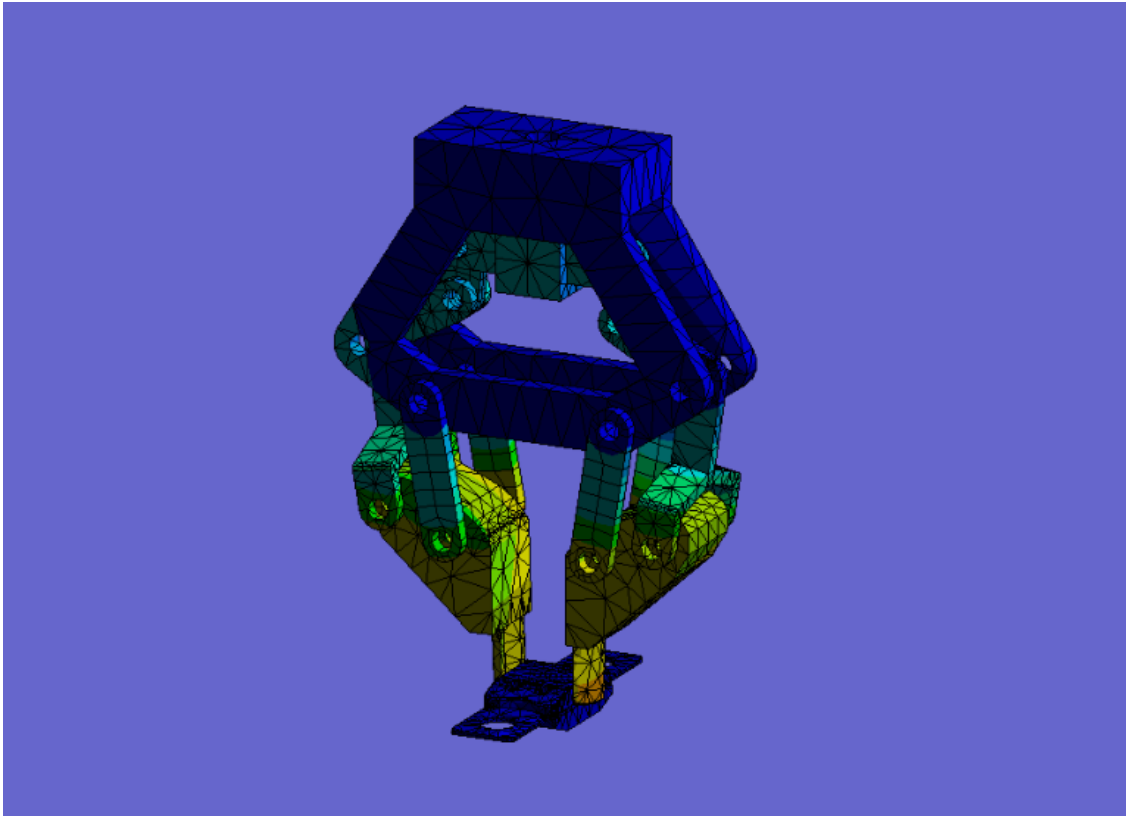# CHALMERS
UNIVERSITY OF TECHNOLOGY

Designing and Testing multi-functional Robot Gripper

Master's thesis in Production Engineering

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Designing and Testing multi-functional Robot Gripper

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Cover: Total Deformation analysis of the gripper was conducted in the ANSYS Workbench software showing the strucutral loadability of the material.

Gothenburg, Sweden 2019

Designing and Testing multi-functional Robot Gripper
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Abstract

This paper analyzes how multi-functional gripper tool can be designed and implemented into the assembly process of battery fuse box. To answer this question, 6 steps methodology has been used to construct the thesis in a structural way. The purpose of designing multi-functional gripper tool is to handle the variety of products and improve the ergonomics for the operators at Volvo Trucks. An integrated collaborative robot has a key role in the industrial applications for several operations such as pick and place, assembling. The 3D modelling of a robot gripper was proposed, and the design parameters of robot gripper were developed by using various methods and techniques. However, due to knowledge constraints, the designed multi-functional gripper tool was never tested in reality. Instead, to analyze the performance of robotized picking, placing and fastening tasks, simulation of assembly process was tested in Visual Components 4.1. The multi-functional gripper tool was integrated with Universal Robot with a proper cell layout in the robot cell-simulation program. It was found that multi-functional robot gripper is suitable for the assembly process and can safely handle the product variation. The ergonomics for the operators will be improved since the robot will perform the tedious and repetitive tasks. However, fastening the nuts could be hard for the robot, since there are some uncertainties in process simulation. Further research is needed to test gripper tool in the real world and identify other factors that could be effective for the development of robotic gripper.

Acknowledgements

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Anar Jafarov and Matlab Mustafayev,
Gothenburg, October 2019

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1

Introduction

This Chapter presents the general background about master thesis along with scope of the thesis.The Aim, Limitations and Research Questions are also stated in this Chapter.

1.1 Background

Volvo Truck has an assembly station where battery of truck (see Figure 1.1) is assembled with the low level of automation and high product variation. Assembly process consists of picking and placing fuses and fastening nuts. Today, assembly process is done manually which is monotonous and has bad ergonomic for the operators.

Figure 1.1: Fixtures and Fuse-box

Volvo Truck also wants to investigate possible solutions to improve quality, ergonomics and efficiency with the high level of automation. A Collaborative robot (cobot) is versatile design and can be used for the assembly line – can reduce ergonomic problems, while improving quality, productivity and safety [1]. The concept of cobots is that robots is collaborating with human operators in manufacturing assembly lines. According to the statistics of the Occupational Safety and Health Department of the US Department of Labour, more than 30% of European manufacturing operators are suffered by spinal, lower back pain which leads to important social and economic costs [1]. By using collaborative robots, collision avoidance is guaranteed by a minimum-security distance and provide to lighten the burden on human in the first case [2]. Most of the automotive manufacturers are gradually implementing collaborative robots in their human production line [3], since mass customization requires technological flexibility which is possible by integrating both

automated and human-based assembly. A similar sight with the recent EU project "ROBO-PARTNER" [4], that purpose with integrating assembly systems and human capabilities. The main aim is safety of the shared work cell while optimizing task distribution between operators and robots and avoiding collisions as well [5]. To achieve the product variation and assembly process, the robotic gripper plays a significant role in replacing operations. The gripper is the most vital part of automated robot systems which gripper is the unit between the work piece and robot. Therefore, the selection of robot gripper is very important. The robotic grippers have versatile skills for handling materials with high reliability at high speed, and without any collisions [6]. The design of gripper should be adapted to the components of fuse box to handle the gripping process successfully. By using multi-functional gripper, it is possible to handle the high level of automation.

Multi-functional robot gripper should be designed for industrial applications which can handle high product variation and assembly process. This type of robotic gripper is like a human hand and can pick up the products that have varying sizes and shapes [7]. Some designs will be proposed for regarding concept that developed and analysed by using CATIA V5 and SolidWorks software. Robotic gripper will be constructed using 3D printer with plastic material. In this project, Markforged Onyx Pro 3D printer has been used whereas composite raw material can be used also, this 3D printer material can be upgraded to carbon fiber which allows to print more durable and reliable parts.

Thesis will be conducted in the SII lab by two master students during approximately 30 weeks. A collaborative robots (cobots) may be seen as a solution to remove repetitive tasks and to provide better work environment for assembly station. Therefore, new robot gripper will be designed, and additive manufacturing will also be used to print out the gripper.

1.2 Aim

The collaborative robots have effective inroads into various industrial application. Collaborative robots have a key role in the industrial applications for several operations such as pick and place, assembling. The usage of collaborative robots is an important component of the total investment. Robot gripper is the vital part in the robotic assembly system which it is very important for reducing cycle times, ergonomic problems and repetitive tasks. It is very important to design and develop the best appropriate robot gripper for assembly process which requires mathematical calculations, as well as analysis. The purpose of thesis project is to design and test the feasibility of a 3d printed gripper for assembling battery fuse boxes.

During the thesis project, 3D modelling of a robot gripper will be proposed, and the design parameters of robot gripper will be developed by using various methods and techniques. The design of gripper will be modelled in the 3D-CAD program CatiaV5 and the designed gripper will be simulated in the robot cell-simulation program. The aim of using simulation software is to test how the gripper works in the reality that will be operated as they programmed in the simulation program. A

possible assembly application will also be explored as a part of the thesis.

1.3   Scope

The scope of this thesis project is to design a multifunctional robot gripper for handling the variation of products. The thesis will be focused on investigating and implementing several parameters which gives more flexibility and functionality to the robot gripper. Well-designed robot gripper can develop the system reliability, inaccuracy, processing time and eliminate the ergonomic problems and repetitive tasks for operators.

It is also important to find out which robot configuration is best option for being more flexible with the simple system. New gripper design should be adapted to assembly process while investigating these features and possible designs. In industry, multifunctional robotic grippers are new idea of smart grippers, which can perform the several operations without tool change.

The design of parts and the test of integrated gripper with collaborative robot will be the main challenge of the thesis project. This master thesis will focus on designing a robot gripper which will be more functional and flexible without tool change in assembly process and also prototype of 3D printed gripper.

1.4   Limitations

- How to integrate pneumatic system into the collaborative robot was main constraint due to the lack of expertise in this area.
- Cost of material which will be used to print out different prototypes.
- A prototype of a multi-functional robot gripper which only will be used to test possible solutions.

1.5   Research Questions

RQ1. How multi-functional robot gripper can be designed, and which parameters should be considered during concept generation?

RQ2. How Collaborative Robot can be used to increase the efficiency and improve the work environment in assembly station

2

Theoretical Framework

This Chapter gives an general understanding about Robot Gripper, Types of Gripper and Cobots which are used as background information for the thesis, including 3D printing as well.

2.1 Robot Gripper

In robotics, robot gripper is the major part of the robot manipulator. Robot gripper is the end effector of robot mechanism which is connected to the end of robotic arm and designed to interact with the environment. It performs as robot's hand and allows the robot to manipulate objects. Recently there is more necessity for robotic grippers for various tasks in different fields [8]. Robot grippers are vital for a wide range of applications - industrial warehouse operations, military which involve dirty, hazardous tasks such as high-temperature welding, handling radioactive materials, defusing bombs, mines and exploring shipwrecks [9]. Moreover, robot grippers are also used for complex operations such as the fabrication of micro-electronic structures, surgery and repetitive work [8]. That is why, it is really important to select the most appropriate robot in robotic system. In a mechanical framework, robot gripper has different types - jaw type, vacuum and magnetic grippers are used in different areas. Jaw type mechanical grippers is the most commonly used one which has fingers that move parallel. Depending on jaw design, two or more gripping fingers apply the forces internally or externally while grasping the object [10]. There is an increasing competition from industrial robots to perform different tasks effectively. Therefore, diversity of robot gripper is developed for being more flexible and multi-functional [10]. By using multi-functional robotic gripper, it is possible to grasp variety of objects and materials in the working environments. Robotic arm is desirable and versatile since it provides robotic system to avoid multiplicity of gripping tools which is normally required [9].

2.2 Types of Gripper

2.2.1 Pneumatic Gripper

Pneumatic grippers work with pneumatic actuator gripping system which includes tooling jaws or fingers to grasp an object. Pneumatic grippers use compressed air to make jaws move and controlled by pneumatic solenoid valves, pressure cylinders. This kind of grippers provide high force and speed at low unit of cost [11]. The

important characteristics of pneumatic grippers is that force and speed are independent of each other and can be easily controlled [12]. These grippers are the most economical when the amount of deployment matches the capacity of compressor [12]. Pneumatic grippers are widely used in industry, because of their light weight and compact size. In industry, the most used pneumatic grippers are 2 jaw parallel and 2 jaw angular grippers [13].

Figure 2.1: Pneumatic Gripper(Source: [54])

2.2.2 Hydraulic Gripper

The working principles of hydraulic grippers are same with pneumatic grippers, but instead of compressed air, it works with in-compressible liquid from a pump. Hydraulic grippers provide the most strength and that is why they are used for applications that require high amount of force. They can provide forces 25 times [14] greater than pneumatic cylinders in equal sizes. They can also provide pressure up to 2000-4000 psi [14]. Compared to other types of grippers, hydraulic grippers are messier, due to oil used in the pumps. They may also require more maintenance due to the force used through the pump.
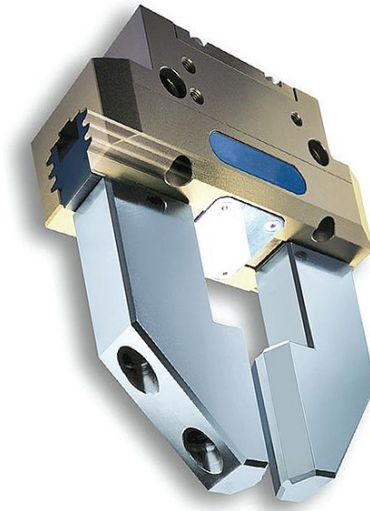
Figure 2.2: Hydraulic Gripper (Source: [55])

2.2.3 Vacuum Gripper

Vacuum grippers are mainly used to grip an object for picking or placing commands. This type of gripper works with Bernoulli Principles [8] which generates high-speed flow between the robot plate and surface of object. Created vacuum is used to lift flat, smooth sheets of materials such as wood, glass, metal and plastic panelling [8]. Vacuum grippers consist of suction cups for picking objects. The suction cup is made of rubber or polyurethane that can resist to temperature between -50 and 200 °C [15]. The working face of suction cups are very well suited for a wide variety of needs and circumstances. They are made of elastic, flexible materials and rubber suction cups to hold the objects. End effector of vacuum gripper must typically be designed for the intended applications[16].

Figure 2.3: Vacuum Gripper (Source: [56])

2.2.4 Electric Gripper

Electric grippers are becoming more competitive in industry, because of their control. Electric grippers are actuated by electric motors such as servo, steppers to make their jaws move. In contrast to pneumatic grippers, electric grippers have precise control and positioning and have less operating cost [13]. The advantages of these grippers are that positioning, and speed can be easily controlled. These grippers are highly advanced and flexible and useful for handling variety of material tolerances. They are cost effective and the application of electric grippers are in bin picking, handling, machine tending and more[17]. Step motors are an economical option for precise positioning at lower speed [13].

Figure 2.4: Electric Gripper (Source: [57])

2.3   Collaborative Robots

2.3.1   Cobots

A collaborative robot (or cobot) is an industrial robot that can work near people safely without any guard. Mostly, cobots are safer than the robots because cobots are speed and force limited which can stop running when contact with an obstacle [18]. Flexibility and cognitive ability of people still are needed in industry whereas cobots can be good integration to human work environment. Since human-cobot-collaboration is expected to increase the quality rate and performance efficiency [19]. Nowadays, companies are more interested in human robot collaboration while cobots are not common in production industries. Although, it seems that highest potential of cobots application should be manual assemble processes [20]. Even cobots have the safety problems from operator perspectives which is primary factor to achieve an acceptance of cobot application. There are various standards regarding robots such as ISO 10218-1, ISO 10218-2 which first one is general standard for robot itself whereas second one cover robot system and integration [21]. These kinds of standards are used to ensure the safe work environment with collaborative robots [22]. In this master thesis, UR3 collaborative robot (Figure 1) has been used which is compact kind of table-top robot. This table-top
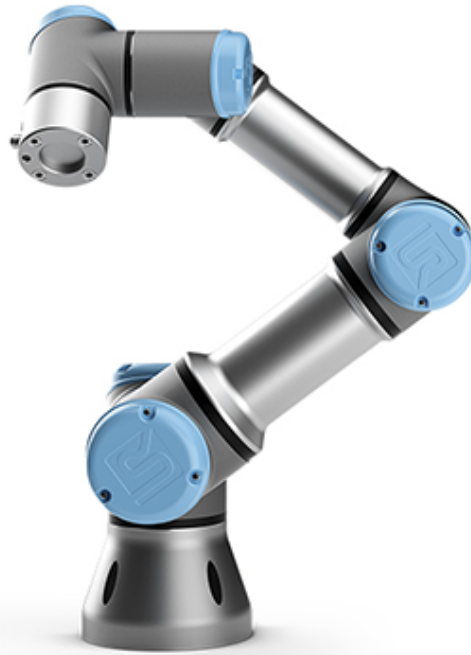
Figure 2.5: UR3 Collaborative Robot (Source: [58])

cobot weight is only 11 kg whereas it has 3 kg payload. The cobot is better for light assembly tasks and it has 360-degree rotation on both positive and negative direction for all wrist joints as well [23]. Furthermore, one of the main advantages is the cobot has fully rotatable end joint which allows customer to use cobot to fasten nuts or tighten screws.

Table 2.1: UR3 Collaborative Robot (Source: [59])

Specifications	Data
Repeatability	±0.1 mm
Work environment temperature range	0-50 Celsius
Payload	3 kg
Degrees of freedom	6 rotating joints
Reachability	500 mm
Noise	70dB
Footprint Diameter	128 mm
Weight	11 kg
Materials	Aluminium and PP plastics
Tool Connector type	M8

2.3.2 Benefits of Cobots

According to the A.Berglund and M.Akerman (2016), more than 90% of tasks in Swedish industry are performed by humans. Product volume and product variants can be considered as the most common way of determining when it needs to be automated or not. It also says in the article that it is hard to motivate the investment of robot, if the production volume is too small [22]. Therefore, middle volume products are still performed by humans. Collaborative robots are intended for direct interaction with human for handling shared payload with the benefits in ergonomics, productivity and quality aspects.

Industrial robots steadily have improved their capacity and cost efficiency for many years, although the implementation of robots in industry still requires substantial resources for programming, safety measures and handling of inflexibility [24]. As it says in the article, still there are some problems such as handling complex and soft components are the main problems which hinder implementation of them. Due to Advancements in several fields such as programming, robot sensors, environment recognition, human–machine-interfaces and safety system technology make it possible to change this [24]. Based on these advancements it is feasible to collaborate and control robots by operators without safety risk in workplaces.

2.3.3 Parameters of Cobots

According to the article S.Grahn and B.Langbeck, (2014), there are several parameters that should be considered significantly while using cobots in industry. **Ergonomics**: It is possible to handle heavy part in workplace which can be seen safety risk for operator. On the other hand, it is obvious that most of the assembly processes are done completely manually by operators. By using cobots, it could be possible to remove repetitive task and the task which requires more precision in terms of quality assurance. Apart from this, the case in the article related with aero panels indicates that ergonomics can be a key factor for justifying an investment.

According to the Nof (1999), while evaluating robot cells, there are many parameters that should be considered such as labor cost, product quality and material waste. On the other hand, Cil (2004) emphasizes that robot benefits should be considered on several levels such as strategic, operational and economic [24]:

Set-up time: Kus, et al. (2008) have analysed the requirements of small and medium enterprises (SME). According to the analysis, one of the most important disadvantages of using cobots is that reprogramming requires expert knowledge. However, by using teach mode, robots can be programmed by taking robot's arm and showing the coordination that should be done. Then, it can reduce the time it takes to integrate robots into factory operation from typically 18 months, to 1 hour.

Based on Kruger analysis, they have analysed potential benefits from tact time reductions using a net present value calculation. They found that a hybrid collaborative robot solution had an NPV that was 25% higher than a standard robot cell and substantially higher NPV than a manual solution [24].

2.3.4 Cobots Safety

Robots are the machines that improve productivity by executing repetitive tasks much faster than humans[25]. Industrial robots usually used in the highly secured production cells that is out of reachability of operators. However, complex tasks cannot be easily operated by the robots that requires the human execution whereas collaborative robots are emerges as solution to this type of problems. Classic industrial robots usually have isolated workspace to avoid direct physical contact with human operators but cobots have shared common work environment with human and cooperate with operator to fulfil the task requirements [25]. The most significant factor to implement the cobots to the industry is safety since there is a high risk of collision between cobot and human. According to Fritzsche et al., provide a solution to monitor the contact force between human and cobot by covering the robot's body with a tactile sensor such as skin [26]. Furthermore, Park et al. introduce the solution that is to cover the robot's body by the implementation of viscoelastic material which can lead to reduce the contact force between human and cobot [25].

UR3 collaborative robot has highly secured safety system which allows operators to cooperate with them easily and safely. The cobot as the Universal Robots Safety System URSafety 3.1 which enable cobot has a more than fifteen safety function such as emergency stop, safeguard stop, joint torque limit, joint speed limit, TCP force limit, etc which gives the safer and more controlled workspace to operator and all these safety functions are certified by ISO 13849-1. Also, it has TUV (German Inspection and Certificate service) certificates which ensure that has a safe cooperation with human operators [23].

2.4 3D Printing

3D printing uses an additive manufacturing process where parts are created layer-by-layer through a series of cross-sectional slices. 3D printers working principles are similar to normal printers, but it uses powder that built into an image on the layer-by-layer basis [27]. Additive manufacturing enables to manufacture the design of more complex and customized parts which makes it possible to use fewer parts and different types of materials [28]. Furthermore, additive manufacturing allows the people to change globally centralized or large-scale production to more local production systems. For instance, it will be potential advantage that performance can be increased, products functionality should be improved, as mentioned above weight reduction will occur and it allows the companies to customize the products for more specific applications or individual customer specifications. Additive manufacturing also great innovation that reducing need for assembling whereas product should be appropriate for functional integration [29]. In this thesis, Markforged Onyx Pro Desktop 3D printer has been used which enables to use composite raw materials by strengthen carbon nylon with the continuous supply of fiberglass. This composite raw material leads to print composite parts that are ten times stronger than parts which are printed by normal plastic. Moreover, one of the advantages is that can be upgraded in order to print parts by using carbon fiber which enables parts as

strong as aluminum. As the most 3D printers, it uses STL file to print parts and use world's most advanced EIGER 3D printing software that enables customers to print plastic, metal and composite parts just from your computer browser to 3D printer [30].
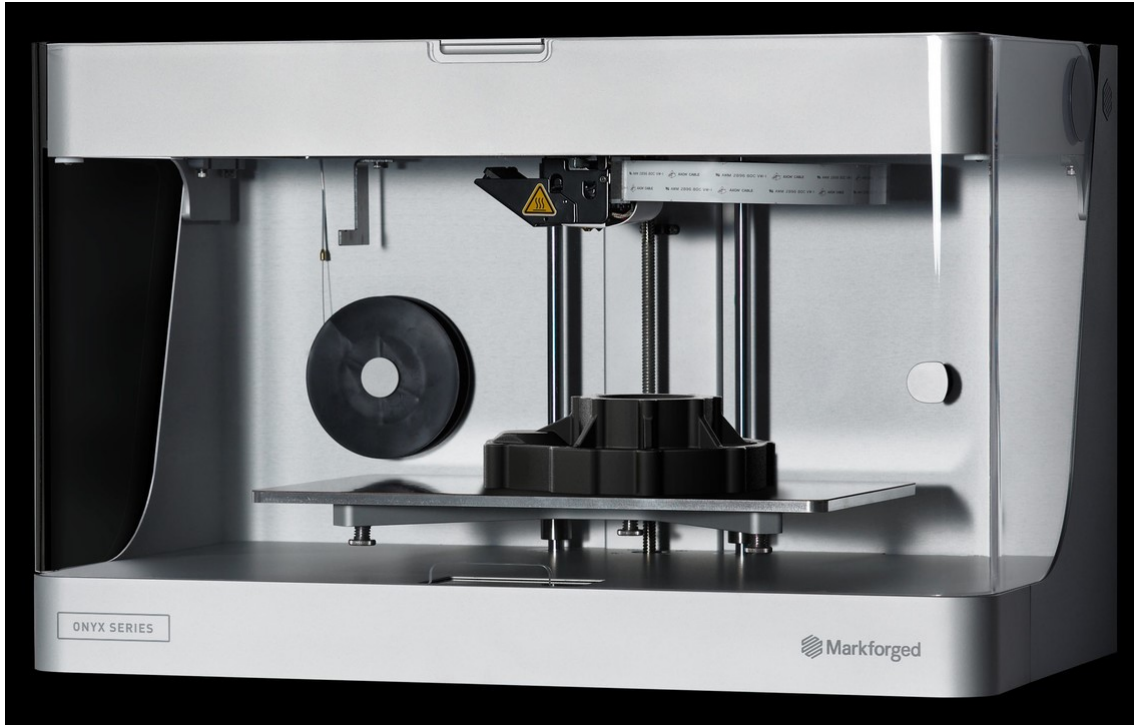
Figure 2.6: Markforged ONYX Pro (Source: [60])

Table 2.2: Markforged ONYX Pro (Source: [60])

Specifications	Data
Build Volume	320 mm x 132 mm x 154 mm
Layer Height	100 µm default, 200 µm maximum
Weight	16 kg
Machine Footprint	584 x 330 x 355 mm
Parts Ultimate Tensile Strength	590 MPa
Parts Max Flexural Stiffness	22 GPa
Materials Plastics Available	Onyx

3

Methodology

This chapter will describe the different methods that will be used to obtain the results within this project. The methods that mainly will be used are problem definitions, literature study, quantitative data from company.
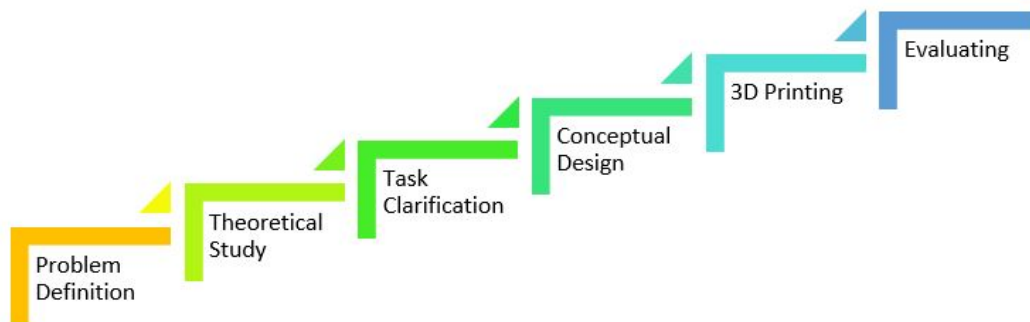
Figure 3.1: Steps through master thesis

3.1 Problem Definition

According to Art Markman article, how you define the problem determines whether you solve it [31]. That shows the how problem definition important as much as solution. Most of the people who come up with a solution to the problem has relative straightforward way that is finding a solution by the help of people who works on the problem and who has a better understanding of problem [31]. We have experienced exactly this situation in our thesis, at the beginning of thesis, we have focused on how to solve the problem since we had not deeply realized and understand problem. Visit to the work station of our truck battery and observed how battery installed and assembled together. Talking with people working on the problem was useful that gave a better understanding of problem. As Art Markman said, if you want to get info from your memory you need to give cue to your brain then you will get information with respect to that cue. For example, doing a creative problem solving, definition of the problem is the cue to your brain which trigger your memory to take out related info about your problem solving. In order to find new solutions to problem, problem definition should be changed in a way to give a various cue to your brain to draw out new info from the memory [31].

Figure 3.2: Fishbone Diagram for Problem Definition

To define the problem and to get the better view of understanding we have been used Fishbone Diagram which is Root Cause Analysis tool to discover the ma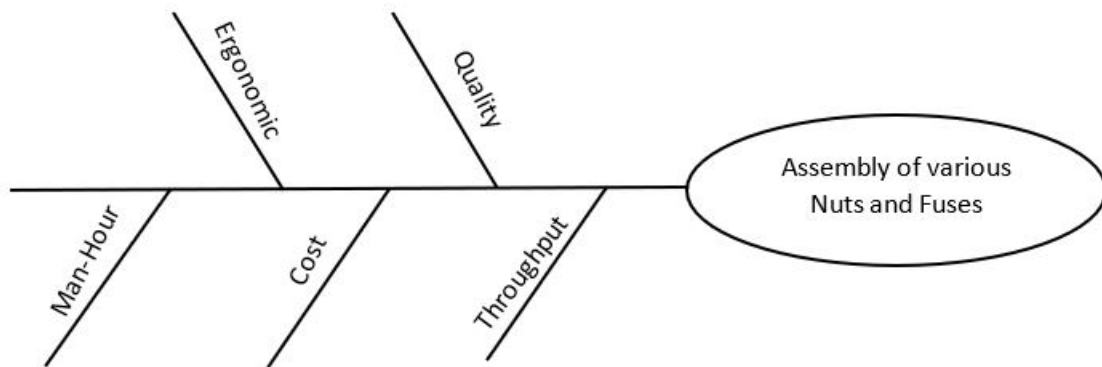in causes of the problem. This method is simple and systematic way to sort out causes of the problem and allow us to define the problem better [32]. In our case, problem is to automate the assembly process of the fuse box and we got two main which are throughput time and quality and three basic causes; cost, ergonomic and man-hour. Causes are identified by using company and customer specifications. As Dwayne Spradlin said in his paper (The Power of Defining the Problem), innovative solutions come from well-defined problems. Even developed companies are not aware of the importance of the problem defining and they are mostly focused on attempting to solve. This way can lead organizations to miss possible opportunities and waste resources. One of the significant things in defining the problem is ask the right questions so that you tackle the problem in a right way [33]. We have implemented this theory to get the better understanding of our thesis problem.

3.2   Theoretical Study

Literature review part of the thesis was inspired by Lawrence A. and etc, book "The literature review : six steps to success". Literature study summarizes and evaluates the current knowledge on a specific topic which aims to generate a position on the state of that knowledge [34]. As it is defined in the book, literature study is a written document which promotes a thesis position by creating a case from credible evidence [34]. Primarily, literature study pushes the writer to gain the as much information as possible from the chosen thesis topic [35]. One of the main purposes of the literature review is to answer the study's question. The cycle below shows how we followed the literature review process and idea of the cycle inspired by Lawrence A. Literature Review book whereas it is modified with respect to our way to produce a literature review.
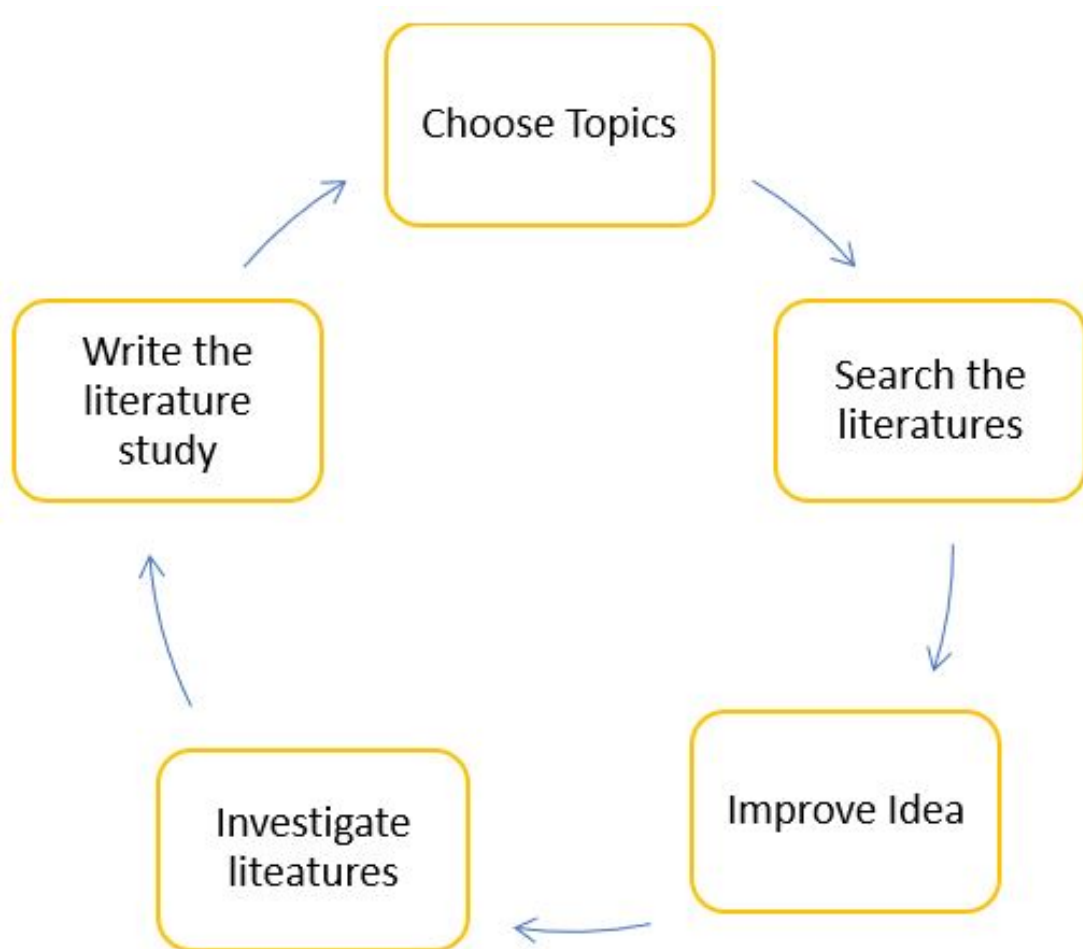
Figure 3.3: How theoretical study was conducted

First step in this process is to select the appropriate topics which needs to be reviewed. These topics should be well-defined and should have significant role in thesis [34]. Defined topics will automatically provide the way to step 2. The step that named literature search determines what type of literature will be analysed and reviewed. In this step, main idea is only using the data that has strongest evidence to support the thesis topic [34]. How the searching procedure works, first you should preview the literature by using the skimming scanning skills then you organize the data for study. Next step is to develop the idea that you got from literatures which is the useful way to argue the thesis successfully. This step is mainly helpful to form our case and to arrange logically what ideas we got from literatures [34]. Step 4 is to check and investigate the literatures aimed to use in literature review. This step is mainly focused on to check the credibility of the literatures that is mainly done by checking the information at least twice in different resource. The most appropriate source to use as evidence in a literature review is articles, papers and academic journals [35]. Last step is to start writing the review, this writing should transform the literature knowledge into relevant thesis document [34].

3.3 Task Clarification

The design task is normally presented as three forms which are development order, definite order and request based [36]. Our thesis design task is mostly looking like request based since it required by assembly staff to facilitate the assembly process of the truck battery box. The task clarification or description should not only consist of product specification and functionality but also statements about deadlines [36]. There are some questions you must ask yourself in order to make good and functional design, what characteristics or properties must it have? what objectives may be gained by implementing new design? In order to answer these questions, you should prepare the appropriate design requirements list and clearly elaborate the objectives under which circumstance requirements should be met. Next step is to clarify requirements either as demands or wants [36]. Following figure shows how steps are followed in order to make appropriate requirements list for design process.
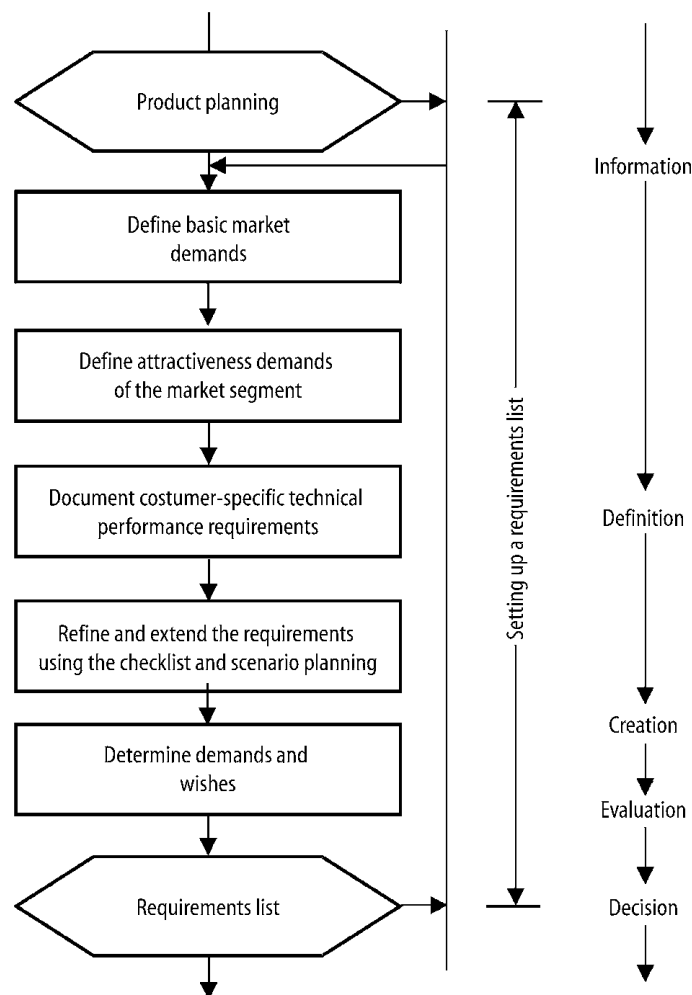
Figure 3.4: Main steps in order to create requirements list (Source: [36])

Demands are requirements which have to be met under any type of situation which means that if there are any requirements that are not fulfilled then design or solution cannot be acceptable [36]. In our thesis, pick&fasten two different size of nuts and

pick&place two different type of fuses are demands that have to be done by the new design of gripper. However, wants are requirements that should be taken into consideration as much as possible which means that these requirements don't have to be fulfilled mandatorily. For example, these requirements are increasing the assembly speed of the process faster than operator, this requirement should be as wish which was not demand by the company.

3.4 Conceptual Design

One of the main parts in design process is conceptual design which creating process of the function structures and combining all the working principles, function structures into one working structures [36]. In this thesis, conceptual design phase is the following step of task clarification since requirements list created in task clarification phase is prerequisite for the conceptual design stage. Requirement list was beneficial way to focus on the problems involved and it increase the detailed information level. Next step in conceptual design is to elaborate the requirements list then combine the data gained from requirements list to the concept of design [36]. While implementation of the requirements list, it should be prepared clearly and sort it out in the order of importance. In this step, exclude the requirements that does not have direct relation to functionality of the gripper. How this methodology implemented in our thesis? Primarily, requirement list generated then they were made it in order with respect to their importance and relation to functionality of design. For instance, in our thesis some requirements are pick&fasten two different nuts, pick&place two different fuses, should have at least same cycle time as operator, have to be safe and so on. However, according to the conceptual design methodology in this thesis work, we have sorted out the all these requirements as it is mentioned above with respect to their importance and direct relation to the functions of the gripper. It is obvious that pick&place two different fuses and pick&fasten two different nuts are the most significant and related requirements in the conceptual design phase. Therefore, our design mostly inspired by these two requirements determine the function and design idea works smoothly in theory.

3.5 3D Printing

This step has significant role in the thesis since it generates the physical object from virtual concept. 3D printing technology has been based on layer by layer fabrication technology and input of the 3D printing machine is computer-aided design (CAD) file that has three-dimensional construction [37]. After completing part design, 3D printer software slicing part into several cross-sectional layers then each layer printed at a time [38]. Input of this step comes from previous step conceptual design which has been generated the three-dimensional CAD file of the gripper design then this file sent as input to the 3D printing stage to generate the tangible parts.
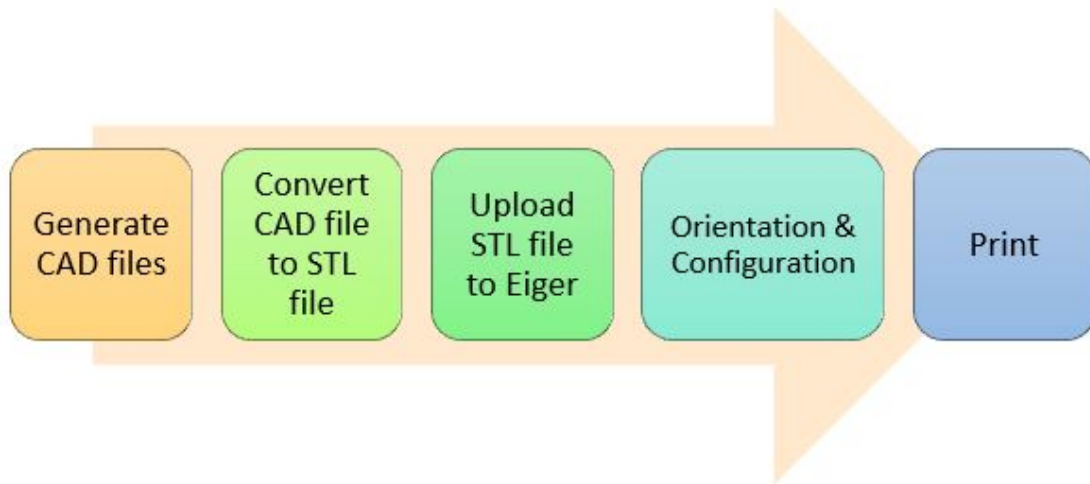
Figure 3.5: Steps for 3D Printing

How 3D printing process works? Firstly, CAD files of the all parts has been created by using CATIA V5 software. Second step in this phase was to convert the CAD files to STL file since STL is common and universal input file type for 3D printers. After this step, converted STL files should be uploaded to 3D printer slicing software and in this master thesis, Markforged Onyx Pro has been used for 3D printing that has slicing software called Eiger. Eiger is compact and easy to use which importing and slicing 3D models directed from the web browser. After importing STL file to the software, orientation process should be done for stability and reliability of the parts then material selection and other 3D print configurations should be done. Let the Eiger software to automatically start the process of your parts and slice parts into thin layers and determine appropriate tool paths for each layer individually [38]. Last step is to press the print then part will be printed layer-by-layer and print time depends upon part size.

3.6   Evaluating

Evaluation is concerned with assessing the methods whether goals have been achieved. According to Jackie Green Evaluation book, Evaluation is the systematic examination and assessment of the features, in order to produce valuable and reliable information. The main purpose of the evaluation is to measure the effects of the methods against the goals [62]. There are various types of evaluations exist such as experiments(practical experiments), virtual evaluations (software) and etc. Virtual evaluation has been used in this thesis and there was two different analysis first one is structural analysis and second one is process analysis [62]. Mainly two different software have been used for different purposes in, Ansys Workbench(structural analysis) and Virtual Components 4.1 (process analysis). Ansys workbench has been used for analysing and evaluating the reliability and durability of the gripper components. All components of gripper have been added to the software and assembled internally in the Ansys Workbench. At the end, gripper has been tested

structurally in Ansys Workbench. Weakest components have been revealed and observed that gripper can work properly up to 15 Newton. Second software has been used for simulation purposes which appropriate work environment has been created in the software. Work environment means that tables and cobot(UR3 cobot) has been added to our project from software library then gripper, fuses, nuts and fuse box have been added to project. Virtual twin of the work environment has been created by combining all these parts in one project. Last step was simulating the whole assembly process and then it has been observed that gripper can handle whole assembly process.

4

Gripper and Design Configuration

This Chapter gives deeper insights about Gripper designs and configurations. It also includes information about Mechanical Actuators and Motion of the Jaws, It also covers Actuators selection table.

4.1   Design Challenges

The gripper is the main part of the robot which directly interacts with the objects and the workplace for grasping object without a collision [39]. To fulfil the requirements and expectations placed on gripper system, Causey and Quinn (1998) offered two guidelines for designing robot gripper quickly and with the high confidence level [39]. By using these guidelines, it is possible to improve the efficiency, accuracy of robot and also help to design multi-functional gripper for performing several tasks without tool change. These two guidelines focus on increasing the reliability of the system and improving the throughput of the system. They are two different directions, sometimes guidelines may be partly overlapped [39]. Therefore, it is not possible to apply all guidelines into one direction. Each guideline should be analysed carefully, and these guidelines are listed as below [39]:

Guideline to Increase Throughput:

- Minimize the Gripper Footprint: is the additional area around the object for grasping well.

- Chamfer the Exterior of Gripper Fingers: helps for displacing neighbor part as the target part is approached.

- Minimize the Gripper Weight: this allows the gripper to increase the speed.

- Grasp Parts Securely: helps robot to perform the task at higher speed and with the less cycle time.

- Avoid Tool Changes: compared to previous one, this one directly applies into whole gripper system, not only to the gripper fingers.

- Grip Multiple Parts with a Single Gripper: this is one of the main guidelines which is applied for avoiding tool changes and handling variety of parts with similar size or shape. And this also helps to reduce processing time and cost as well.

- Install Multiple Grippers on a Single Wrist: while multiple grippers are ready for using, it allows to reduce cycle time as previous guideline. Moreover, allows the robot to handle multiple parts at the same time, which will be resulted to decrease robots' total motions.

- Include Functionality in Gripper Fingers: it improves the functionality of robot system.

Guideline to Increase Reliability:

- Grasp Parts Securely: this guideline directly affects the reliability of system which allows to reduce the possibility of insecure grasping and avoid changing the position of part during the operations.

- Fully Encompass the Part with the Gripper: help gripper to hold the part securely and align the part between gripper jaws.

- Do Not Deform the Part During Grasping: while grasping the parts, try to avoid deforming the parts, especially plastic parts.

- Minimize Finger Length: ensures the secure grasping, since long fingers may be deflected during operation.

- Provide an Ample Approach Clearance: with the complex gripper design, it could be difficult to visualize all the clearances. Therefore, it should be ensured that there is ample clearance to approach the part without any collision.

- Design for Proper Gripper-Part Interaction: if the surface of gripper jaws matches the shape of the part, it gives the better reliability.

- Fingers should Align Grasped Parts: this allows robot to align the part securely while the grippers jaws are being closed.

4.2   Motion of Gripper Jaws

4.2.1   Parallel Motion

Parallel gripper is the most popular end effector that is used in industry. However, it is hard to handle complex tasks, because of its simplicity [40]. The gripper jaws move in parallel motion in relation to the gripper body. In industry, majority of parallel jaw grippers are used for manufacturing and assembling fields [41]. Compared to other style grippers, parallel grippers are typically more accurate. It need force to grasp an object and speed for opening and closing its jaws. Generally, parallel jaw gripper is mounted at the end of a manipulator as an end effector.
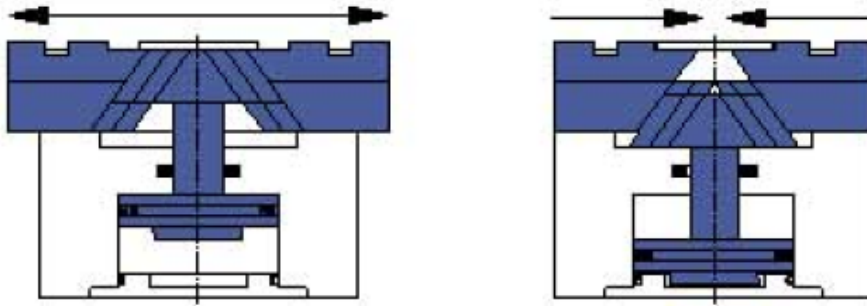
Figure 4.1: Parallel Motion (Source: [41])

4.2.2 Angular Motion

Angular motion grippers provide the lowest cost design, but the arching motion of the jaws may require additional tooling clearance and will grip at varying points as part width varies. Angular gripper is driven by a pneumatic cylinder which is an integral part of the overall gripper length. Angular grippers have advantages in compactness of design, displaying only limited interfere contour [42]. There are many impactive angular grippers with several specifications in industry. It is interesting that angular mechanism is used in excavators and also occasionally used for the handling of bulk materials [42].

Figure 4.2: Angular Motion (Source: [41])

4.2.3 Toggle Motion

These types of gripper have high energy density which provide high gripping force[42] to weight ratio. Toggle grippers are non-reversible mechanism and driving mechanism is guided along the entire stroke. Toggle grippers are suitable for heavy industrial applications[42].

Figure 4.3: Toggle Motion (Source: [41])

4.2.4 Selection of motion of jaws

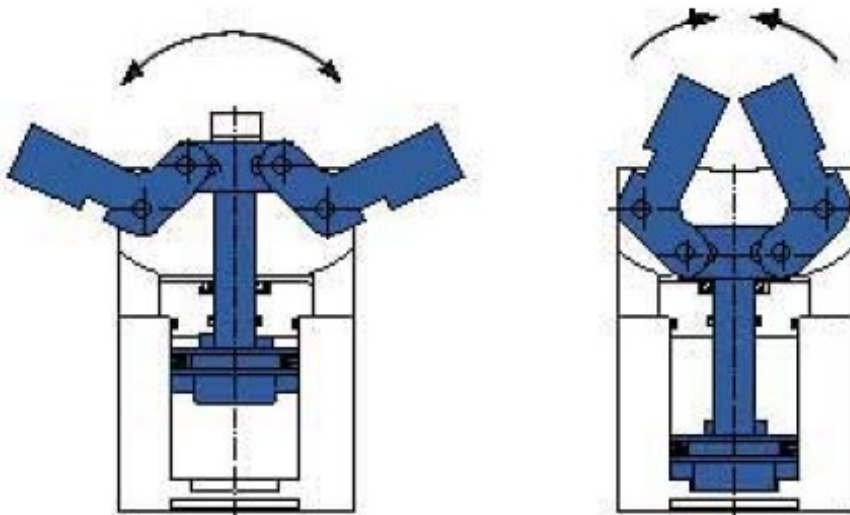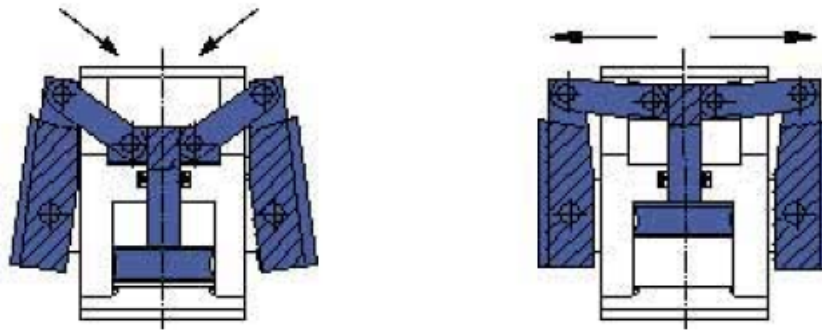While comparing these three motions of gripper, it is obvious that parallel motion gripper is most appropriate one to operate the task for this workstation. They are the simplest to tool and can compensate for some dimensional variation [42]. Moreover, parallel jaw grippers provide a highly versatile and flexible design. In this case, the motion of jaws will be integrated with pneumatic cylinder that compressed air forces the piston up and down, which through a mechanical linkage [42], pushes the gripper jaws open and pull strokes closes the jaws.

Table 4.1: Comparison of Jaw Movement

Parallel Grippers	Angular Grippers	Toggle Grippers
• Most common • Most accurate	• Limited space • Clearance	• High mechanical advantages • Over centering

4.3 Mechanical Actuators

4.3.1 Pneumatic System

Pneumatic is the system that works with mechanical properties of compressed gases whereas air gas is used mostly instead of others [43]. Nowadays, most important characteristics of the air are conversion of the pressure to force that let translational motion of the piston and produced forced can be controlled by the help of pressure regulator or flow control valve. However, air compressibility is considerably high that makes difficult to control the velocity of pistons. When we are analyzing the pneumatic systems easily can be seen that the pressure of air and amount of air used per unit time (i.e., air flow rate) is important factors to choose the right pneumatic system.

Cylinders convert the pneumatic energy to mechanical work and cylinders (single-

ended piston rod) are mainly double sided, which means that compressed air can be transferred on both sides of the piston to open or close it. There are two main parameters to choose the right cylinder: Stroke length and piston diameter [43]. In our case, it has been decided that 50 mm stroke length and 20 mm piston diameter (or bore diameter) can be used which fits better to our gripper design.

Directional control valves are used to control the direction of the air flow between two sides of the cylinder. There are two main ways to differ the directional control valves: switching positions and type of operations. Switching positions has two main characteristic's ports and positions, ports are a total of air input and output and positions is the main air output that used to open and close the cylinder. Mostly used, valve is 5/2-way valve which has 5 ports and 2 switching positions that means 5 ports are 2 exhaust, 2 output for switching and 1 compressed air supply [43]. There are mainly two types of operations that are electrical and mechanical (or Pneumatical). Electrical system uses electric signal to change the position of the flowing air and mechanical system used lever to change flow direction between the ports.
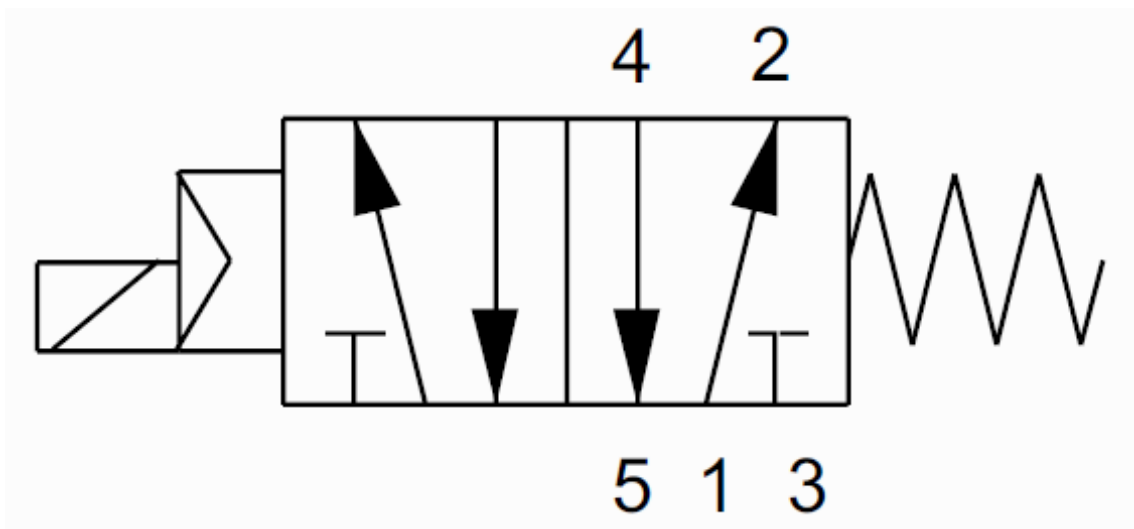
Figure 4.4: 5/2-way valve, monostable(Source: [43])

Flow control valve main functionality is to control the flow rate (speed of the pneumatic cylinder) and this action can be done in one or both directions [43]. This valve is mostly used when there is a requirement that cylinder speed should be controlled where high speed can leads to damage the product (gripper in our case). This valve has a simple working principle that turn of the adjusting screw cause to either expand the way of air flow or narrower the way of flow. This is the most useful way to control the speed of pneumatic cylinder.

4.3.2 Electric Systems

While looking for a source of power for robotic gripper, one of the major choices is Electricity which are fairly new technology [44]. Therefore, Electric Grippers

are becoming more popular in industry because of the fact it is easy to control the motion of the gripper jaws. Electric Grippers are mostly used for applications which are require light or moderate grip force and high speed. The typical application for electric grippers system is handling and assembly of sensitive, lightweight parts [45] Electric Grippers are highly flexible and possible to handle different material tolerances. By the helping of microprocessors, electric grippers are more adaptable while grasping the objects, parts. Compared to other actuators, electric actuators ensure certain positioning, control and have low operating cost [46]. Apart from this, Electric Grippers are cleaner than either pneumatic or hydraulic which they do not pollute environment. On the other hand, compared to pneumatic and hydraulic systems, electric systems have lower forces.

Figure 4.5: Electric Gripper(Source:[61])

Electric actuators include the mechanical actuator to transfer motor rotation to linear speed and thrust [47]. Electric actuators consist of acme, ball and roller screw which is connected to electric motor. By the helping of electric motor screw rotating and it moves the piston which is attached to the rod. The rod carries the loads.

For electric actuators, motors are divided into two: steppers and servos. Electric motors require gears box to control the motion [45]. Depending on positioning accuracy, sometimes Brush dc and ac motors are used with limit switches. Servos are closed loop, and ensure high performance at high speeds, although it has higher cost [47]. Compared to servos, steppers are more economical option for accurate positioning with lower speeds.

4.3.3 Actuator Selection

Table 4.2: Comparison of the robot gripper actuators (Source [11])

Characteristics	Pneumatic system	Electric system
Complexity [48]	Simple configuration	Complex configuration
Force [14]	High	Good
Position accuracy [14]	Good	High range of accuracy +/- 0.008 mm
Efficiency	Low	High
Environmental	High noise level	Minimum
Working environment [48]	• Safe in hazardous and flammable areas • Easily resist overheating • Able to withstand wet and moisture-ridden environments	Not suited for all environments
Loadings	Can be high loads	Can be high depending on speed and positioning desired
Acceleration [48]	High	Moderate
Speed [49]	High speed	Fixed and moderate speed
Purchase cost	Low	High
Maintenance cost	Low	Low
Operating cost	Moderate	Low
Maintenance	High, components require maintenance or replacement	little maintenance
Torque-to-Weight Ratio [49]	High	Low
Duty cycle [50]	With 100% duty cycle	With 25% standard duty cycle that may be increased

Considering separately, both actuators indicate good and bad characteristics which depending on their application, one must weigh while determining the right actuator (Table 3 above). While considering which characteristics are more important from the start, it will be easier to select a certain actuator based on the needs [11] and relation to performance, component costs, systems cost and productivity gains [12] by determining these two actuators, both are able to perform the necessary tasks efficiently. While comparing these two actuators, pneumatic actuators provide high force and speed at low unit cost in a small footprint [13]. One of the important characteristics of pneumatic actuator is that speed and force are independent of each other and can be easily adjusted [51]. On the other hand, pneumatic components costs are low. However, electric actuators have more position accuracy, pneumatic actuators are able to provide appropriate accuracy for the given project. While considering these advantages (Table 4.2 above), pneumatic actuator is selected to control the motion of gripper jaws.

4.4   Jaw Configuration

In industry, the most commonly used type of mechanical gripper is a jaw type [15]. The jaws are conventional tooling that designed to reliably hold the object while performing the task. Two jaw type grippers are the simplest design which consists of 2 fingers that apply force externally or internally depending on the configuration of objects. They make direct contact with the object and requires correct jaw design since it has significant factor in the force of gripping actions.

There are two types of gripping actions:

Friction: Friction gripping jaws require particular force of gripper to hold the intended object. They are the easiest to produce and may need more force for holding [39] . This is common for parts which do not have flat surface since parts can be deformed by applied forces.

Encompassing or Retention: these kinds of gripping jaws cradle the object in the jaws while holding. Compared to friction jaws, this is the preferred method since it increases stability for holding the part [39] and also requires less gripping force to hold.
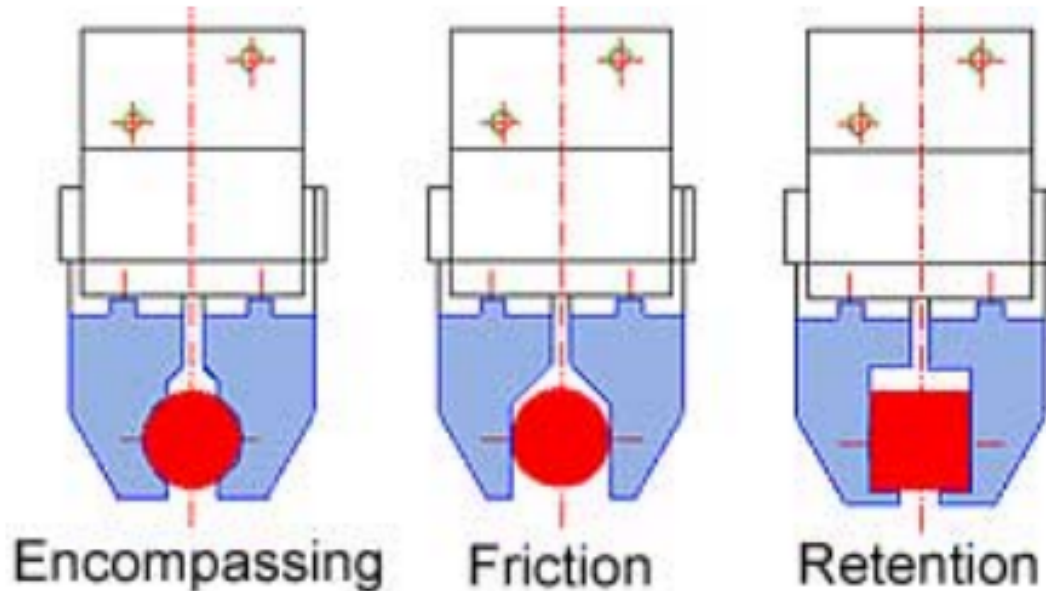

Figure 4.6: Jaw Configuration (Source: [39])

While comparing these two gripping designs, both have different advantages and disadvantages. In this case, Friction type was selected to pick up the object during the operation. Using friction type in the gripper provides some advantages compared to other type. The space for grasping the nut is so limited, therefore Retention type

may require more space while opening the jaws for safe grasping. Although Friction type requires more force for holding the object, the size of nut is small and does not require extra force for holding the object.

4.5 Gripper Configuration

Selection of Four-Bar linkage mechanism

A mechanism is one of the most important part of a machine. A four-bar linkage, also called a four-bar mechanism, is an example of movable closed chain linkage [42]. Mechanical linkages are mainly designed to transform a given input force and movement into desired output. Robot gripper with the four-bar mechanism provides some advantages compared to conventional gripping systems, such as [52]:

- This allows the robot gripper to reduce total workspace, therefore less space will be required for operation [52].

- Helps to reduce the risk of deformation of the part when grasping the object [52]. By using four bar linkage, force will be applied gradually while picking the object.

There are several ways to control the motion of jaws. In this case, Parallel motion linkage was selected as a gripping mechanism for this griper which is a specific design of Four Bar Chain. The Four-bar linkage or parallelogram mechanism is a bit complex to understand. The fundamental thing about the four-bar linkage is that, all the bars have a fixed length and the lengths of opposite sides of the parallelogram are equal and make sure that input and output motions remain parallel [53]. This kind of linkage consist of two tied rods on both sides. Generally, there is one actuated pivot and when it goes up and down, linkage follows the movement which makes the jaws open and close. So, the movement system of gripper will be driven by pneumatic actuator with the linear motion. All the part will be made of super-plastic materials.

5

Results

This Chapter consist of 4 sections which are about Design Overview, Ansys Workbench Analysis, Force Analysis and Simulation. It describes how thesis result was conducted.

5.1 Design Overview

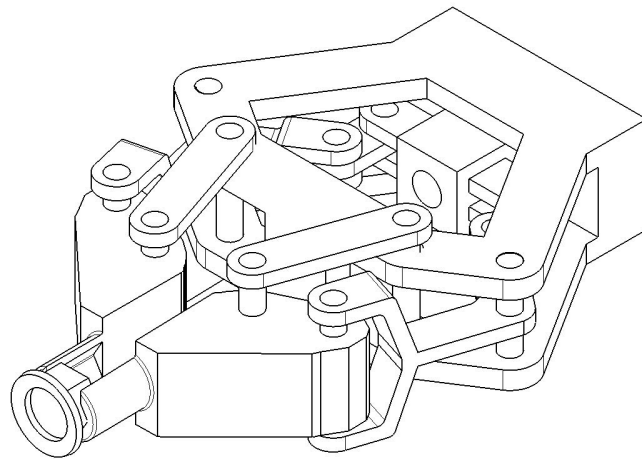The design of gripper tool can be seen below in figure 5.1.

Figure 5.1: Design of the Gripper while gripping big nut

The different design discussions resulted the project in possible solution. This result was drawn in 3D by using Catia V5. During the designing process, there were some challenges for the design of gripping system. First, it was planned to perform the assembly process without tool change, so all the components had to be handled by one gripper tool. The main idea on this design process was to create the tool much more robust and multi-functional. Second, while fastening the nuts into holes, there was only limited space for the jaws, and it was 2mm for each side. Therefore, the thickness of the jaws should be as thin as possible. The selection of material was also important which was directly related with this challenge. The final design of gripping system was 3D printed at University lab that was made of plastic. The working principle of design was inspired from another device which was used for only pick and place tasks and controlled by electric motor. The new design of gripper tool was developed based on the requirements of this project. This process followed

by the guidelines that listed in the previous chapter. The base frame of device was redesigned for the pneumatic actuator and the dimensions of parts were also developed for this project.

Multi-functional gripper tool needs to be designed to handle four products variation, so tool change must be avoided. It is clear that the hardest part of the designing process was to handle the nuts and fastening them into the target bolts. Moreover, fastening nuts through the treads requires more accuracy than other tasks. By following design guidelines, it was determined that designing the gripping part plays a significant role of how well the assembly process could be automated. Therefore, the jaws of gripper were designed based on the shape of nuts. As it seems from the figure 5.1, the shape of the jaws was designed like a triangle. Since gripper tool will handle the nuts from the edges which ensure the surface of jaws is fit for the nuts to be grasped. By handling from the edges, gripper tool prevents the sliding of the jaws while fastening nuts into the threads since there are more intersection points and it creates more friction against sliding. after designing the shape of jaws, the next step was the size of jaws. It can be seen that there is only limited space for the gripper to fasten the nuts. If it was designed based on big nuts, it could not be possible to fasten small nuts due to limited space. Therefore, the size of gripper jaws was determined based on small nuts, so it was feasible to fasten both nuts and handle fuses without tool change.

The gripping jaws were designed to be compatible with the shapes of components which cause to the secure grasp of each object. By following design guidelines, final gripping system was capable to handling four parts reliably without tool change.

5.2   Ansys Workbench Analysis

Ansys is the engineering simulation software which help to solve the most complex design challenges in the engineering field, and it allows the customer to understand how the product design will behave in the real world [63].Ansys Workbench software has been used for structural analysis of the gripper. Structural analysis is purposed to determine the stresses, strains and forces in the structures or components which is caused by the external loads [63]. Total deformation results have been considered significant factor for thesis's purposes since it shows the how force affect the different components individually.
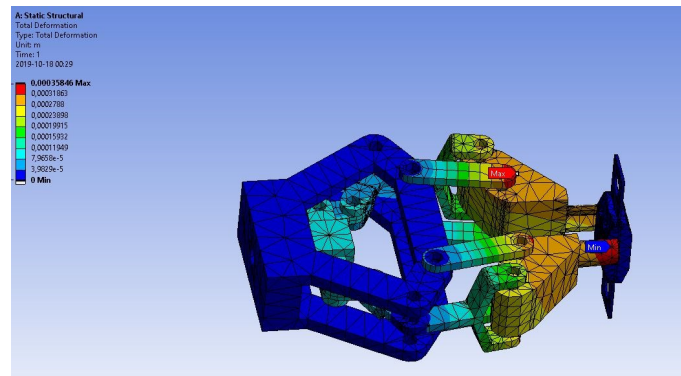
Figure 5.2: Total Deformation Analysis of the Gripper

All parts have been introduced as an individual body to the Ansys workbench then assembled in an appropriate way. After assembling next step was to assign the proposed movements(Revolute joints have been used for most of the components) for all joints that gripper has. Then conditions were given to the software which force had been changed from 5 N to 25 N and it was appeared that after 15 N, gripper can be cracked from some points(which are the red parts on the picture above). That's why, normal force max has been taken 15 N in the force analysis calculations.

5.3   Force Analysis

If you would like to lift an object, there are three types of force appears which are Weight (Fw), Normal force (N) and Friction force (Ffr). Friction force is the force that generated when an object affords to move. Frictional force is calculated by frictional coefficient times normal force (Ffr = µN) [64]. Frictional coefficient is the parameter that differ between the material types since it describes how different materials slide on each other. Regarding to our case, it has two different material contact which are plastic on plastic (µ = 0.50) and plastic on metal (µ = 0.325). Another main factor must be considered is weight of the object, after the weight measurement it was appeared that big nut has the highest weight 7 grams (m = 7 x 10-3 kg).

$$F_{fr} = \mu N \qquad\qquad F_{fr} = \mu N$$

$$F_w = mg$$
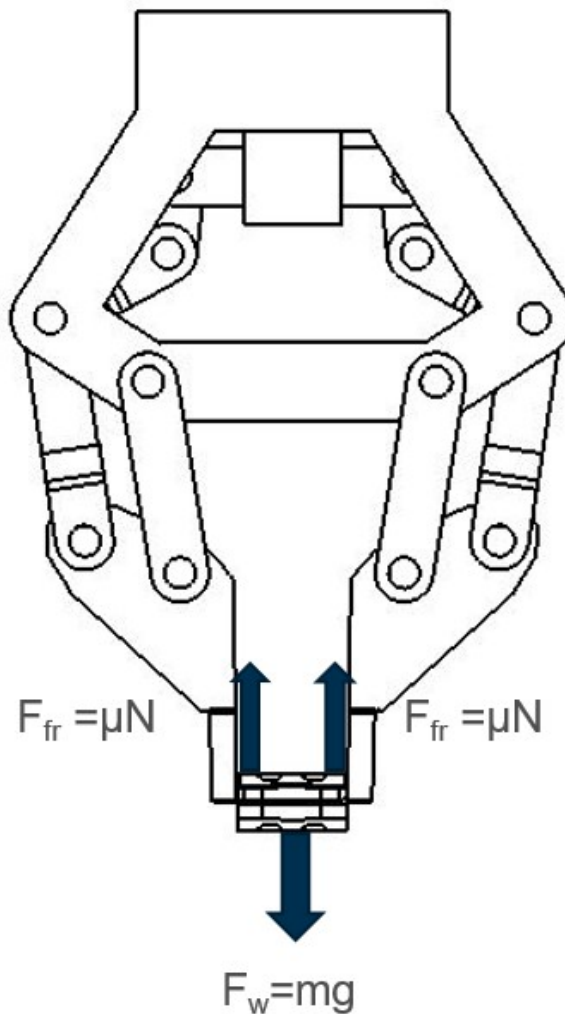
Figure 5.3: Force Analysis of the Gripper

On the other hand, frictional constant between metal and plastic is smaller (more tends to slide during lifting) which means that it is harder to lift the big nut. Due to all these factors we have calculated the force with respect to big nut lifting. Maximum normal force that gripper withstand is 15 Newton which has been gained from the Ansys workbench structural analysis.

If $F_w < 2F_{fr}$ part can be lifted

m – Mass

g – Gravitational Constant

μ – Friction Coefficient

Fw – Weight

Ffr – Friction Force

N – Normal Force

Figure below shows the calculation of friction force and force that required to lift big nut.

Normal Force Max = 15 N
Gravitational constant = 9.8 m/s^2
Coefficient $\mu_{s.p}$ = 0.325
Mass of Big Nut = 7x 10^{-3} Kg

F_w = m x g = 7x 10^{-3} Kg x 9.8 m/s^2 = $\boxed{0.0686 \text{ N}}$

F_{fr} = $\mu_{s.p}$ x N = 0.325 x 15 N = $\boxed{4.875 \text{ N} > 0.0686 \text{ N}}$

Figure 5.4: Calculation of the Lifting Force

5.4 Simulation in Visual Components 4.1

The purpose of this experiment was to test designed robotic gripper but also to analyze the performance of robotized picking, placing and fastening tasks during the assembly process. The description of the proposed workstation will be indicated in this chapter.

Simulation modelling provides safe and efficient solutions for real-world problems. It has several benefits such as creating realistic scenarios, improving retention and can be prohibitive about time and money. Simulating the process avoids repeated prototyping and implementation which can result costly.

The proposed solution was built up in Visual Components 4.1. There is a Universal Robot (UR) in this system as seen in figure 5.5. The designed multi-functional robot gripper was assembled into the UR which performs pick&place and fastening tasks.
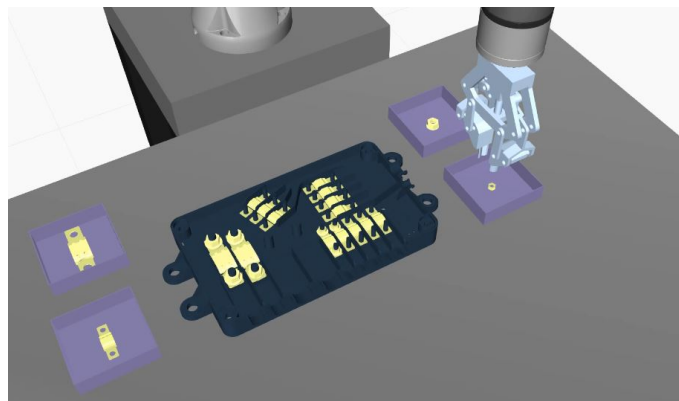
Figure 5.5: Layout of Proposed Solution

The experiment started with building the layout of the workstation. The first step was to coordinate the items (fuses, fuse box and nuts) into right places based on world-coordinate-system which this is base for everything that is being imported to the program. Next step is to teach the collaborative robot and gripper tool the tasks that are supposed to do. This step starts with creating the target positions that should be reached and to activating the multi-functional gripper tool; input

and output signals were created in order to control the gripper functions (open and close the gripper). The comparison of the tasks that are being performed can be seen in Table 5.1 below.

Table 5.1: Processing time

	Big Fuses (2)	Small Fuse (12)	Big Nut (4)	Small Nut (24)	Total (42)
Time(s)	3.5 sec	29 sec	22 sec	132 sec	186.5 sec

As it seems from the simulation video, see reference [64], there are four different tasks that must be done during the assembly process. All the tasks were operated in a sequence of big fuse, big nut, small fuse and small nuts. The whole assembly process includes forty-six tasks: two big fuse, twelve small fuse, four big nuts and twenty-four small nuts. It is obvious that, handling the fuse is the easiest part and it takes approximately 1.8 seconds (for one fuse) and fastening nut takes 5.5 second depending on the speed of robot. Based on the simulation, multi-functional robotic gripper performs the assembly process approximately in 187 seconds. However, the speed of cobot was determined based on estimations which it was assumed as ideal speed in the simulation program. Therefore, it needs to be tested in real environment to get more realistic results of assembly process.

6

Discussion

This chapter represent discussion regarding the key outputs of the thesis and implications of the result. It also suggest some future recommendations for the future researches.

6.1 Results Discussion

The result achieved from this thesis indicate that various type of parts can be picked and placed by using multi-functional gripper. Design process should consider all factors which have direct impact to the design such as design of the components, battery box and so on. Result of the thesis shows the analysis of the designed gripper and simulation of the assembly process. Analysis of the gripper confirms that gripper can withstand the load required for pick&place and fastening of nuts. The data gained from analysis part approves that simulation of the assembly process can be implemented. Mostly, result of the analysis has been met thesis expectations since it approves that design can be implemented and tested in the real world. In line with the thesis result gripper design can integrated to the cobots to increase the efficiency and improve the operator work environments. This thesis provides a new insight into the relationship between multi-functional gripper and cobot. Thesis findings contributes a clearer understanding of the cobots and multi-functional gripper efficiency. These results build on existing evidence of the cobot effectiveness to the assembly process. Overall thesis result should be taken into account when designing the multi-functional gripper and making force analysis of the components. While most of the previous researches have focused on the efficiency of cobots, but these results have mainly focused on how assembly process can be improved by integrating designed multi-functional gripper to cobots. The generalizability of the result is limited by virtual evaluation and analysis of the gripper since all the evaluations and analysis have been done in the virtual environment. The reliability of this data is not as same as real world analysis data since real-world environment has much more uncertainties and factors that affects the analysis of the design. Due to the lack of available data about how designed and 3D printed gripper can be implemented to cobots, the result cannot confirm that 3D printed gripper can be integrated to the cobots. It is beyond the scope of this study to integrate the gripper to the cobots by using pneumatic systems since it requires more professionality in that field and more time to implement the pneumatic system.

6.2   Future Recommendation

Further research and more practical work are needed to establish thesis in a more practical way to test and evaluate the gripper in a real-work environment. More research about pneumatic systems can be done to identify that how pneumatic systems should be integrated between gripper and cobot. Apart from research about pneumatic system, it requires at least one professional worker from field of pneumatic systems. Another main recommendation can be material selection since plastic has been used for 3D printed gripper. Plastic has durability for pick&place, but it does not suit for fastening the metal nuts to the bolts so material type can be changed to the metal. 3D printer which use metal powder for printing can be used to model a metal gripper which can be more compatible and durable for the fastening nuts by using gripper.

7
Conclusion

This Chapter represents the conclusive information about thesis work.

The aim of this thesis to automate the assembly process of battery box by using new designed multi-functional robot gripper was achieved. The purpose of designing new multi-functional gripper tool was to handle the four products variation for the assembly process of the battery box.

RQ1: The designing process was developed by following design guidelines in the Chapter 4,1 (Design Challenges). One of the important parameters was that the surface of gripping jaws should be compatible with the shapes of parts which ensures the secure grasp of parts. The motion of gripping jaws was controlled by parallel four-bar linkage. The proposed gripper tool was made of plastic material.

New designed multi-functional gripper tool was integrated with UR3 and simulated in Visual Components. Using simulation was good to visualize the conceptual solution of the battery box. However, the speed of robot is higher than reality in the simulation program. Therefore, proposed solution requires a testing in a real environment to analyze practical results of cobot in the assembly station.

RQ2: Based on thesis results, collaborative robot could replace the operators of doing tedious and repetitive tasks and makes the better working environment. The flexibility and cognitive ability of cobots cause to increase the quality rate and performance efficiency. Moreover, it was also found that multi-functional gripper tool could be beneficial to improve the ergonomics and increase the production efficiency.

Future areas of research are to implement designed gripper tool into real world application and to investigate possibilities for improving assemble process of battery box.

7. Conclusion

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