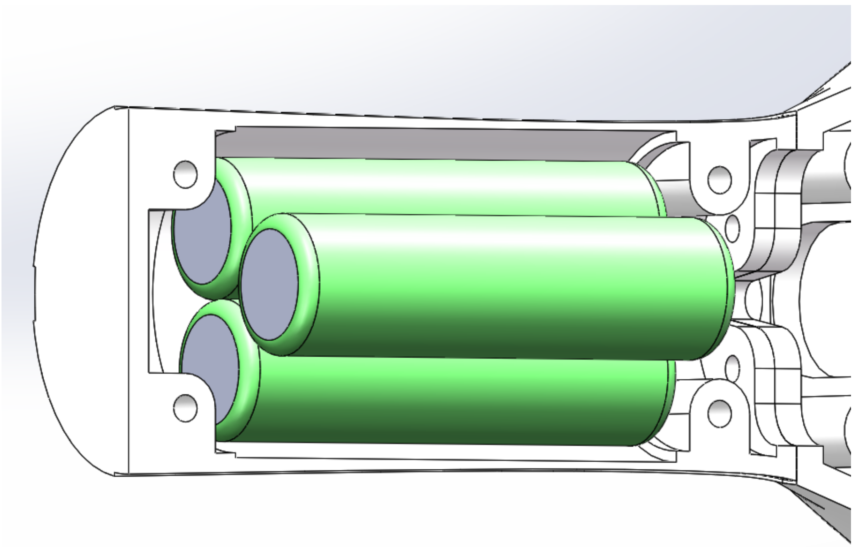


Figure 37: A CAD rendering showing the back handle.

During the beta prototype development, the team did a great deal of ergonomic testing for both the front and back handles. During the testing phase, the team found that the handles needed to be more comfortable for the users in terms of the material on the handle. The research proved that a rubber grip would allow for more cushion and comfort for the operators. An analysis of the resources on campus proved that there was a 3D printer that would be able to print a rubber like plastic for the rubber grips that the team wanted to incorporate into the design. The next step was to understand where these rubber grips should be located. The team again recruited a small group of users to give feedback on where they felt the grip would be most effective. The feedback led to the new design of the back handle which has half inch rubber grips going down all four sides of the handle, as shown in figure 38

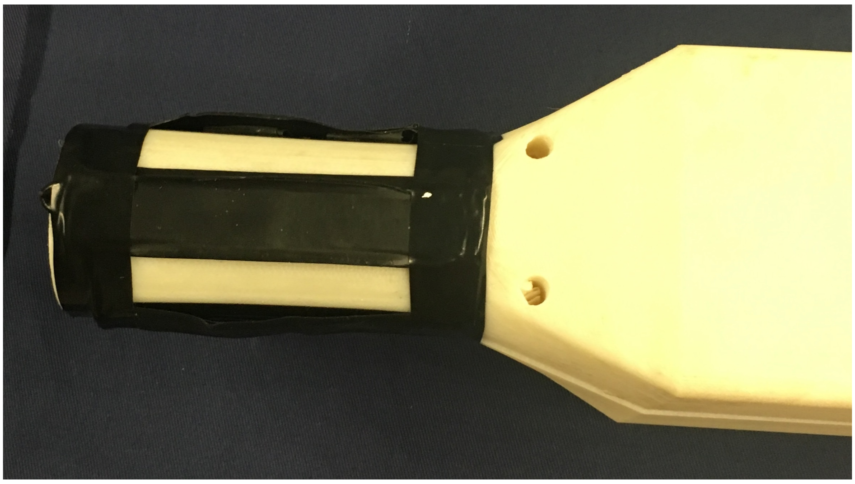


Figure 38: Rubber Grips

10.3 Trigger Lever

The front handle was designed to be able to fit the motor and chuck of the tool during this phase, therefore the design is longer and sleeker than the back handle. Figure 39 shows that the front handle is exactly tailored to the drive system in order to limit the mobility of interior components during operator use.

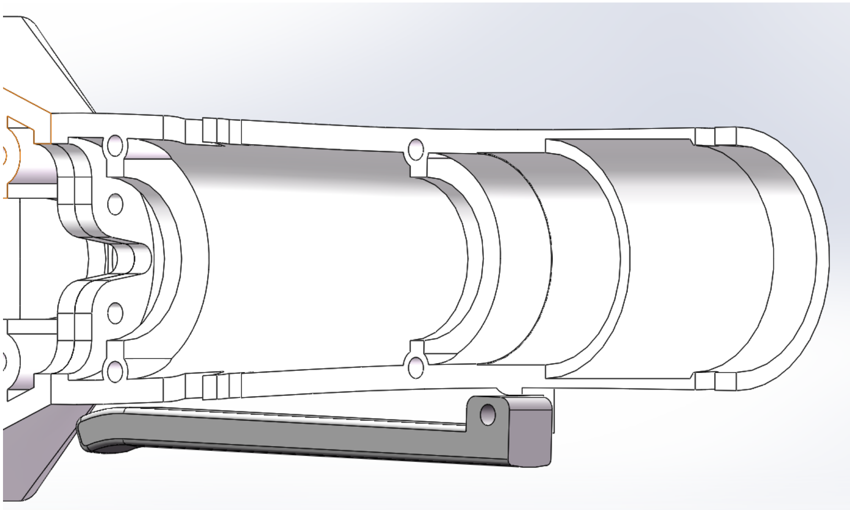


Figure 39: A CAD rendering showing the front handle.

Also shown in figure 39 is the newly added lever. As the tool was constricted to the shape of the Milwaukee torque wrench, the team faced the challenge of adjusting the trigger to a comfortable position. Because the heavy motor led the tool's weight distribution to being heavy in the front, the importance of addressing this issue was amplified. The team's solution consisted of using a lever which pivoted at the front and met the trigger in the back of the handle. This not only solves the dilemma of the constraint mentioned above, but also serves as an ergonomic solution as the operator may activate the tool with distributed pressure along the lever and not at a focal point.

10.4 Electronics and powertrain

The electronics and power train that were used in the Gamma prototype are all from the Milwaukee tool. The electronics consisted of a brushless DC motor and a planetary gearbox that went to the bit, a speed controller that gave the motor power and a potentiometer that worked as a trigger, see figure 40 that describes the electronic chart.

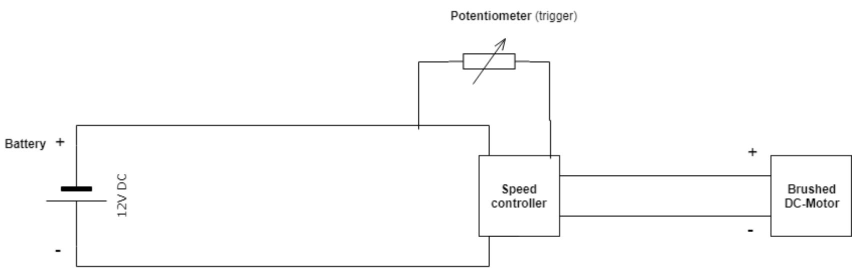


Figure 40: Connection chart electronics

The potentiometer works as a type of throttle by giving a variable resistance and thus sending out a different voltage/signal. The speed controller then gets that difference in voltage/signal and adjusts power accordingly. The power to the speed controller came from a modified 3 cell (12v) battery that used three 18650 batteries connected in series with a power and balance connector attached to it (see figure 41 and 42).

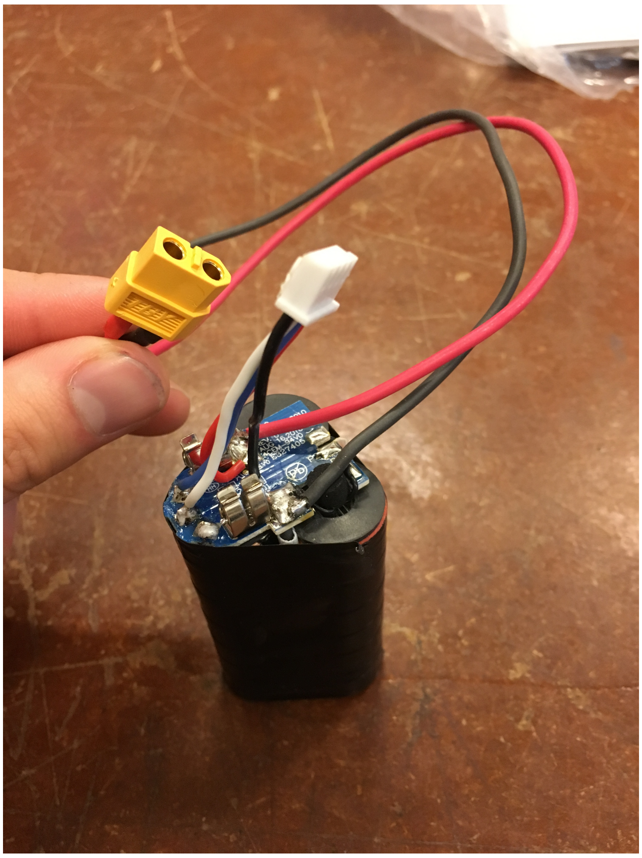


Figure 41: Assembled Battery

The batteries that came with the Milwaukee tool used the same type of cells but had a plastic casing that was too thick for the battery to be integrated into a slim handle. What was done was to remove the plastic casing and use the existing serial connection for the batteries and solder on the connectors necessary as can be seen in figure 42. The original battery connector had a third connection, in addition to the standard positive and negative poles, that had to be connected to the speed controller for the tool to work. A connection was therefor made by soldering a connector directly to the battery and speed controller respectively (Insert picture of solution). That enabled the battery to be easily removed and charged. It was not entirely clear what this connection was for but the team had two theories: that is was for monitoring temperature or voltage. As mentioned earlier in this section, a balance port was also added to the battery. The balance port enables each cell to be monitored for any variance in cell voltage, since that usually indicates that a cell it starting to fail. A failing cell can result in the other two cells being overcharged and starting a fire.

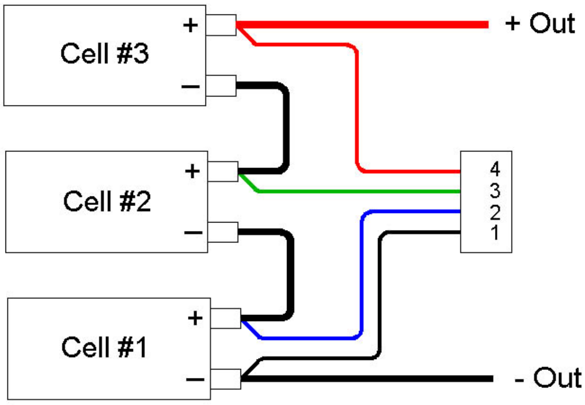


Figure 42: Battery connection

This project had as a vision that the tool would work with ROS, as requested by Volvo. Due to problems with the computer holding the operation system Ubuntu, a delay with a functioning ROS system occurred while in the beta phase. After a failed attempt to get a new computer that could host Ubuntu a decision was taken with supervisor that this part of the project would be dropped. Another focus point would instead be on what kind of sensors that could be integrated into a future tool.

10.5 Sensors

During the project there have been ideas on how sensors could be used alongside with the tool and how that would function. One of the ideas that emerged was if the angle of the tool could be sensed and how Volvo Group would benefit with this information. One of the ideas was to use an application which could be used for helping the operator to understand how the tool should be positioned in order to mount or demount the screw or bolt the correct way. For example, an application on an Apple Watch or such could be used for visual control and guide the operator when it can be difficult to see the object being mounted or demounted.

The two sensors, gyro and accelerometer, can be combined into one unit, which is called an inertial measurement unit (IMU), and it can among other things sense rotational motion and changes in orientation (Sparkfun, 2018). These two changes can be difficult for an operator to sense if the variety is small. A sensor like this can be used for various applications, where one of the application is angle sensing, since the unit can sense up to six degrees of freedom. If integrating a unit like this into the developed tool it could help the operator to navigate when mounting or demounting screws or bolts.

Due to limitations with time and since the team are using another tool's electronics, an IMU has not been integrated in the design. To emphasize how the IMU could be useful in future stages of the project a dummy proposal of how the angle sensing could be used is presented below in figure 43. The figure shows how the operator in this case with the use of an Apple Watch can easily see how the tool is oriented in relation to the screw or bolt that are being mounted or demounted. First, as seen in figure 43, the operator needs to find the correct horizontal and vertical angle. Then secondly, when the operator has found these than the operator needs to find the correct rotational angle by rotating the tool as seen in figure 44. If the operator finds all of these three angles, then the application shows that it is approved to press the lever and thereby start the tool.

Figure 43: Finding horizontal and vertical angle

Figure 44: Finding rotational angle

This is just concept images showing how the IMU could be used if integrated. Depending on what kind of work the operator is doing, different angles could be important. The idea behind this concept is that the operator has a certain order that he or she shall mount or demount the screws or bolts. Depending on what step the operator is performing the application should be able to change the desired angle.

10.6 Assembly and 3D printing compatibility

In the Beta prototype, all assembly solutions had been decided except for how to connect the original Milwaukee motor, gearbox and tool-head to the rest of the body. This was solved by mimicking the original mounting solution in the Milwaukee tool and combining it as a front handle. After the CAD-parts had been designed and put together in a virtual assembly to check that everything fits, the next step was to 3D print all the components. The 3D printer used was a Ultimaker 3 using ABS plastic for the body and PVA plastic for the support. PVA is water soluble which eliminates most of the need to do finishing work after the print is completed.

When the parts had been printed they where assembled in two halves using m3 screws and nuts, see 45. To connect the two halves together a thread was added to one of the halves by melting them into the holes, see figure 46. This eliminated the need for nuts and made it easier to assemble and perform later maintenance.

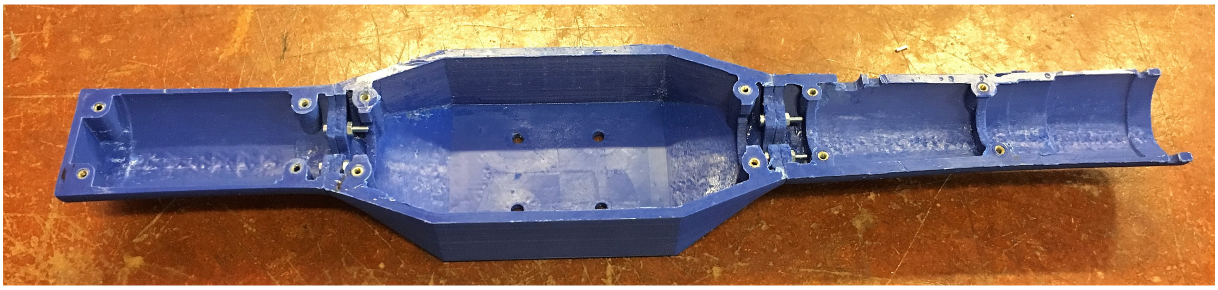


Figure 45: Assembled half of body

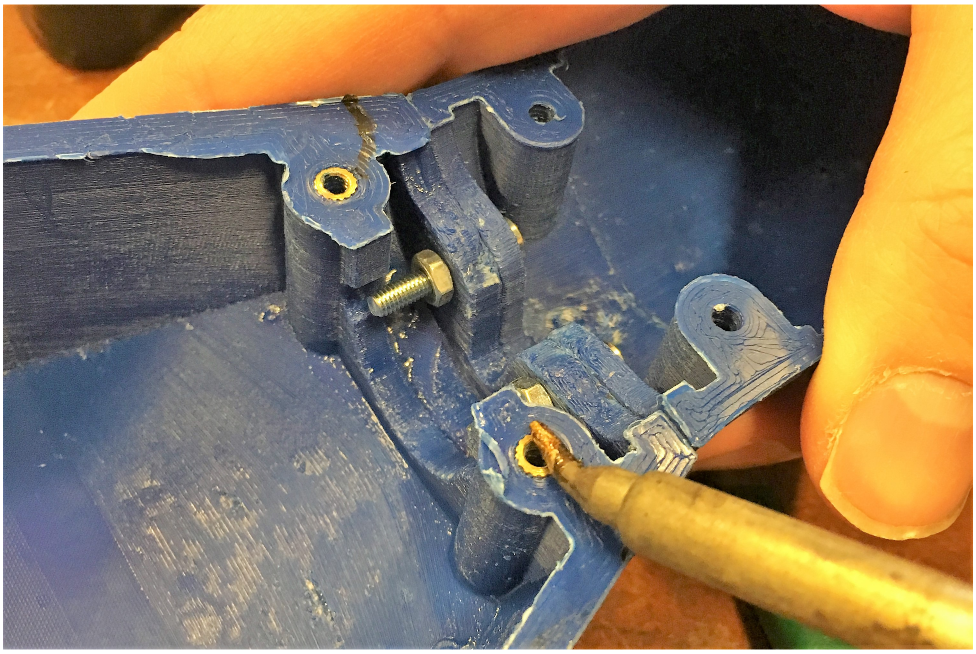


Figure 46: Inserted m3 threads

The next step was to incorporate the powertrain where several modifications had to be made for everything to fit. The speed controller was moved back to the middle section by adding length to the cables from the trigger and the motor, see Figure 47. The original design to fit the trigger did not work as planned and some slight modifications using a dremmel was required.

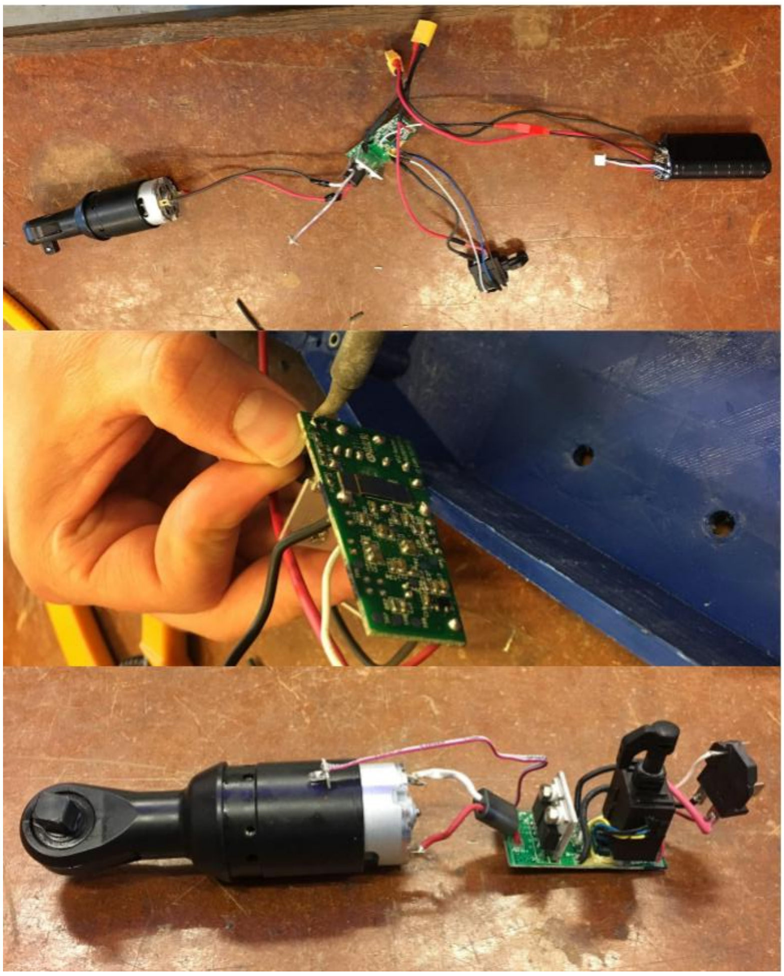


Figure 47: Original powertrain on the left and modified on the right

After all the parts where test fitted and modified everything was fastened by using hotglue, and for the trigger wooden supports to secure it 48. At this stage it became apparent that the inner diameter for the front handle was to small to properly fit the motor and tool head. This was solved by taping the front section and also gave some structural support when the tools is used. Lastly the lever was fixed with a m3 screw, nut and washers.

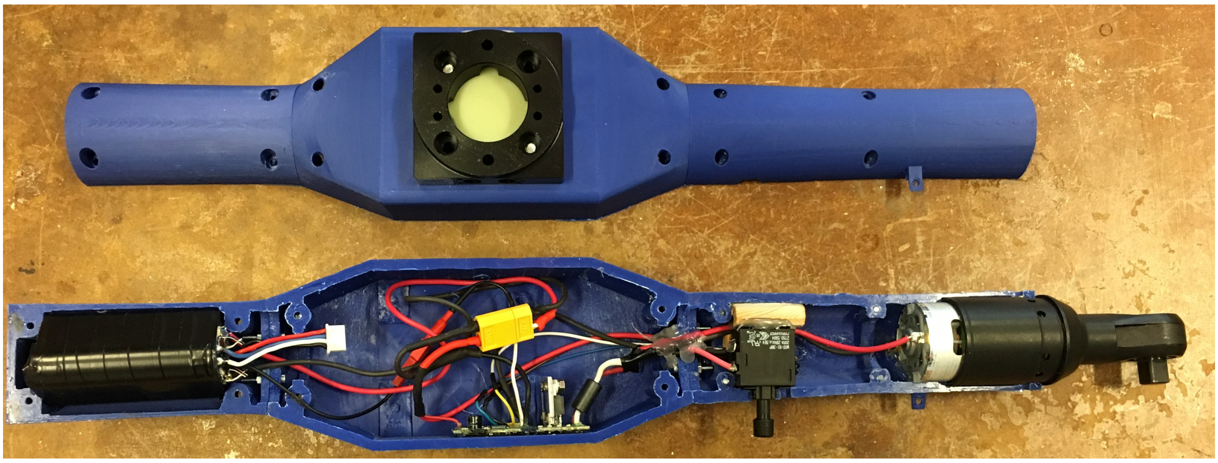


Figure 48: Opened Tool

10.7 Testing prototype

To make sure that the prototype full fills all the requirements the group decided to do a few simple tests of the prototype. The finished prototype can be see in Figure 49. It weighs 1.25kg and is 2 kg lighter than last years prototype, but also it still manages to have a rigid body. The overall impression of the tool is that it is well built, robust and has a strong structure integrity.

Figure 49: Gamma Prototype

After the new design from the Beta testing no huge changes were made on the ergonomic front. The prototype fits well in the hand and is intuitive to hold, but has a center of gravity that is skewed towards the front of the tool. This is something that needs to be balanced when the prototype moves out to production.

An assembly line test were made to see if the tool could be used both by left and right handed people, see Figure 50. This were no problem, the prototype were comfortable during both test and it were as easy to navigate in both cases. During this test the group had no access to any robot so the RSP-connector could not be tested.

(a) Front hand left

(b) Front hand right

Figure 50: Assembly line test

The prototype was also drop tested to see if it met with the drop resistance requirement. The test was conducted from a height of 1 meter and for the test to be as thorough as possible, the prototype was dropped on the angle where it was deemed most fragile. This resulted with no damage on the prototype. After the drop test a basic Screwing test were made to see if the prototype full fills the torque requirements and battery length. A torque meter were used during the test and the prototype manged to screw the bolt at the 47 Nm 5 out of 5 times.

Due to shortage of time the group could not test the battery length of the required usage for a 8 hours shift. A voltmeter were used instead to check the voltage of the battery and see if any extraordinary loss of power were found. After a many tests the battery seems normal and the conclusion was drawn that it would not have any problems with being in use for a normal 8 hours shift.

11 Conclusion and Discussion

Over the past four months, the team was able to produce a functioning prototype that would allow for the mounting and dismounting of screws and bolts on the assembly line. The team combined the learning's from the previous iteration of the project and needs from the sponsor to redesign the tool. The tool consisted of a front and back handle, a middle compartment, a Milwaukee 3/8 ratchet tool, three 18650s, and two mock robot connections. The main focus of this redesign was operator comfort, size and weight of the tool, and robot compatibility. The project began with a complete change in shape for the tool itself. The team decided to change the tool from a vertical body to a horizontal body. This allowed the team to incorporate a front and a back handle for the operator leading to a more stable support structure for the operator to hold onto. Operator comfort was a large part of our focus, therefore, there was a great deal of ergonomic testing and design concentrated on the handles of the structure. Multiple iterations of the handles resulted in a front handle that included the drive system, chuck, and trigger of the tool. A lever was added for easier use of the trigger. The back handle included three 18650s that were the battery for the tool, and incorporated a curved design to fit the natural shape of the hand. The team also added rubber grips to add comfort to the handles. This overall analysis and design of the handles targeted the operator comfort concern of the sponsor.

The coming subsections of the report will state however the project's main objectives have been accomplished and how. There is also a section with a brief economic analysis on how Volvo can gain the most use out of this developed tool. The economic analysis have been broken down into two different parts: the plastic part of the tool and the drive system.

11.1 Discussion

In this project there have been five main objectives to fulfill, these were:

The project's main objectives were:

- Generate a tool for both humans and co-robots to utilize.
- Create a functional prototype that can produce >40 Nm to screw in bolts.
- Allocate space in tool for sensors, such as camera and accelerometer.
- Achieve a low weight (<2.5kg) without sacrificing structural integrity.
- Produce an optimized design proposal for a light and rigid body based on a finite element analyses.

The first objective was that the tool should be able to produce over 40 Nm when mounting bolts. The tool can after finalizing the Gamma prototype mount bolts with 40 Nm. This is possible due to the fact that the team have used an exciting tool integrated in the Gamma prototype. The tool that has been integrated is called Milwaukee M12™ Cordless 3/8" 12-Volt Lithium-Ion.

The second objective to reach was that it would be enough space inside the tool to fit future integrated sensors. The middle compartment of the tool had plenty of space for the intended Raspberry Pi and for future sensors that could be used to communicate with the tool, and any speed controller additions. In addition, the outside of the compartment was rectangular on all four sides to incorporate two robot connections perpendicular to each other. This was targeted toward the increased compatibility with the robot for our sponsor. Since the gamma prototype have additional space, there would be no worries for future project's to implement sensors on the already existing gamma prototype.

Another objective to reach was that the tool should hold a low weight under 2.5 kg without sacrificing structural integrity.This was solved through the horizontal restructuring of the tool. The tool lost a great deal of surface area by condensing the drive system and battery to the handles limiting the electrical components to the central compartment. This reduced the weight of the tool to around 1.25kg. The horizontal structure also allowed more connection points for the robot making it easier for the robot to use the tool in multiple directions. The structural integrity has not been compromised by having robust connection points between the three modules and using a cylindrical design for the smaller front and rear handle to increase the rigidity without adding to much weight.

Produce an optimized design proposal for a light and rigid body based on a finite element analyses was the last objective that the team wanted to reach. Finite element analyses was made in an early stage of the project after the Alfa concept had been chosen. This analyses helped the team to visualize where the maximum stresses occurred. Results showed that thickening the inner walls of the grips would help make the structure more rigid. Therefore it is safe to say that the design proposal was optimized based on the finite element analyses that was made in an early stage of the project.

Overall the redesign was extremely successful with targeting the principal concerns of the sponsor and reaching the objectives that was set for this project.

11.2 Economic Analysis

An economic analysis was made in order to find out how Volvo can gain the most use out of the developed HRC tool that this project have developed. The analysis on how to do so was broken down into two categories: plastic and drive system. The results of this analysis were that the tool must be mass produced in a cost effective manner in order for Volvo to gain the most.

11.2.1 Plastic

For practical purposes, the outer shell of the tool was created using 3D printing. On a small scale, 3D printing offers users the ability to deliver a single design relatively quickly which is suitable for this environment. However, there are several reasons why the team recommends Volvo to use injection molding to form the tool on a massive scale. The first and largest advantage that injection molding has over 3D printing is that, in scale, injection molding is much more cost effective. As 3D printing is still a growing field, it doesn't offer the cost advantages that injection molding does. As injection molding can be automated, the initial capital and labor costs are reduced heavily as well. The next advantage is that, in the long run, the production time for injection molding is greatly reduced compared to 3D printing. Printing each part of a prototype can accumulate to over 40 hours whereas injection molding can handle several entire models at a time. Finally, injection molding allows for the use of several materials in one design at once. This would facilitate the development of the rubber grips on the rear handle instead of having to print them each separately.

11.2.2 Drive System

As previously mentioned, Volvo possesses the necessary resources to develop their own compatible battery system. The motor, gear-box, and tool head must be procured from somewhere else. In order to complete the prototype, the team purchased an existing torque wrench from Milwaukee for roughly $80. This cost can be significantly reduced however, due to the fact that a lot of the Milwaukee tool, such as the outer shell, was never used. Because only the drive system is needed, a deal can be made with Milwaukee to purchase only the relevant components for a subdued price. Along with this, the price can be further reduced if Volvo purchases a certain amount at once due to economies of scale. Finally, the tool will need to be assembled at a Volvo facility, meaning that several more costs need to be taken into account such as inventory space/cost, and labor hours.

12 Future Development

During this project there have been various thoughts from the team's members on what future project's can develop further. Everything from focusing on delimitations of this year's project to elaborate details from this year's project and even to develop unexplored details linked to this project.

The delimitations of this project were:

- include functionality for sensors.
- include working software functionality for between co-robot and prototype.
- give exact speed for fastening bolts.

All these delimitations can be of interest for a future development of this project. If using the body that was made during this project an other team could focus more on these delimitations and thereby develop an even better prototype, which could be even more useful.

For example, this project have only quickly examined what type of sensors that could be integrated into a future prototype. But, it could be really useful if a team could continue this search and actually integrate it into the prototype.

Likewise, since this year's project has not been able to work out a functioning ROS program, this is a also a good continuation project. A future team with more experience in electronics and coding would have a better chance to please the sponsor by having a prototype that can be controlled by a computer and used by a robot. As the middle section has a lot of room available, there should be no problem adding or changing the electronics to realize such a prototype

The last delimitation, that is related to both of the above statements, is that a future project could incorporate a solution that can measure the exact speed for fastening bolts.

During the project there have been details that the team have not had time to explore further. Some of these will be stated below as suggestions for future development of the tool created during this year's project.

Details that are possible to elaborate:

- positioning of the trigger in the back handle
- placement of connection points in order to hang tool from above
- use rechargeable batteries and being able to recharge them easily

Due to the fact that the team used, and modified, an already existing tool for the prototype to work and time limitations the team had to position the trigger in the front handle. This was because of how the existing tool looked when dismounting it. For an operator it would be better to have a trigger in the back handle since it would be even more ergonomically correct. It would even out the work force since the hand holding the front handle would only have to focus on the counter torque. Of course the other hand holding the back handle also feels the counter torque, but the assumption is that it would be less difficult to also focusing on pressing the lever with this hand.

Placement of connection points in order to hang tool from above is a request from the sponsor. Just like the lever time was limited and this was a request that this year's team could not meet. The tool would in a real work environment be hanging from the ceiling if used by a operator and that is why this was a request from the sponsor, to make the tool balanced enough to be easily grasped by the operator.

In the early stages of the project the team could not find a easy enough solution to incorporate rechargeable batteries that was easily accessable. This was difficult since the electronics of course needs to be connected together with the batteries. The team ended up using three 18650 rechargeable batteries which connect to the drive system with soldered wires. Unfortunately these batteries are not easy to recharge since batteries only can be accessed if disassemble the tool. Remodelling of the back handle in order to making it detachable and thereby being able to use the recharging functionality would be a good continuation project for another team.

There is also elements that have not been explored during this project, one of them is:

- build own electronic components for a better size fit and optimization of usage

This is an interesting thing to develop since it would help make the middle part of the design a little bit smaller and probably also give the full tool a lighter weight than using full-size already existing electronics. For example, if a team would be able to design their own control board then that part could be more optimized for the tools size and performance needs.

As stated in this section, there are several fields that can be further explored connecting to this project. If a new team could use the body developed from this year's project there could be new opportunities in what the tool can do and how it can function.

Best of luck,
Team 2018

References

The analytic hierarchy process. (2018). (http://www.dii.unisi.it/~mocenni/Note_AHP.pdf)

Bryman, A., & Bell, E. (2015). *Business research methods (4th ed., pp. 128-145).* Oxford: Oxford University Press.

Gerbers, R., Mücke, M., Dietrich, F., & Dröder, K. (2016). Simplifying robot tools by taking advantage of sensor integration in human collaboration robots. *Procedia CIRP*, *vol. 44*, pp. 287-292.

Hinds, P. J., Roberts, T. L., & Jones, H. (2004). Whose job is it anyway? a study of human–robot interaction in a collaborative task. *HUMAN-COMPUTER INTERACTION*, *vol. 19*, pp. 151-181.

Hugo göthberg's working experience. (2018). (Gothenburg)

J.Krüger, T.K.Lien, & A.Verl. (2009). Cooperation of human and machines in assembly lines. *CIRP Annals*, *vol. 58, no. 2*, pp. 628-646.

KUKA. (2017). *Human-robot collaboration (hrc).* (https://www.kuka.com/en-us/technologies/human-robot-collaboration)

Meeting with sponsor. (2018). (Gothenburg)

Sparkfun. (2018). *Accelerometer, gyro and imu buying guide.* (https://www.sparkfun.com/pages/accel_gyro_guide)

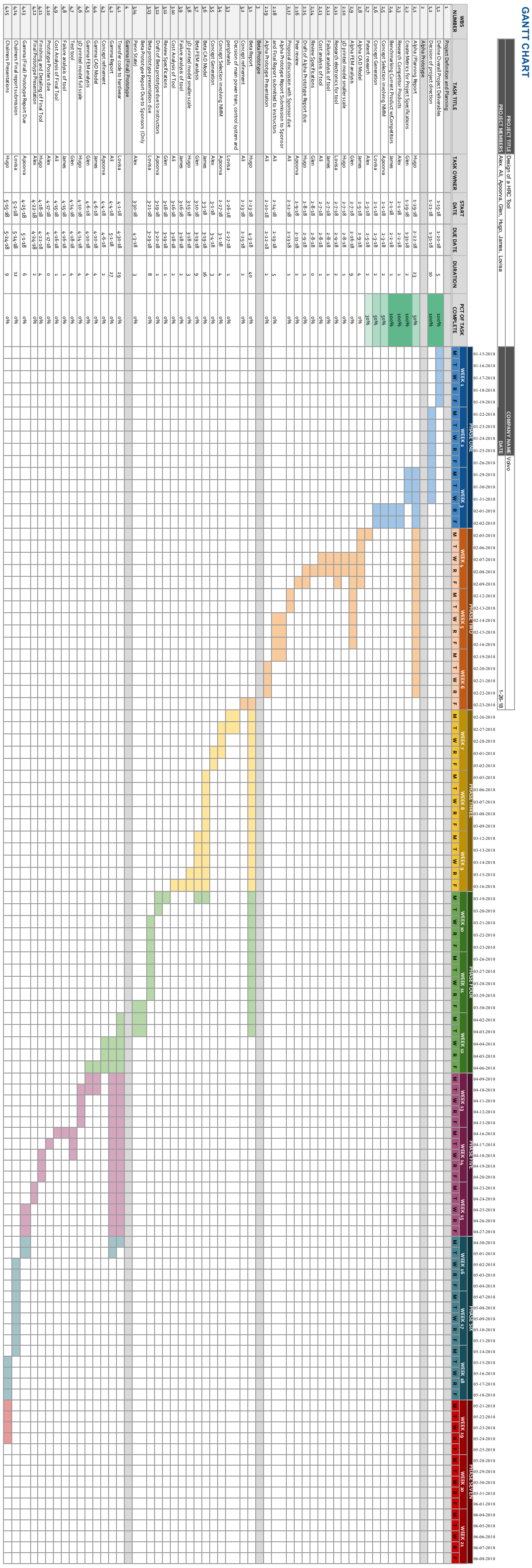
Tsarouchi, P., Matthaiakis, A.-S., Makris, S., & Chryssolouris, G. (2016). On a human-robot collaboration in an assembly cell. *International Journal of Computer Integrated Manufacturing*, *vol. 30, no. 6*, pp. 580-589.

U.s. patent no. us20090259412a1. (10/15/2009). (Washington, DC: U.S. Patent and Trademark Office)

U.s. patent no. us6876173b2. (04/05/2005). (Washington, DC: U.S. Patent and Trademark Office)

U.s. patent no. us7235940b2. (06/26/2007). (Washington, DC: U.S. Patent and Trademark Office)

Appendix A Gantt Chart



Appendix B Beta Prototype

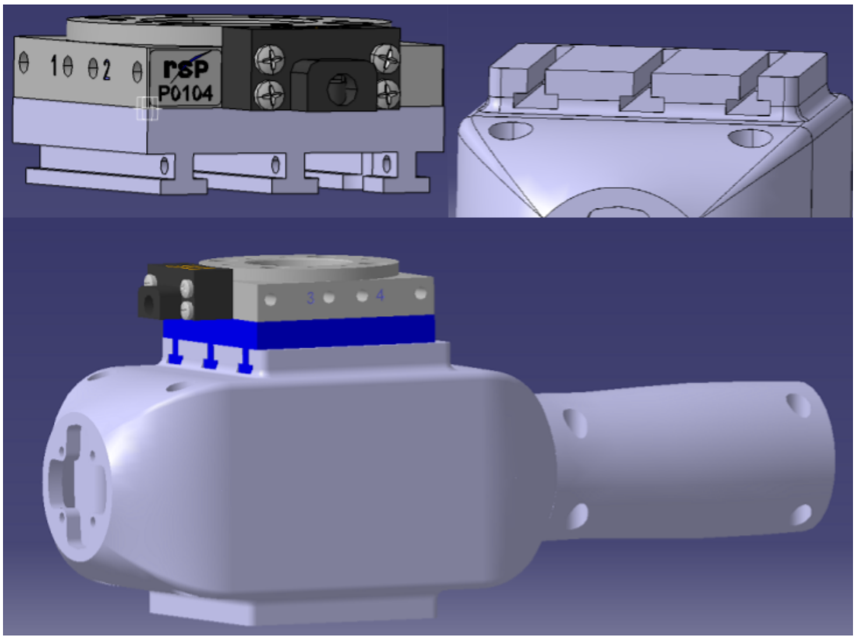


Figure 51: Guidance rails Attachment

Appendix C Milwaukee Tool

SERVICE PARTS LIST

BULLETIN NO. 54-47-0230

SPECIFY CATALOG NO. AND SERIAL NO. WHEN ORDERING PARTS		REVISED BULLETIN	DATE Sept. 2017
M12™ 3/8" RATCHET		WIRING INSTRUCTION See Reverse Side	
CATALOG NO. 2457-20	SERIAL NUMBER D54A		

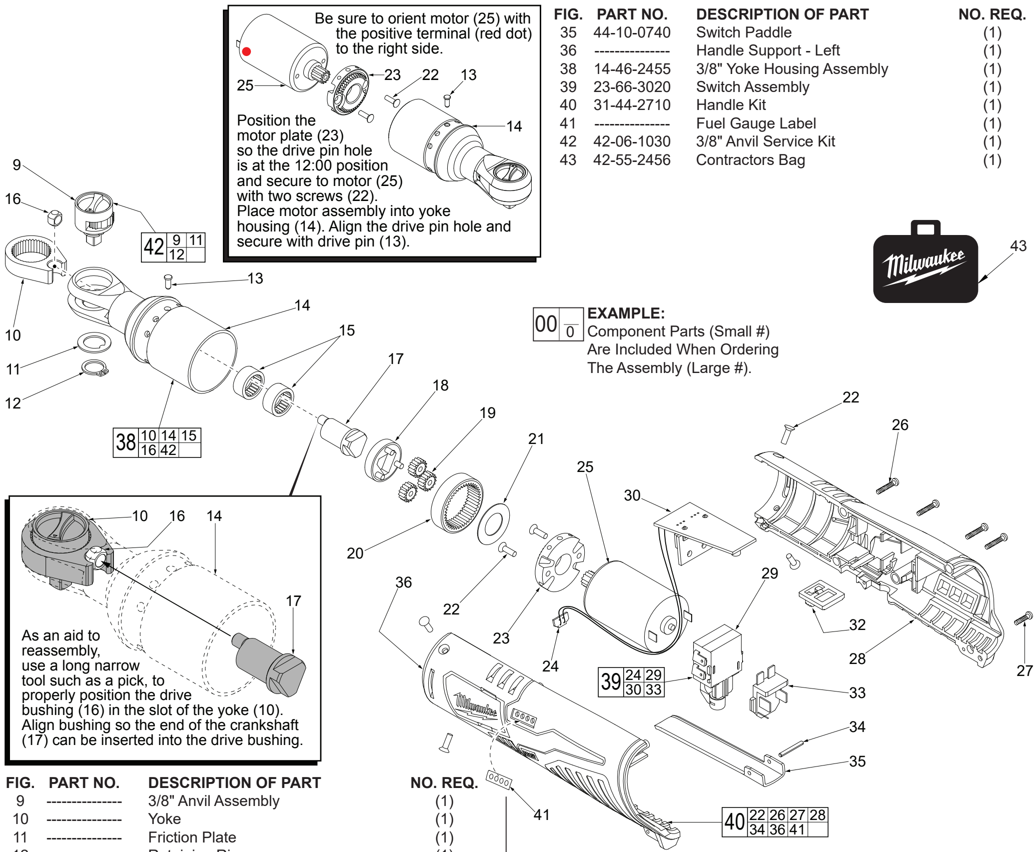


FIG.	PART NO.	DESCRIPTION OF PART	NO. REQ.
35	44-10-0740	Switch Paddle	(1)
36	---------------	Handle Support - Left	(1)
38	14-46-2455	3/8" Yoke Housing Assembly	(1)
39	23-66-3020	Switch Assembly	(1)
40	31-44-2710	Handle Kit	(1)
41	---------------	Fuel Gauge Label	(1)
42	42-06-1030	3/8" Anvil Service Kit	(1)
43	42-55-2456	Contractors Bag	(1)

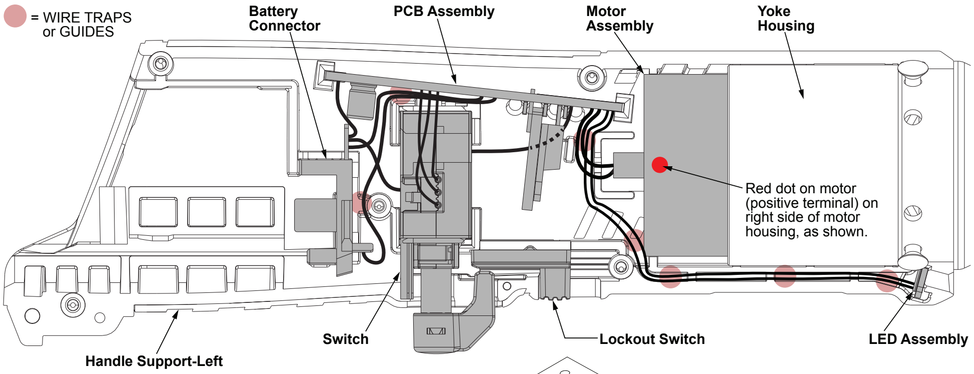
FIG.	PART NO.	DESCRIPTION OF PART	NO. REQ.
9	---------------	3/8" Anvil Assembly	(1)
10	---------------	Yoke	(1)
11	---------------	Friction Plate	(1)
12	---------------	Retaining Ring	(1)
13	44-60-0890	Drive Pin	(1)
14	---------------	Yoke Housing	(1)
15	---------------	Needle Bearing	(2)
16	---------------	Driver Bushing	(1)
17	36-17-0300	Crankshaft	(1)
18	28-23-0500	Carrier Assembly	(1)
19	32-62-0400	Planet Gear	(3)
20	32-65-0350	Ring Gear	(1)
21	45-88-2105	Washer	(1)
22	05-81-0105	M3 x 10 T-10 Screw	(6)
23	44-66-1240	Motor Plate	(1)
24	---------------	LED Assembly (Component of PCBA)	(1)
25	23-30-0650	Motor Assembly	(1)
26	06-82-2385	M2.6 x 14 ST T-8 Screw	(4)
27	06-82-2395	M2.6 x 10 ST T-8 Screw	(1)
28	---------------	Handle Cover - Right	(1)
29	---------------	Switch	(1)
30	---------------	PCB Assembly with LED	(1)
31	12-20-2454	Service Nameplate (Not Shown)	(1)
32	23-66-2910	Lockout Switch	(1)
33	---------------	Battery Connector	(1)
34	44-60-0575	Spring Pin	(1)

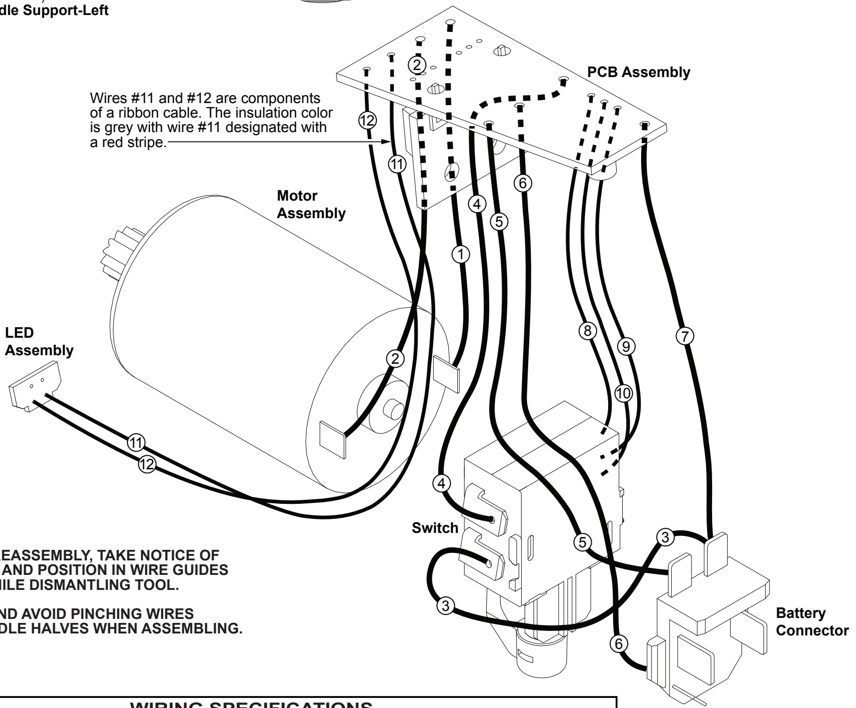
FIG.	LUBRICATION (Type 'E' Grease, No. 49-08-4122):
17	Apply a moderate coating of grease to the small cylindrical surface that goes into driver bushing and to the large cylindrical surface that is surrounded by the two needle bearings.
18	Apply a moderate coating of grease to the three axles of the carrier assembly prior to installing the planet gears.
20,25	Apply a heavy coating of grease to the inside diameter gear teeth of the ring gear and the teeth of the motor pinion.
21	Apply a light coat of grease to the surface of the washer.

FIG.	NOTES
28,31	Prior to installing a new service nameplate, apply isopropyl alcohol to the handle cover with a clean, lint free applicator and allowed to dry.
34	Use a similar size tool or pin to remove the spring pin from the handle halves and switch paddle. When reinstalling pin, align the holes and carefully press or tap the pin in place.

MILWAUKEE ELECTRIC TOOL CORPORATION
13135 W. LISBON RD., BROOKFIELD, WI 53005

Drwg. 5





AS AN AID TO REASSEMBLY, TAKE NOTICE OF WIRE ROUTING AND POSITION IN WIRE GUIDES AND TRAPS WHILE DISMANTLING TOOL.

BE CAREFUL AND AVOID PINCHING WIRES BETWEEN HANDLE HALVES WHEN ASSEMBLING.

WIRING SPECIFICATIONS

Wire No.	Wire Color	Origin or Part No.	Gauge	Length	Terminals, Connectors and End Wire Preparation
1	Red	23-66-3020	--	--	Component of the Switch Assembly.
2	White	23-66-3020	--	--	Component of the Switch Assembly.
3	Red	23-66-3020	--	--	Component of the Switch Assembly.
4	Black	23-66-3020	--	--	Component of the Switch Assembly.
5	Black	23-66-3020	--	--	Component of the Switch Assembly.
6	White	23-66-3020	--	--	Component of the Switch Assembly.
7	Red	23-66-3020	--	--	Component of the Switch Assembly.
8	Yellow	23-66-3020	--	--	Component of the Switch Assembly.
9	Blue	23-66-3020	--	--	Component of the Switch Assembly.
10	Black	23-66-3020	--	--	Component of the Switch Assembly.
11	Grey w/ Red Stripe	23-66-3020	--	--	Component of the Switch Assembly.
12	Grey	23-66-3020	--	--	Component of the Switch Assembly.

BULK LEAD WIRE - BULLETIN 58-01-0003

NOTE:
All leads must be held to ± 1/16".
All lead lengths are before stripping.

TERMINAL DESCRIPTION

Code	Part No.	Qnty.

CONNECTOR DESCRIPTION

Appendix D CAD Drawings

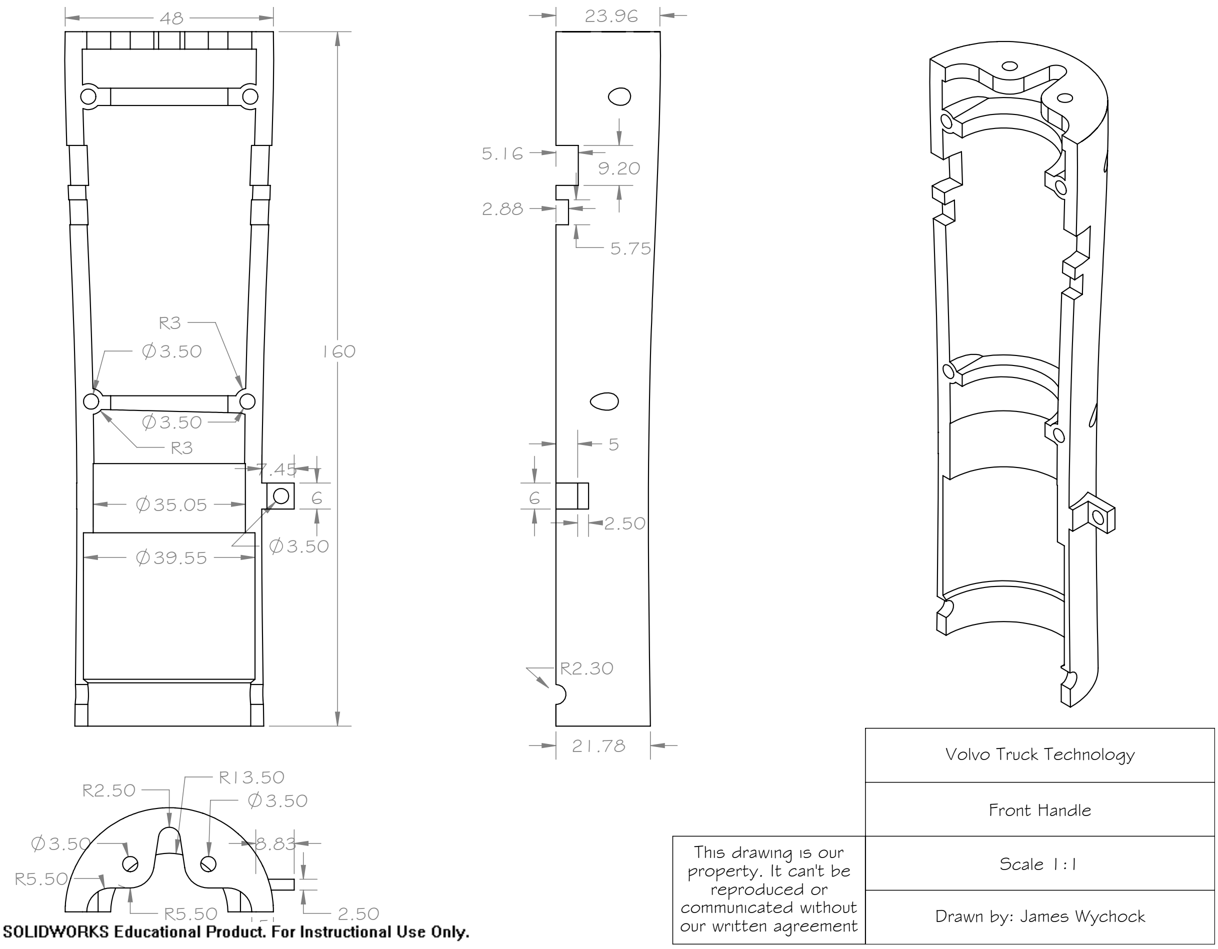


Figure 52: Front handle

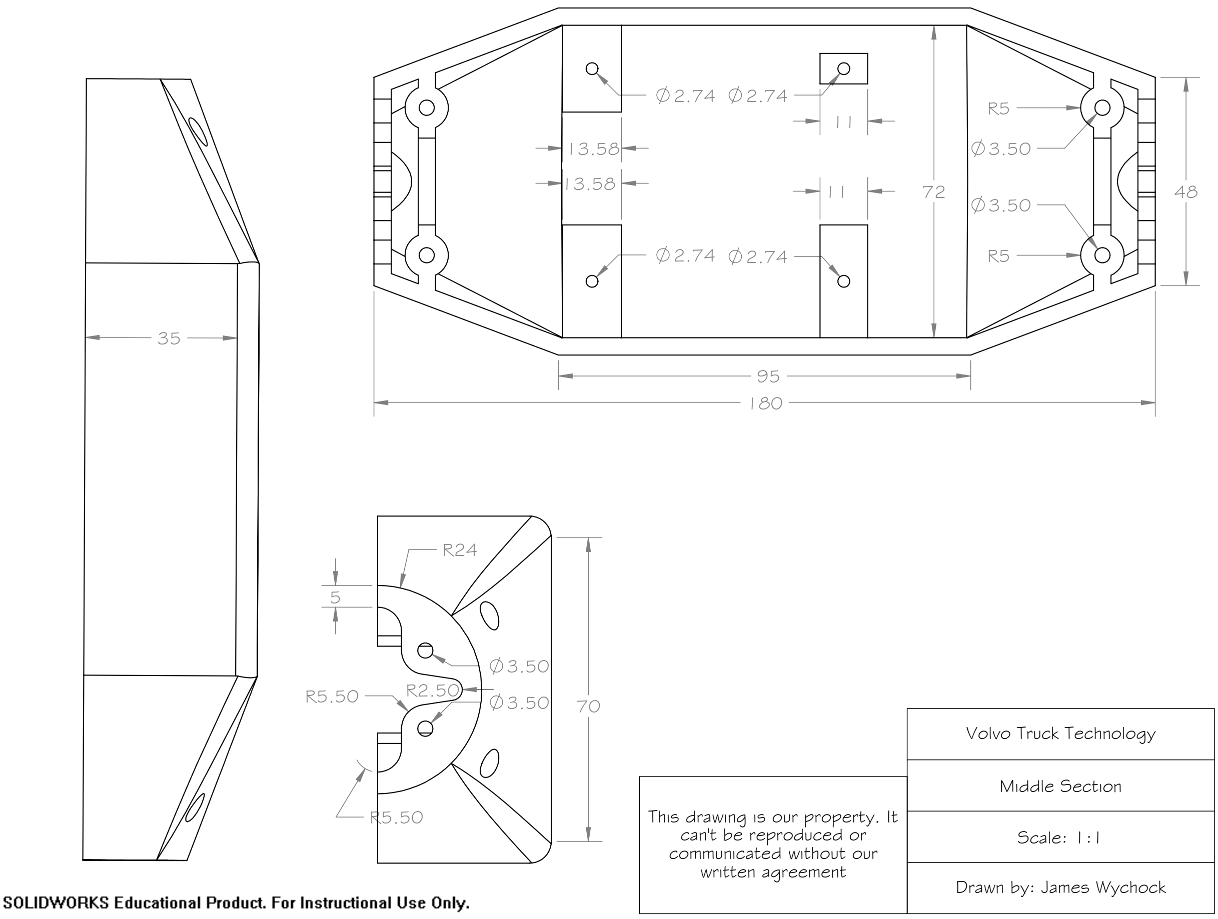


Figure 53: Middle section

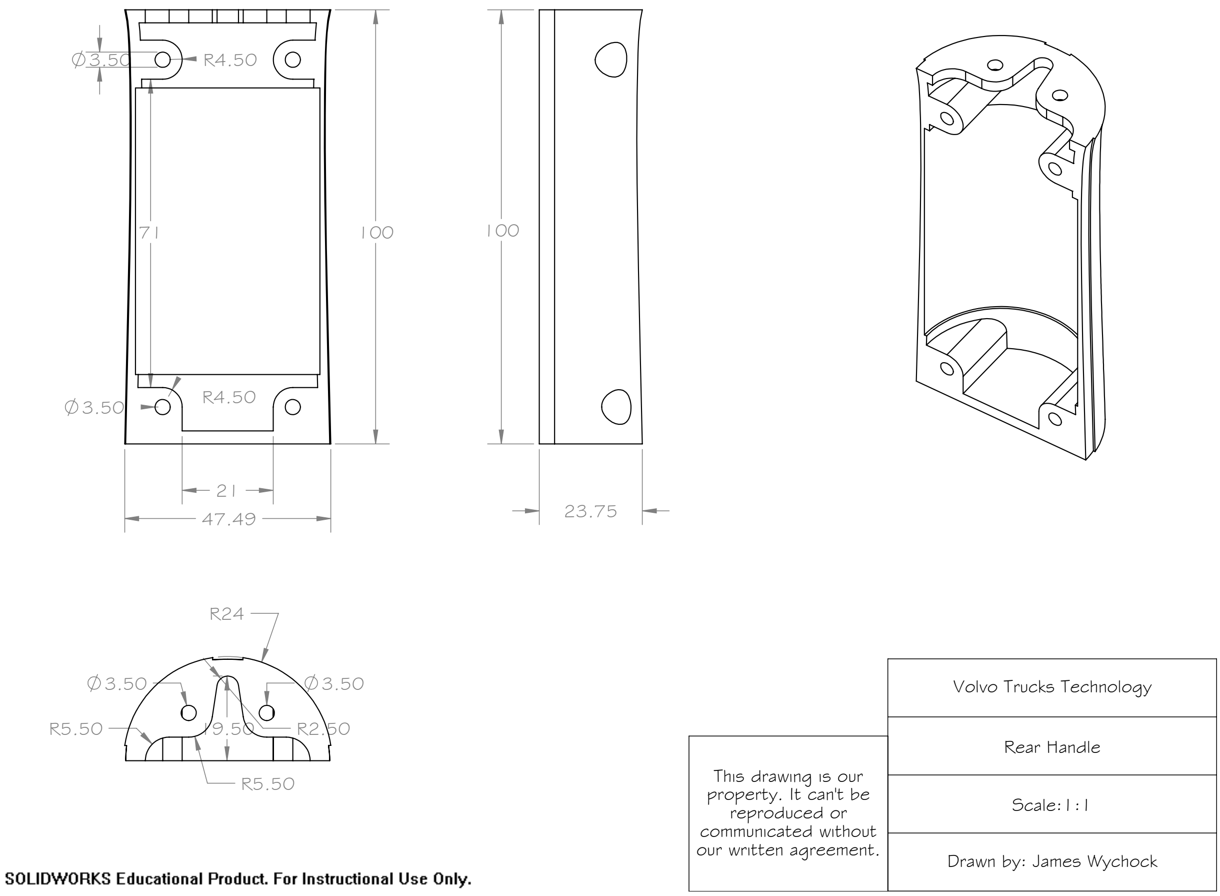


Figure 54: Rear handle