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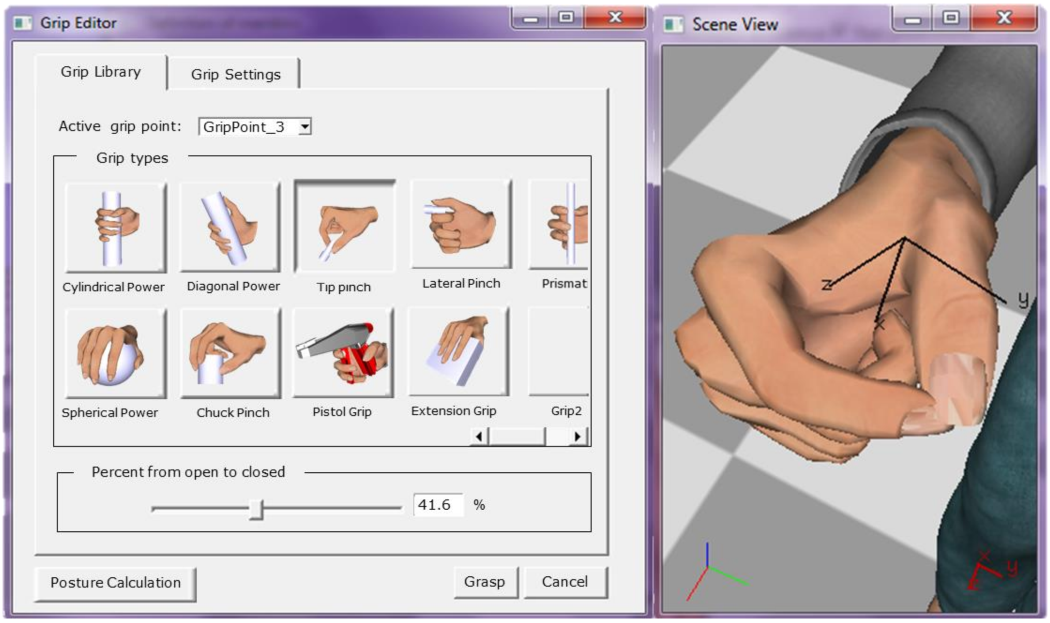

Development of a hand grip library intended for implementation in an ergonomic simulation tool

As a part of the IMMA research project at AB Volvo

Master of Science Thesis in the Master Degree Program, Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2013

Department of Product- and Production Development
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Cover photo: The picture shows a graphical user interface suggestion intended for the grip library in IMMA.
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Abstract

Intelligent Moving Manikin (IMMA) is an ergonomic simulation and analysis tool, created by a research group consisting of industry and academic partners. This master thesis is commissioned by AB Volvo as a part of the IMMA research project with purpose of creating a hand grip library for the manikin to use in different ergonomic simulations and analysis. This function is needed for the software to be more useful and the task is to identify a set of typical grips that are used in different assembly situations and implement these in a library in the IMMA demonstrator, and also to develop a framework for how to use these by identifying variables regarding the hand ergonomics, this will then be a base for a possible future automatic grip recognition function in IMMA.

Two plants have been visited to investigate what grip types are being used while assembly and a large data gathering from theory, research and interviews have been made to be able to strengthen the choices and also to find the variables for the framework. The results of the tasks are integrated in a graphical user interface which is to show possible ways of how the implementations could be presented in the software for the end user. Eight grip types are implemented in the grip library and three variables suggested for the framework. These variables are to distinguish different grip types from one another and for each categorise values to be able to, in a particular context, identify the most suitable one for that specific task.

Keywords: Grip Library, Grip types, Intelligent Moving Manikin (IMMA), AB Volvo, Ergonomic Simulation, and Digital Human Model.

Preface

This report presents a master's thesis project work of a 30 ECTS at Chalmers University of Technology in Gothenburg. The project was commissioned by AB Volvo, with time frame during the spring of 2013, from January to June. The thesis is the final step of the Masters of Science programme in Industrial Design Engineering at Chalmers University of Technology.

I would like to thank the project owners and my mentors at AB Volvo, Emma Hillberg, Business Consultant in the Manufacturing Engineering area at Volvo Information Technology AB and Maria Gink Lövgren, Ergonomics Specialist at Group Trucks Technology, Advanced Technology and Research (former Volvo Technology AB), who have truly supported and assisted me during the project. Without your effort this project would not be possible.

Appreciation to my examiner I.C. MariAnne Karlsson, Professor (chair) in Human Factors Engineering and Head of Division at Design & Human Factors, and my supervisor Ralf Rosenberg, coordinator of the MPDES, at the Department of Product and Production Development, Chalmers University of Technology, for your input during my work.

I also want to give recognition to Niclas Delfs, Stefan Gustafsson and Peter Mårdberg at The Fraunhofer-Chalmers Research Centre for Industrial Mathematics for all the support and for helping me with the implementation of the grip library. A warm gratitude to all IMMA project group members who assisted me with input during my work, with additional thanks to Dr Lars Hanson at Scania CV AB, leader of the IMMA research project, and Dr Dan Högberg, Associate Professor at the University of Skövde.

Last but not least I would like to express thanks to Meta Lundqvist and Lena Sperling for your help during the project, and also my friends and family who believed in me during my entire study time.

Pantea Marandi
Gothenburg, June 2013

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1 INTRODUCTION

1.1 BACKGROUND

Intelligent Moving Manikin (IMMA) is a ProViking funded research project where a digital human manikin is built and is to be further developed. The research project consists of several participating parties both from industry and research namely, AB Volvo, Scania CV, Volvo Cars Corporation, SAAB Automobile (during 2009-2011), Virtual Manufacturing Sweden, Innovatum, Chalmers University of Technology, University of Skövde, Lunds University, The Fraunhofer-Chalmers Research Centre for Industrial Mathematics and the Virtual Ergonomics Centre. The research project started in 2009 and ends in December 2013.

IMMA is supposed to be a user-friendly, non-expert, individual independent path planner tool for simulating different tasks in a digital environment, in order to analyse ergonomics in assembly work amongst other functionalities. Ergonomic simulations are performed for efficient production planning and development, which enable higher product quality as design errors and ergonomic problem areas are detected at an earlier stage. This prevents poor ergonomics and quality problems in production. The reason for not performing a higher number of ergonomic simulations in industry today is often the complex and time-consuming work behind the simulations. The purpose of the IMMA manikin is to exploit the full potential of ergonomic simulation and make the work more efficient by reducing the times for simulations and analyses with at least 40% and to perform all simulations automatically with a small amount of manual work [1]. The aim of the research project is to create a new ergonomic manikin that provides the users with the functionality that existing software lacks.

IMMA aims to find a collision free way for the object and the human at manual assembly, to consider human diversity and minimize biomechanical loads and increase assembly quality and efficiency, and to be more effective and easy to use than the tools on the market today. The innovative functions of this ergonomic simulation tool are that it possesses better handling of the motion algorithms, offers more automatic simulation features, allows user independent simulations and analysis, provides better opportunities for dynamic simulations, provides a better biomechanical 3D model and a better manikin appearance.

1.2 PURPOSE

This master thesis project has been commissioned by AB Volvo, as a contribution to the IMMA research project. The given task aims to gather data for creating a grip library for the IMMA demonstrator to use in different ergonomic simulations and analyses. The grip library is a final element that must exist for the software to be useful, due to the impact that a grip has on the appearance of a manikin and on ergonomic loads and bad postures in assembly work and therefore also on the results of the ergonomic analysis.

The main tasks have been to (i) identify a set of typical grips that are used in different assembly situations and implement these in a library in the IMMA demonstrator, and (ii) to develop a framework for how to use these by identifying parameters regarding hand ergonomics and other possible factors that could affect the human grip and the grasping of an object. These parameters are to distinguish different grip types from one another and for each type categorise values to be able to, in a particular context, identify the most suitable one for a specific task. This will form a base for a possible future automatic grip recognition function in IMMA. The results of the two mentioned tasks will be integrated in (iii) a graphical user interface which is to show possible ways of how the implementations could be presented in the software for the end user.

1.3 DELIMITATIONS

The limitation of the project lies in the possibilities of developing an automatic recognition of a manikin grip that fits a specific object. This function is limited because of the possibilities of creating a framework with enough variables to fulfil such a function. This is due to the limitations of what parameters that can be implemented in the proposed framework. Therefore some are given as considerations and essentially as suggestions for further development.

This project involves development of a potential grasp feature and the related framework, whereby the development of algorithms and the programming are the responsibility of IMMA project representatives from The Fraunhofer-Chalmers Research Centre for Industrial Mathematics.
The project is furthermore limited to only investigate the hand including the wrist as an independent body part. The development work of the grip library is limited to contain a maximum of 10-12 grips, this to provide industrial partners with a variety of grips that are considered relevant and also a work extent suitable for the project duration. For these 10-12 grips should be constructed at least 2-3 use cases in specific simulation environments, selected together with the supervisors.
There may be some limitations within the software where some parameters are not possible to impose and thus take into account in the current versions of IMMA but perhaps these can be pointed out as suggestions for further development and hopefully treated in the continuation project CROMM.

2 PROJECT PROCESS AND METHODS USED

The aim of the project falls within the previous mentioned project scope. The work is defined in four larger process phases shown in figure 2 to the right; data collection, identifying and implementation of grips in IMMA, a framework and design of graphical user interface for the grip library.

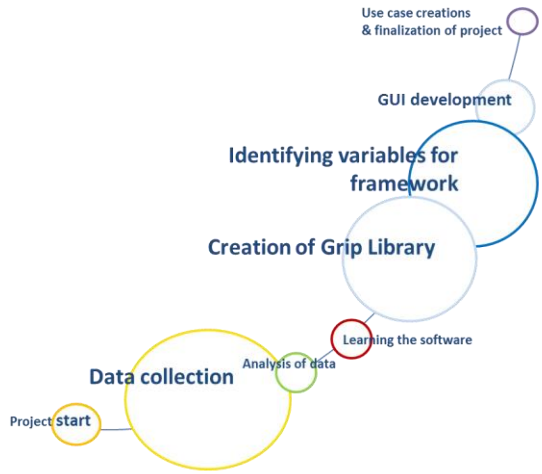


Figure 2. Picture of project process.

2.1 PROJECT PLANNING

The project start required a strategic plan for how to solve the project problem and the work initiated from this point. This phase included identifying the competences within the IMMA project group, and deciding the work process and documenting the strategy in a planning report. The work included also to set up a time schedule and map the project scope, limitations and content.

2.1.1 Gantt chart

Gantt is a type of bar chart that illustrates a project schedules. The chart shows the start date and the end date of each event in a project process by horizontal bars on a timeline. Vertical lines could mark and show special dates in the time schedule. This method is usually used early in the project process, in the planning phase [2].

The Gant chart constructed for this project listed the different project phases in rows and Swedish calendar weeks in columns; the amount of time planned for each phase was then marked with horizontal bars. Vertical lines where then marked out for special dates when specific deadlines where determined, which were described as gates in the planning report.

2.1.2 Weekly meetings

To maintain the contact between the project advisors and the project operators, weekly meetings can be conducted. Here all questions are asked and discussions are held, further planning are stated and potential deadlines identified.

For this project weekly meetings were held continuously with the advisers from Volvo, these dates were determined at the project start and scheduled on a specific time every week during the whole project time.

2.1.3 Project log book

A project log book is to be written continuously throughout a project process. This is for the operators to log the process of each activity, decision or result, if ever required to trace an event. This project was logged during the whole project time, and the log was used for personal account mainly.

2.2 DATA COLLECTION

The project process initiated with a data collection. Literature studies of earlier research and attending seminar, plant visits and observations, interviews, surveys, and benchmark of competing products were conducted to gather the required data. Since there was no previous experience within the subject a very detailed and extensive gathering of data was required to have a firm base to refer to. As for the framework, since there were no previous ideas of what variables that could be of interest to include, these were to be identified during this phase. Meantime the current IMMA demonstrator was also to be learned and investigated.

2.2.1 Literature studies

Literature studies are used to gather background information for a study [3]. The relevant literature was found as books, scientific articles from journals found at the Chalmers library catalogue and the Volvo Technology library. Company research and standards from industry were provided by IMMA project partners and other published material were found by searching the Internet.

2.2.2 Seminar

A seminar was arranged where partners from the IMMA project group participated. Associate professor Lena Sperling was invited to hold a guest lecture of hand ergonomics and on previous work and research that could be of interest for the group and for this project in particular. Transcribed notes can be found in appendix 1, and specific details of interest are presented further in the coming sections.

2.2.3 Plant visits

Two plants were visited and observations were made (for results see chapter 3) of specific details of hand grasping in assembly work. Observations are described as an objective method for data collection on how humans behave in different situations [3]. The method was used to investigate how different workers grasp in certain assembly situations, for example while machines were being used or parts moved and then mounted. All observations were made in field environment. Volvo Truck's plant in Tuve was visited two times. Here visitors have to be assisted in companion of an authorized person or line manager, since it is dangerous to walk alone and visitors usually have no access to the factory. Filming or photography may only be permitted for authorized persons with a license, documentation of events were therefore limited. Photographs and videos were taken with the help of an authorized ergonomist and these where then approved for further publication. A plant visit was also made to Volvo Car Corporation; this was an overall visit through the whole plant. Later the documented photographs and videos were observed to find details of different cases and postures. Documentation by hand notes were also taken.

2.2.4 Focus group

Interviews are an efficient way of collecting data of what people think and feel about a certain matter, by answering a set of questions [3]. Both qualitative and quantitative data can be gathered depending on the structure of the session. In a focus group the questions are asked to all participants in a group, with purpose of encouraging to discussion.

The invited participants were two simulation engineers at the Volvo Group Truck Operations, with questions formulated with purpose of identifying the priority level of the manikin hands in the simulation work, which software is used, what the most commonly used grips are, what problems they see with the grip library tools, and pros and cons with the tools (see appendix 2 for all questions and answers). The session was performed by sitting together with the project supervisors and the invited participants talking about these questions openly, having the questions projected on screen.

Later the same questions were asked to an ergonomic specialist at the Volvo Trucks Technology, who works with ergonomic analyse of products in competing software. This interview was conducted over an online meeting and was more of a discussion than a formal interview (see appendix 3).

The same interview guide was used when visiting the Volvo Car Corporation, meeting a simulation engineer from the IMMA project group. Here the process simulation tool was discussed and the notes from the visit can be found in appendix 4.

2.2.5 Survey

A survey is usually conducted to gather data through the use of questionnaires, this to collect data on feelings that cannot be observed, such as opinions. There are two types of questionnaires, and in this project a cross-sectional version was used on a population at a single point in time. A poorly designed questionnaire can result in unusable answers that do not provide the information needed. Also the appearance of the survey is of importance for the first impression and the indication to actually answer the survey [4]. The survey used for this event was a very simple looking survey (see appendix 5) with three short questions with the fallowing formulation:

- How would you like the grip library in IMMA to present the different possible automatic grasp postures?
- Would you like IMMA to choose the grip automatically or would you want to have control over the choice by going into the library and enter the demanded grip?
- Do you think the realism and aesthetics of the manikin hand are important for the final product? How important?

The first and the last questions were choice forced and the middle one was an open ended question. The survey was distributed on a workshop with industry people participating. Another set of surveys were sent by an online application on Google Drive to a list of AB Volvo IMMA network contacts.

For the opened ended question about the automatic function, majority of the participants answered that they would like to have such function but with the possibility to interact and make the last call them self. It also showed that there was a difference in the percentage of the answers between the two different groups in the choice forced questions. As for the realism and aesthetics of the manikin hand, the online survey showed that 50 percent of the participants found that it was not important or of neutral importance, while 72 percent of the workshop participants thought it was of higher importance. For the question about the way of presenting the pre-set grips in the library, majority wanted pictures of the manikin hand. For both the groups almost 50 percent wanted to see a picture of the manikin hand with the reference objects its grasping. The answers of the two different groups are compiled in diagrams and can be found in appendix 6.

2.2.6 Benchmark of competing software

A benchmark is an analysis of the competing market. The pros and cons of competing designs are to be analysed to identify inputs to new design work or redesigns and to prevent potential flaws. The analysis is often carried out as an expert-based heuristic evaluation or in some cases by usability testing [5]. In industry benchmarking is done between several competing products to decide which that is the most appealing to use for the organization.

For the IMMA project it is of interest to know how competing software are structured, since it is still in a research stage and has to be further developed. A benchmark was conducted on five competitors grip libraries and grasp functions, with the main emphasis on tool interface, grip types provided, the grasping function, and the ability of adjustment of joints. The results of analysis are presented in chapter 4.6 and the tree charts representing the user interface of the grip library can be found in appendix 7.

2.3 DATA ANALYSIS

The collected data were analysed to screen out the important factors that can be used in the grip library creation, in the framework and in the GUI design. The qualitative data were visualized as a map to get an overview of all the gathered information and then translated into a list of requirements. The quantitative data were put in tables and some plotted as graphical diagrams shown in the results of the development work.

2.3.1 Data mapping

When having much data in a pre-study phase, a visual plot and structuring of the information usually help to divide the data in groups and key parts are more visible, any missing sections are identified. In order to facilitate the division of total data, colour codes and also symbols were used.

2.3.2 List of requirements

A list of requirements was listed where the defined functions from the data collection phase are weighted and the demands for each stated in either requirements or wishes. A description for each is provided where quantitative values or limits are presented.

2.4 CREATION OF GRIP LIBRARY

For this phase it should be identified which grips are needed mostly in simulation work and why. Research of grip theory and hand ergonomics was done to identify how humans grip objects and what grip types that exist. The benchmark of DHM software provided information about what grip types that are provided in their libraries and a list of grips in assembly work was identified on each of the visited plants. These were then compared and the needed grips identified.

The grips were then implemented into the IMMA demonstrator as predefined grip structures and for each grip there was set a grip span with three defined sizes that construct a comfort curvature.

2.4.1 IDENTIFICATION OF FRAMEWORK VARIABLES

The gathered data was analysed to indicate parts that could be interesting for the framework of an possible automatic grip selector in IMMA. The framework was provided with requirements that follow the hand behaviour and ergonomic factors that affect a grip. The identified hand ergonomic factors that were pointed out during the data analysis were now further analysed and hand biomechanics were calculated to provide suggestions of values of variables that could possibly be used in a future framework.

2.4.2 DEVELOPMENT OF GRAPHICAL USER INTERFACE

After implementation of the library and the investigation on framework variables, a development of a graphical user interface design was started. The data gathered from previous phases was used as a basis and with close attention to how the demonstrator is designed today and the language used; a consequent proposal was given presented as pictures and illustrations, but not as a workable tool in IMMA. The design was created in PowerPoint for presentation purposes only and is shown as pictures in this report. This phase was truly time dependent and controlled by the two earlier mentioned phases. Therefore a mock-up was not created and therefore not tested.

2.5 USE CASE SIMULATIONS

To be able to show the usage of the grip function in IMMA, three use cases were decided to be created for presentation purposes. One use case of the assembly of a part, one use case of contacting and cable gripping, and one use case when using an handheld tool in assembly is shown. The first and second use cases were created, but the third scenario was implemented into the second whereby there were two cases shown on the final presentation. The simulations were created and shown in IMMA demonstrator, but the pre work of creating paths for objects and the manikin hands were done in the IPS software, which is an intelligent path planner tool created by FCC.

3 THEORY

Here some theoretical facts are presented, this for the readers who are not so familiar with the topics of digital human models, ergonomics and grip theory. This chapter will describe the basics of the subjects for being able to understand the following report chapters. If previous experience and knowledge are possessed within the areas available, this chapter can be disregarded, as it explains the fundamentals of the topics without further going in to details.

3.1 DIGITAL HUMAN MODELLING TOOLS

With the high competition between different software editors and the high demands on realistic models, motions and behaviour the digital human development has become a widely multidisciplinary area, where Jack and Process Simulate Human, Delmia V5 and V6 Human, Creo Manikin and Ramsis are some software that are analysed during this project. The different software contains different levels of computer graphics, biomechanical models, and population anthropometry, ergonomics analysis of different human factors amongst other functionalities.

The use of digital humans in simulations with virtual environments, ergonomic analysis and modelling software has opened up for early testing and evaluation of workplace environments, plants and products. The use of ergonomic simulation tools have has had been of a great importance for industries, particularly the automotive, where they are able to in early stage of development test, analyse and evaluate their designs and also study the interaction between human and product and the usage and workability of the products and its impact on human beings during for example assembly work [6]. These tests then save resources in terms of shorter development time, reduced development cost including prevention of unnecessary prototype constructions.

The importance of being able to set up and manipulate an accurate virtual environment and simulate as truthfully and realistic as possible, requires that the digital human manikin is intelligent and behaves correctly to user manipulation. This includes the manikin's ability to grip an object and sustain in an accurate body posture while grasping. In automotive industry the results taken from an ergonomic simulation analysis is often to be presented for another part in the organization. The appearance of the digital manikin is therefore of great importance, since a realistic and accurate model is important when presenting and discussing the results: if the manikin is to appear unnatural, or if joints are behaving unrealistic then the acceptance and trust of the result will be questioned [7].

3.2 ANTHROPOMETRY

Anthropometrics is defined as the science of human body proportions [8]. This science has especially studied evolutionary changes and investigated ethnic and national differences between the human populations. This can refer for example to measurements of body size and shape, strength and work capacity.

In ergonomics (see next chapter), anthropometric data can be used in the design of different systems, products, workspaces etc. when designing for the user and for individual adaptation. In DHM software, anthropometric data is being used to create specific selections of a population. This could be a specific percentile of the national deviation. The software can be loaded with data from anthropometric databases available on the market, and in IMMA's case measurements of the hand is originated from a study made by Grahn 2005 [9].

3.3 ERGONOMICS

Ergonomics is described as the doctrine of human work. The term originates from Latin, where "ergon" mean work, and "nomos" means law [8]. Ergonomics is the science of interaction between human, the physical factors and the psychological factors when performing a task in a surrounding environment [10]. Ergonomics is explained as a multidisciplinary term including anatomy, engineering and psychology in the analysis of the interaction between human and tools [8].

The different domains of specialization under the term of ergonomics theory are described as being Cognitive Ergonomics, Physical Ergonomics and Organisational Ergonomics. Physical ergonomics is concerned with anatomy, anthropometry, biomechanics, and physical loadings. Cognitive ergonomics concern mental processes and organisational ergonomics concerned with the optimization of sociotechnical systems [11].

3.4 HAND BIOMECHANICS

Hand biomechanics is an interaction between the mechanics, structure and functionality of the human hand. The human hand contributes with manipulative movements, and functions as a sense organ. In theory hands are often described as an extension of the brain, and use the fingers and thumb to operate [12].

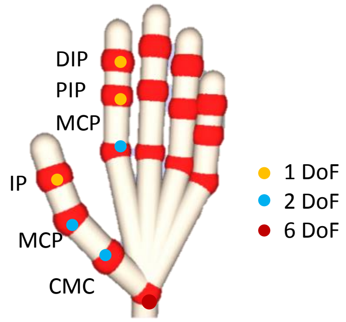


Figure 3.4 Picture of a hand with showing phalangeals and DoF.

The anatomical study of the human hand shows that each finger (number 2-5) has three joints with four degrees of freedom (DOF) respectively. The joints are Meta Carpo Phalangeal (MCP), Proximal Inter Phalangeal (PIP), and Distal Inter Phalangeal (DIP), see figure 3.4 to the right. The MCP joint allows bending and abduction/adduction while the PIP and DIP joints enable only bending. The thumb is fixed with a MCP and DIP joint and a third slightly different type of joint called the carpometacarpal (CMC) joint, with a total of five DOF, leaving the wrist with six DOF and the whole hand with a total of 27 DOF.

Reed explains how finger postures involve interaction, since they do not vary independently, and this was also shown by the joint constraints (shown in table 3.0 below) [13]. There are also restrictions of the MCP joints to only work in one degree of freedom at the time. If the fingers are spread, bending is not possible and vice versa.

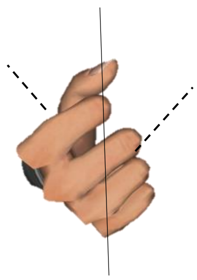
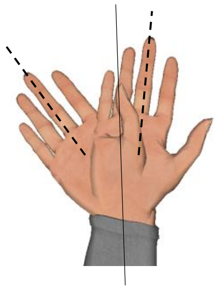
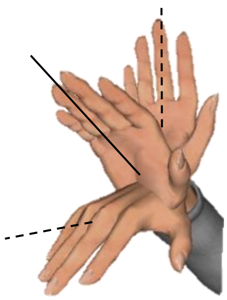
Table 3.0 Fingers (2-5) and thumb joint constraints, set by Park and Cheong [14].

Limits of finger joints:	Restriction of middle finger:	Serial effect of bending in PIP to DIP of the same finger:
$0° \leq \theta_{MCP(B)} \leq 90°$ $0° \leq \theta_{PIP(B)} \leq 110°$ $0° \leq \theta_{DIP(B)} \leq 90°$ $-15° \leq \theta_{MCP(A)} \leq 15°$	$\theta_{MCP(A)} = 0°$ (Middle finger)	$\theta_{DIP} = ⅔\theta_{PIP}$
Limits of thumb joints:		
$0° \leq \theta_{IP} \leq 90°$ $-40° \leq \theta_{MCP} \leq 90°$ $0° \leq \theta_{CMC(A)} \leq 70°$ $-45° \leq \theta_{CMC(B)} \leq 20°$		

Amis explains in her study that joints do not really get affected by object diameter [15]. The index and the middle finger exert the greatest force amongst the fragments in a grip [16]. The joints are separated by simple line segments, of which Buchholz et al. studied the relationship between segment lengths and hand lengths. They developed an equation and constants for calculating each segments length for different individuals depending on the hand length [17].

The wrist of the human hand can be flexed and extended from neutral position of 0°. The wrist also allows ulnar and radial deviation as shown in table 3.1 below, the constraints of possible angular deviations are also shown here, in degrees [18].

Table 3.1 Constraints of wrist joint angles and forearm rotation [18].

	Joint	5th %ile	50th %ile	95th %ile	SD
	Pronation	37	77	117	24
	Supination	77	113	149	22
	(Radial deviation) Wrist abduction	12	27	42	9
	Wrist adduction (Ulnar deviation)	35	47	59	7
	Wrist flexion	70	90	110	12
	Wrist extension	78	99	120	13

3.5 GRAPHICAL USER INTERFACE DEVELOPMENT

A definition of a GUI could be a way of ease the communication line between the user and the computer by using graphical symbols for presenting the required information. The GUI has replaced the command languages with visual display representations of user-task objects and actions [19]. Shneiderman and Plaisant showed a method for the designer to create the interface and make the interface actions visible to users. This method is called the object-action interface (OAI) model, and it consists of a hierarchy tree of objects and actions for a specific task and interface concept [19].

There are also some guidelines stated by Shneiderman and Plaisant which are rules for navigation, the organisation of the display, on how to get the user's attention and facilitating data entry. They also state more fundamental principles regarding the user's skill levels, the identification of task, and the interaction style. Where they explain how a successful designer always begin with a thorough task analysis and a careful specification of the user communities. For expert users, predictive models that reduce the time required to perform each step are effective, but for novice users, focus on task objects and actions can lead to useful constructions of metaphors of interface object and actions. But they state that all designs still need extensive testing and iterative refinement after the development process.

They also state some rules for interface design. The rules involves the strive for consistency, cater to universal usability, offering informative feedback, designing dialogs to yield closure, prevention of errors, permitting easy reversal of actions, supporting internal locus of control and reduce short-term memory load. These principles are developed to increase the feelings of competence, mastery and control over the system [19]. Shneiderman and Plaisant explains how graphical user interfaces needs suitable layout design in form of proper font sizes, drawing boxes to clarify groupings, the use of highlighting and indentation, and frequent use of buttons. Orderly alignment of similar items and consistent layout design reduces the scanning needed to locate distant items for the user. Comprehensibility, predictability, familiarity, visual appeal, and relevant content are preferable to provide for the user to shorten the process of a command [19]. An aesthetic and inviting user-friendly interface can affect an operator's choice to use the software or switch to a competing alternative.

4 REASERCH FINDINGS

4.1 GRIP THEORY

Grip is defined as a tight hold, a firm grasp or the pressure or strength of such a grasp, in a manner of grasping and holding mostly to control or move an object [20]. According to Pheasant and Haslegrave, a grip action is a closed kinetic chain which encompasses an object and holds it in place through the mechanical opposition of parts of the hand [18]. The gripping actions are often divided into power grips and precision grips. The gripping function of the human hand is limited by the task and the dimensions of the hand. The human hand has a neutral position of rest, where the hands and fingers occupy a 60 degrees arc of a circle of diameter 125 to 175 mm. There is a minimum load on the hand in this position and the optimal handgrip would be to come as close as possible to this position. According to Helander, the power grip is divided into three different force positions, one where the force is parallel to forearm and force at an angel to forearm, torque about the forearm. For the precision grip there are two different types, whereby one is hold with the object inside the hand and the other with the object pinched between the thumb and the digits [21]. The strongest fingers in precision grips are the index and middle fingers.

Napier is one of the most mentioned researchers in the field of grip taxonomy and grip theory, in 1956 he divided the human grip types after prehensile and non-prehensile movements. He shows that movements of the hand consist of two basic patterns of movements which are termed precision grip and power grip. These two grip categories cover the whole range of prehensile activity of the human hand, which is explained as movements in which an object is seized and held partly or wholly within the compass of the hand [22]. In precision grip the object is pinched between the flexor aspects of the fingers and of the opposing thumb. In power gripping the object is held as in a clamp between the flexed fingers and the palm, with counter pressure being applied by the thumb.

A more recent taxonomy has been developed by researchers Bock and Feix in which they identified and processed hundreds of grip types. The results of the taxonomy can be seen in their short grasp list which contains 31 different grasp types. They divide the grips in power, precision and intermediate grips, and they list features in opposition type, thumb position and virtual fingers interacting in the grips, to differentiate the large amount [23].

For a specific task different operators may use different grips depending on the size of the hand, handedness, the size and shape of the grasped object, the material stiffness and flexibility. Objects can only be grasped with contact surfaces that are not further apart than the maximum spread measured between the thumb and ring finger [24]. These factors also affect the use of tools in an assembly task.

4.2 GRIP STRENGTH

Grip strength is exerted in force which is expressed in Maximum Voluntary Contraction (MVC). A percentage ratio (%MVC) of the applied force can be measured, or a resulting moment on a joint, if considering the same muscle group in the same posture and expressed in the same units. When talking about maximal grip or finger strength, it is always referred to the MVC. When referring to the exerted grip force in a specific case the %MVC can be measured.

Operations by hand or handheld tools should not require a strength even near the maximum. There are guidelines specifying that force that needs to be exerted continuously for a period of time should not exceed 10 to 15 % of maximum strength, see figure 4.2.0. Forces that are exerted over a short period of time or frequent intervals should not exceed 30 % of maximal strength [25];[26];[18]. In forces that are exerted only occasionally and for a brief moment, force exertion should not exceed 60 % of maximum strength [18]. Static load by 20% and above reduces the blood circulation in the muscles and it will result in muscle fatigue with the risk of adverse effects [27].

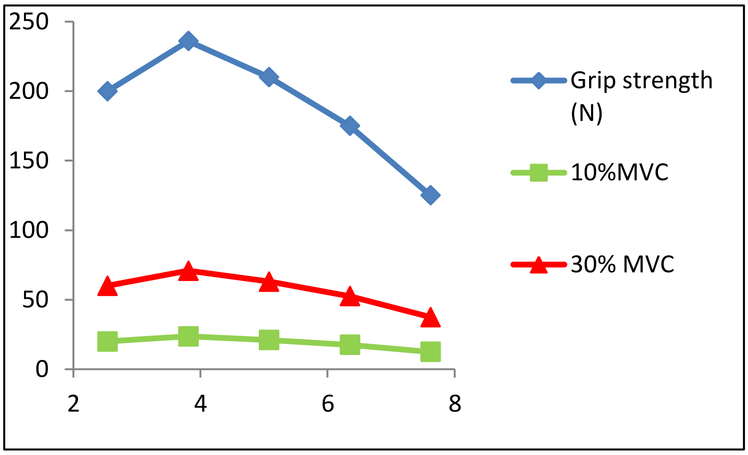


Figure 4.2.0 Showing the limits for %MVC. Values from a study of grip strength versus grip diameter [28].

A study made by Irwin and Radwin, demonstrates that even though mean grip force magnitude decreases from the optimal cylinder size of 38.1 millimetres to the largest allowed, flexor tendon tension in fingers increases with the diameter. They explained how the hand muscles and tendons can be working more than research has shown earlier when they looked upon grip force values as a single parameter [28].

The %MVC defined for power grips are the total grip force when pressing the object around its diameter, which results in an inner torque in the object presented by Pheasant and O'Neill in the following equation:

$$T=\mu*G*D \quad (1)$$

were D is the diameter of the object acting as moment arm of friction forces [29]. The equation was later rewritten to contain (n) numbers of segments of the hand in contact with the object. The grip strength for a power grip around a cylindrical object is measured to produce its peak force at a diameter of 38.1 mm. In some studies the value is mentioned to have its peak around 50 mm. Seo et al. measured the MVC to 442 N with SD (±107) for males and 215 N SD (±101) for females. Flexion strength was measured to 15.6 Nm (± 5.1) and 6.2 Nm (±3.2) respectively, and extension strength to 11.6 Nm (±3.6) for males and 5.9 Nm (±2.0) for females [29].

Wikström et al. present data on MVC for different grip types as plotted in figure 4.2.1 below [25]. Here it is shown that the grip strength is a linear function of precision level, where higher precision decreases the exerted force capacity.

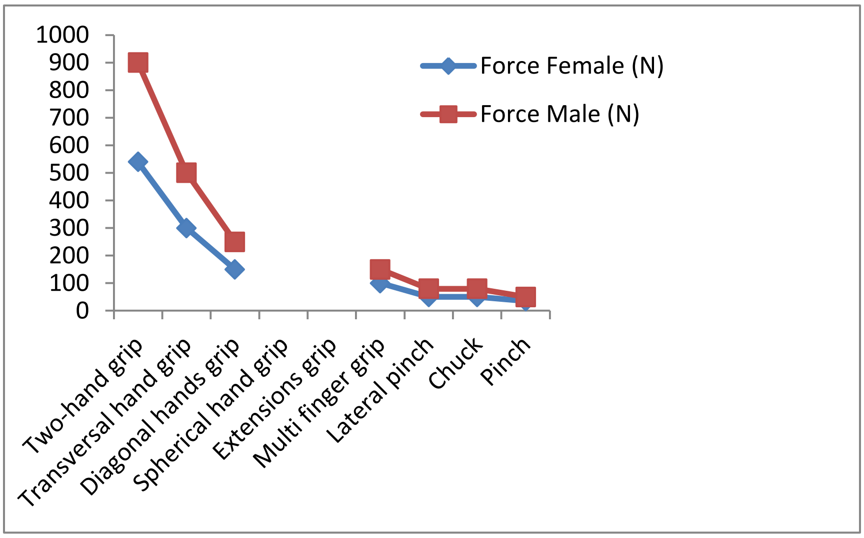


Figure 1.2.1 Diagram of force vs. precision [25].

In research the grip strength are often divided into finger force when a precision grip is used and according to Radwin et al. the index and the middle finger are the strongest contributors to the MVC, each delivering approximately 30 % to the total force, whereby the ring finger and pinkie contribute with about 15 % each [16]. The middle finger is shown as the strongest finger in this study.

Wrist torque exertion together with the pinch force is highly dependent of the pinch type direction and interaction. The pinch force, F_p, required to support an object, W, is related to both the weight and friction, μ, of the object. The force is set up in an equation:

$$F_p=W/2* \mu \tag{2}$$

There are many factors that play a role in the hand grip strength: gender, age, handedness, grip span, wrist position, muscle contraction, vibration sensitivity, and environment temperature.

Since women in general have smaller hands and lower muscle strength than men, they are affected by a higher load for a specific task, whereby they work with a higher risk for work-related musculoskeletal disorders. Hägg referred to a study where it is shown that women, on average, perform 2/3 less in muscle strength, than do males. Because of this fact it is of interest to consider the differentiation, for example between the 50^{th} percentile women and the 95^{th} percentile man, when developing workplaces and assembly tasks in production [27].

The maximum gripping force is reduced by about 25% from the peak at 20-25 years of age compared to 60-65 years, while the tip pinch force only decreases a few percent over the same age range [26][27].

Pheasant and Haslegrave stated that the grip force of the dominant hand is 6.5% stronger than the other. Hägg describes in his ergonomics report that this number is usually mentioned in research to be approximately between 3-10% for the dominant hand [18][27].

The hand strength for many gripping and twisting actions is strongly influenced by grip span. Wrist position is very sensitive in this case and the grip strength is at its peak when the wrist is in neutral position. The strength decreases with angulation in any direction, but mostly when the wrist is flexed which has shown a reduction of 43% MVC [18][30]. This is due to ease of tension in the fingers when the wrist is flexed [27].

4.3 THE CUBE MODEL

The cube model was developed for classification and analysis of work with hand tools and for communication of different ways of solving problems related to manual handling of certain tools. The cube has three variables; force, precision and time. Each dimension is divided into three levels of low, moderate and high demands respectively, where the variables create constraints in the requirement setting of hand tools (see table 4.0 below). The cube is divided into acceptable (green), non-acceptable (red) use areas and areas where situations that have to be further investigated are located (yellow) [31], as shown in figure 4.3. The arrows in the illustration show the direction in which the variables grow from low to moderate to high. The different sub cubes create 27 areas. For each a full case scenario is defined in the report written by Wikström et al. which will provide the tool designer with constraints and information to be able to develop the optimal tool for that specific usage scenario [25].

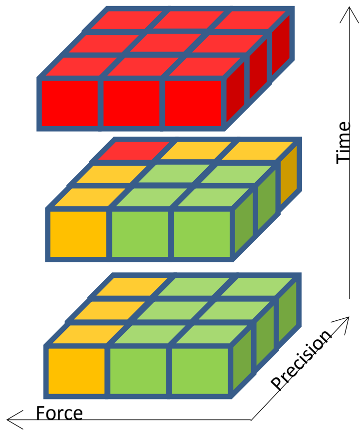


Figure 4.3 Illustration of the cube model.

Table 4.0 Variable values from the cube model [25].

	Low	**Medium**	**High**
Force	<10 %MVC	10-30 %MVC	>30 %MVC
Precision, force exertion	>10 %	2-10 %	< 2 %
Precision level of positioning	> 5 mm	1-5 mm	< 1mm
Time, deviated during the day	<1 h	1-4 h	> 4 h
Time, concentrated	<10 min	10-30 min	> 30 min

Sperling et al. define the grip use as factors involving the user, the workplace, the tool and the work organization [31]. Users' gender, age, body dimension, and training affect in terms of hand size, hand strength and fine motor skills. The work place affect the body position and thereby the wrist position. At the seminar Sperling described how a use of a hand grip in a situation is dependent of three different interacting factors, namely individual, environmental and product factors (see Appendix 1 for notes) [26]. For example the size of the hand affects the wrist, elbow and shoulder angles in a specific hand position. Likewise the working height for the hands affects the grip.

Sperling et al. made a study of grips during everyday life, and defined a set of fundamental grips that are also used in the cube model [31]. The list consists of eight different grips; lateral power grip, diagonal power grip, spherical power grip, extension grip, multi-finger pinch grip, lateral pinch, chuck grip, and fingertip pinch.

Wikström et al. also provides guidelines for surface pressure and surface properties according to the cube model. They state that the problem is highly linked to the surface friction and this decides how much grasp is used in the gripping of an object or tool. With surface pressure they mean an extern pressure against the hand skin. Low pressure is optimal, but also low pressures can cause pain when the repetition is high or for a long time. If the load is continuous for four hours or more, at a pressure of 10 kPa the tissue will be damaged. Highest acceptable pressure for women under a longer period of time is 100 kPa, and 200 kPa for men. The pressure limit when the feeling of pressure turns into pain is 500 kPa for women, and 750 kPa for men. The highest short time pressure is stated at 700 kPa [25].

4.4 ERGONOMIC STANDARDS

RULA worksheet is a method on which many industries base their ergonomic standards. In Swedish industry the Work Environment Authority also have influence, publishing checklists with limit values of what is physically and mentally stressful for the working people in different types of environments [10]. In February this year (2013) they published a Hand Arm Risk Assessment Methodology (HARM). This provides with knowledge of occupational health hazards caused by load, it assists in determining the main causes of risk of musculoskeletal disorders, and shows how to follow-up on action to find out if it had the desired effect, see a part of the checklist in figure 4.4 above showing the load scoring. This method works in a similar way as the RULA sheet with a score scale and calculation of the total score as an assessment of data for high, medium, low load on a worker. The HARM sheet shows a constraint of force exertion versus weight load, and also uncomfortable working poses, vibration velocity and exposure time.

Steg 2: Den mest aktiva handen	ringa in						höger/vänster/båda
Steg 3: Bestämning av kraftpoäng							
Steg 3A		**Steg 3B**			**Steg 3C**		
Ange den mest aktiva handen (H,V,B)		**Hur länge varar kraften i sek/min. (för varje rörelse/moment)**			**Antal kraftansträngningar/ minut (frekvens)**		
Kraft	**Beskrivning och exempel**	**< 4**	**4 - 30**	**31 - 60**	**< 4**	**4 - 30**	**> 30**
liten Vikt<100g Kraft<1 N	Litet tryck med fingrar (t.ex. hålla en blyertspenna med 2 eller 3 fingrar), sortera, trycka lätt med fingrar	0	1,5	3	1	2,5	4
Medel V 100 – 1000 g K 1-10N	Hålla litet motordrivet verktyg med fingrar/hand. Ta/gripa, hålla delar, montera, trycka hårt	0	2,5	4	1	2,5	4
Stor V 1-3 kg K 10-30N	Stadigt grepp med handen (användning av kniv/tång, hantering av delar el. verktyg, genomförande av tyngre delar (t.ex. kassaarbete)	0	3,5	6	2	3,5	6
Större V 3-6 kg K 30-60N	Mycket kraft med armen, (tunga verktyg, tung manöver)	0	4,5	7	2	4,5	7
"peak"	Slå med handflata eller knytnäve	-	-	-	3	5	8
Steg 3D Kraftpoäng = högsta inringade värdet					=	......	
Obs! Om belastningen överstiger 6 kg bedöms den med annan metod (t.ex.för skjuta/dra eller manuell hantering)							

Figure 4.4 The HARM assessment tool

Scania, the Volvo Group and Volvo Car Corporation have their own standards that they use. These are based on previous mentioned regulations, national regulations, research and ergonomic measurements.

4.4.1 AB Volvo and Volvo Car Corporation standard

According to the Volvo standards, STD 8003.2 and VCS 8003.29 for ergonomic requirements, there are some parameters specified for the hand. In summary there are regulations of posture, weight, and force exertion for different types of controls etc. Furthermore some of the measurements and constraint of interest for this work are mentioned [32].

An upper hand grip allows a lift of maximum 0.5 kilograms, a under hand grip allows a maximum weight of 5 kilograms, and a weight over 5 kilograms requires a two-handed grip.

The wrist position affects the gripping force where a flexion of the wrist causes a reduction of the maximum force by 60 %. In a neutral position there is a full gripping force and at extension of the wrist there is a reduction of force by 70%.

The allowed MVC of single control motions are stated in the standard and shown in table 4.1 below.

Table 4.1 Control interaction and maximum allowed force exertion [32].

Finger	15 N
several fingers	30 N
whole hand	50 N
Control/button Finger regulated	5 N
Levercontrol	20 N

General factors that affect the work with hands using handheld tools are:

- Form of the object;
- Grip ability-(material stiffness/surface structure);
- Work load and frequency;
- Object weight;
- Lift duration;
- Posture;
- While precision work-visibility;
- Size of a handle (>120 mm) and an object;
- Environment/object temperature;
- Vibrations

4.4.2 Scania ergonomic standards (SES)

The SES gives recommendations and constraints for wrist position, grip diameter, and lift weights, only to mention a few [33]. It is the SES that is implemented in IMMA today, when carrying out the ergonomic analysis on the manikin.

Neutral wrist position is stated as green here, and when not in a neutral wrist angel it is estimated as red values. The constraints are set as: larger than 30° extension, larger than 45° flexion and larger than 10° deviation at any direction. Hand grip diameter are estimated as green values between 20-40 mm, as yellow values at 6-20mm or 40-70 mm, and as red when smaller than 6 mm or larger than 70 mm. The weight limits are identical with the ones of the Volvo standards [32][33].

4.5 COMFORT

Comfort is a subjective experience felt by a person, including relaxation and wellbeing. The opposite would in this case be measured as discomfort, meaning the feeling is turned into a first step of inconvenience or some kind of pain; this can by time be developed into injury depending on the level and frequency. This is a complicated state since pain cannot be objectively measured in the same way as for example muscle contraction, in the same way comfort is not a scientific measurement.

4.6 BENCHMARK OF COMPETITORS

All software has some kind of library where the user can chose a specific grip for the chosen hand (see appendix 8 for screenshots). The ways of presenting the different grips are several. In Jack 7.1 they present the grips in a list bar with their names, while in the Siemens Process Simulate version they present the grips with pictures taken of the manikin hand in the different postures and also with an explaining name under each picture. In Delmia V5 Human there are illustrations of the three existing grip types, showing the grasping of the specific geometry. In Ramsis the grips are presented as pictures of the manikin hand in different postures but in a grid mesh mode, which makes the interpreting of the pictures quite difficult. However the pictures are complemented by the grip names underneath each. The Creo manikin presents the different grips with pictures of the manikin hand and arm posture.

For the more in-depth investigation of graphical interfaces and functionality of the different competitor software, function trees were plotted, where the functionality could be overviewed. These are summarized in table 4.2 below. The different software all have a choice where the user is supposed to specify for which hand the chosen grip is to be set. Mostly there is a choice of "both" hands as well. There is also a possibility to copy the settings from one hand to the other. This is for cases where the user has made some manual changes of joint angles for fingers or similar, and is done by right click on the hand and selecting "copy hand". All software except for Creo gives the expert user the possibility to manually adjust joint angels, for making the posture look more accurate. The V5 Human gives the possibility to set the angle of all fingers at the same time in the hand grasp setting. In Jack this feature is built so that the user needs to choose a starting position and an ending position, which are two grip types selected from a list, and then one must choose how many per cent the starting position should change to resemble the end position. The Jack and Process Simulate software have a collision detection function which stops the fingers when contact is made with the target object surface.

In a demonstration of the Process Simulate software by a Simulation Engineer at VCC, described is how the grasp function does not fulfil the needs of a user. Adjustments must always be done, the automatic function of setting the target location does not work as it should, and since the hand does not find the object surface (see appendix 4 for further notes from this session).

Table 4.2 Analysis of the different competitors

	Jack 7.1 (by Siemens)	**Process Simulate (by Siemens)**	**Ramsis (by Human Solutions)**	**Delmia V5 Human (by Dassault Systems)**	**Creo (by PTC)**
How many grips are there in the library?	28	21	30	3	
How are the grips presented in the library?	Text/Name of grip	Pictures of manikin hand postures	Pictures of manikin hand postures, but without skin. Only as a mesh.	Illustration with geometry	Picture of manikin hand and arm
Providing options for left or right hand	Yes	Yes	Yes	Yes	Yes
Providing options for both hands at once	Yes	No	No	Yes	No
Providing manually	Yes (the % function) And	Yes	Yes	Yes (the degree of fingers)	Not that we could

adjustment of joint angles	also manual adjustment of each joint.				find?
Collision avoidance	Yes	Yes	Yes	Yes	
Grip the object per automatics	Yes	Yes		There is a fourth grip option called "Auto grasp" which has a hidden grip catalogue to search from. But apparently it does not work as it should!	
Posture interpolation	Yes	Yes	Yes		
Providing a save grip function for the user	No?	Yes		No	

The framework of the Jack software uses the graphics environment, forward kinematics and the location of object to grasp it. There is a difficulty in solving the issue with automatic grasping, this due to the high context dependent information that is required. Therefore the ergonomic simulation tools all provide manual adjustments and not really try to provide a correct automatically grasp synthesis.

From the focus group session it was noted that the ability of having predefined grips in the software is preferable. Here it is mentioned that three grips, in the case of the V5 human , does not fulfil the needs and even though cylindrical power grip were mentioned as the most commonly used, there is a great lack of grips in this software (see appendix 2 for further notes). Here it was also mentioned that the grips are pre-set to be positioned in a specific forearm rotational angle. There would be preferred to be able to change this in an easier way.

4.7 SUMMARY

A list of requirements were defined from the facts gathered during the survey and the interviews, but mostly from the benchmark of the competing software. The list shows upon the features identified for a grip library tool for a digital human model (see table 4.3 below). The list was used as a checklist during the development stage of the GUI, in order to achieve the set of demands on the market. Here the functions of the tool are defined and the demand column is divided into requirements (R) or wishes (W). The requirements have been weighted against each other to show how important the feature is for the functionality. Five points is the most important requirement.

Table 4.3 List of functions with requirements

Function	Demands	Description
Provide a choice of right/left/both hands	R (5)	When to apply a grip
Provide different types of pre-defined grips	R (5)	Around 10 specific grip types
Present the grip types in an understandable way for user	R (3)	By pictures preferably
Provide a fast function of changing the grip span	R(4)	User friendly

Provide manual adjustment of joints	R (4)	
Illustrate the automatic grips in the library	R (4)	User friendly
Offer possibilities to set grip points	R (3)	Target location
Offer possibilities for the software to feel the surface of the object and to recognize it	R (3)	Intelligence. For the automatic function. “Object to grasp”
Offer possibilities for the manikin to avoid collision with hand/fingers/body whit objects	R (4)	Avoid intersect by any kind or predefine the level of deviation.
Provide information for the adjustment of parameters	W	Usability, user should get feedback.
Provide the possibility to set an adjustment of parameters on one hand to the other hand	W	Copy the joint parameters/ pose
Adapt the grip by gender, percentile and hand	W	Should look and act natural
Adjust a grip around a imported object/geometry	R (4)	Define which object to grasp and on what point.
Provide possibility to change grip in an easy way	R (3)	User friendly
Provide possibility to save a new grip	R (4)	Create a grip and save it in the library
Feedback when choosing a grip for the manikin hand	W	Direct feedback showing the selected grip
Possibility to adjust the grip to object automatically	W	Match exactly
Possible to change wrist position in an easy way	W	User friendly
Possible to change elbow rotation and flexion in an easy way	W	User friendly
Possibility to set weight on object	R (3)	Weight vs. force
Ability to measure distances	W	Between two points on hand or between fingers, between finger and object.
Ability for IMMA to identify when the hand is “over loaded”	R (3)	See framework chapter for further details of the limits allowed for grips
Ability for IMMA to identify the relation between a wrist posture and a grip	W	
Ability to calculate the applied force	W	The pressure force allowed for One finger: 15 N Several fingers: 30 N Whole hand: 50 N
Ability for IMMA to identify when an object does not fit the chosen grip.	W	Framework variable values
Possibility to easily go back to neutral position for both hands	W	User friendly, allows undo.
The grip library/tool should match the language of the current version of IMMA	R (5)	
Possibility to take an ergonomic analysis on the hand posture for an assembly	W	Based on the current analysis presentation

5 IMMA FUNCTIONALITY

5.1 THE PROJECT PROBLEM

Many attempts have been done by researchers in the recent years to create a fully automatic grasp synthesis and the effort has been put on creating systems that find the optimal grasp for the manikin. The grip type in most cases is to be chosen by the user, but the process of actually grasping around the object and on the right grip point on the surface, depending on the object form and structure, was to be defined by an automatic database controlled by variables.

In the case of IMMA the predefined demands were that the software would suggest the best grip for the user, with focus on identifying the position that is best for the individual and for the task to be performed, more than creating an automatic function to grab the object. The feature in the form of positioning the hand around an object with collision avoidance is already available in the current version, whereby the need for having grip points set out by automatics does not count as a coveted function at this very time in the research project.

When the participants of the survey were asked whether they find an automatic grip library interesting and if they could imagine working with a fully automatic tool or if they would rather have a manual library, the majority answered that both functionalities should exist. Several persons described the optimal function as the software being able to suggest the best grips, but for the users to actually take the decision to use any of them or not.

5.2 THE IMMA HAND MODEL

The hand model in IMMA is based on a set of skeleton links with connecting joints of a total of 20 degrees of freedom (DoF) for each hand (see figure 5.2 to the right). Torque is set on joints in the software as it functions today. The joints are listed under each body part in the specification tree in the white window on the left hand side of the screen and a menu for each will be open when right-clicking on the joint name. The angles are adjusted with a bar slide illustrating the angular functional span with the ends as constraints and defined as extreme values. The joint constraints are presented in table 5.0 below. In comparison with a real human hand, there is a significant difference in thumb joint constraints, where the major difference is shown in the proximal spread angles. This can constrain and thereby affect the ability of constructing realistic poses with the manikin hand. Comparing with for example the Jack 7.1 manikin, one can see that for the thumb joints, the grip joint is set for an extension of 0°-40° and the proximal spread, abduction of 0-110°. This shows up on a big difference of what degrees of freedom is provided for the IMMA manikin today.

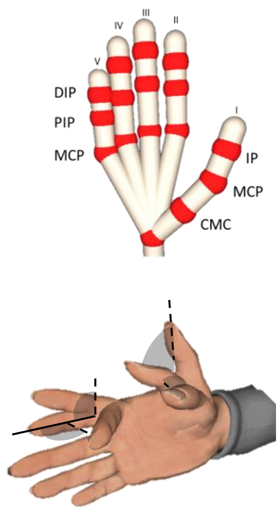


Figure 5.2 The IMMA hand model.

Table 5.0 Joint angles of the IMMA digital manikin hand model in degrees.

	Proximal spread	Proximal grip	intermediate	distal
Digit I	-30 to 15 (add/abd)	-30 to 25 (ex/fl)	-10 to 70	-10 to 60
Digit II	-20 to 10	-80 to 10	-80 to 10	-80 to 10
Digit III	-10 to 10	-80 to 10	-80 to 10	-80 to 10

Digit IV	-10 to 10	-80 to 10	-80 to 10	-80 to 10
Digit V	-10 to 20	-80 to 10	-80 to 10	-80 to 10

5.3 GRIPPING FUNCTIONALITY

In the latest version of IMMA there is a grip editor GUI implemented where user can save a posture as a grip. This function was implemented for this project by Fraunhofer-Chalmers Research Centre, as a tool to make the creation of the library possible. The library is adjustable manually by an xml file in which it is possible to make changes of the angles and the grip type name. The values that need to be set are the angle of each joint of the fingers and thumb for the manikin hand model structure.

To grip an object in the current version of IMMA, a grip point must be created on the surface of an object. These are created by setting out the target points of the wrists on to the object and by adding grip points where those are placed. The grip points are illustrated with a green sphere (as shown in figure 5.3). It is possible to create grip points anywhere on the surfaces of an object and these are independent of each other so it is permitted to create as many as required.

Since IMMA is still in a development state, the current version is a demo application; some definite functionality is yet to be implemented. The intended functions for further development, that are directly correlated to the grip library, are; the possibility to save grip points that have been placed on an object, and to delete these, and the function of automatically grasping an object by telling the manikin to close his fingers around the object until joint limits are reached or a collision inhibits further motion. The last mentioned function will be set by using reverse kinematics. Having the size variable it is possible to describe a maximum deviation for each segment of the hand.

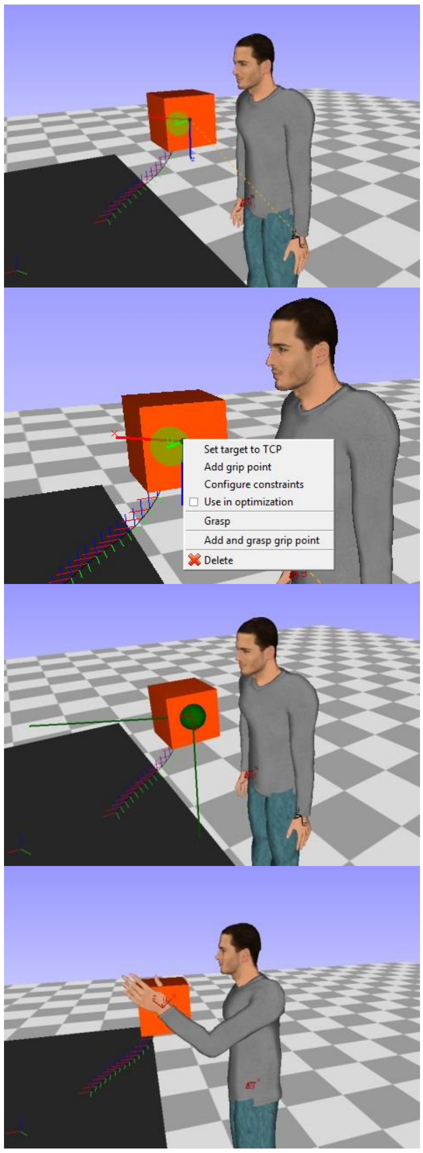


Figure 5.3 The steps of creating a grip point in IMMA.

6 THE GRIP LIBRARY

A hand grip library was developed with eight grips implemented into the software, for the manikin to use during ergonomic simulations and analysis.

6.1 SELECTION OF GRIP TYPES

Cylindrical power grips are those used most commonly by simulation engineers, according to the interviews made at AB Volvo and VCC. Here it was also mentioned that there is a lack of grips or hand postures that illustrate the lean positioning or for holding in to a detail while assembly. At VCC it was also mentioned that a steering wheel grip is frequently used, but mostly mentioned was the tip pinch grip.

The grip types identified, during observations, are listed in appendices 9 and 10. There were recurrent grips found in the notes from the visits and these were compared with those from Sperling's study of grips used in everyday life. It appears clear that the fundamental grips that Sperling mentioned at the seminar and also have used in the cube model, are those most commonly used in all sectors of hand activity [26][31][23].

The grips chosen for the grip library in IMMA are shown in figure 6.1 below, it is the eight fundamental grips used also in the cube model. The pictures chosen for the presentation in the IMMA grip library are pictures of the manikin pose with the specific geometry grasped in its hand.

Some other grip types such as the “Thumb press” and the “One finger Push” etc. were initially chosen for the library, but were later screened due to the fact that measurements and values were lacking for the grips to be able to be implemented in the library in an accurate way. This deliberately because of the fact that this grips were of open pressing motion type, not of closed force grip types, so it is not possible to save them as different spans, since they are fixed and therefore neglected in this state. For the library to become complete these kinds of grips must be included in future development. Therefore some force parameters related to push controls were listed based on the Volvo standard. Another grip that was deliberately neglected is the “neutral hand”, because the IMMA manikin is set to having the hands in neutral position initially when created and is reset to that same position by one single mouse click.

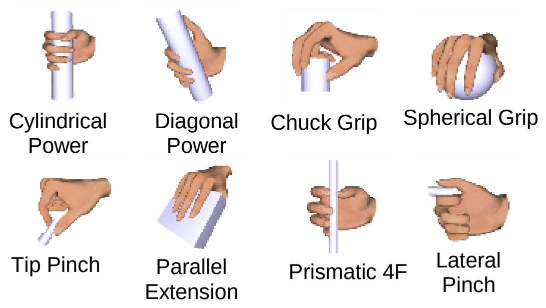


Figure 6.1 Grip types with grasped geometries.

6.2 GRIP TYPE CREATION AND SETTINGS

As mentioned in the previous chapter about the IMMA functionality, the grip edit function implemented in the IMMA demonstrator for this project was an saving function where "open hand" value, "closed hand" value and "neutral" hand were to be fed (see figure 6.2.0). Here the neutral hand would be a proportion of open to closed hand. Moving towards the extreme values would increase the level of discomfort in the hand. The value is set from zero to one, and the curve slope depends on how fast it becomes uncomfortable after passing the neutral hand. It is also possible to set the neutral value as one of the end values.

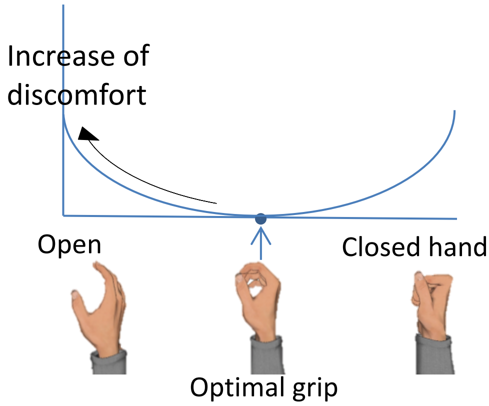


Figure 6.2.0 Illustration of the hand settings

A Cylindrical Power Grip is the most commonly used grip type in assembly work and with handheld tools. This grip is a transversal full hand power grip, of a palm type, having the palm as one fragment and the fingers number two to five as the others. The thumb is interacting passively in abduction. Here the open hand is the largest possible functional spread that is given by anthropometrical studies of different percentiles of men and women. The maximum functional spread for a 50th percentile man is according to Pheasant and Haslegrave anthropometric list, 142 mm. A man this size should consequently be able to hold a cylinder with diameters less than this value in one hand [18]. In IMMA, when a 50th percentile manikin was created and tested with this size of a cylinder, it showed that the diameter was too large to fit in the hand. This could be because of differences in anthropometric measurements of the human body for different nationalities; in IMMA a Swedish database of measurements has been stored. After testing different diameters a cylinder with diameter of 127 mm was identified as the largest one the manikin could grab, whereby the angular values of the finger joints were set as the open hand limit for this particular grip type. The closed hand was positioned as a closed fist, this because there is no smallest limit to what a person can grip in this pose. Neutral position was set to be when holding a cylinder with diameter of 50 mm which is the "best" size for comfortable gripping for a cylindrical or conical geometry with a power grip. In different research the diameter of 38.1 mm is often mentioned as being the optimal grip size of cylindrical power grips, but this in the manner of maximum emitted grip force. For the sake of grip comfort diameters around 45 to 65 mm are often mentioned to be the optimal tool size for power gripping [25][34]. Overall a spread of diameters between 25.4 to 76.2 mm is functional in tool design.

A Spherical Grip is a power grip, of the palm type. Interacting fragments are firstly the palm and secondly the fingers number two to five. The thumb is not included in the required structure, but it is participating inactively in abduction position. Open hand is the maximum functional spread of the 50th percentile man, a sphere of 142 mm in diameter. Closed hand is the minimum spherical grip that the manikin can structure with its hand without losing the grip type, which is set as the same as neutral grip with a diameter of 70 mm which is the median of the optimal grip size for all percentiles [25]. Closed hand was set to this diameter because a minimum size was not found in theory and after testing in the digital environment with different sphere diameters this size was the limit for the manikin grip before losing the grip type structure.

Tip Pinch is the most precise precision grip with interacting fragments primary the thumb and secondary the index finger, with the thumb positioning in abduction. All contact points are of the pad type and this pinch grip has an alternative structure where the whole distal phalanges of the two segments participate. It is then called a palmar pinch. The Tip pinch is implemented in the library and the closed hand is set when the index finger and thumb meet tip to tip. Open hand is set as the maximal functional spread between the two segments, a spread of 76.2 mm [35]. Comfort values mentioned in the literature is a minimum grip size of six mm [25].

Diagonal power grip is related to the earlier mentioned cylindrical grip and the structure is similar with primary palm contact points and secondary fingers two to five, but tertiary having the thumb as a stabilizing fragment in adduction. This increases the precision degree but decreases the force exertion linearly. The maximum open hand has been set with a cylinder of 127 mm in diameter. Closed hand is the minimum possible diameter of a cylinder, which for the manikin is set as a closed fist but with the thumb in fullest possible adduction. The grip range of this type is not defined in literature and in the screening report made by Wikström et al. it is mentioned that this must be determined by practical trials since it is clearly context based [25]. Since the diagonal and the transversal power grips are similar in the posture structure, also here the neutral grip size is set to a diameter of 50 mm.

Prismatic four finger pinch is a precision grip structured as a pincer with primary the thumb as first claw and secondary fingers two to five as an opposite claw. The thumb is positioned in abduction and all contact points are of pad type. The open hand is set as a maximum spread of 76.2 mm and the closed when the two claws meet, more specifically when the thumb tip meets the index and middle finger tips [35]. Neutral position is defined as a pinch with grip span between 9.5 to 12.7 mm, and therefore set as median 11.1 mm.

The chuck grip is structured by a precision type with pad contact of primarily the thumb and secondary fingers number two and three, where the thumb is positioned in abduction. This grip is a type of tripod chuck grip which could be structured with the third finger on the side instead of on the tip and thereby become a writing grip or a lateral tripod. Open hand is set to be the maximum spread in this position (spread of 76.2 mm) and closed should be set when the first and second fragments are in tip contact. Neutral position should be set as the comfort grip size of 15 mm in diameter [25]. However, as the manikin has restrictions in that finger structuring the closed hand and neutral hand required the same position after some testing with the geometry. This is mostly because of the restrictions in spreading the fingers and for the thumb to meet the tip of digits two and three.

The lateral pinch is classed as a pinch grip but of the intermediate type with both pad and side contact points where the thumb is the primary and the index finger the secondary interacting part. This grip is one of the often-mentioned grips in literature, also recognized as the key grip. Here the closed hand is set to when thumb pad and index side have contact. The open hand is set to when the thumb is lifted up so the thumb is angled towards 0 degrees for the two first joints, but with the distal joint angled down in 45 degrees. Neutral is set to having a planar surface with a thickness of 5-10 mm between the two fragments [25].

Parallel extension is an overhand precision grip, of pad type, where thumb is the primary and fingers number two to five are the secondary and these are positioned parallel. The open hand is set to having all the fingers in neutral position and the thumb in full adduction. Closed hand is set as the possible smallest size of the grip, where MCP joints of the fingers are all flexed to the largest angle and the PIP and DIP is neutral (at 0 degrees), whereby the thumb is in pad contact with the middle phalange of the index and middle fingers. Neutral is set as the open hand, because of the closeness to the by theory “neutral hand” position (all joints in 0 degrees).

Staple Pistol grip is set as a trial of bringing tools into a simulation with attention of showing the use of the grip library (see figure 6.2.1). The open hand is set as the perfect fit around the tool in a passive state. The closed hand was supposed to be set as the state when a staple has been cut, more specific when the handle with trigger is pushed back against the thicker weighted handle, but since the tool is not possible to actually cut with in a simulation, the closed was set as the same as open whereby only a fix grip is saved. However this grip can also be created each time wanted with choosing the cylindrical grip and letting it grasp around the tool. It might need some manual adjustment so for industry partners who use this tool very often it could be of interest to have such grips as pre-defined types in the library. Creating the grip with a cylindrical power grip makes it possible in the simulation to show the different ways of holding and using the tool in assembly.

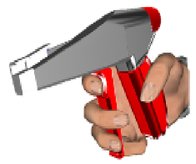


Figure 6.2.1 Pistol grip with a Volvo standard staple tool.

Balance grip is a support grip for the manikin to use in different assembly tasks, to lean towards a plane surface for example. These types of unenclosed grasps are not really defined as grips in literature, (as mentioned earlier), but they are mentioned by many researchers and also requested by the simulation engineers at the focus group. They were therefore added and tested in the IMMA grip library. However after attending a IMMA workshop in the late May, it became known that the software possesses a function called “add contact point”, which is located in the right-click menu where joints are being adjust. With this it is possible to add a contact point between the hand and the surface of an object and hereby add force in the interaction. This will be calculated as if the manikin is leaning or pushing against that point and thereby the whole body pose of the manikin will adjust to accommodate to this requirement.

6.3 FUTURE DEVELOPMENT SUGGESTIONS

The way of applying these postures is a very hard way of saving a grip and to be performed accurate by an end user of the IMMA software. It might be preferable for some expert users, but in most cases it almost impossible to find an exact number for each of the joint angle values to feed in to the system for each and every finger participating in a grip. Perhaps this method could be used by the software developers to pre define the grips listed in the grip library, but to provide an alternative way for the end user to save grips.

The degrees of freedom has to allow the hand model to reach the hand posture for any grasping task. In this sense, it is important that the model considers not only the thumb and finger movements but also the palm arching. For the manikin hand to look more realistic in the predefined grip types an investigation of the joint limits has to be done. The thumb abduction and rotation around the index finger need to have a larger span since it is not currently possible to bend the thumb so that it is positioned exactly opposite the fingers. This causes a deficiency as the accurate picture of the grip is not possible to be recreated. This can be seen very clearly in the cylindrical power grip, in the parallel extension grip, chuck grip and in the four finger pinch. When the participants of the survey were asked whether they think it is important for the software to show an aesthetic and realistic view of the hand posture and if it is important for the final product, they answered that it is of importance. Therefore a calibration of these joints will be required.

In the grip library a group of prehensile grips have been taken under consideration and also implemented. Furthermore have a set of non-prehensile grips to be included in the library to be complete. The grips found in the research stage of this project were thumb-press, index press, pushing motions with the whole palm or with fingers. Also hook grips that are used, mostly when lifting objects with handles. The pushing motions need a functionality that makes it possible to apply the level of force needed in a specific task, both on the object and from the interacting digits.

7 FRAMEWORK

The framework is a basis for an attempt to develop an automatic function which is expected to identify when a grip is uncomfortable and thereby give suggestions of the most optimal grips from the grip library. In current implementations of grip libraries in different Digital Human Manikin tools the selection of grasp types is left to the user.

According to the survey made amongst industry partners who work with this kind of tools, the majority of the participants could consider having automatic grip recognition, as long as they have to approve the suggested grip. They would choose to keep the manual grip library for possible adjustments and modifications.

7.1 VARIABLES AFFECTING THE GRIP QUALITY

Analysing the data found in research for hand ergonomics, there are clearly a complicated and truly context based matter. The biomechanics of the hand is so complicated, that no one has clearly stated that there is a certain way of calculating or predicting a grip structure. During data collection the different foci identified in the research on hand grips concerns the structure of opposite and interacting contact points, the grip force and maximum exerted force during a task, size of the grasped object, the weight of the object, the size of the hand, the surface pressure on skin in the grip contact points. Also grip positioning in relation to wrist posture and forearm posture in a certain time and frequency, grip type as a function of object form, how far from "neutral position" the hand and wrist is, and the level of precision of an assembly task.

After discussion with the IMMA project group members, it was decided to further investigate the two variables *force* and *precision*. Also with the grip library settings of "open and closed hand", a variable of the human hand size versus object size is already defined.

7.2 FORCE

Armstrong describes the primary factors affecting the grip force as weight, resistance and reaction forces, object size, object shape and surface friction of the gripped object. To maintain an object in a grip, a grip force perpendicular to the load force is exerted by the human hand. This is done automatically since the sensibility in the skin contact with an object is so high that it is possible to feel when the object is starting to slip or deform. However there is always some people that exert considerably more than the minimum force to keep objects from slipping from their hand [36]. When measuring the force value dynamometers have often been used in research, but in later years alternative methods have been developed. Lowe et al. developed a hand force measurement system based on a sensor glove. The pressure is measured on the pulpar regions of the phalangeal segments and palm that is in contact with the grasped object [37]. The force variable is already defined by the report of Wikström et al. as the MVC for the fundamental grip types used in the grip library [25]. These values will be used as the framework values.

Based on research and the ergonomics standards three levels of allowed fore exertion were defined, less than 10 % MVC (green), 10-30% (yellow) and more than 30% (red) [25]. This would look like table 7.0 below. The MVC would be pre-defined and also the limits for green yellow and red values, but the exerted force would in a current version of IMMA be typed in by the user. The user would then have to take measurements in the specific assembly task in real life and insert the measurements for each task in the simulation.

Table 7.0 Force measurements for the grip types

		MVC	<10%MVC	10-30%	>30%MVC
Two-handed grip	Female	540 N	<54 N	54-162 N	>162 N
	Male	900 N	<90 N	90-270 N	>270 N
Cylindrical power grip	Female	300 N	<30 N	30-90 N	>90 N
	Male	500 N	<50 N	50-150 N	>150 N
Diagonal power grip	Female	150 N	<15 N	15-45 N	> 45 N
	Male	250 N	<25 N	25-75 N	> 75 N
Spherical grip	Female	150 N	<15 N	15-45 N	> 45 N
	Male	250 N	<25 N	25-75 N	> 75 N
Extensions grip	Female				
	Male				
Prismatic 4F pinch	Female	100 N	<10 N	10-30 N	>30 N
	Male	150 N	<15 N	15-45 N	> 45 N
Lateral pinch	Female	50 N	<5 N	5-15 N	>15 N
	Male	80 N	<8 N	8-24 N	>24 N
Chuck grip	Female	50 N	<5 N	5-15 N	>15 N
	Male	80 N	<8 N	8-24 N	>24 N
Tip pinch	Female	35 N	<3.5 N	3.5-10.5 N	>10.5 N
	Male	50 N	<5 N	5-15 N	>15 N

7.3 WEIGHT VARIABLE

After discussion with IMMA project group members who have knowledge in what is implementable in the software, it was decided that an optimal object weight for each grip type would be a better way of screening the grips from the library. Here the user only needs to input the object weight, which is much closer at hand than the exerted force. Also the function of putting weight on the imported geometry in IMMA already existed in the software.

Weight limits found during data collection were the ones found in the standards, as shown in figure 7.3.0 below. Armstrong made a study of 23 subjects using 32 different handheld tools. Almost all tools with masses less than 1.5 kilograms were rated as having just the right comfort level when hold in hand during assembly work, while tools with a mass greater than 2.25 kilogram were rated as too heavy. These weight recommendations were also found in guidelines for handheld tool design (1.75 kg respective 2.3 kg) [18];[38]. According to the Scania and Volvo ergonomic standards it is permitted to lift up to 5 kg with a one hand grip [32][33]. The HARM checklist, showed in the analysis chapter, gives a scoring checklist of tool weight and load force where they divide grips in different tasks and thereby into four force levels (see table 7.1) [10].

Table 7.1 HARM load force score [10].

<100 g	Ex. Chuck grip
100-1000g	Lateral, 4F pinch
1-3 kg	Diagonal power grip (steady grips)
3-6 kg	Full power grips, force from arm needed

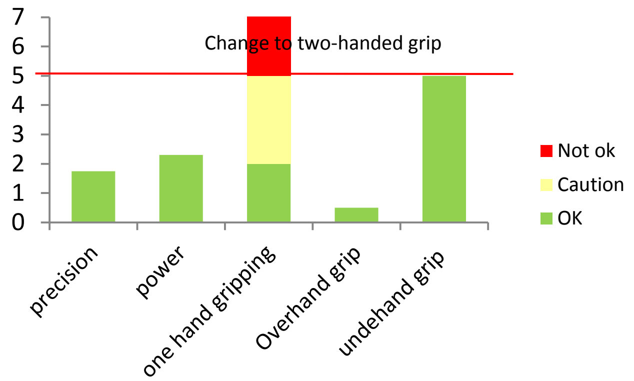


Figure 2.0 Weight limits and recommendations by standards

Radwin et al. plotted average total grip pinch force against load weight in their study of a prismatic four fingered pinch grip, 15 N for 1 kg, 20 N for 1.5 kg, and 30 N for 2 kg [16]. Whereby it shows that it is not possible to assume (as in the HARM) that 1 kg exerts a force of 10 N. Seo et al. showed for pinch grips that even though there is no lifting associated with a task, the grip force exerted is affected by grip surface friction [29]. This needed to be further analysed before any conclusions could be made and weight limits set. Below are shown some attempts to calculate of the optimal object weight.

In chapter 4.2 equation (2), it was stated that the pinch force needed to exactly avoid slipping. It is thereby equal to two tangential forces in the opposite direction of the object load, as shown in figure 7.3.1. When further analysing the equation it was found that the coefficient of friction is context based and not possible to be calculated. Further assistance of mechanical expertise was acquired and the conclusion was that such values need to be experimentally verified by a large sample of cases. However, it is still a material and contact surface property specific coefficient and therefore there is not possible to make any tests since there is a large amount of different assembly situations to take in to consideration.

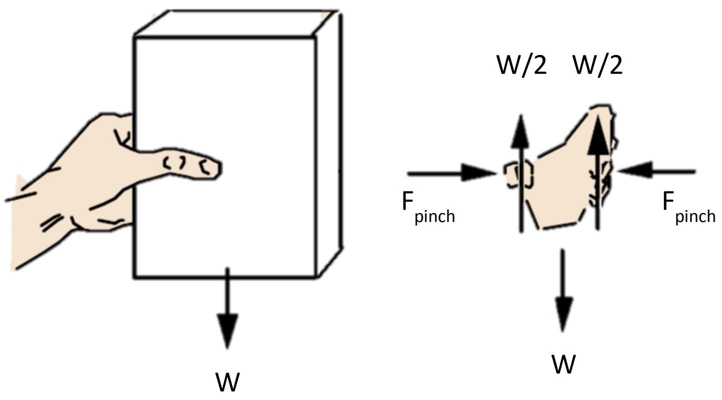


Figure 7.3.1 Illustration of the force equilibrium in a pinch grip

After discussions with several parties of the IMMA project group it was decided to calculate an approximated value with the assumption that the object is grasped in a firm grip avoiding slipping exactly. Sandpaper on wood has usually friction coefficient between 0.6-0.8 depending on the surface structures. For a firm grasp a coefficient of 1 is approximated, which will indicate that the friction is so high that the grasp is exactly preventing the object from gliding. This will change the equation to not consider the friction coefficient. The result is the values listed in Table 7.2 for precision grips. For all calculations it is assumed that the centre of mass lies in the grip centre of the hand, where the grip centre is defined as the symmetric distance between the opposite contacts points of the grip structure that grasps around the object.

Table 7.2 Weight constraints for the implemented grip types in IMMA

Grip type	**Weight (kg)**					
	Men			Women		
Tip pinch	1.018		3.055	0.713		2.138
Chuck grip	1.629		4.887	1.018		3.055
Lateral Pinch	1.629		4.887	1.018		3.055
Prismatic 4F Pinch	3.055		9.165	2.036		6.109
Parallel extension	0.5		>0.5	0.5		>0.5
Spherical	2.545		7.637	1.527		4.58
Diagonal power	2.545		7.637	1.527		4.58
Cylindrical Power	5.09		15.27	3.05		9.16

The power grip types are calculated applying equation (1) from chapter 4.2. This gives a lower limit for the diagonal power grip and the spherical power grip than for the prismatic four finger pinch, which indicates that the power grip calculations might be inaccurate. It might be better to set all the power grips to have a limit of five kilograms as the green limit and then to interpolate, since the standards allow for one hand lifting up to that weight. Tests need to be done to identify whether these values are feasible or not, before being implemented in the software. The assumption of setting the friction coefficient to 1 causes an error that needs to be taken under consideration, given that the weight limits become higher than in reality.

7.4 PRECISION

The precision tolerance is, according to the study of Sperling et al. [31], measured in positioning in the wrench point of the used object. The precision capability depends on the grip type features. Control assistance in the form of support could reduce the demands of active precision for a task. The distance between the grip and the wrench point should be as small as possible for optimal precision level. The power force and the precision torque should not coincide. This way it is possible to screen the grip types through precision level where high precision demands a positioning within 1 mm or less. The medium constraint lies within positioning of 1-5 mm and the low when the positioning does not demand more than 5 mm in tolerance, the values taken from the Wikström et al. studies (see table 7.3 below) [25].

Table 7.3 Precision constraints

Precision tolerance	
Cylindrical power	>10 mm
Diagonal power	5-10 mm
Spherical	5-10 mm
Parallel extension grip	5-10 mm
4F Pinch	1-5 mm
Lateral pinch	1-5 mm
Chuck	1-5 mm
Tip Pinch	< 1mm

The value of precision is measured according to how precise the task requires the grasp motion to be carried out. For example low demand with a cylindrical power grip would be in a matter of just putting the object on a table, while a lateral pinch would be to place the key in the lock. Here the user needs to know what precision level the intended task requires, this is usually stated when the product is constructed, but it is also relatively easy to approximate a value for the task in question, perhaps not in detail but possibly roughly. A way of making the functionality in IMMA user friendly would be to have a list of pre-set choices instead of requiring the user to input an exact number. Here the user would be possible to read in the manual an explanation of every level and thereby learn how to use these.

The further out along the lengths of the finger height the contact points are located when grasping an object, the higher control and precision level will be. When stability or security is needed in the grip structure digits will be added to the grip structure. Precision correlates with the size of the object. Having a very small object the task will require a higher precision level, however the number of digits activated in the structure will be less because of smaller contact areas.

7.5 SIZE OF THE OBJECT VERSUS GRIP SPAN

When it comes to the object size versus the size of the hand, it is in some attempts to automatic grip libraries in other software implemented a calculation of finger breath in mm versus the size of the possible contact area on the object surface. That gives an assumption of how many fingers that can participate in a grip structure and from that the grip library will be screened on possible grips types for grasping the specific object.

In IMMA there are implemented a size constraint versus the spread of the hand, as in when it gets uncomfortable to hold a grasp around an object of a specific size. This has been treated in chapter 6 where the grip library was presented. The grip types in IMMA have a grip span saved from largest possible spread to the smallest possible hold for the same grip and hand. This gives a span of different sizes of the same grip structure with which different objects can be grasped, depending on the shape and size. In some research it is mentioned that the neutral hand position, where the fingers are not flexed and all joints rest in 0 degrees, is the most comfortable position. Then it might be of interest to have this state as the “neutral hand” when saving a grip and for the software to calculate how much the grip structure differs from that position.

7.6 SIMILAR WORK

There has been research done on rule-based methods of grasping, by segmenting the primitive geometries and decide how each of these are to be grasped.

Reed et al. [13] developed an automated grasp model which is based on a data-based, kinematic grasp simulation method, which is integrated into a whole-body motion simulation framework.

Many of the other attempts to automatic gripping objects in digital environments have set a list of primitive geometries. The imported object is reviewed to match the closest one and then selected. These primitive geometries have predefined coordinate systems for each grip and it is based on where the midpoint axis of an object is to be placed in that certain grip type [39].

7.7 FURTHER DEVELOPMENT

The purpose of having a framework is to be able to give information to the user of the "optimal case" and to, in the future, make the whole grip library function completely automatic. The current versions of suggested framework variables are very basic. If a part is implemented in an early stage in the IMMA project, then the functionality will be easier to evaluate and test while at the same time being further developed.

Given the three variables that is suggested in this report it will be possible to screen grip types and give proposals to the user of which would be the most optimal choices. Some grips should be proposed to avoid deviances in variable values, and it will be required from the user to select the one suitable. For the framework to be able to give suggestions of different grip positions during a motion it will be required to apply force constraints and torque constraints on muscles. The software will furthermore need to have a functionality of calculating how much effort is required in a certain position of work to be able to calculate the more optimal position in the same task motion. The manikin MVC versus exerted MVC% for a specific task could potentially cover this function, however the user should not need to input those values for each task.

Other variables providing more specific context based parameters should and can be implemented in the software; time and frequency variables and skin pressure values are some. These are very important factors that should be considered in the future, and was delimited in this project due to the limitations of the software and the need of making tests and measurements to be able to get the right values and variables.

8 THE GRAPHICAL USER INTERFACE

8.1 GUI DEVELOPMENT

For presentation of the hand grip library tool in IMMA, a suggestion of a graphical user interface was developed. This interface was developed for the current version of the IMMA demonstrator, for the grips to be presented and the functionality to be implemented in a user friendly way. The interface matches the current language of the IMMA software and the functionality is possible to implement in the software in a near future. This part of the project was added due to my own interest and; in addition, if the suggestion is to be implemented it will facilitate some of the remaining work for the IMMA project.

8.1.1 Requirements

For the grip library interface development, the list of requirement was screened and the functional requirements were identified which are possible to implement in the current version of IMMA.

The main function would be to present the pre-defined grip types in a list, for the user to be able to select easily, preferably by pictures. For the choice of hand it is not possible to have this function since the hand is automatically defined when creating the grip point, likewise with the function of rotating the forearm. A fast function of changing the grip span would be preferable. A saving function of new grips should be in the library. Feedback should be provided of the selected grip on the manikin hand directly. There should be an easy way of resetting the hands to neutral position again if needed. It should be possible to exit from the library in an easy way if needed. There should be shown on what point on the object surface to grip. It should be allowed to adjust the joints manually. The grip should adjust automatically after the object shape, by collision avoidance and reverse kinematics.

8.1.2 Process

The development of the GUI was done by sketching different interface suggestions and showing them to stakeholders for feedback. The interface was in this way both evaluated and developed at the same time. Reflected facts during development were the points listed in the list of requirements and also considerations of the current functionality in the IMMA demonstrator. Also alternative methods for presenting some surrounding functionality regarding the grip motion in the IMMA demonstrator were identified.

8.1.3 Ideas of presentation

In the current IMMA demonstrator the joints do not show when they are actively being changed and therefore the user must know each joint name. Having a “fast” joint angle adjustment function by clicking on the desired joint would facilitate the adjustments, this can be highlighted as a coordinate system projected on the specific joint and allow the user to drag the coordinates to change joint angle directly on screen (see figure 8.1.0). Other possibilities could be to directly input the angle by numbers in a command prompt, or to adjust it by the bar slide (as today) but at the same time see the active joint as shown in the figure to the right.

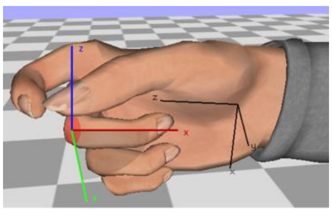


Figure 8.1.0 Joint coordinate system.

Two alternative suggestions of the appearance of the grip points are presented here, in an additional effort to make IMMA as user friendly as possible. The current grip points are represented by a green sphere with a coordinate system showing in what direction the constraints are set. In figure 8.1.1 is shown how the grip points reflect the name of the point so that the user knows which one to select. Here it could be valuable to provide feedback to the user when a grip point is selected, by swithing the colour from red to orange for example. The grip points should show where the centre of the grip will be located.

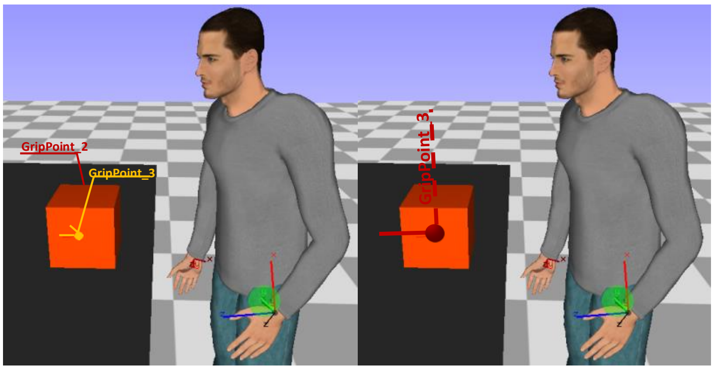


Figure 8.1.1 Grip point appearance and presentation

8.2 RESULT

The result of the grip library tool interface design is shown in figure 8.2.0. Here the grip types are presented by pictures of the manikin hand in the specific grip type posture with a typical geometry for that structure, showing the changes of the hand structure in a detailed scene window of the hand.

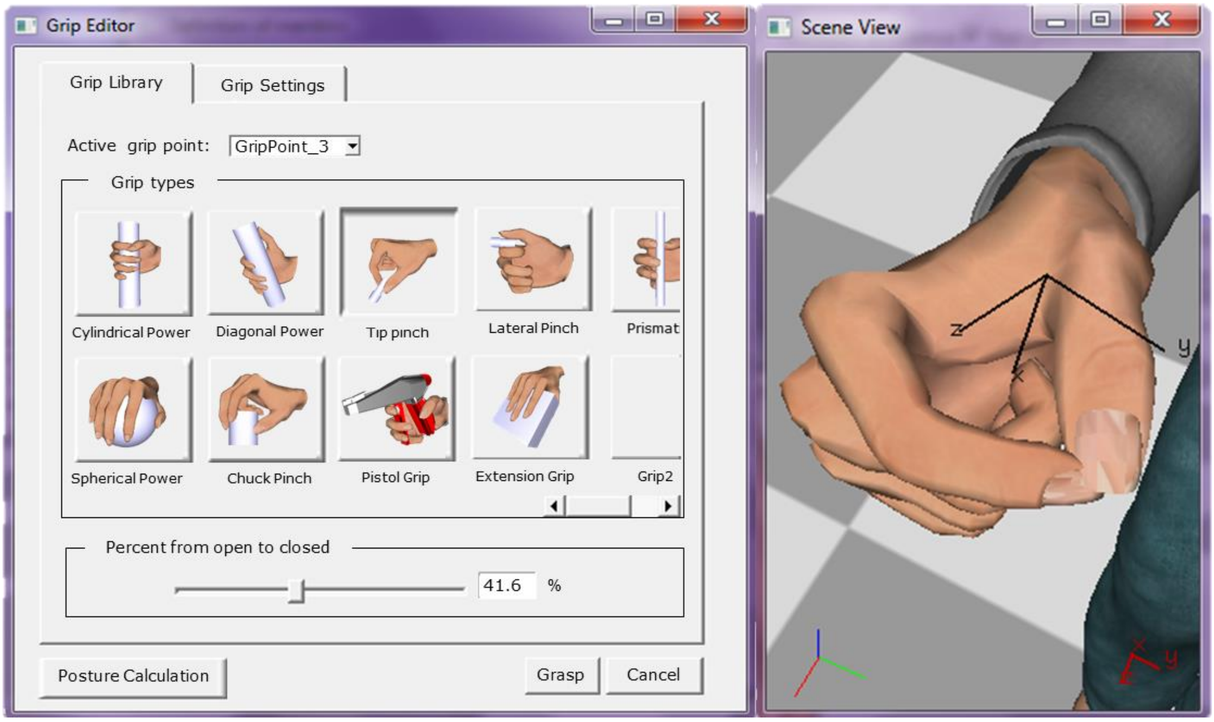


Figure 8.2.0 GUI of hand grip library developed for IMMA

The grip library tool is divided into two tabs: The first is the grip library and the second is the grip settings. When choosing a grip from the list, the active one will always show as marked so that the user gets feedback on what grip type is chosen. There is also a bar that controls the percentage from open to close hand. This one is controlled by dragging the bar or by typing in the per cent in numbers in the white text box. There should be white text boxes for all value bars so that the number could be typed in if preferred. The bars should also show of what scale and unit the function is using.

Choosing the posture calculation the framework will be used to screen the grip types to find the most optimal one (see figure 8.2.1 below). Applying the already chosen grip is done by pressing grasp from here (see appendix 11 for flowchart).

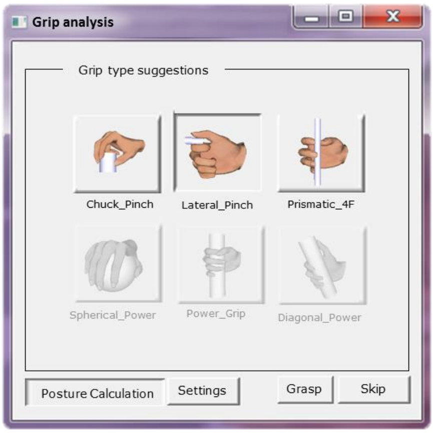


Figure 8.2.1 Grip analysis window

When the user wants to add a new grip to the library, some difficult points are defined; firstly the framework values will not be defined for that grip structure. Secondly the grip will be saved as a pose and will not be able to be screened through the framework. One option would be to let the manufacturer only set the predefined grips in the library and thereby all the variables in the framework, and instead provide the user with only a save pose function where the exact position of hands and structure of fingers are saved with a set name so that the user can reuse that same structure in another case. A second option would be to provide a list of task-based sub groupings of different grip types defined in theory and thereby pre-set the variables for each grouping (see figure 8.2.2). Whereby, for each saved structure, one task based type would be required to be defined and with that the saved grip will obtain roughly assumed values for that sub group. This would reduce the required information from the user, since they do not have access to such values and it would be very problematic to find these and not preferred. The variable values will not be as accurate as the grip types predefined in the software, but it would still allow the grips to be screened when having an automatic grip suggestion function.

For the advanced saving function an expert user is provided an alternative way of saving grips. In this caseit is required to manually input all variable values, see figure 8.2.3 below. Open, neutral and closed hand options are provided as in the predefined grip types from the library. Text boxes to input values for the other variables need to be defined for the saved grip. This way of saving the grip makes it possible to screen the grip through the framework and to be participating in the automatic suggesting function.

In both the regular and the advanced grip setting tab a list of saved grip points are shown, because of a suggestion of having possibilities to delete and rename the points from here and also if possible to see what grip type have been applied to it. In both windows it is possible to take a snapshot is able to be taken for the software to use in the grip library as listing. All buttons and functions are placed to match reading a page from left to right. Therefore action buttons are aligned to the left and cancel buttons are placed to the right. This will prevent the user from selecting the wrong action.

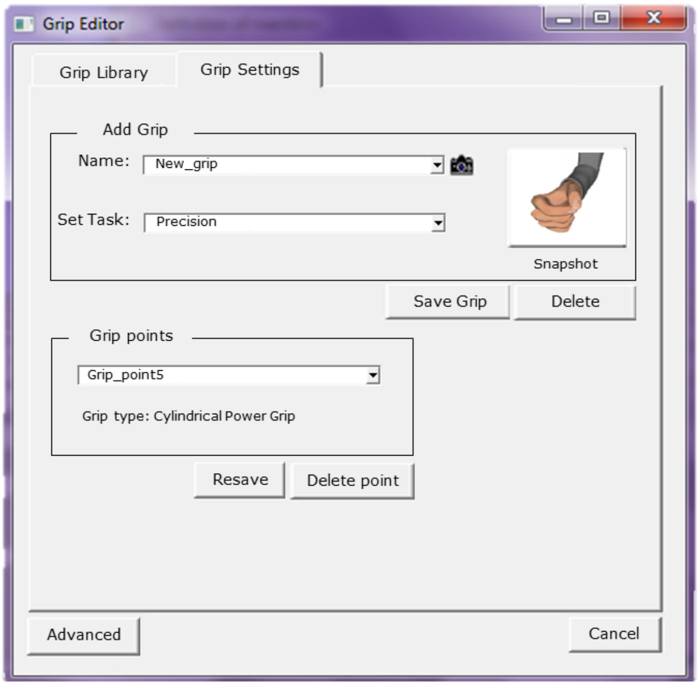


Figure 8.2.2 Grip saving function

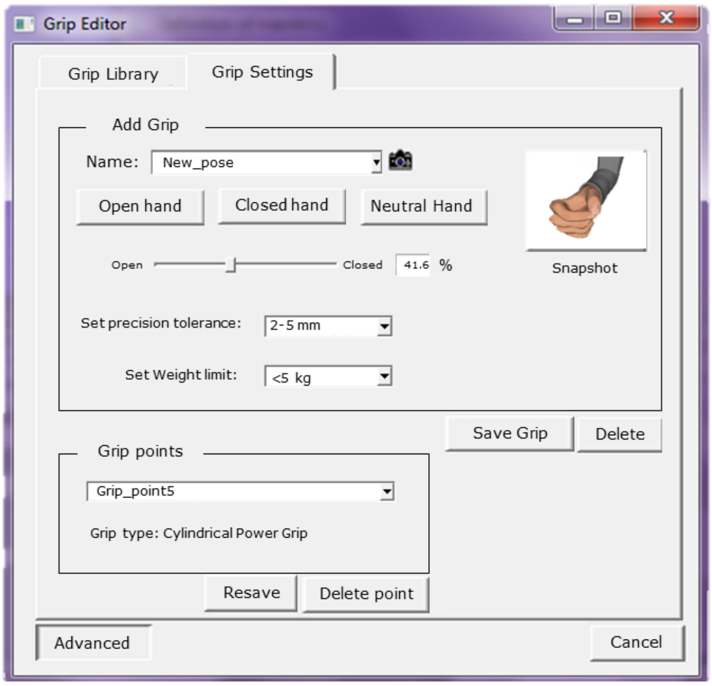


Figure 8.2.3 Advanced grip saving function

8.3 FURTHER DEVELOPMENT

The interface design is very simple way of presenting the grip library. A thorough evaluation is needed for the tool to be useful. The user interface and the tool should be further developed and later built as a mock-up and tested by the end user to truly get a fair evaluation of the functionality. This interface is developed to be used in the current version of IMMA; the tool is not suitable for a future fully automatic grip library.

Having the open-closed-neutral function when saving a grip makes the flow of the grip span limited since the neutral hand is not saved as an own pose. It is merely calculated by percentage from open to closed pose. If however the grip editor would have a three step saving function where the open, neutral and closed are three separate saved poses and the bar would change the hand between these three poses instead of calculating the neutral, there would be a more correct span of grip sizes of the same grip structure. The positive fact here is that it would work in some cases when the calibration of joint angles is not optimal. But the optimal case would be when the joint angles are set to adapt in the most realistic way possible for the digital manikin hand. The joint angles could be set to actually have constraints between each other so that the hand motion would be more realistic.

9 DISCUSSION AND CONCLUSION

The purpose of the project has been fulfilled; a grip library has been developed and implemented. However the functionality of the grip library, with all suggested features, needs to be tested by the end users. This could easily be done at one IMMA network workshop by implementing the grip library interface into the software and letting the participants use it when creating one of the use cases.

The final grip library consisted of eight fundamental pre-set grip types. In the delimitations it was from the project start decided to define about 10-12 different types. This could however be explained as being a complication of the attempt to find framework variables for the different ones and be able to save them in the way decided in IMMA. Perhaps if not for the lack of time, some additional grips would have been implemented into the library and most likely these would be of the lacking non-prehensile type. Of course other grips that have not been prioritized in this project must be included into a complete grip library, for example, the pressing motions. These grip types have been observed during the plant visits, but were deliberately unexamined because of delimitations in the saving function in the grip library and because of the framework variables. The framework was developed so that it would be possible to be implemented in the current version of IMMA, this is a base for a later more advanced framework that can allow for automatic recognition of optimal grip types, optimal positioning while working and suggestions on when to change position and grip. The variables and the implementation in the software should first be tested and analysed together with end users. The framework should consider other variables that could be possible to include in a future version of the software.

The data collection and research stage, preparing for the development of the framework, was the most time consuming part of this project work. This because it was not stated what factors were interesting to consider, which ones were implementable, which ones were interesting for an ergonomic simulation analysis tool to use. The research found about hand ergonomics and grip types was very general and partly diffuse, and therefore the decision of what variables to use was the hardest judgment and assistance was required from the IMMA project group members.

At times during the project work it could be felt that perhaps more programing knowledge was required. It was mostly for understanding of what is implementable and what is not in such a type of software. Likewise for the interface functionality it was very hard to know what features were applicable. The IMMA software was provided for the project group with updated versions and licenses continuously during the work. Since the work involved a new functionality that was added into the software, many complications in the form of bugs and crashes were experienced. The software was learned and used during the project work; the work consisted of trial and error mostly, since the software demonstrator is in a research stage and is continuously changing. A grip library edit was created for the project, and the functionality malfunctioned for quite a while until it started to obey the commands. A lot of time would have been spared if the functionality had worked without any exceptions or if the saving functions would have been developed earlier, and if participation in a workshop had happened earlier.

When doing the benchmark studies of competing software, unfortunately no access to software licenses was available, so questions needed to be answered by simulation engineers and in most cases snapshots were provided from the grip library in the software. Therefore it was not possible to look upon exact functionality of the gripping motions and the surrounding functionality in all software. Only Delmia V5 and Jack were accessible for usage and this on the computers at Chalmers University. For example when going through the Creo software there was some complications in the software and an experienced user was not found to be able to explain the functionality, so a fair experience was never obtained. However the functionality suggested for IMMA is considered to be a very simple but yet a functional way of handling the tool, and compared to the functionality in the competing software's there are the same but more intelligent functions provided in IMMA, since these are automatic and thereby not controlled from the grip library manually. A framework with variables through which screen the grip types and hand positioning, is not provided by any of the competitors on the market, which will make the grip library tool in IMMA unique in its segment.

9.1 Further development checklist

A checklist has been overrated, with important points that needs to be further analysed (see table 9.0), this is for the organization to have a specific strategy to work from for the future development of the grip library in IMMA.

Table 9.0 Checklist for future work strategy.

Action	Notes	√
Look upon how to implement non-prehensile hand movements into the grip library.	Pressing and pushing motions with force applied.	
Check if it is possible to take into account the usage of protective gloves while doing an assembly in the software.	In most stations and in most tasks the hands are protected with gloves and with this the worker loses some precision level, flexibility and the area occupied by the hand and each finger increases.	
Look at the dynamic loads on hands.	In this project there where only considered static loadings.	
Investigate how it is possible to implement time and frequency factor to the framework and to be used during ergonomic simulation of assembly situations.	The most important factor for the musculoskeletal ergonomics. Affects the hand posture naturally and with this it is possible to calculate when it is a risk of musculoskeletal injuries.	
In CROMM, when the manikin potentially possesses muscles, the grip strength for each anthropometric variance of population should be specified and implemented as a variable to the framework.	This will give a functionality of analysing the musculoskeletal ergonomics and being able to calculate if a specific worker has the capacity to perform a specific task.	
Evaluate the grip library with the grips already implemented, perhaps amongst industry partners, to see if there is a lack of pre-set grip types.	The grip library needs to feel useful to be able to fulfil its purpose.	
Testing the grip library functions, including the usage of the framework.	Perhaps by implementing the parts that are of interest and then to include a use case to a workshop where the IMMA team network and project group can test and evaluate the tool. Also usability test of the interface before implementation,	

	examining the functionality and logics.	
Investigate how the calculation of changing grip and positioning while in motion would function.	This function would be created with different framework variables coordinating with each other and providing enough information in a sequence of assembly so the software can calculate what a “better” positioning would be in that specific situation, moment and context.	
There is a need of calibration of the thumb joints in the manikin hand model. Also the skin of the manikin hand is in some cases shadowed so that it looks a bit odd.	The spread joint is the one needing adjustment the most.	

10 REFERENCE

[1] Hillberg, E. & Lövgren G. M. (2012) IMMA presentation by AB Volvo. Gothenburg, Sweden.

[2] Johannesson H., Persson J.-G. & Pettersson D. (2004) *Produktutveckling: effektiva metoder för konstruktion och design*. Stockholm: Liber AB

[3] Osvalder A.-L., Rose L. & Karlsson S. (2008) *Arbete och teknik på människans villkor*. Stockholm: Prevent

[4] Palmquist, R. A. (1999) *Survey Methods*. The University of Texas at Austin, Graduate School of Library and Information Science. [Online] Available: https://www.ischool.utexas.edu/~palmquis/courses/survey.html [Accessed May 27, 2013]

[5] Usability Partners (2012) [Online] Available: http://www.usabilitypartners.se/ [Accessed March 30, 2013]

[6] Siemens (2013) *Jack and Process Simulate Human*. [Online] Available: http://www.plm.automation.siemens.com/ [Accessed May 27, 2013]

[7] Lövgren, M. G. & Andersson, L. (2012) *Benchmark Digital Human Modelling -Appendix 1*. Report at Volvo Trucks Technology.

[8] Nationalencyclopedin (NE) (2013)[Online] Available: http://www.ne.se/ [Accessed May 27, 2013]

[9] Delfs, N. (2011) *Manikin in Time; Development of a Virtual Manikin with Inverse Kinematics and Comfort*. Thesis work: University of Gothenburg, Department of Mathematical Sciences.

[10] AV (2013) [Online] Available: www.av.se [Accessed 27th May 2013]

[11] Iea, I. E. A. (2000) *What is Ergonomics* [Online]. Available: http://www.iea.cc/01_what/What%20is%20Ergonomics.html [Accessed 9th June 2013]

[12] Kuo, L-C. (2011) *Hand biomechanics*. Department of Occupational Therapy, Institute of Allied Health Science, Motion Analysis Group, Hand Research Group. *National Cheng Kung University, Taina: Taiwan.*

[13] Reed, P. M., ZHOU, W. & Wegner, M. D. *Automated Grasp Modeling in the Human Motion Simulation Framework* [Online]. Available: http://media.univ-lyon1.fr/iea-dhm2011/abstracts/2236.pdf [Accessed April 1, 2013]

[14] Park, J. & Cheong, J. (2010) *Analysis of collective behaviour and grasp motion in human hand*. International Conference on Control, Automation and Systems at KINTEX: Gyeonggi-do, Korea.

[15] Amis, A. A. (1987) *Variation of finger forces in maximal isometric grasp tests on a range of cylinder diameters*. Journal of Biomedical Engineering, Vol. 9, issue 4. pp. 313-320.

[16] Radwin, R. G., Oh, S., Jensen, T. R. & Webster, J. G. (1992) *External finger forces in submaximal five-finger static pinch prehension*. Ergonomics, Vol. 35, no. 3, pp. 275-288.

[17] Buchholz, B., Armstrong, T. J. & Goldstein, S. A. (1992) *Anthropometric data for describing the kinematics of the human hand*. Ergonomics, vol. 35:3, pp. 261-273.

[18] Pheasant, S. & Haslegrave, M. C. (2006) Bodyspace: *Anthropometry, Ergonomics and the Design of Work.* Third Edition. Florida, United States of America: Taylor & Francis Group.

[19] Shneiderman, B. & Plaisant, C. (2005) *Designing the user interface*. Fourth Edition. United States of America: Pearson Education, Inc.

[20] The Free Dictionary (2013) (Online) Available: http://www.thefreedictionary.com/ [Accessed March 30, 2013]

[21] Helander, M. (2006) *A Guide to Human Factors and Ergonomics*. (2ed edition). Boca Raton: CRC Press

[22] Napier, J. R. (1956) *The Prehensile Movements Of The Human Hand.* The Journal of Bone and Joint Surgery, Vol. 38B no. 4: London, England.

[23] Bock, O. & Feix, T. (2011) *Grasp.* [Online] Available: http://grasp.xief.net [Accessed May 27, 2013]

[24] Rijpkema, H. & Girard, M. (1991) *Computer Animation of Knowledge-Based Human Grasping*. Computer Graphics, Vol 25 (4), SCAN; Groningen, the Netherlands.

[25] Wikström, L. et al. (1991) *Kriterier vid val och utveckling av handverktyg*. Undersökningsrapport: Arbetsmiljöinstitutet, enheten för tillämpad arbetsfysiologi, Stockholm.

[26] Sperling, L. (2013) Hand Seminar the 12th of April at FCC, SciensPark Gothenburg

[27] Hägg, G. M. (2001*) Handintensivt arbete - En belastningsergonomisk kunskapsöversikt gällande människans kapacitet och interaktion med verktyg och arbetsuppgifter*. Arbete och Hälsa 2001:9

[28] Irwin, C. B. & Radwin, R. G. (2008) *A new method for estimating hand internal loads from external force measurements*. Ergonomics, Vol. 5 no. 2, pp. 156-167

[29] Seo, N. J. & Armstrong, T. J. (2008) *Investigation of Grip Force, Normal Force, Contact Area, Hand Size, and Handle Size for Cylindrical Handles*. The Journal of the Human Factors and Ergonomics Vol. 50 no. 5, pp.734-744.

[30] Imrhan, S. N. (1991) *The influence of wrist position on different types of pinch strength*. Applied Ergonomics, Vol. 22 no. 6,379-384. Arlington Texas, USA.

[31] Sperling, L. et al. (1993) *A cube model for the classification of work with hand tools and the formulation of functional requirements*. Applied Ergonomics, vol. 24 (3), pp. 212-220.

[32] Volvo standard STD 8003.2 and VCS 8003.29 (2009) *Ergonomic requirements-Application*

[33] Scania (2008) *SES* (Scania ergonomistandard)

[34] Lee S. J., Kong Y. K., Lowe B. D. & Song S. (2009) *Handle grip span for optimising finger-specific force capability as a function of hand size*. Published in Ergonomics, Vol. 52(5) ,pp. 601-8.

[35] NIOSH (2004) *Easy Ergonomics: A Guide to Selecting Non-Powered Hand Tools.* [Online] Available: *http://www.cdc.gov/niosh/docs/2004-164/pdfs/2004-164.pdf* [Accessed May 27, 2013]

[36] Armstrong, J. T. (1998) *Upper Limb Musculoskeletal Disorders and Force.* [Online] Available: http://www-personal.umich.edu/~tja/Force/Force.html [Accessed April 20, 2013]

[37] Lowe, B.D., Kong, B.D. & Han, J. *Development and application of a hand force measurement system.* National Institute for Occupational Safety and Health.

[38] Armstrong. *Biomechanical Aspects*. [Online] Available: http://colleges.ksu.edu.sa/AppliedMedicalSciences/HEALTHREHABILITATION/Documents/Books%20And%20Articles/3%20biomechanical%20aspects%20of%20handork.pdf [Accessed May 27, 2013]

[39] Sanso, R. M. (1994) *A Hand Control and Automatic Grasping System for Synthetic Actors*. Eurographics Vol. 13 no. 3.

Appendices

Appendix 1

Transverse full hand grip (Volar grip/power)	Contact with the palm, thumb unites on top of fingers
Diagonal full hand grip (Volar grip/wrench)	Thumb is stretched and used as for maintaining balanced
Spherical volar grip (orange)	Released in a dynamic finger grip
Extension grip	
4 or 5 finger grip	
Key grip (Lateral pinch)	Much power
Pencil grip (Chuck grip)	Movements in the wrist, small finger movements for precision
Fingertip grip	The finger muscles provide high precision range

Notes from hand seminar the 12th of April with Lena Sperling

Literature often divides grips in two groups of prehensile and non-prehensile types. This is indicated of weather the grip uses the thumb or if it is inactive. Lena describes the fundamental grip types by power and precision rate. They identified the 8 grips below in the table as the most common used grips in daily life. Lena describes the action of grasping an object as a four stepped action, where the first would be to lift the hand against target, second to set grip, third step is to use the effect grip and the last letting go of the grasp. She describes how the purpose of an activity decides which grip type to be used. Here the main factors would be power and precision, and also the shape of the object is taken in to account.

A grips use situation is controlled out of three different interacting factors, namely individual, environmental and product factors. For example the size of the hand affects the wrist, elbow and shoulder angles in a specific hand position. Likewise the working height for the hands affects the grip. Grip force reduces with age and humans have their best power around the age of 20-24 years.

Appendix 2

Interview guide

Attendies: Henrik och Muzzafar 2013-02-28

Operators: Pantea Marandi with assistance from Maria Gink Lövgren and Emma Hillberg

Place: AB Volvo Celsiusgatan 10, Eriksberg

What software is being used?

Delmia- Catia V5

Is it hard to set grips for simulations? How does it proceed?

Problems while adjusting, since one needs to test until the result looks okay. It is manual adjustment.

Do you find the tool as being easy to handle? How is parameters set and is there any automatic functions?

There are 3 pre-set grips. The auto grasp is very unintelligent, the software adjust the posture after the object form.

What grip types do you use the most? How many are there?

Cylindrical. Leaning against for balance support. The pre-set grips are: cylindrical, spherical and pinch.

What is positive with the tool? What do you feel are lacking, alternatively needs to be improved?

More pre-set grips! More degrees of freedom of the hand. The grip is locked against the object centre point, offset is to be used here, but the functions don't function as it should.

Is there anything extra important to include in an grip function for the manikin?

Reverse kinematics. Different positioning of a grip in the tool (360 degrees). Now this has to be done manually.

Other points?

Alternative for simulation cases that does not give a good result.

The whole picture needs to look good, but in real life the back, shoulders and whole body position is more important.

50% of the cases have focus on the hands.

- A tip to talk to Elisabeth about these questions.

Appendix 3

<u>Interview with Lina Andersson at Volvo Truck Technology via Microsoft Lync online meeting</u>

Participants: Maria Gink Lövgren, Pantea Marandi, Lina Andersson

What software is being used?

Ramsis (product development simulations)

Is it hard to set grip? How is it done?

Chose grip posture, then what surface on object and then there is a contact between a point on the hand and on the object surface (can be set by distance in mm also). It is possible to copy settings from one hand to another.

Is it an easy tool, how is the parameters adjusted? Is there any automatic functions.

No need for manual adjustment. All grips are pre-set with different.

What grips are used most common? How many are there?

Grasp softly and finite, touch.

Other points?

Licence in Ramsis in one month.

Appendix 4

Notes from on-plant visit at Volvo Car Corporation, 25th of March 2013

Present parties: Daniel Ekström (VCC), Emma Hillberg (Volvo IT) and Pantea Marandi (Chalmers)

This visit at Volvo Car Corporation where conducted on behalf of Daniel and the schedule where set to look into the work process and use of the Process Simulate software and VCC simulations in it to identify different inputs for the grasp wizard.

Factors which Daniel pointed out:

- Grips are in the larger cases only for the visual matter. They do not go into further detail with the hands and the use of grip types etc. If not a precision work which would be very much to look upon the hands and the surrounding geometry and weather the hands will fit to assembly or manage with the real human posture.
- The grasp library allows the user to choose a certain grip type for the chosen hand and there is a feature to "set target location". Here the hand should find the object surface. But this function does not work as it should. The hand is set in one specific use direction/position and in most cases one should set the joint jog manually.
- Then there is a function where one can choose for the hand to grasp around the object,
- The most used grips are machine grips, precision grips and neutral hand.
- Daniel suggested that IMMA should find the optimal grip with the optimal position for a specific object and thereby also for the assembly.

Grips identified during the visit through the plant:

- Push with thumb (101)
- Overhand grip with cylindrical finger position (101)
- Pushing the strips on the car door with underarm force with a wrist position of 30 degrees.
- Strip and isolation around the window, pushing whit overhand grip position and all fingers. The operator will use a hammer and sledge at the very end to precision the assembly.
- Assemble isolation under the car hood with pinch force.
- Hose installation, holding with power grip
- Lateral pinch grip clicking clips
- Contacting detail with chuck grip
- Underhand grip
- Cylindrical and diagonal power grip when holding a power screwdriver tool.

Appendix 5. The survey form

Intelligent Moving Manikin (IMMA)

How would you like the grip library in IMMA to present the different possible automatic grip postures?

It is possible to select combinations.

- ☐ Only by text
- ☐ Picture of the manikin hand
- ☐ Picture of the manikin hand and text
- ☐ Picture of a manikin hand and an object its grasping
- ☐ Picture of the skeleton
- ☐ Picture of a real human hand
- ☐ Picture of the manikin mesh (without skin)
- ☐ Illustration of the grip

Would you like IMMA to select the grip by automatics, or would you want to have control by going into the library and set the demanded grip yourself?

Do you think the realism and aesthetics of the manikin hand is important for the final product?

How important?

Not important

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5

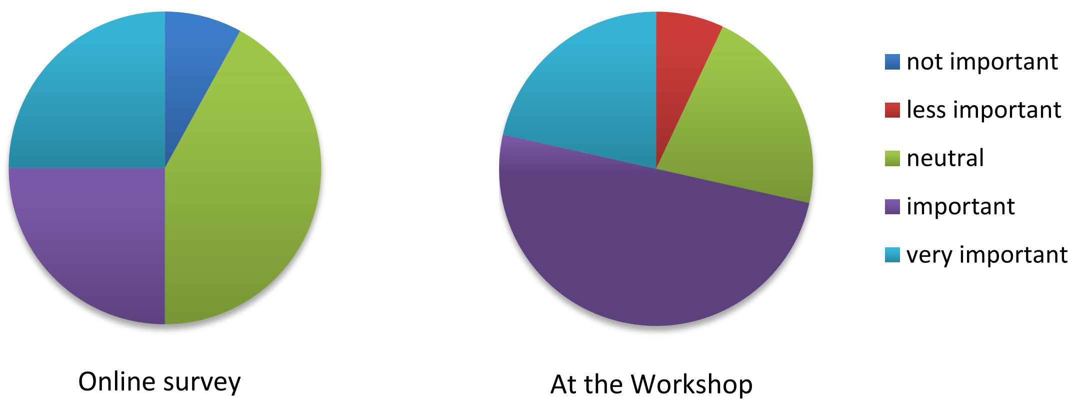
Very important

Thank you for participating.
Kind regards,

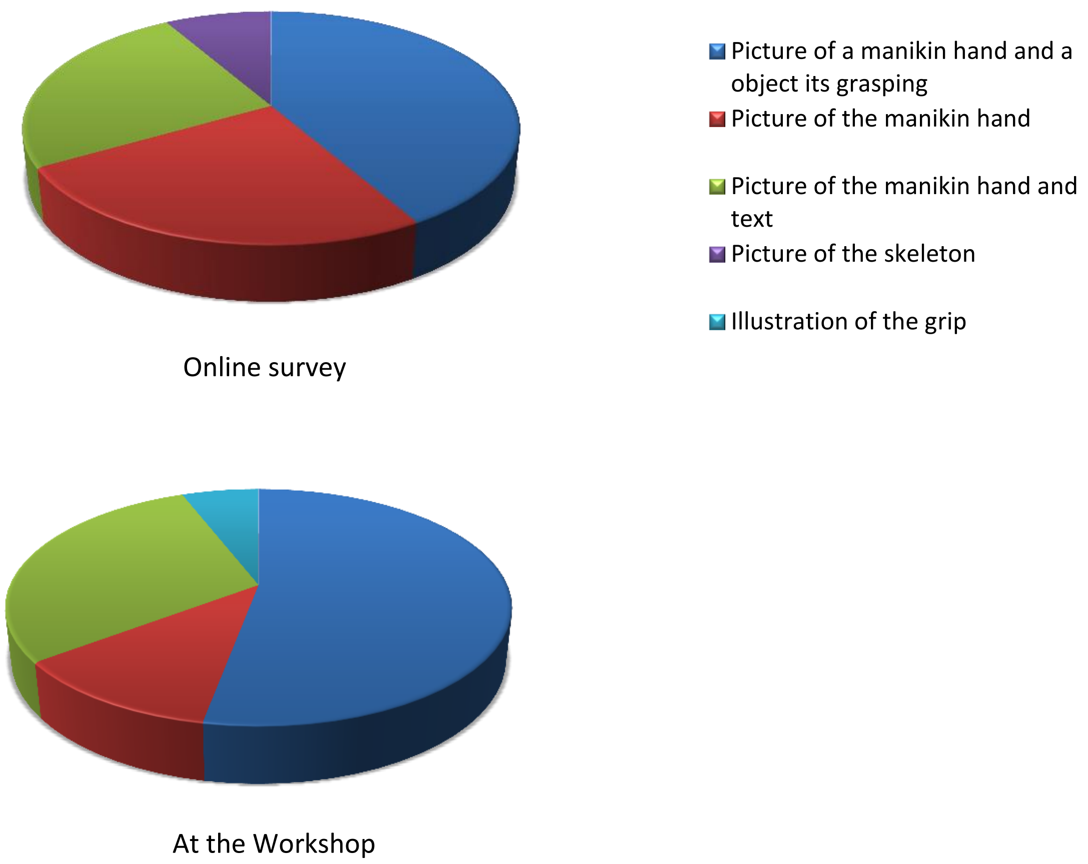
Pantea Marandi
Thesis Worker
VOLVO INFORMATION TECHNOLOGY AB
pantea.marandi@volvo.com

Appendix 6. The result of the surveys

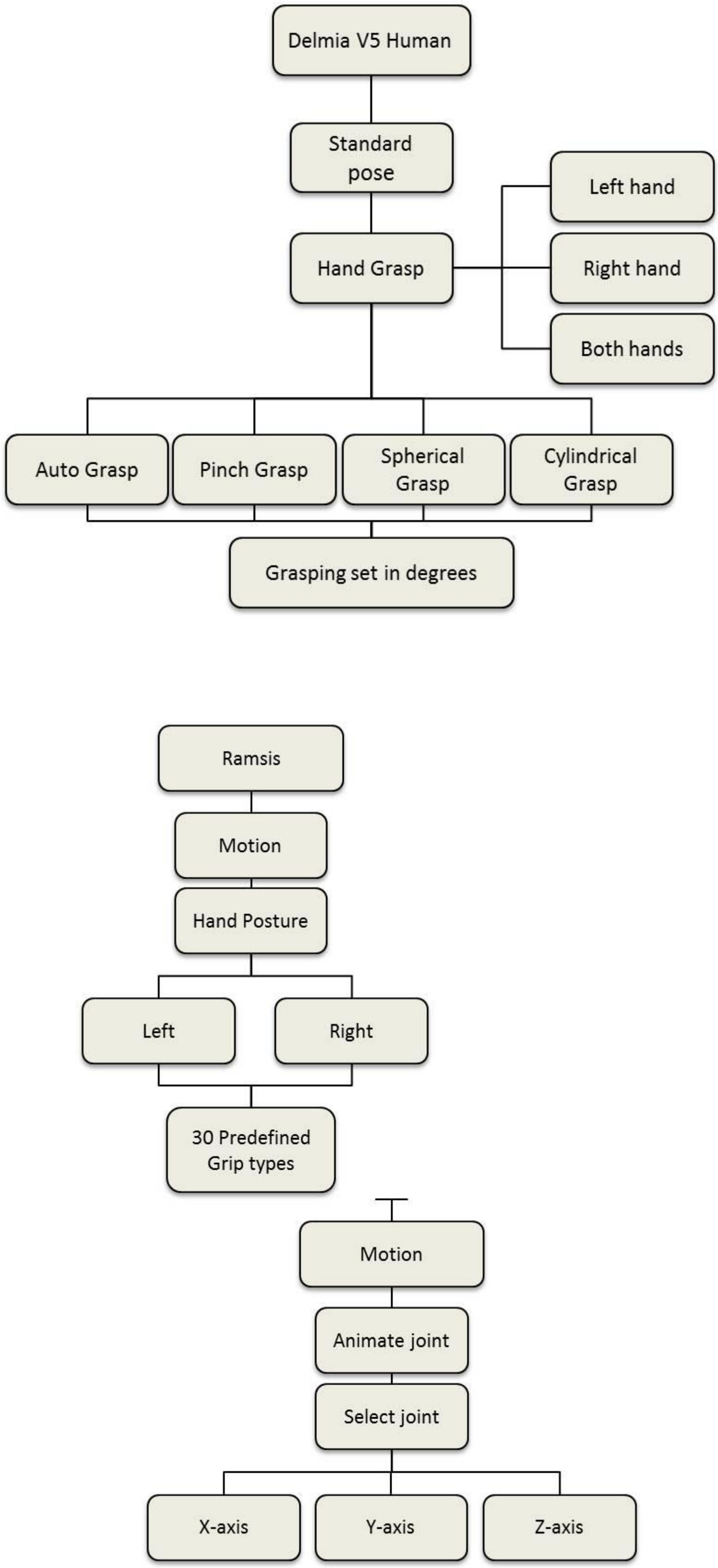
Do you think the realism and aesthetics of the manikin hand is important for the final product?

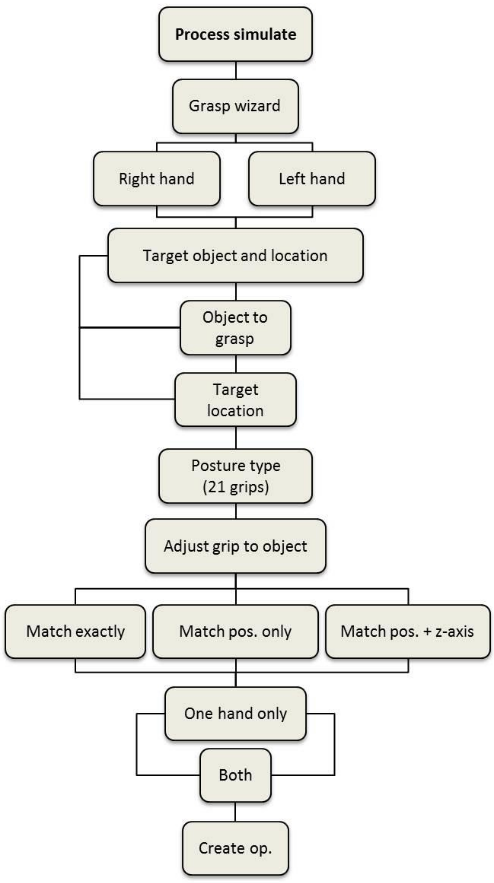


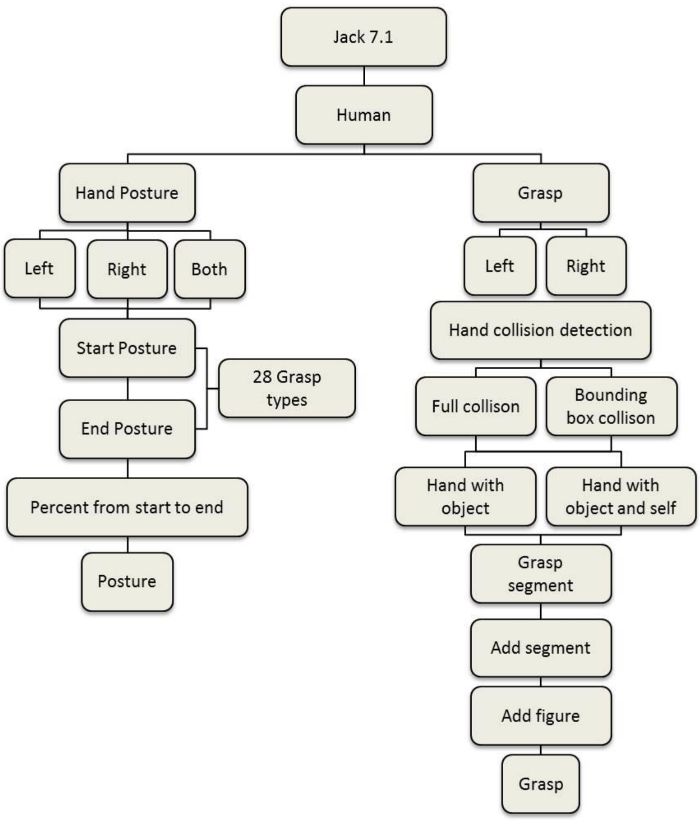
How would you like the grip library in IMMA to present the different possible automatic grip postures?



Appendix 7. Tree chart of competing software functionalities

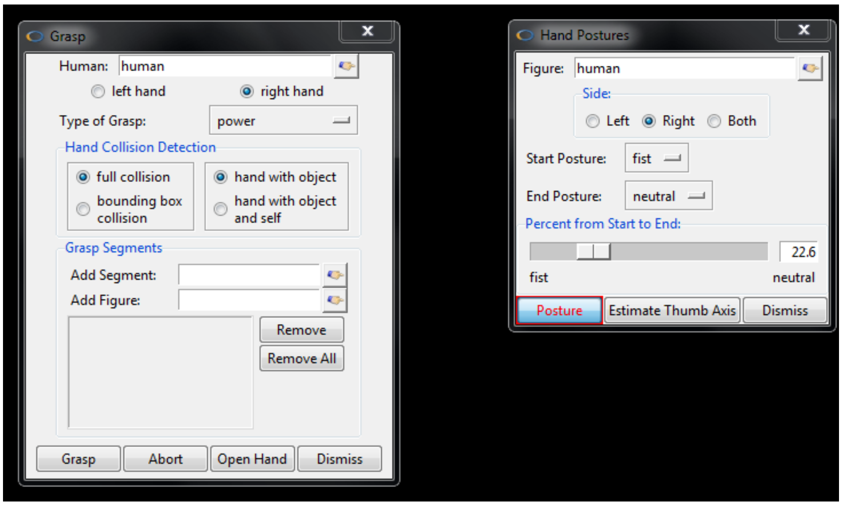



Process simulate
Grasp wizard
Right hand
Left hand
Target object and location
Object to grasp
Target location
Posture type (21 grips)
Adjust grip to object
Match exactly
Match pos. only
Match pos. + z-axis
One hand only
Both
Create op.

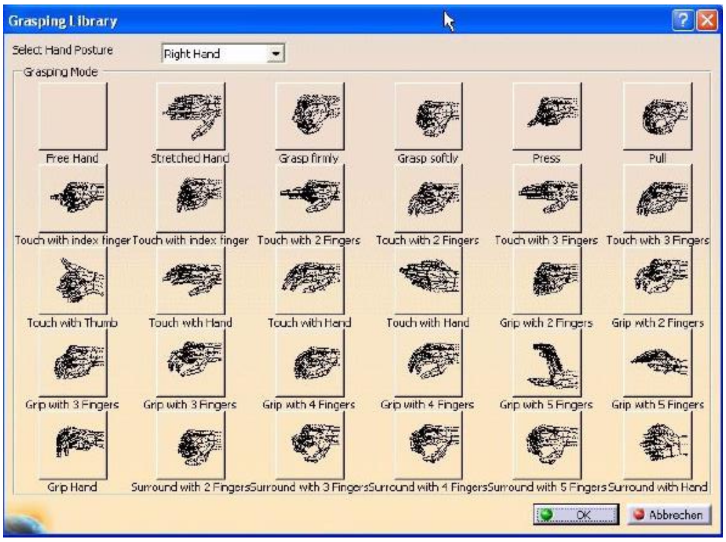

Jack 7.1
Human
Hand Posture
Grasp
Left
Right
Both
Left
Right
Hand collision detection
Start Posture
28 Grasp types
End Posture
Full collison
Bounding box collison
Hand with object
Hand with object and self
Percent from start to end
Posture
Grasp segment
Add segment
Add figure
Grasp

Appendix 8. Competitors interface of grip libraries

Jack 7.1

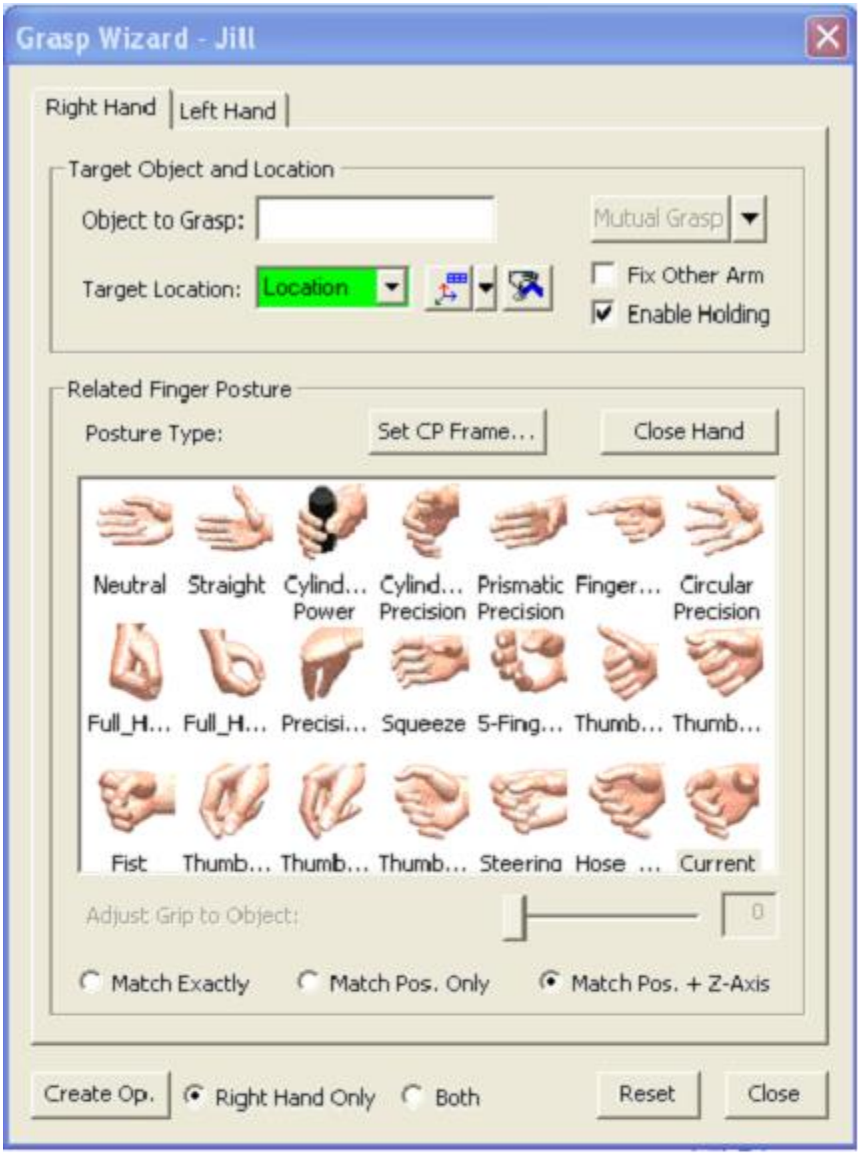


Ramsis



V5 Human

Process Simulate



X

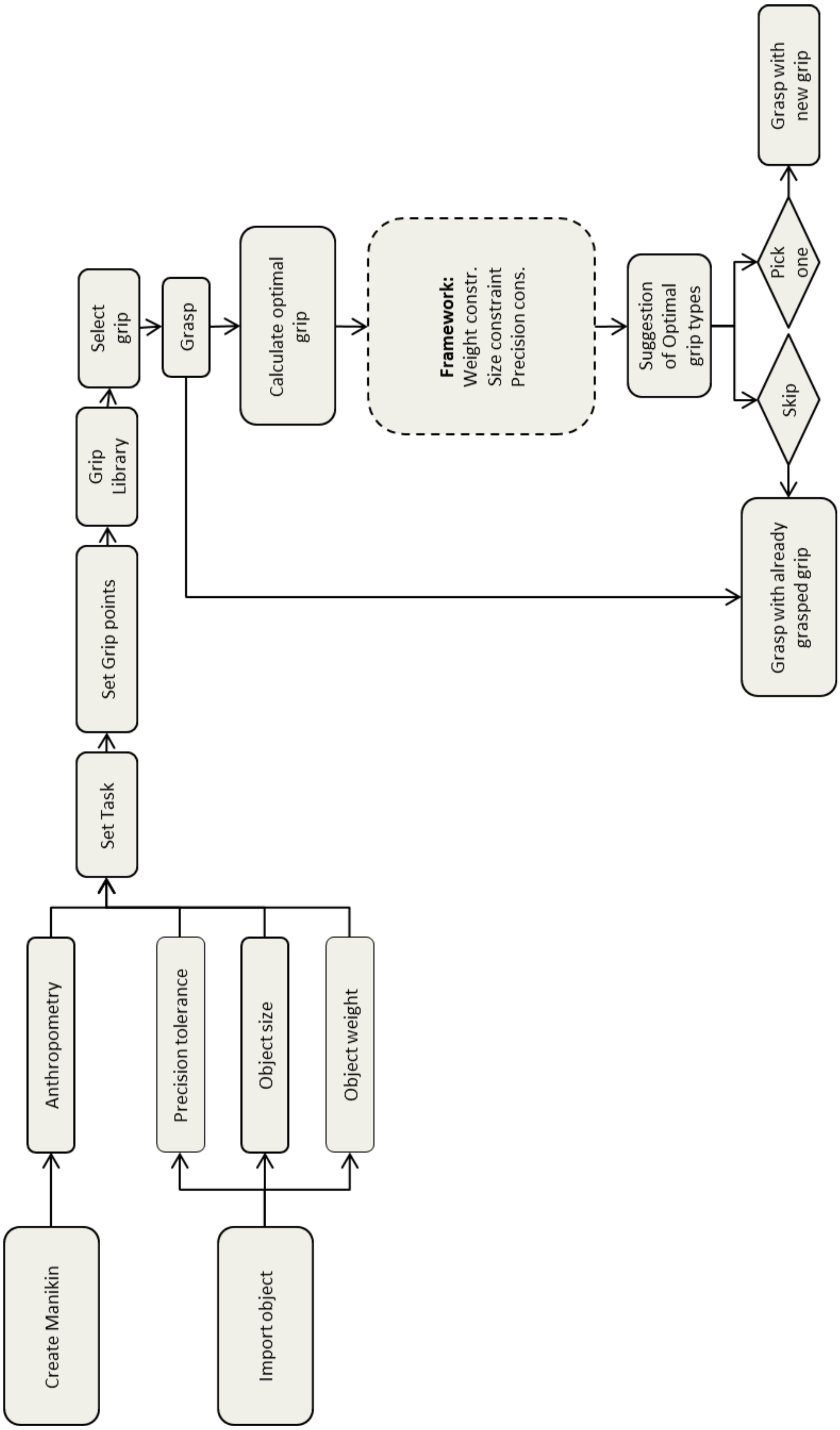
Appendix 9. List of grips identified at the Tuve Factory while on plant visit

- Cylindrical power grip with a shutter button which can be controlled with both the pinky finger and the thumb depending on the gripping.
- Drill: power grip with a “stabilisations grip” on top.
- Power grip with thumb as stabilization and with index finger shutter button.
- Hook grip-overhand –lifting heavy objects
- Using a wrench –diagonal power grip and a screwdriver with lateral power grip
- Cable: diagonal power grip
- Lateral pinch: thumb index
- Screw driver: power grip with a “stabilisations grip” under. Index finger used for shutter.
- “Staple pistol”: Pistol grip
- Hook grip: underhand: lifting something heavy with handle
- Cable plugin: precision thumb-index
- Thumb pinch? Looks like a key grip? Two cables with contacts are disconnected with power.
- Overhand grip around a handle, lifting a heavy box and then helping by putting the other hand underneath. Is also possible to lift the box with a underhand grip
- Balance grip: holding on to chassis.
- Thumb push on control fixed on the wall
- Pressing with the palm
- Two key grips when contacting two parts
- Pinch grip with thumb-index-middle finger around a nut
- Plier: looks like the pistol grip
- Holding a screw driver still by holding the tip with a pinch grip
- Two hand grasping. A big cylindrical piece that need to be assembled on a cylindrical rail
- Underhand grasping: “hook” grip. This detail weight about 10 kg and is supposed to be assembled by one hand.
- Screwdriver with power grip and index finger shutter button
- Thumb control that hangs from the ceiling. Controls a lifting tool that is stabilized with a lateral power grip.
- Two hand lifting

Appendix 10. Table of fundamental grip types identified on plant visits.

VCC	Tuve	Lena Sperling studies (the fundamental grip types)
Key grip (thumb pinch)	Key grip	Key grip
Cylindrical grip	Cylindrical grip	Transversal full hand grip
Pinch grip (all fingers)	Pinch grip	5/4 finger grip
Pinch: thumb-index	Pinch: thumb-index	Fingertip pinch
Pinch: thumb-index-middle	Pinch: thumb-index-middle	Chuck pinch
Diagonal full hand grip	Diagonal full hand grip	Diagonal full hand grip
Underhand grip [hook]	Underhand grip	(Identified but not used as the fundamental)
Palm press alt. Finger press	Palm press	
	spherical	Spherical grip
	Two-handed	(Two-handed: used as fundamental in some cases)
	Overhand	
		Extension grip

Appendix 11. Flowchart of the framework functionality



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