Bachelor Degree Project

UNIVERSITY OF SKÖVDE

STRATEGY TO ASSESS WORKSTATION ERGONOMICS USING VIRTUAL MODELS OF PRODUCTION

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Authors:
Fermin Aranda Avila
José María González Hernández-Carrillo

Company supervisor: Mikel Ayani Eguia
University supervisor: Aitor Iriondo Pascual and Estela Pérez Luque
Examiner: Erik Brolin

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Assurance of own work

This project report has on 06/06/2021 been submitted by Fermin Aranda Avila and José María González Hernández-Carrillo to University of Skövde as a part in obtaining credits on basic level G2E within Product Design Engineering.

We hereby confirm that for all the material included in this report which is not our own, we have reported a source and that we have not – for obtaining credits – included any material that we have earlier obtained credits within our academic studies.

Fermin Aranda Avila *José María González Hernández-Carrillo*

Abbreviations

WRMSD	Work-related musculoskeletal disorders
MoCap	Motion capture
VR	Virtual reality
VE	Virtual environment
DHM	Digital human modeling
IMU	Inertial measurement unit
HMD	Head mounted display
JSON	JavaScript object notation
EPP	Ergonomics in production platform
AGV	Automated guided vehicle

Abstract

Background: Work-related musculoskeletal disorders (WRMSD) are a disadvantage for companies both from the health and economics view. To reduce them, workstation ergonomics need to be accounted for. Previous ergonomics assessments involved spreadsheets filled and analysed by ergonomists and were regarded as time and resource-consuming, but recent improvements in virtual reality (VR), motion capture (MoCap) and digital human modeling (DHM) tools have open new options for analyses. Workstation redesign is one of the most common ways to improve working conditions, but a proper strategy that allows recording a sequence of actions using VR and assesses ergonomics is needed.

Limitations: The strategy was designed for Simumatik, software for virtual commissioning of workstations that wanted to also consolidate itself as a DHM tool. Simumatik and HTC Vive were used as MoCap system and Ergonomics in production platform (EPP) as the assessment tool.

Method: Literature review – prestudies and definition of use cases to test strategy and implement in it - requirements and wishes – strategy development – validation of use cases – evaluation.

Results: Compared to manual simulations performed manually in IPS IMMA where the user performs same tasks, the strategy output accuracy of 73.3%. However, there are some misinterpretations to fix within the performance of the strategy that would fairly raise it and make the study more realistic, concerning the use cases studied. These mistakes include the posture prediction of the neck and some minor issues with the performance of the use cases.

The number of resources vs. development was also studied and it showed that fixing the minor mistakes would raise accuracy close to 80% in the use cases. Adding a chest tracker could make it close to 100% compared to manual simulations in IPS IMMA.

Conclusions: The strategy steps were tested and concluded that worked fine, because of the accuracy reached. However, further development of all the parts concerning the strategy is needed. The aim reached was to achieve rough results that could democratize physical ergonomics assessments.

Key words: Ergonomic assessment, motion capture, digital human modelling, virtual reality.

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1 Introduction

1.1 Background

High-specialized products and their variability in a worldwide market have made companies produce and sell smaller quantities of products. This, added to an efficient distinction between production, distribution, and assembly tasks, has led to better care of warehouse management (Battini et al., 2014). Modern industry is becoming a synergy between machine production processes and human workers collaborating in the same place. This collaboration has drawn some important questions regarding workers' health and safety, as well as the need to study other human factors, to avoid monetary costs (Alexopoulos et al., 2013). The productivity of workers and operational safety depends on these factors as well (Battini et al., 2014).

1.1.1 Work-related musculoskeletal disorders (WRMSD)

There is a need to study the well-being of workers based on the manual tasks they perform and how they are affected by them (Battini et al., 2014). WRMSD are the most common injury that affects workers (Sultan-Taïeb et al., 2017). They are degenerative or non-traumatic inflammatory disorders of the musculoskeletal system found in the neck, back, upper and lower limbs. Ergonomics assessment and further actions can limit their appearance, as they are multifactorial. Their emergence depends on physical, psychosocial/organizational, and individual risk variables (David, 2005). Nowadays, governments are implementing more health and safety measures to make companies aware of these problems, such as the risk assessments that companies that carry out activities that may cause WRMSD must take (proposed by the European Council in 1989) (Eliasson et al., 2017).

1.1.2 Ergonomics

Ergonomics (or human factors) is the discipline that concerns the study of humans and their relations with other elements of a system; it covers parts such as anthropometrical model, posture, model tasks, human reactions, and human factors analysis. But it can also be the profession that applies theory, principles, data, and methods, to improve the well-being of the workers and the productivity of the system. Ergonomists evaluate tasks, workstations, products, and environments to adapt them to user needs, aims, and limitations, trying to harmonize the system and the user (IEA, 2021). Therefore, programs to reduce working risks should be based on ergonomics principles and should have a general approach to all elements that make up a system (tasks, workstation, legal factors, workers´ needs, and organization) (David, 2005).

Ergonomics have different fields of domain (IEA, 2021):

- Physical ergonomics: related to physical activity (e.g. material lifting). Evaluate tasks according to anatomical, anthropometric, physiological, and biomechanical features of users.

- Cognitive ergonomics: related to the mental activity (e.g. human-machine interaction). It concerns perception, memory, reasoning, and motor response.
- Organizational ergonomics: aim to improve socio-technical structures (e.g. better management).

A. Physical ergonomics assessments

Since 1940, ergonomics studies were limited; however, in the '80s they were recognized as fundamental pillars in the industry (Honglun et al., 2007). Since then, traditional strategies of studying ergonomics in workspace setups have been both time-consuming and resource-consuming, as it was needed to develop mock-ups and place workers in the proper conditions (Alexopoulos et al., 2013). These strategies were based on statistical analysis from studies and formulas extracted from them (Jayaram et al., 2006). Workplace ergonomics have been taken care of with a reactive attitude, and nowadays, there is a tendency to change it into a proactive approach through virtual simulations (Jayaram et al., 2006). However, most Virtual Environments (VEs) use subjective data introduced by observers and users, not allowing an easy automatic assessment (Jayaram et al., 2006). Nowadays, there are Digital human modelling (DHM) tools for VE, hardware tools for MoCap, and software for ergonomics assessment; however, a strategy that connects all of them is sought (Iriondo et al., 2019).

A.1. Digital human modelling (DHM)

DHM tools are virtual representations of human bodies, with their proper movements and features attached to them that interact in a computerized ambient or virtual setup. They have positive effects, such as improving designs and products before they are even built and unconstrained working conditions, but need improvements in several matters (e.g. vision field and touch) (Alexopoulos et al., 2013).

It is important to represent the human body in DHM tools. Its structure is used for model operation, animation, ergonomics optimization, and evaluation. There are two different models needed for DHM (Honglun et al., 2007):

- Model of human structure: this is a widely used model that contemplates the measurements of the contour, the limits of the joints and the relations between them, and the structure of the skeleton. It is formed by linked points that make body segments; objects are represented the same way, so they can interact with body parts.
- Perception model: the relationship between the human skeleton model and the device allows giving reality to all these virtual simulations. The perception model uses the human structure model to immerse it in the VE created; this means that the human structure model is simply a skeleton, and the perception model controls it. Therefore, the collaboration of both is needed for DHM tools. The perception model also consists of: 1. A motion perception model that captures the movements of the real human and represents them later with the skeleton; 2. A vision perception model that includes human sight and helps to set distances and directions for objects in the environment, enhancing the realism; 3. A haptic perception model that represents the relation between the human model and the

dynamic forces of the environment, collected through skeleton-objects collisions.

DHM is used to represent posture data for later assessment. There are different approaches to do this, based on the cases studied.

- Establish real-time communication and sharing of data between the action sequence in DHM tools and evaluation software, so evaluations are delivered meanwhile carrying out the actions (Jayaram et al., 2006). Snapshots of the actions in the DHM tool can also be taken and assessed later (offline).
- Implementing ergonomic assessments into DHM tools (e.g. Jack or IPS IMMA) (Jayaram et al., 2006). Evaluation can be carried out alike online or offline.

In the context of ergonomics assessments, offline means that each step is not done in real-time, each step is processed manually. One process is not started until the other is finished so that a whole sequence can be studied together. On the other hand, online involves real-time assessment: while carrying out the tasks in a VE, resulting scores are given so that postures can be immediately changed by the user (Iriondo et al., 2019). This is deeper studied in the Literature review.

In the case of connecting DHM tools and ergonomics evaluation software, there is code needed for easy transmission of posture data (Iriondo et al., 2019). The posture data for DHM manikins can be introduced directly in the computer or obtained from users/workers through MoCap and/or VR. Different methods are used for MoCap and will be introduced later on in A.3. Motion capture (MoCap).

A.2. Virtual reality (VR)

The combination of VR software and DHM tools has eased data collection, especially for companies producing complex products (e.g. vehicle industry) (Alexopoulos et al., 2013). VR is a three dimensioned virtual world where the user can interact with its surrounding, both environment and objects, and have a feeling of presence in it (Wilson, 1999). Users like to be part of this virtual world and see how it immediately changes because of their actions (Burdea & Coiffet, 2003).

VR is usually complemented with controls that enable interactive features and head-mounted displays (though they are not a must) (Wilson, 1999). Throughout history, definitions of VR have been based on the devices used in the simulations, which have changed over the years (Burdea & Coiffet, 2003).

VR can be even compared to alternative real worlds, but that has its limitations: spatial issues and problems delivering the proper information to each sense to create a more immersive experience. How the user can navigate through it, visual depth, latency, real-time interaction, and display design need also deeper study (Wilson, 1999). These problems can be seen in Vignais et al. (2013), where workers felt less comfort, got tired easier and took more time to finish a set of tasks when they were in a VE instead of a real one. This technology needs further development to be closer to real-world assessments.

VR has been used in psychology university departments with simple VEs to study cognitive processes, as well as in human factors studies for manufacturing purposes with more complex VEs (Wilson, 1999). We can find several applications for this technology related to industry as factory and process planning, workers training, and maintenance procedures. Wilson et al. (1999) carried out an experiment where workers were tasked to change an internet card within a computer processor, some with VR training, some with video training, and others with no training. The results of the group with VR training were reported to be the best in terms of shortest time and fewer errors made, as well as the most motivational method. This was because VR is regarded as an easy and interactive way of representing information, free from more complex representations (e.g. CAD planning), and therefore an easy way to implement ergonomics assessments. There is even a symbiosis between VR and ergonomists: ergonomists are developers in most VR research groups, as well as users of the VR technology created (Wilson, 1999).

A.3. Motion capture (MoCap)

MoCap can be defined as capturing the large-scale movements of body parts, mainly the head, arms, torso, and legs, as well as the subject as a whole. This means seeing the human as an item or as a skeleton with some degrees of freedom (Moeslund & Granum, 2001). Tracking of small-scale body parts, such as facial expressions, has been recently developed and improved, and it´s studied in a sub-category of MoCap called Face MoCap (FMC) (Kawaler & Czyżewski, 2019).

Application of MoCap falls within three groups (Moeslund & Granum, 2001):

- Surveillance: track subjects to study the relationship between their movements and behaviour.
- Controlling: body movements are used to control several functionalities. It is used for VE and video games.
- Analysis: track and analyse movements for clinical studies. Deep data is gathered, usually in a laboratory.

Technologies that can be used for MoCap (Moeslund & Granum, 2001):

- Active sensing: devices are placed on the subject and around the place, and they exchange signals. This method is best for well-controlled environments, like clinical studies.
- Passive sensing: the subject is tracked through natural signals, like electromagnetic wavelengths and visual light. This method is less intrusive and doesn't interfere as much with the user´s perception.

The main parameters defining MoCap are its robustness, accuracy, and speed. Robustness is needed in uncontrolled environments, where sense can´t be dependent on changes of lighting, weather, the number of people (e.g. surveillance). In well-controlled ones, where assumptions are usually made, the system's robustness is not an issue. Accuracy is needed when really sensitive body movements are captured (e.g. telesurgery). In other cases, just recognizing that there is a subject is enough. Speed is categorized in online or offline capture. When the subject is tracked in a controlled environment, frames can be studied afterwards, but processing speed is quite important when real-time actions need to be identified (Moeslund & Granum, 2001).

Further development of MoCap could be found in other subjects, such as speech recognition. A series of postures and positions of human body parts could be introduced as an alphabet, like phonemes in voice recognition. This could make pose recognition a way easier task. Overcoming general assumptions (slow and continuous body movements, the subject not leaving the workstation and moving on flat ground, etc.) and tracking the overall environment needs to be studied and improved (Moeslund & Granum, 2001).

As stated before, VR, MoCap, and DHM tools can reproduce manufacturing tasks, and this is where this thesis project focuses. Ergonomics assessments such as vision analysis, posture analysis, lift analysis (e.g. NIOSH), push/ pull, and carry analysis are carried out in DHM or other evaluation software. Thanks to these assessments, engineers can design workstations including human point of view and prevent future drawbacks early in the development process (Alexopoulos et al., 2013). Some limitations found in ergonomics assessments are:

- Ergonomics assessment methods are designed to be understood and carried out by experts. The democratization of knowledge needs to be applied, so even regular workers could understand the results of assessment methods.
- Most ergonomics assessment methods are based on snapshot analysis. A frame with a human displaying a specific posture is analysed, then the next one. This method does not allow a complete understanding of the ergonomics assessments when it comes to a sequence, as it analyses a heterogeneous set of data, not the sequence itself as a single unit. As well, DHM tools may represent body movements but not perform ergonomics assessments. In these cases, it is needed to take data from the DHM tools and introduce it in an assessment software.
- There are not standard ergonomics assessments. Companies have their strategies to evaluate human factors and ergonomics and usually differ from those implemented in the DHM tools (Alexopoulos et al., 2013). Furthermore, we also find differences depending on geography and depending on companies´ overtime(Plantard et al., 2017).

These limitations don't allow carrying out efficient ergonomics evaluations. In this project, we tried to overcome these limitations.

1.2 Organizational setting

The project was carried out in collaboration with Simumatik AB. It has its office in Skövde Science Park, and it is lead by Mikel Ayani Eguia.

The company´s efforts go towards the development of software related to virtual production engineering and virtual commissioning. The name of their software tool is also called Simumatik.

1.3 Formulation of the problem

The purpose of the project is to prove that a predefined strategy to assess workstations' physical ergonomics is feasible and efficient. This strategy is targeted at small companies that want to provide better health conditions to their workers without spending a vast amount of resources.

This strategy has been formulated but hasn´t been developed, tested, nor evaluated. The strategy steps are: 1. MoCap with VR in Simumatik; 2. Represent body movements (DHM tool) in Simumatik; 3. Communicate a DHM tool and an ergonomics evaluation tool; 4. Evaluate physical ergonomics in EPP.

The problem tackled is connected to Product Development, although no product is developed but a strategy. It works with an ill-defined problem, as the strategy outline is drawn, but the different bits need to be connected, and that can be done in many ways. As well, it includes a methodology where requirements and wishes are gathered and representative use cases built. Reiteration is present in all steps.

1.4 Aim

- Study a predefined strategy to assess physical ergonomics using Simumatik software as a DHM tool. Review literature about the different parts of the strategy and the software and hardware used: VR and MoCap, DHM tools, data communication, and ergonomics assessments; HTC Vive, Simumatik, and EPP.
- Gather requirements and wishes of Simumatik AB. Gain insight into the resources available for the project and about the actual needs of the company.
- Implement, test, and further develop this strategy:
    - Generate representative use cases. Gathering information from the literature review about previous studies and experiments in MoCap, ergonomics assessment methods features, sensors placement, and body part prediction define cases were:
        - Assessment methods (chosen) are suitable to study. Don´t perform tasks that involve variables that these methods can´t evaluate; don´t perform tasks that don´t represent the effectiveness of these methods.
        - Real situations from industry are represented.
    - Test strategy with use cases. Study for each use case different sensor placements, the number of sensors used, and prediction of body parts needed. Evaluate the effectiveness of the ergonomics evaluation methods chosen for the use cases. Re-think use cases if the methods don´t work for them. Reiterate between use case generation and validation.

    - Define use cases as part of the strategy. Set several use cases studied as models that the user can take to evaluate his/her tasks. Include information regarding sensor placement and number, as well as the efficiency of ergonomics assessment methods for each specific task.
- Evaluate the results of the strategy by comparing them with an existing DHM tool. Test the studied tasks both with our strategy and with other DHM tools and compare results.

The purpose of the strategy is:

- Reduce injuries: cases of WRMSD will drop down improving working conditions and well-being for workers in factories. Due to wrong performance of manufacturing processes, physical injuries could be eliminated if workers trained these tasks in VR before attempting them in the real world.
- Improve the design of workstations: give insight into workstation redesign to improve workers´ well-being and optimize resource waste. Changes to make manufacturing processes easier and efficient for human anatomy will mean fewer error products and less harm over time for body parts.
- Better economics for companies: through fewer injured workers and optimized workstations, profits would be greater. However, initial investments to assess ergonomics and make changes would be needed: outcomes would surpass implementation investments thanks to this easy and efficient strategy. Sultan-Taïeb et al. (2017) explains that cost-benefits relation in workstation optimization are positive, especially if new implementations are properly carried out with supervision and a positive attitude.
- Democratize the use of physical ergonomics assessments: make these physical ergonomics assessments available for small companies that want to improve their workers´ health.

1.4.1 Delimitations

A. Imposed delimitations

Simumatik AB and University supervisors pre-set the steps of the strategy roughly: 1. Perform tasks in a VE generated by Simumatik using VR device HTC Vive; 2. MoCap with HTC Vive and Simumatik; 3. Representation of the tasks virtually in a manikin (DHM tool) with Simumatik; 4. Transfer of body postures data from Simumatik into an ergonomics evaluation tool; 5. Evaluate physical ergonomics in EPP.

Reasons for these delimitations: using Simumatik software as a DHM tool was the main aim of Simumatik AB, and therefore, it was the first condition set. HTC Vive was the device the company had been using for VR, and it was already implemented in the software, so it was convenient to immerse the user in the VE and to do the MoCap with it. EPP is a piece of software from the University of Skövde, developed by our supervisor Aitor, so it was familiar for him to perform ergonomics evaluations in it.

B. Studied delimitations

Along with the pre-study phase, when the different parts of the strategy were studied, some new limitations popped out:

- The device used to track postures is HTC Vive. It comes with an HMD and two controllers for the hands, so head and hands positions can be tracked. The company supervisor Mikel added three more sensors that could be positioned in several settings on the human body.
- The transfer of body posture data from Simumatik into EPP was carried out with a JSON file. This file was coded in Python and was regarded by our supervisors Aitor and Mikel as the most suitable format.
- EPP had only implemented two ergonomics evaluation methods, RULA and REBA. Others could be introduced but needed further development.
- Simumatik AB established the use cases environment to be an AGV carrying an engine.
- The project depended on the VE created with Simumatik software. However, its manikin had positioning problems up to a month before the final presentation, and it was needed for the use case testing. Therefore the amount of time spent in the experimentation phase was short.

1.4.2 Sustainable development

Sustainable development has been defined as improving our societies taking care of the present needs, but not compromising the needs of future generations. It underlines the idea of an inclusive, resilient and sustainable future for both environment and humans. Three main elements need to be joined for this purpose: economic growth, environmental preservation, and social inclusion (Figure 1)(UN, 2021).

Figure 1. The 17 sustainable development goals (*UN*, 2016)

These core areas are aimed through the 17 sustainable development goals. This project is targeted towards aims (3) good health and well-being; (8) economic growth; (9) industry, innovation, and infrastructure; and (12) responsible consumption and production. It will bring positive effects to society with a better working environment and living conditions.

A. Economic sustainability

Highly industrialized countries like the USA show in their Illnesses, Injuries, and Fatalities (IIF) program that there are around 5.2 million occupational illnesses amongst workers, and 5.7 out 100 U.S. factory workers have injuries related to their job (Jayaram et al., 2006). WRMSD covered 40% of the economic compensations for injuries, resulting in $45-54 billion/year. In the European Union, WRMSD rise to 40 million cases, with 0.2-0.5% of GPD lost because of them (Hu et al., 2011). This means, products that don´t meet standards, compensation costs for both health treatments for workers, as well as days off work and need of substitutes (Jayaram et al., 2006).

There have been studies about the relation between ergonomics implementation costs and results of those implementations (lowering expenses related to WRMSD), such as in Sultan-Taïeb et al. (2017). In this paper, studies of companies (189) were analysed and selected through criteria concerning accuracy and amount of data. Nine studies passed that filter and showed the following insight: seven resulted in positive benefits, one negative, and one mixed (negative cost-effectiveness, but positive net benefit). However, there was a variable that also conditioned these studies, and that was analysed. Studies that yielded positive had a big implication for the supervisor with helping workers, high amount of resources and great participation and attitude from workers. On the other hand, the negative one was found to have low control from supervisors and that the worker´s needs were insufficiently covered. As a result, redesigning and adapting workspaces to be more productive depended on the redesign itself and the way it was implemented. 78% of the studies resulted in positive effects, which means that better ergonomics procedures translated into less WRMSD and less money invested in workers´ health. With VR and a strategic plan to implement the advice into workers' movements (with supervisors or virtually), this % could be greater.

Therefore, our strategy would mean future savings for the company, thanks to fewer workers´ injuries and the drawbacks and monetary losses that come with them. This would be achieved by improving the workstation design and how workers perform tasks. However, the implementation of these new measurements needs to be controlled for proper results.

B. Environmental sustainability

Environmental sustainability aims to protect the future needs of people, leaving them with the same natural resources we have. It intends to understand human culture and the living world: the last decades' production and business patterns are seriously endangering biodiversity and inefficiently using resources (Evans, 2020). Through our project, we were studying a strategy that could be used to redesign workstations virtually without the need for physical mock-ups or prototypes that would be wasted. Furthermore, workers could train tasks with this method and produce fewer wrong products when working in the real environment, reducing material spent. Dropping WRMSD cases means a lower health budget for governments that could be used for environmental causes.

C. Social sustainability

The main intention of social sustainability is to create healthy communities where citizens want to live. A healthy community is characterized by being democratic, diverse, fair, and connected. Usually, this aspect of sustainable development is misregarded, but it is strictly related to the other two areas (ADEC ESG Solutions, 2021). Concerning economics, the application of our strategy will save money to companies, which can be invested in better working conditions (salary, facilities, and protection equipment), improving workers´ well-being. Reducing WRMSD would also improve it, and allowing workers to train tasks before performing them would up-rise their productivity.

Democratizing physical ergonomics assessments means making them available to small organizations and widening the positive effects on workers´ health. It means shortening the breach that exists between big and small companies´ resources.

1.5 Objectives

- Learn how to search amongst papers: discover what parts of a paper contain useful information and how to interpret it. Realise which are the keywords of the project. Learn to combine all the information collected into a structure.
- Learn to select use cases based on: sensor setting, and features of ergonomics assessment methods.
    - Understand how different sensor placement/number influences the accuracy of the MoCap system. The amount of body parts to be predicted is also dependent.
    - Learn how different methods to study physical ergonomics depend on the conditions of the case. According to the workstation environment and the features that are the most representative of the case, resources and knowledge of analysts find a way to select the most appropriate method.
- Understand how the Simumatik interface works as a DHM tool. Suggest any recommendations for further development.
- Test to transfer human posture data to external software. Implement data from Simumatik into EPP through a JSON file created with Python.
- Create criteria to validate the adequacy of use case implementation. Establish certain minimums that the use cases need to fulfil. Reiterate if not.
- Prove efficiency of our strategy. Compare our results with the other DHM tools´ ones.

1.6 Method

- Literature review: reading of scientific articles and books related to ergonomics and ergonomics evaluations.
- Perform several pre-studies: study of ergonomics evaluation in DHM tools (e.g. IPS IMMA, JACK), study EPP assessments, and learn how to perform an ergonomics evaluation according to different methods; study of

sensors setting and prediction of body parts; study of use cases according to ergonomics evaluation methods and sensor placement; study of Python, learn how to code basics.

- Requirements/wishes of the data gathered: contact Simumatik and discuss and differentiate the company's requirements and wishes related to ergonomics evaluations. Communication with the company must be clear. Check requirements/wishes fulfilment at the end.
- Half-time presentation: current prototype updated, including knowledge about ergonomics assessments and sensor placement.
- Test and implement strategy:
    - Use VR and MoCap for data collection in Simumatik: use MoCap sensors and headset in VR to collect all the necessary data for the prototype.
    - Implementation of the prototype: generate a data file in Simumatik with the information from MoCap, introduce it into EPP, and get an ergonomics assessment report.
    - Validation of the use cases studied: prove that sensor placement and ergonomics methods have been efficient. If not, reiterate the process from the pre-studies, where use cases are defined, and change features with the new insights.
    - Implementation of physical ergonomics evaluation: if time is enough, display ergonomics assessment report into Simumatik.
- Evaluation of the study: analyse the strategy's accuracy compared to the results of other DHM tools. Explain the obtained results and how they were obtained.
- Writing report: reflect all the work done in the thesis in a document to hand in to the University of Skövde.
- Presentation: present prototype in Skövde University and Simumatik AB.

This strategy used some software for different steps through the process: Simumatik as a VE for the MoCap and as DHM tool to represent the posture data collected; EPP as the ergonomics assessment toolkit; and IPS IMMA as DHM tool and ergonomics assessment toolkit to compare our strategy results. HTC Vive was the VR and sensors package used, and the coding format JSON selected for the connection between Simumatik and EPP.

1.6.1 Simumatik

Simumatik is a software tool that allows emulating workstations and their features, digitalizing your systems and processes. Its main key points are: cloud-based format, reduction of commissioning time and costs of workstation designs, training for workers in a safe environment, development, and testing of PLC and robot logic, and performance optimization. It is offered for both education and professionals, as it can also be used as a learning platform to teach basic engineering lessons (Simumatik, 2021). The new incorporations to Simumatik intend to add physical ergonomics studies into the software, to gather data and understand the effects of the tasks on the workers' well-being and the optimization of the whole process. These studies concern the improvement in the productivity of a workstation and the entire factory.

1.6.2 HTC Vive

Vive is a VR system developed by HTC. It tracks your movements thanks to two sensors placed around you, a headset connected to a computer via a long cord, and wireless controllers. However, several extra trackers can be added and placed on body parts for better tracking. It can be used for education, business, art, design, medicine, amongst other areas, as any specific environment can be created in VR for any task required. E.g. Penn State University in Pennsylvania has been training students with practices in VR before they try them in the real world. The main disadvantage is the possible motion sickness after long periods of using the system (Grand Valley State University, 2021).

1.6.3 JavaScript object notation (JSON)

JSON is a file format that contains simple data structures and objects in JavaScript Object Notation (JSON) format. Usually, it is used to interchange information between a web application and a server. Files are lightweight, easily read by humans, have text format, and can be edited with a text editor (FileInfo, 2021).

1.6.4 Ergonomics in Production Platform (EPP)

EPP is an ergonomics evaluation toolkit that allows the performing of ergonomics assessments. Positioning data of body parts is introduced through a file from DHM software (e.g. JSON), and then several options for evaluations are displayed: RULA and REBA cover the whole body spectrum. Afterwards, evaluation scores can be extracted and displayed.

1.6.5 Jack & IPS IMMA

Tools to check validity and accuracy of the strategy:

A. Jack (Jayaram et al., 2006)

Jack is a human factors and ergonomics assessment toolkit. It allows the user to position virtual manikins properly into a VE, task them and study and analyse the performance of their different body parts. For this, some built-in assessments are included: lower back spinal force analysis, strength prediction, NIOSH lifting analysis, RULA, and fatigue/recovery time analysis. Jack is great for evaluating ergonomics in products and workstations tasks but has some drawbacks:

- It only allows static postures analysis.
- It has a VR function; however, it takes loads of time to run the VE, and until it´s not completely loaded, immersion is deficient. Therefore, real-time evaluations are not useful here.

B. IPS IMMA (Ruiz Castro et al., 2017; Fraunhofer-Chalmers Centre, 2021)

IPS IMMA is a DHM tool developed by the Fraunhofer-Chalmers Centre, Industrial Path Solutions (IPS), and the University of Skövde, in collaboration with several Swedish automotive companies. It allows developing a VE where the evaluation of human motions can be carried out. The main assessments are contact force, joint torque, and joint angle for static postures, which help to prevent future joints and muscle problems in personnel. When it comes to manufacturing sequences, there is a special module with collision-free path generation, as well as in-built RULA assessment that evaluates each manikin in a family (regular RULA scores and graph of RULA scores vs time for each body part). Therefore, IPS IMMA increases the efficiency and quality of products and decreases simulation and analysis time compared to traditional evaluation methods (Fraunhofer-Chalmers Centre, 2021).

2 Pre-study

2.1 Literature review

2.1.1 Previous experiments

To understand the strategy that we tested and implemented, we looked for previous attempts in the matter. We gathered a selection of strategies through a deep search of papers: aims, processes, resources, and results. We specifically focused on studying the dichotomy between communication vs. implementation of ergonomics assessment methods into DHM tools. This is presented in the following discussion. A survey of these experiments, where a deeper study is carried out concerning the approach, MoCap, and assessment method, as well as conclusion, can be seen in Table 7 in Appendix A: Ergonomics evaluation methods.

A. The dichotomy of ergonomics assessments implementation

Numerous literature pieces relate to the study of our project. In the article by Jayaram et al. 2006 data is shared in real-time between DHM software and ergonomics assessment tools. They wonder how to link these two parts: VE performs dynamic sequences, and most assessment tools are based on snapshot analysis. They offered two pathways:

- Implementation of the ergonomics assessment methods in the DHM software: the main disadvantage with this approach is that each analysis method must be coded independently. Apart from that, the ergonomics evaluation and the VE are closely coupled, and the immersion is more realistic.
- Connection between the VE and the ergonomics assessment toolkit: shared memory is used to make the positioning data from the body sensors accessible to both VE and the assessment toolkit. It is the fastest mode of inter-process communication (IPC). The main disadvantages with this approach are that communication between VR and assessment toolkit software is difficult, frame rates and data rates must be synchronised to avoid lag, and matching the human model to the real user is more difficult. Add to this the fact that specialised system integrators are needed for the tasks, and the immersive experience is not complete. This second option was chosen for the development of the project strategy, as it was set in the limitations of the project.

A.1. First approach: communicating between a DHM tool and an ergonomics assessment app

Some authors, such as Alexopoulos et al. 2013, seek the development of ergonomics through ergonomics assessment software, something very similar to what was asked for with EPP in the project strategy. However, the author uses the ErgoToolkit application, a piece of ergonomics assessment software with several functions. Firstly, it includes posture definition (where postures can be established as valid or invalid) and posture recognition (where a posture is studied from a static snapshot, a snapshot of a sequence, or MoCap; and then compared with the posture database to conclude its validity). This idea is similar to the project strategy carried out, but unlike Alexopopulos et al. 2013, the strategy didn´t consider cognitive ergonomics, only physical ergonomics. He also reports that it is unnecessary to create new methods to study ergonomics, but those existing ones can be copied, which is why the strategy didn´t include a new ergonomics model but a new implementation of these existing models.

In the case of Iriondo et al. 2019, they created a software tool that allowed to study and manage postural data. The input could be through real workers performing tasks (MoCap with sensors) or DHM tools and yielded ergonomic assessments. The main objectives were to redesign workstations from a better physical ergonomics point of view and give feedback to workers while performing their tasks through an intuitive interface. The discussion in this work focuses on the distribution of information between the different levels of the tool interface. Therefore, two modules were developed: one in which users had an intuitive approach to the information that allowed feedback to be obtained at a glance; the other in which ergonomists analysed the information collected in the evaluation by going deeper into the tool. The structure of these modules implies a top-down structure. Even so, this is ongoing research so that future development will be included in the tool. This paper helped to understand how information could be organised if it was decided to implement the ergonomics assessments back into the Simumatik platform. Therefore, it could be useful for future work.

Plantard et al., 2015 took a different perspective to study and develop an app for. They created a strategy to assess physical ergonomics with Kinect camera capture. However, they realised that it was hard to obtain trustful data in real environment situations and decided to perform the tasks in VE. An app was developed to find out the effectiveness and accuracy of evaluating a specific posture with the Kinect system. For the output of our strategy, it was decided to generate a list of recommendations for the use cases, depending on the accuracy and results obtained. This approach is similar to what is explained in the paper but performed manually.

Later on, Plantard et al. 2017 offer another document with more in-depth studies on Kinect capture. They test the system with the new Kinect occlusion-resistant skeleton data correction in two different ways. First, they compared the posture estimation with actual postures in a controlled environment, such as a laboratory. Secondly, they compared RULA scores from the system and those provided by experts in a cluttered workstation. In both cases, single-key postures were studied.

A.2. Second approach: implementation of ergonomics assessment tools into DHM

In the article by Vignais et al. 2013 real-time ergonomics assessments are performed. Sensors are used to track the movement of a subject, which is subsequently computerised into a biomechanical human model. RULA assessment is also included in the software and used to analyse the subject's postures. These results are displayed to the subject in real-time via an HMD, with visual and auditory cues. Four manufacturing tasks, such as screwing, unscrewing, and moving mechanical parts, are tested. The project strategy got insight for the use tasks from this article and ideas for future work to include real-time feedback to the user.

Battini et al. 2014 follows the approach of Vignais et al. 2013, and he is able to develop an ergonomics assessment system that allows real-time feedback to the worker through a small screen. The body positioning data is collected by 17 Inertial Measurement Units that allowed full body MoCap. This system is considered more efficient than optical sensor systems, as no cameras or special adjustments are needed to avoid occlusions. This means more freedom of movement for the worker since it is not constrained to the Motion Capture system. The collected data were studied in DHM tools, where selected ergonomics assessments were performed and returned to the worker via a colour scale displayed on his/her screen. Due to the limitations of the project, it couldn´t be done, but it is an approach to be considered for the future of the strategy as it would save on future costs and waiting times.

2.1.2 Ergonomics assessment methods study

Ergonomics assessments were widely studied to gain insight about them. Although the limitations were just using RULA and REBA, other methods could be implemented in EPP if it was regarded as a need, or recommend using more/different methods for further studies.

A. Means for an ergonomics evaluation

There is a vast variety of activities that can be performed within a factory environment, involving many body parts that are different from each other. Due to this, different methods of ergonomics assessment need to be studied. Moreover, the ergonomics assessment methods can be studied through different means (Battini et al., 2014; David, 2005; Iriondo et al., 2019; Plantard et al., 2015):

- Self-reports: self-reports are offered in questionnaires or forms and especially focus on physical workload, body discomfort, and work stress. They are easy and fast to perform, and they don´t need the help of an ergonomist to gather the results. However, analyses are highly subjective and need to be properly validated.
- Observations: observations are usually carried out on-site or recorded for later assessment. The assessment is easy and covers a wide variety of tasks. It uses standardized sheets, and the results can be easily compared as are in the shape of indices. However, they are time-consuming and need an evaluator to analyse the postures.
- Virtual simulations: virtual simulation assessments are carried out with 3D human models in VE. Therefore, they work great for virtual models and allow an objective and fast assessment. However, they need to have implemented the assessment methods in the software used.
- Direct measurements: direct measurements are great to get accurate information from an objective point of view. It works great for controlled environments and to study specific movements. However, it creates a huge amount of data that needs to be properly structured for easy access. Two main branches can be found within direct measurements to do the MoCap, camera image pattern recognition, and sensors on the body.

A.1. Camera image pattern recognition

Camera recognition is suitable when sensors can´t be placed on the body, so it´s less intrusive. It may uses markers on the body for better tracking (Iriondo et al., 2019; Moeslund & Granum, 2001), e.g. Kinect system. This system is a cheap, easy-to-use, calibration-free, markerless option. It consists of an infrared projector of structured light and an infrared camera that returns an image at 30 Hz. The main disadvantage is that workspaces are usually full of occlusions and several objects and subjects moving around, leading the camera to lose track of the human. Furthermore, several postures lead to inaccuracies and must be avoided, plus noise also disturbs the image recognition. The camera needs to be placed in front of the subject (recommended position), or error increases rapidly in complex motions with auto-occlusions (Plantard et al., 2017; Plantard et al., 2015).

A.2. Sensors on the body

They are faster and more accurate than camera recognition systems and therefore better for clinical studies. Duration has been improved in the past years, allowing better virtual simulations (Iriondo et al., 2019; Moeslund & Granum, 2001). Different kinds of sensors can be found in the market, according to Moeslund & Granum (2001), such as goniometric devices, magnetic systems, and inertial sensors. Goniometric devices may discomfort humans when wearing them and result in uncommon behaviour, plus can only record planar movements. Magnetic systems capture joints with six degrees of freedom but are sensitive to electromagnetic disturbance from machines and ferromagnetic materials. Inertial sensors are quite accurate but can´t handle vibrations, e.g. IMUs, which are cheap, low-power, small devices that track the movements of body part segments in real-time (Vignais et al., 2013). All these depend on the human body and need calibration between the system and the skeleton (Moeslund & Granum, 2001; Plantard et al., 2017).

However, there have been developments in sensors where egocentric cameras support magnetic systems to avoid electromagnetic disturbance. It makes these sensors more robust and suitable for field application (Vignais et al., 2013).

B. Methods for ergonomics evaluations

In Eliasson et al. (2017), ergonomics evaluations were carried out without using a established method. Ergonomists analysed risk levels of several tasks based on their knowledge and resulted in pretty poor reliable conclusions. Therefore, it was decided that following an assessment method enhances the reliability of results.

The methods used to study physical ergonomics are several, and their choice depends on the application and the aims that need to be covered. The main factors that influence the choice are speed, easiness, skills of workers, and cost-effectiveness. In some of the methods work, exposure is also studied, and it is defined with three parameters (David, 2005):

- Level: the intensity of force.
- Repetitiveness: frequency between different levels.
- Duration: the amount of time with a task.

A survey of the ergonomics evaluation methods can be seen in Table 8 in Appendix A: Ergonomics evaluation methods. Concerning the project strategy, there were predefined limitations for ergonomics assessment methods, which involved RULA and REBA in EPP. Therefore, RULA and REBA were deeply studied. However, other methods could be implemented for future work e.g. NIOSH to assess lifting tasks or OCRA for repetitive movements.

RULA and REBA are methods used to identify body positions that involve risk of WRMSD and perform a quick evaluation of them with snapshots (Jayaram et al., 2006; Hignett & McAtamney, 2000). They can be carried out with no special equipment, only pencil and paper, as with other observational methods (Hignett & McAtamney, 2000). REBA is a development of RULA, which covers more body parts (Hignett & McAtamney, 2000).

RULA was originated in the garment and clothing industry, where the use of machines caused injuries, or packaging operations were serious problems for workers. The manufacturing sector was also badly affected with WRMSD amongst their employees due to the handling of muscular loads (McAtamney & Nigel Corlett, 1993). However, REBA was developed by and for the health care and services sector (Hignett & McAtamney, 2000).

These methods are quite subjective and need an ergonomist trained to analyse the work visually; therefore, it´s time-consuming, as the main disadvantage (Hignett & McAtamney, 2000; Iriondo et al., 2019). The subjectivity relies on the approximation of projected angles of joints, from video recordings (Plantard et al., 2017). Nowadays, these methods can be carried out automatically thanks to body sensors and image pattern recognition (Iriondo et al., 2019).

Both RULA and REBA are usually carried out with assessment worksheets (Figure 2; Figure 3). These sheets convert quantitative measured data into qualitative that later can be displayed in categories and generate warning signals if category limits are exceeded. Individual scores for body parts are given based on body positioning (angles and location of body parts). Other factors are also analysed and added as scores. Predefined charts with data are studied, and a general score of the assessment is obtained (Jayaram et al., 2006; McAtamney & Nigel Corlett, 1993; Hignett & McAtamney, 2000).

RULA studies top body parts only: arms, wrists, neck, and trunk. It takes as factors frequency (repetition of activities and speed), workload, and muscle use. Age and experience must also be considered (Jayaram et al., 2006; McAtamney & Nigel Corlett, 1993). However, it doesn´t study factors that evaluate low back pain, such as lateral trunk velocity and spinal compression forces (Vignais et al., 2013). The final score of RULA is translated into warnings: acceptable, investigate further, investigate further and change soon, and investigate further and change immediately (Jayaram et al., 2006).

REBA studies the same body parts as RULA, as well as leg positioning. Factors are the same as RULA, but taking into account the coupling score for gripping actions. Results are categorised between: action is not necessary, may be necessary, necessary, necessary soon, necessary NOW (Hignett & McAtamney, 2000).

REBA and RULA are useful tools for ergonomic assessments, but to be more accurate, it is recommended to combine them with OWAS, NIOSH, and biomechanical models, amongst other ergonomics evaluation methods. They can also be part of more comprehensive studies concerning epidemiological, physical, mental, and organizational factors (Hignett & McAtamney, 2000; McAtamney & Nigel Corlett, 1993).

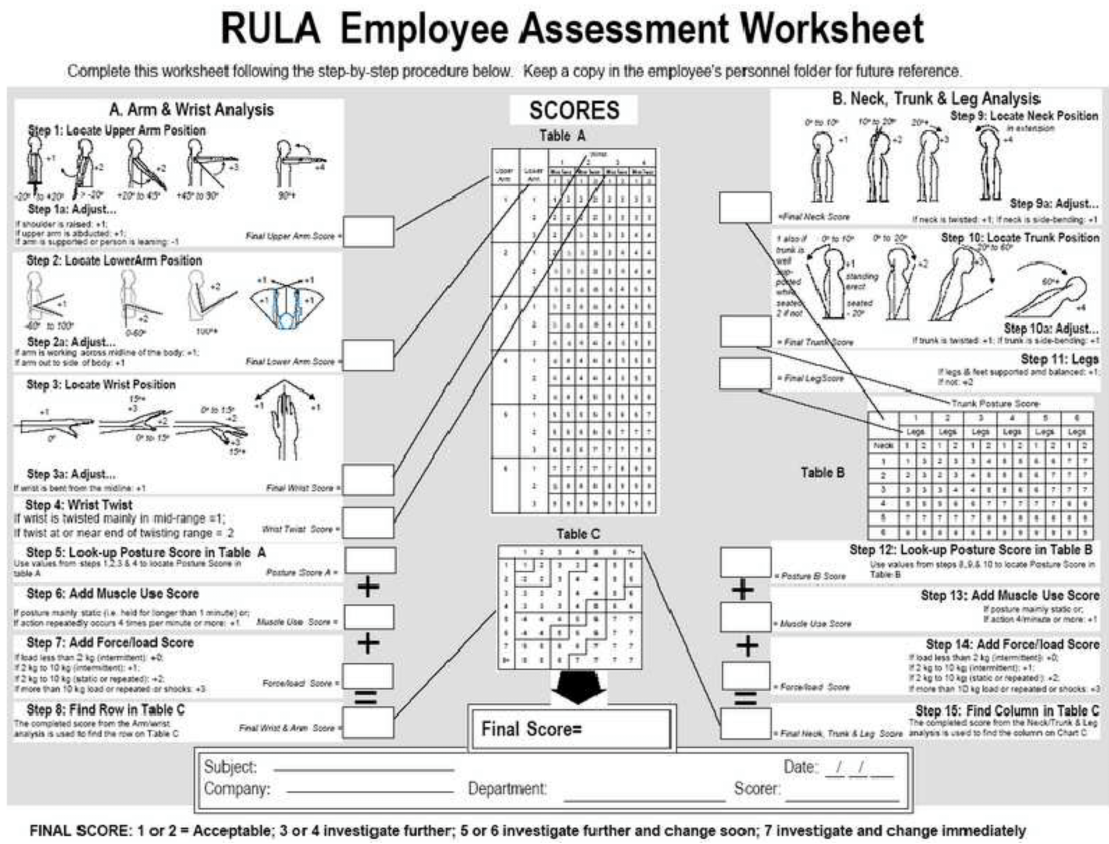

Figure 2. RULA assessment worksheet (Khairul et al., 2015)

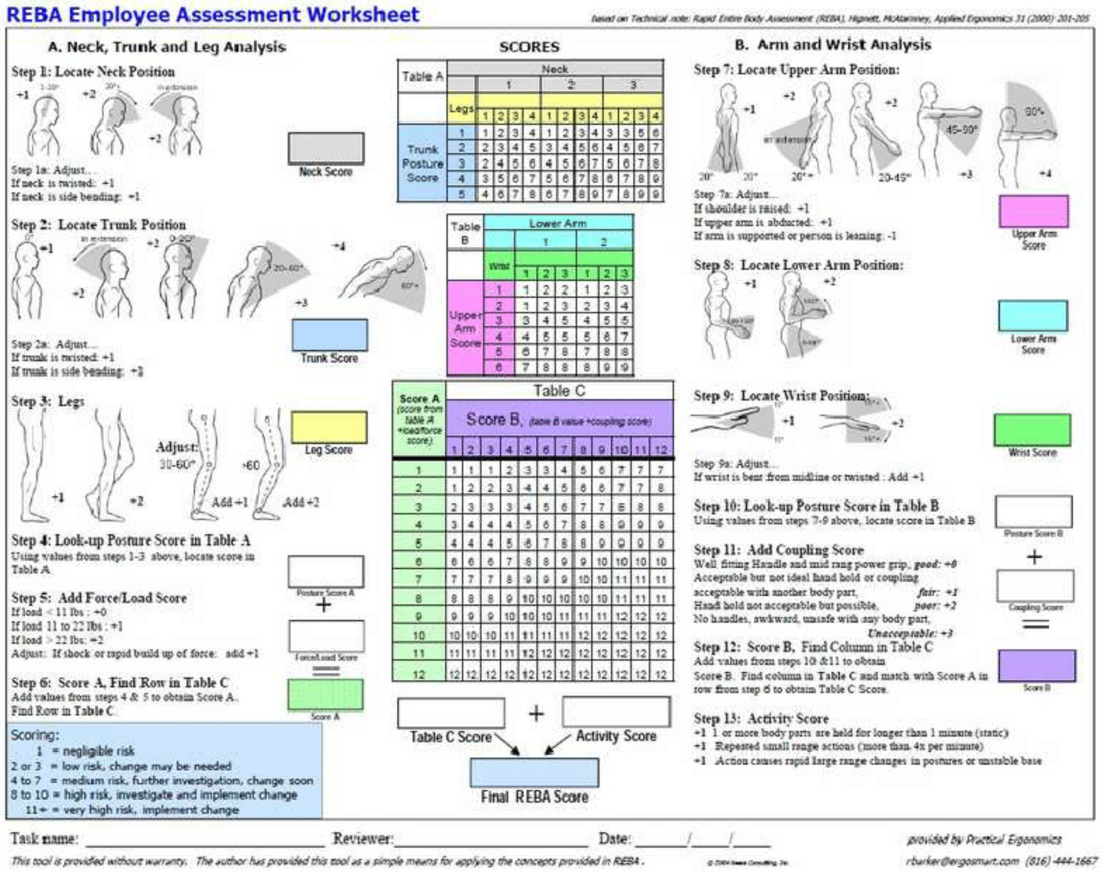

Figure 3. REBA assessment worksheet (Khairul et al., 2015)

2.2 Empirical studies

Several pre-studies were made:

- Study sensors: sensors for positioning and body parts prediction were studied to gain insight regarding different settings, the accuracy to represent and capture the human body parts, and the parts that would need to be predicted.
- Study ergonomics assessment methods: especially RULA and REBA were studied. Understand how they work and what they are most efficient for.
  - Study how to perform ergonomics assessments (RULA and REBA) in Jack and IPS IMMA; and EPP. IPS IMMA was needed for the evaluation part and EPP to perform the ergonomics assessments of the strategy.
- Learn Python: this coding language was used to transfer posture data from Simumatik into EPP. Online lessons in video format were used for this purpose (Programación ATS, 2018).
- Study workstation environment proposed by Simumatik AB: gain insight about what is an AGV and what it is used for, so use cases are related to it.

2.2.1 Sensors and body parts prediction study

Different placement for trackers on the human body was studied from previous experiments explained on papers. As well, these papers showed how the prediction of the rest of the body parts was achieved with their trackers' distribution and the untracked parts remaining. The experiments differ in the number of trackers and how the body parts were predicted: Jayaram et al. 2006 and Vignais et al. 2013 used seven trackers each. Meanwhile, Battini et al. 2014 used 17. The purpose of all of them was to track the full body. The first two had to build the human model with complex vectors and equations to predict body parts (upper arm, lower arm, lower limbs, etc.). Meanwhile, the other had all the information needed and just used a pipeline procedure to build the human model. Specific data about the trackers and the calculations used to predict body parts are explained in Table 9 in Appendix B: Experimental studies.

Jayaram et al. 2006 and Vignais et al. 2013 used orientation matrices and differential rotations to predict the untracked body parts. Simumatik used operations with quaternions to orientate the body parts of its manikin and therefore was the method used to predict the body parts later.

2.2.2 Ergonomics assessment methods testing

As explained before, RULA assessment in Jack and IPS IMMA was tried. These studies concerned body parts positioning in Jack and IPS IMMA, as well as RULA analyses. Scores were studied with the RULA worksheet to gain insight into the assessing process. In Table 10 in Appendix B: Experimental studies examples are presented of predefined postures. EPP couldn't be studied because access wasn´t available in this stage of the project and because it takes input data from a DHM tool and it was needed MoCap and Simumatik for that purpose.

2.2.3 Python study

Several tasks/small codes were created to learn the basics of this language: lists, dictionaries, commands as print, output or input, etc. C++ basic knowledge was already known, and therefore Python was found easier to learn and implement in the project.

2.2.4 Use cases predefined environment

In the new smart industry 4.0, there is a need for more efficient and flexible workstations and logistic processes. Automated Guided Vehicles (AGV) are widely studied as an alternative to human-operated tugger trains, forklifts, and other logistic operations vehicles that move goods across the workstation (Hrušecká et al., 2019).

AGVs systems consist of a series of self-operated vehicles that move around predefined paths, aided with magnetic tape, lasers, optical sensors, and gyroscope inertial guidance. AGVs are monitored with wireless connections and are tasked with material handling operations, such as transportation, kitting, and assembly. They can receive instructions such as: stop, start, turn, change the current path or lift and lower. There are different kinds of them, including automated cart and forklift, tugger, and unit load amongst the most common. AGVs are widely used in the automotive, food, beverage, hospital, and material production sectors (MHI, 2021).

The studied use case was a workstation with an AGV carrying out an engine block. It is a quite flexible station, widely used at manufacturing companies collaborating with Simumatik, making it possible to test different kinds of manual tasks, including those usually critical from the ergonomics perspective.

Simumatik VR function allowed interaction with tools and buttons that can be used as part of the tasks. A sequence of actions was planned to be performed by a worker in this setting. The AGV working potential can be seen in a video from another project performed in Simumatik AB in Figure 4 (Cristina Arenas Izquierdo, 2020). It can also be seen the real AGV in Figure 5.

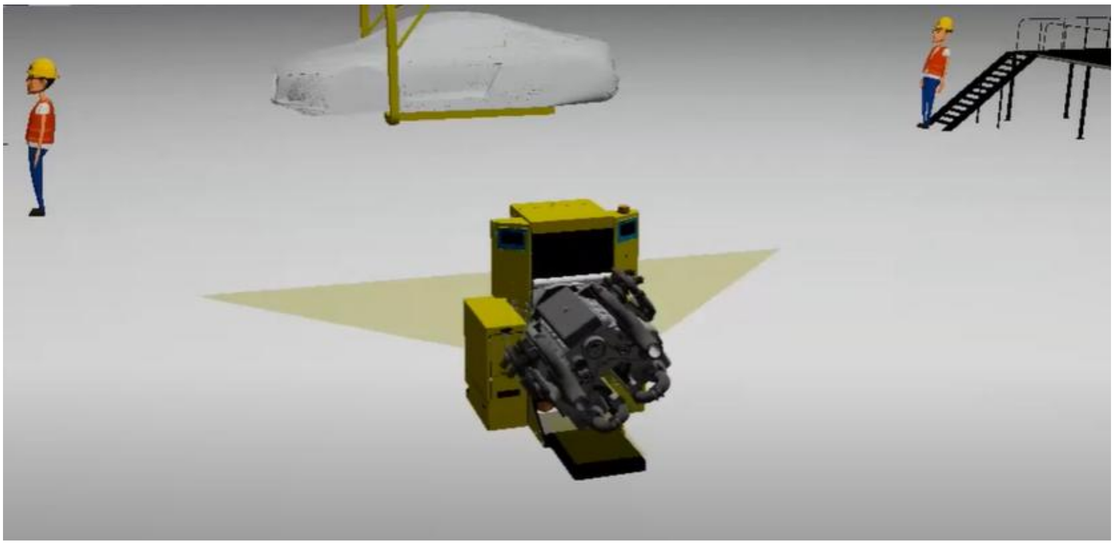

Figure 4. Emulated AGV with attached engine in Simumatik (Cristina Arenas Izquierdo, 2020)

Figure 5. AGV carrying an engine studied in ASSAR Arena

2.3 Design specification

For this project, it was implemented and studied a strategy, not a product. Therefore, the requirements and wishes list was targeted towards the performance of the different steps of the strategy and the analysis of the variables in it. The study of use cases, the selection of their conditioning factors, and how the strategy was approached according to these factors were vital.

Therefore, we divided the requirements and wishes list into three sections, with a top-down design: method, strategy, and use cases. The list can be seen in Table 1, Table 2, and Table 3. The colours on the side of the evaluation column show the level of fulfilment of the task, being red demand partially or not achieved, clear green demand achieved, and dark green wish achieved.

(1) Method							
Category	Sub-category	Definition	Demand	Wish	Unit	Verification	Evaluation
Literature review	References of precedents	Amount of papers/books/other references related to other strategies similar to ours	5	10	Number	Number	19
	References of definitions	Amount of papers/books/other references related to concepts that are used in the strategy	Enough to cover key concepts		Number	Number	20. Enough references
	Graphic content	Images/graphs related to the matter	Enough to cover key concepts		Number	Number	18 figures in the draft report, not counting the appendix
Pre-study	Sensors	Study experiments with different sensors placements	3	5	Number	Number	3. See Appendix B

	Body parts prediction	Study the prediction of untracked body parts. Understand how are they performed and their basics	Upper limbs	Full body	Yes/no	Be able to explain how missing vectors are obtained and their orientation.		3 experiments where body parts were predicted were studied in Appendix B. They concerned both upper limbs and full body
	DHM tools	Study how DHM tools work for future comparison of results	IPS IMMA	IPS IMMA Jack	DHM tool name	Set manikins in different working positions. Freely move parts of the body.		JACK and IPS IMMA. See Appendix B
	Ergonomics assessments	Study how different ergonomics assessment methods work: input, output, cases of use, etc.	RULA REBA	RULA REBA NIOSH OWAS	Method name	Perform easy ergonomics assessments with predefined postures		RULA and REBA were tested in Appendix B. In the other methods, the theory was just studied
	Programming	Study how Python works at a basic level	Yes		Yes/no	Perform easy tasks such as input/ output of data, conditionals use, loops, etc.		Easy tutorials with tasks were reviewed

	Case studies	Study setting of the use cases (AGV)	Online	In-site in Volvo factory	Yes/no	Understand what is an AGV, how does it work and why it is used in industry		We went to ASSAR to study the AGV in-site
Use cases	Definition	(3) Use cases [Table 3]						
	Validation	(3) Use cases [Table 3]						
Strategy	Implementation	(2) Strategy [Table 2]						
	Test of use cases	(2) Strategy [Table 2]						

Evaluation	Results	Compared results of the strategy with other strategies´ ones	IPS IMMA	IPS IMMA Jack	Yes/no	Compare RULA/REBA scores of our strategy with IPS IMMA and Jack ones. Copy sequence of actions of the tasks in IPS IMMA and Jack for the assessment.		IPS IMMA
		Achieve a rough estimation of the RULA scores	Identify which are the 'bad' positions. Accuracy>50% compared to other assessment platforms	Obtain an accuracy>60 % compared to other assessment platforms		Calculate accuracy of the use cases compared to IPS IMMA or JACK		Accuracy of 73,3%

Table 1. Requirements and wishes of the method

(2) Strategy							
Category	Sub-category	Definition	Demand	Wish	Unit	Verification	Evaluation
Use cases	Number	Amount of use cases set to evaluate the strategy	6	10	Number	Number	Overall cases: 6 Subdivided: 15
MoCap system	VR	Use Simumatik as a platform to display the VE	Yes		Yes/no	Yes/no	Yes
	Tracking system	Use HTC VIVE to track body motion	Yes		Yes/no	Yes/no	Yes
	Calibration	Calibrate trackers before testing tasks	Yes		Yes/no	Yes/no	It was needed a Room setup before using them. However, as we didn´t use more than headset and controllers, no more calibration was needed

	Prediction	Predict untracked body parts accurately	Explain how it is done	Do it	Yes/no	Explain how to obtain vectors in a biomechanical model of the human body according to the amount and placement of trackers.		Done in the Python code
DHM	Representation	Use Simumatik to represent posture data captured with the MoCap in a manikin.	Yes		Yes/no	Yes/no		Yes
Communication	File format	Use JSON file to transfer data posture information from Simumatik into EPP	Yes		Yes/no	Yes/no		Yes
	Speed of transfer	The speed at which feedback or results from the ergonomics evaluation are transfer back to the user	Offline	Online	Yes/no	Yes/no		Offline
Ergonomics assessment	Platform	Use EPP as an ergonomics assessment platform	Yes		Yes/no	Yes/no		Yes

	Methods	Methods implemented in EPP to carry out assessments	RULA, REBA	RULA, REBA, NIOSH, OWAS	Yes/no	Yes/no		RULA, REBA
	Scores	Scores are displayed back into the Simumatik interface	No	Yes	Yes/no	Yes/no		No

Table 2. Requirements and wishes of the strategy

(3) Use cases								
Category	Sub-category	Definition	Demand	Wish	Unit	Verification		Evaluation
Environment	Setting	The setting used to perform the use cases	AGV with engine	Different settings in the industry	Yes/no	Tasks are carried out using the AGV model.		AGV setting+shelves+drawers+control panel
	Operators	Number of users performing tasks in the VE	1	2	Users	Number		1

MoCap	Studies	Study different combinations and placement of sensors on the human body to achieve accurate results for each use case	Yes		Yes/no	Yes/no		Yes, but just hypothetically taking into account the RULA worksheet. See Figure 18 in the Draft report.
	Amount of sensors	Number of trackers needed for the use case	6 (headset, 2 remote controllers, 3 trackers)	3 (headset, 2 remote controllers)	Number	Allows a high accuracy MoCap with the least amount of trackers		The tasks that demanded more trackers than the headset and the controllers were not studied. The studied ones had good results but could work better with an additional tracker in the chest
	Body tracking	Parts of the body capture by trackers	Upper body	Full body		Yes/no		Upper body
Ergonomics assessment	Methods	Suitability of the use case for implemented methods	RULA or REBA	RULA and REBA	Methods	RULA can work with upper-body tracking. REBA needs full-body tracking.		The use cases that worked better with REBA were not studied. Therefore all the use cases were perfectly suitable for RULA.
	Key-frames	Range of RULA/REBA scores between two key-frames in a use case	2	3	Score points	Calculate the difference between the RULA/REBA scores of 2 Key-frames evaluated.		The use cases were created thinking that they were going to depict different RULA scores amongst their keyframes. However, most of them displayed the same score for the last two keyframes

Results	Validation	Test and determine for each use case: how many trackers, where to place them, and which methods to use	Yes			Evaluate different options studied and decide the best combination of settings for the use case.		A strategy explanation graph was created depicting them.
	Display	Develop a guideline for each use case: how many trackers, where to place them, and which methods to use	Yes			Yes/no		A strategy explanation graph was created depicting them.

Table 3. Requirements and wishes of the use cases

3 Design

3.1 Definition of use cases

Use cases were applied in the strategy to help the user perform the tasks most accurately concerning the strategy studied. Users that want to perform physical ergonomics studies of a task, need to look for a similar use case studied by us and apply the recommendations for that specific use case in the steps of the strategy.

Use cases in Table 11 in Appendix C: Use cases were initially studied as the main case studies to be carried out, but due to the changes made during the project's development, it was decided to substitute them. It can be seen that these case studies demanded more sensors than we had available. Therefore, they were rejected but still helped to gain insight into sequences of tasks.

To cover a wide range of actions, the new use cases were developed as simple, general tasks that the user could adapt to their study. Insight about RULA and REBA worksheets, as well as about the AGV setting, was taken into account. For the AGV setting, two main sources were analysed: videos related to the functioning of AGVs in workstations and videos related to engine production lines. In the videos related to the functioning of AGVs, it was regarded that operators pushed some buttons to control the parts/goods carried by the AGV. The operators usually stayed in the place to perform cyclic tasks; the AGVs were going around the workstation. In the second, it was regarded that there were shelves and drawers on the sides of the operator’s position containing pieces to mount. These videos are Dematic NV - previously Egemin Automation (2011), (2015), (2016), and GommeBlog.it: Car & Performance (2019).

The chosen tasks to study are explained in Figure 21 in Appendix C: Use cases and can be divided into different groups:

A. Control tasks. Pushing buttons to make the AGV work, as well as quality checks, were included in this group. Twisting the trunk and neck, and stretching upper limbs were the main movements performed.

B. Grab items. In the setting of the AGV, it was added a shelf on the left and a drawer on the right. Therefore, items were grabbed from them and the floor, including bend and twist of the trunk, upper limbs stretch, and squat as main movements.

C. Use tools. Once the tool was in the user's hands, the user interacted with it and the engine on the AGV. Selected tools included drill, spanner, calliper, and a blowtorch, as they were commonly used in the automotive industry, especially when interacting with car parts. Drills are used to make holes to attach pieces that require them; spanners are useful to remove or adjust nuts and bolts; callipers are used to check the tolerances in bearings and other fabrication pieces; blowtorches allow removing thread lock and ease to pull out bolts that are corroded. Upper limbs, and especially hands and wrist positioning, were studied in these tasks.

3.2 Development of our strategy

3.2.1 PHASE 1: Meet the manikin in Simumatik

Simumatik wanted to have DHM features. For this purpose, they had developed a manikin that represented a human with a simple visual. It could be moved freely in the Simumatik platform and used in VR to copy the user movements.

To create this manikin, a new component was made in the Simumatik platform. It was built with boxes that represented parts of the body and joints to join these segments. This can be seen in Figure 6. The rough design of the manikin included top and bottom body parts, but because of problems related to the data management of the trackers, it was reduced to just the chest, head, and upper limbs.

Code in XML was automatically created together with the component. It contained information related to the segments and joints, such as colour, shape, weight, and degrees of freedom and their limits. This last part was roughly studied to define and understand the limitations of the movements of the manikin and copy the natural moves of a human body as much as possible. See Table 12 in Appendix D: Body parts data.

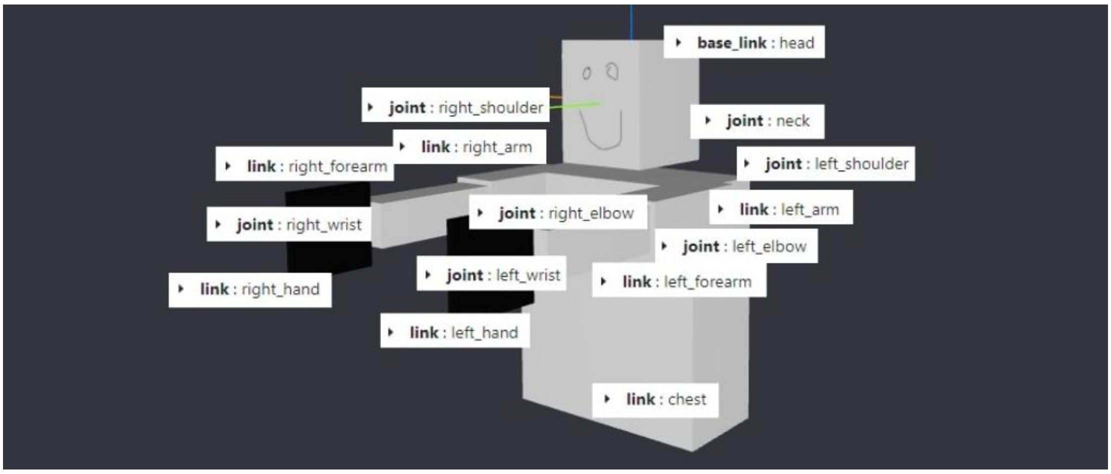

Figure 6. Manikin developed by Simumatik AB to test the tasks

Later on, our industrial supervisor Mikel Ayani decided to remodel the initial visual appearance of the manikin used in the platform because of its roughness. To give it an industrial appearance, it was substituted with a dummy (Figure 7).

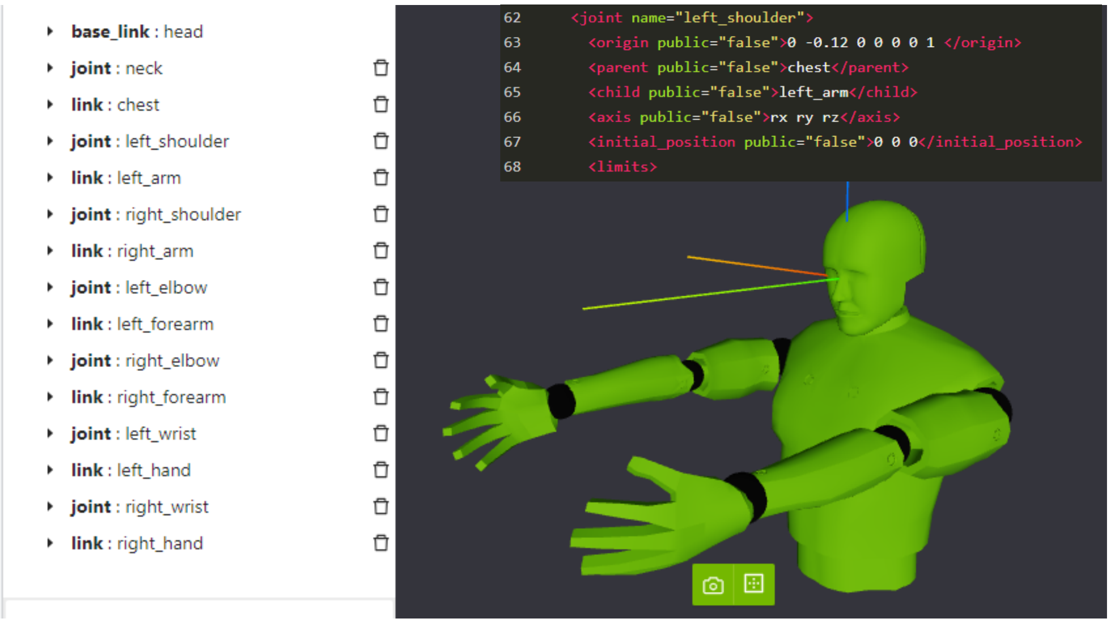

Figure 7. Dummy manikin used by Simumatik AB: body parts, joints and an example of the .XML code

3.2.2 PHASE 2: Definition of the tasks environment in Simumatik

All the predefined components that were explained in section 3.1 Definition of use cases were created in the Simumatik platform. To create them, several steps were followed:

- Find a 3D model online. Several web pages that offered free designs were searched, and CG Trader was regarded as the best one. All the components were found and downloaded from it (CG Trader, 2021).
- Convert 3D files to .glb format, which is the only format accepted by the Simumatik platform. Use several online converters for this.
- Create a new component in the Simumatik platform:
  - Add 3D file as an asset.
  - Introduce this asset as a mesh in the visual tab of the component.
  - Add inertia, friction, and a texture or colour to the component.
  - Add collision blocks to define the interaction of the component with other components and the environment.
  - Save changes and include the component in the Simumatik environment.

The different settings for a component are shown in Figure 8, while the results of the initial environment created are shown in Figure 9.

Figure 8. Settings for components in the Simumatik platform

Figure 9. The initial environment created in Simumatik for the use cases

Our industrial supervisor Mikel Ayani taught us that it was more common to find the control panel hanging from the ceiling, rather than on a table. This control panel would have contained information about task instructions for workers and some buttons to set an end to the task or stop the AGV from working. Therefore, this change was carried out in the environment. As well, the AGV was introduced. It had two buttons to lift up or down and to rotate the engine and a switch button to change between translation and rotation on its left side. The final environment for the use cases can be seen in Figure 10.

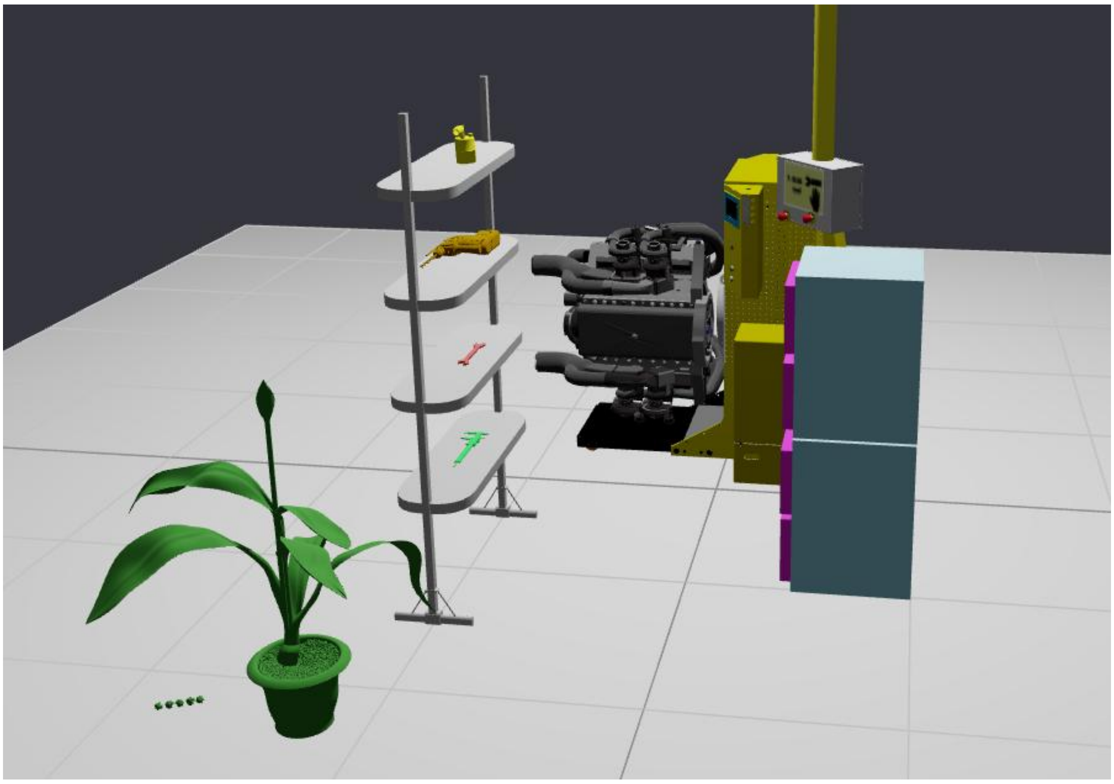

Figure 10. The final environment created in Simumatik to perform use cases

Technical drawings with measurements and top and front views of the environment can be found in Figure 22 in Appendix D: Body parts data.

3.2.3 PHASE 3: Test the movement of the manikin in Simumatik

Throughout the first week of trying out the manikin, several problems with its functioning were found, which were solved by Simumatik AB personnel. The first one was a malfunctioning of the orientation in the VR system, resulting in seeing the environment upside down. Afterwards, the frequency used to send the trackers' data to the Simumatik platform was too high, and the manikin couldn´t keep up with that much data. Usually, VR systems work on a higher frequency than regular computer screens to avoid dizziness. However, it was not needed that high frequency for the Simumatik platform, especially because it was only needed snapshots for the later ergonomics assessments. Therefore it was reduced from 120 Hz to 5 Hz.

Once the VR system was set up right to test the manikin, the VE was tried. The movement of the wrists and arms worked perfectly fine, especially the estimation of the elbow position. Previous experiments with other manikins resulted in inexact positioning of the elbow, so fixing this mistake meant a significant step for the development of Simumatik as a DHM. However, all this perfect functioning worked only on some quadrants, as the software used Euler angles to make rotations of body parts and Gimbal lock happened in some specific angles (-90º and 90º). This means that two rotation axes join into one, and the rotation loses a degree of freedom. Finally, this issue was also fixed with new coding by Simumatik AB personnel.

However, the industrial supervisor Mikel Ayani decided to introduce some changes in the development of the project and the resources that were going to be available for the project:

- Delete the lower limbs of the manikin. It was found to be complex to implement in the amount of time available for the project. Therefore, the trunk of the manikin was going to stay stiff.
- Use only the headset and the controllers´ trackers. The other three available trackers would be used for future development.

3.2.4 PHASE 4: Study use cases in Simumatik

We introduced some changes in this phase. We wanted to study all use cases created following the strategy, testing them with VR in the Simumatik environment. However, because of the new limitations that the company imposed (fewer trackers and the manikin with only top body parts) and the amount of time remaining, it was decided to only test use cases that qualify for Simumatik's new requirements.

Uses cases needed to meet some qualifications to be chosen:

- Involve only movements from top body parts. Therefore, RULA could be the only evaluation method used, as REBA also evaluates lower limbs.
- Involve movements that didn´t study flexion of the trunk.

According to these criteria, the tasks that fulfilled the requirements were (Figure 11):

1) Push the button, verify.

3) Take an item from the left shelf. A shelf with four levels was introduced in the environment. The top three levels could be accessed without bending the trunk.

4) Take an item from the right drawer. Two sets of a chest of drawers, resulting in a total of 4 drawers, were introduced in the environment. The top 2 could be pulled easily by the user; meanwhile, the bottom ones needed squatting.

5) Interact with the control panel. It was substituted with a panel holding from the ceiling. It had an emergency button that the user could push to stop the station if there were any problems, as well as a task finished button.

6) Use tools.

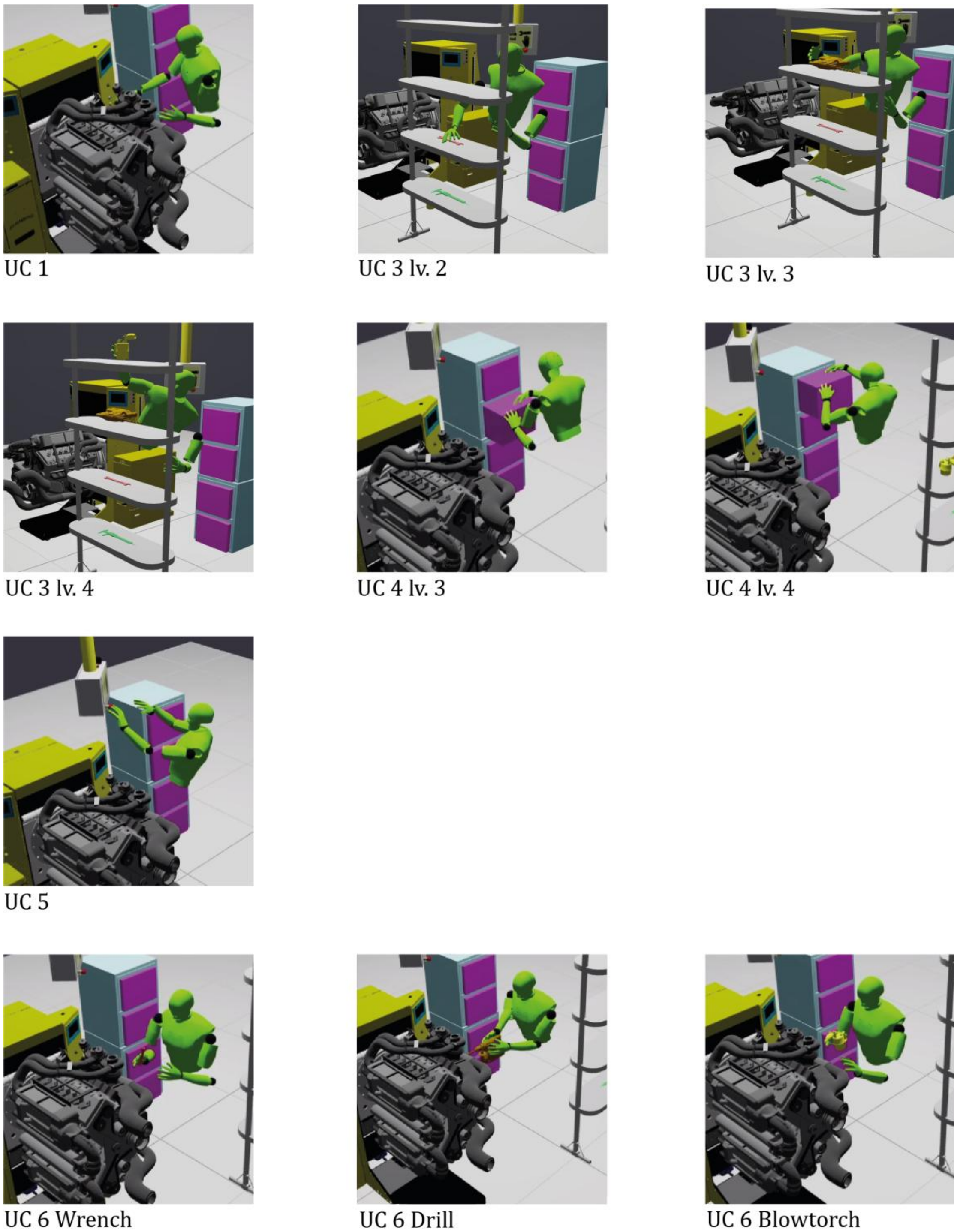

Figure 11. Use cases performed, seen in the Simumatik environment

3.2.5 PHASE 5: Record data and generate JSON file

The industrial supervisor Mikel Ayani added a function in the platform that allowed saving the data position gathered by the trackers into a JSON file. This function could be set depending on the frequency of frames that the user needed to record. It was set to 5 Hz for the studies, as it was just needed to evaluate keyframes.

This JSON file contained the data of a few body parts, but for EPP it was needed a bigger list of parts and joints. This new data was calculated through coding in

Python and saving it back into a new JSON file. Table 4 depicts the data before and after running the code created.

Simumatik		EPP
Head		L5S1
Chest		L3L4
Left_arm		T12L1
Right_arm		T6T7
Left_forearm		T1T2
Right_forearm		C6C7
Left_hand		C4C5
Right_hand		Atlanto_Axial
		Eyeside
		LeftHip & RightHip
		LeftKnee & RightKnee
	Python	LeftAnkleRot & RightAnkleRot
		LeftAnkle & RightAnkle
		LeftToes & RightToes
		LeftAC & RightAC
		LeftGH & RightGH
		LeftShoulderRotation & RighShoulderRotation
		LeftElbow & RightElbow
		LeftWristRotation & RightWristRotation
		LeftWrist & RightWrist
		Left_MiddleCarpal & Right_MiddleCarpal
		Left_MiddleProximal & Right_MiddleProximal
		Left_IndexProximal & Right_IndexProximal
		Left_IndexCarpal & Right_IndexCarpal
		Left_PinkyProximal & Right_PinkyProximal

Table 4. Initial data from Simumatik and the new data obtained for EPP

The university supervisor Aitor Iriondo gave us insight into calculating the new data for EPP and the reference needed. At first, it was decided to divide the body into four parts: the spine, left and right arms, and left and right legs.

- The spine was initially calculated with two references: from the shoulders to the hips used the middle point of the shoulders as the reference; from the shoulders to the neck used the head as reference. However, this method showed that a gap could appear in the neck when the head was leant forward (Figure 12). To fix this problem, the whole spine (hips to head) was obtained from the middle point of the shoulders. The positioning of the head was obtained with the headset tracker, so it had independent movement. This second interpretation carried out problems as well, that are discussed in PHASE 6: Ergonomics evaluation in EPP.

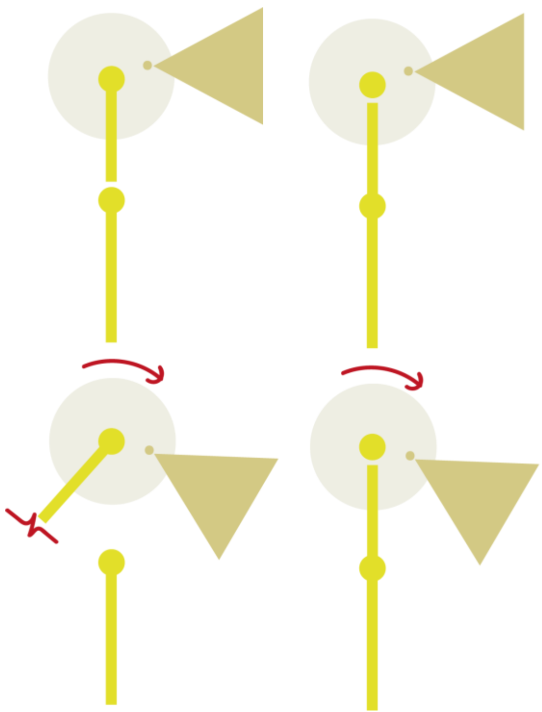

Figure 12. Right: spine calculated with method 1 and the results when bending; Left: spine calculated with method 2 and the results when bending

- For the arms: using the middle point of the top arm we obtained the elbow and the shoulder. With the hand, the wrist and index and middle parts were obtained.
- For the legs: they were calculated with the positioning of the shoulders and therefore, followed the rotation of it.

To see in detail what references and calculations were done to obtain the new data, look at Table 13 in Appendix D: Body parts data.

A. The math behind the Python code:

The positioning data of each body part in the Simumatik JSON file consisted in the coordinates (x,y,z) of the middle point of the body part connected to an absolute reference system and the quaternion (qx, qy, qz, qw) that indicated the orientation of the body part.

{ "time_stamps": [...], "head":{"tx":[...],"ty":[...], "tz":[...], "qx":[...], "qy":[...], "qz":[...], "qw":[...] }, "left_arm":{...}}

To calculate the position of the new body parts needed (e.g. elbow and wrist), calculations with quaternions were required.

E.g. calculate the wrist position in Figure 13:

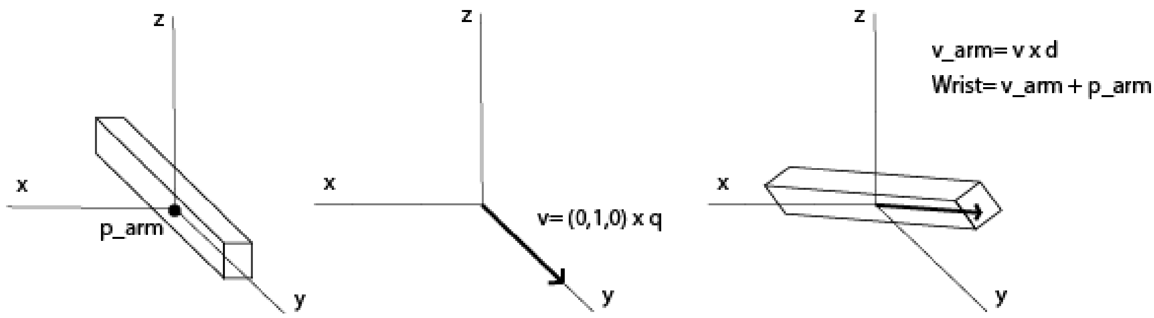

Figure 13. Calculations to obtain wrist position

1. Coordinates of the middle point of the arm in standard positioning in the reference system of Simumatik.
2. A normalised vector is created with the direction of the wrist. Then, it is multiplied by the quaternion. This way it is obtained the orientation of the arm.
3. Multiply the vector by the distance from the middle point of the arm to the wrist (See Table 13 in Appendix D: Body parts data for the measurements). Calculate the coordinates of the wrist with this vector and the coordinates of the middle point.

This method is used to obtain the elbow, shoulder, wrist, fingers, and top and bottom sides of the hand.

Restrictions related to these calculations:

- The movement of the middle point of the shoulders determines the movements of the spine. The different parts of the spine are predicted as a non-flexible group of segments, and therefore the trunk couldn´t bend.
- The movement of the shoulders determines the movement of the lower limbs. Therefore, the legs follow the rotation of the shoulders and the twist of the trunk was not measure. The legs weren´t counted for the ergonomics analyses either.
- The head can freely move, as well as the upper limbs.

B. The user´s interface for the Python code:

The python code created included a field where the name of the JSON file created in Simumatik had to be introduced. Clicking 'run the code', the new JSON file was created with a default name of 'data.txt'. Apart from that, a 3D plot depicting the movements of the manikins was also shown to make sure the movements recorded were the ones that the user wanted to study before introducing them into EPP. This feature was also used to check if the code worked properly. The code can be seen in Appendix E: Python code.

3.2.6 PHASE 6: Ergonomics evaluation in EPP

EPP platform allowed performing ergonomics analyses with the newly created JSON file. It delivered RULA and REBA assessments, which could be studied over time. Graphs displayed the variation of the scores of the assessments over the length of the task.

Some issues related to the performance in EPP were:

- The misinterpretation of the neck joint twist: EPP calculated the neck with the difference in angles between the mid-shoulder and the part of the neck connected to the head. However, because the whole spine was calculated with the position of the mid-shoulder, this difference in angles didn´t exist, and EPP couldn´t calculate the neck twist (Figure 14).

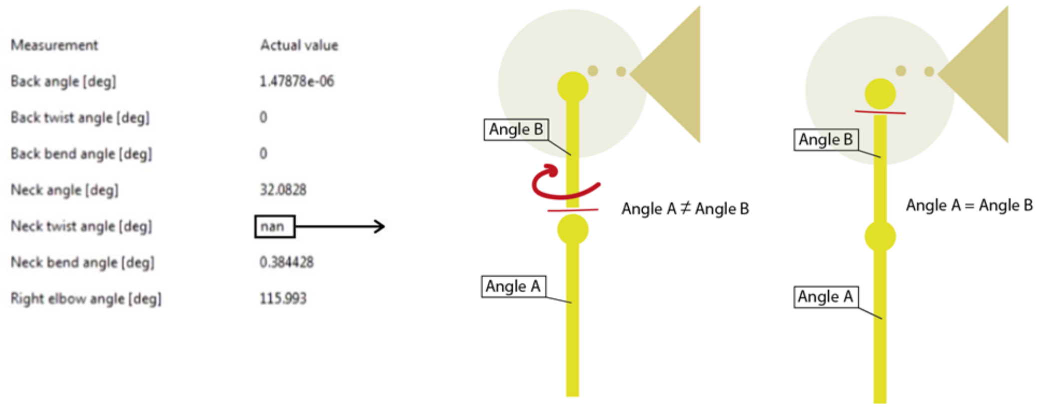

Figure 14. Misinterpretation in the neck twist in method 2

- Optional settings for RULA and REBA: both methods offered settings that had to be introduced manually. In the case of RULA, it was needed to select if it was a static or dynamic posture and the weight of the load involved. In the case of REBA, the same options appeared, plus the adjustment of the grip and the stability of the posture. For our cases, it was decided to keep the settings as simple as possible, as they were also simple tasks that didn´t involve big loads or weird positions. These settings can be seen in Figure 15.

Figure 15. RULA and REBA settings in EPP

3.2.7 PHASE 7: Validation of the use cases and reiteration

The validation of the strategy was carried out through recommendations gathered from the literature review and the skills obtained during the project.

The initial idea was analysing the results of the ergonomics studies in EPP and deciding if accuracy could be raised using more trackers or placing them in different positions. These changes in trackers´ settings would need to be studied in contrast to economics and difficulty. It means that adding an extra tracker for a specific posture may not be worth it in terms of resources spent and difficulty to implement it in the strategy steps.

However, because of time running out and because changing the position of trackers was quite a problem for the Simumatik platform, recommendations were given depending on the use case, based on the results of the experiments studied in the literature review and the insight about the trackers gathered. It can be seen in Appendix F: Comparison between IPS-IMMA & the project strategy on the right side of each evaluation sheet (Figure 25, Figure 26, Figure 27, Figure 28, Figure 29, Figure 30, Figure 31, Figure 32, Figure 31, and Figure 32). Therefore, testing out the real improvements of these changes was left for future work.

3.2.8 PHASE 9: Evaluation of the study

To evaluate the results achieved with the project strategy, we decided to compare them with other DHM software that had physical ergonomics assessments implemented in them. For our research, we used IPS IMMA; however, Jack (Jayaram et al., 2006) or other accurate software could be used for future research.

IPS IMMA (Ruiz Castro et al., 2017; Fraunhofer-Chalmers Centre, 2021) allowed setting manikins in different positions through a system of controllers (e.g. wrist, top head, and lower back) and grip points. This system allows accurate placement of the manikin and to set really specific body parts postures easily; e.g. the handgrip in
Figure 16. To reproduce the tasks in IPS IMMA several steps were taken:

- Create the background for the studies: it was needed to copy the AGV station designed in Simumatik, with the same measurements; objects were created that fulfilled this purpose accurately. It can be seen in
- Figure 16.
- Create a human manikin: the Swedish population database was chosen as a reference and added two measurements (height and weight). These two measurements were the ones of Fermin Aranda (170 mm / 60 kg) because he was the one who performed the tasks in VR, and therefore the height was adjusted to his in the MoCap.
- Set the position: each use case studied was composed of three keyframes that depicted different positions of body parts. Therefore three manikins were set, each with one of these positions. To do this, some main controllers were used:
    - Top of head, for the twisting of the neck.
    - Left/right hands, to grab objects or to hold on to surfaces. This was also carried out with grip points attached to objects.
    - Floor constraints to keep the feet glued to the floor.
- Perform static analysis of the position: IPS IMMA allowed analysing RULA, but not REBA. Scores of the different body parts were shown on the screen, next to an explanatory drawing.

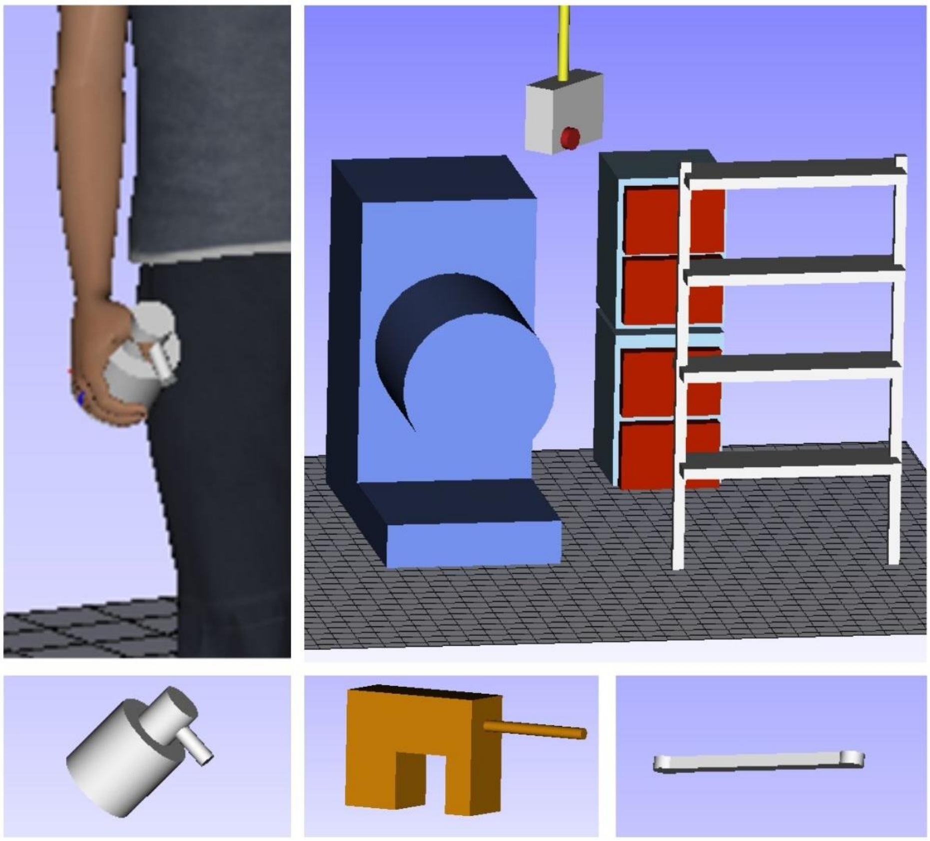

Figure 16. Manikin handgrip for the blowtorch in IPS IMMA. IPS IMMA environment and modelled tools

Then, the RULA scores obtained in EPP and IPS IMMA were compared:

- For each keyframe in a use case, the difference in scores was evaluated and given points:
    - 0→3 p
    - 1→2 p
    - 2→1 p
    - 3/3+→0 p
- A percentage of accuracy was established for each use case, depending on the points it had out of a maximum of 9. However, the first key-frame was not used because it was the same for all use cases and didn´t concern any problematic position; it was just the start standing position. Therefore, the maximum points were reduced to 6.
- A percentage of accuracy for the overall strategy was established.

This comparison can be seen in Appendix F: Comparison between IPS-IMMA & the project strategy, at the bottom of the evaluation sheets. Some mistakes and problems were discovered by checking the results. They are presented in Table 5, with the measurements taken to calculate the accuracy of the strategy and the possible solutions for future work.

Problem	Measurements taken	Possible solutions
Starting position isn't carried out properly	Don´t count it for the evaluation	Perform the strategy again only with that posture and check if it works properly

Work postures imparting stress in hips/knees score affects the score of RULA	Nothing	Calculate RULA scores without its influence
Misplacement of the neck	Nothing	Two solutions: A. Study if the measurement taken to calculate the forearm is the right one. Fix if not. B. Fix the position of the head in Python code or in EPP, moving it a bit backward
Neck can´t twist	Nothing	Fix in EPP. The angle of twist needs to be between the head and neck
Trunk is untracked	Nothing	Add tracker to the chest
Positions in the use cases aren´t performed accurately	Nothing	Perform the strategy again focusing on those postures and check if it works properly

Table 5. Problems discovered in the results of the strategy, measurements taken, and possible solutions

The initial overall percentage of accuracy of the project strategy in comparison with IPS IMMA, concerning those measurements taken, was 73,3%.

It has also been created a graph in Figure 17 plotting accuracy vs. strategy development. It shows the implications that would have to fix the mistakes our strategy presents, and how that would affect the accuracy of the study. This is discussed in Discussion and conclusions.

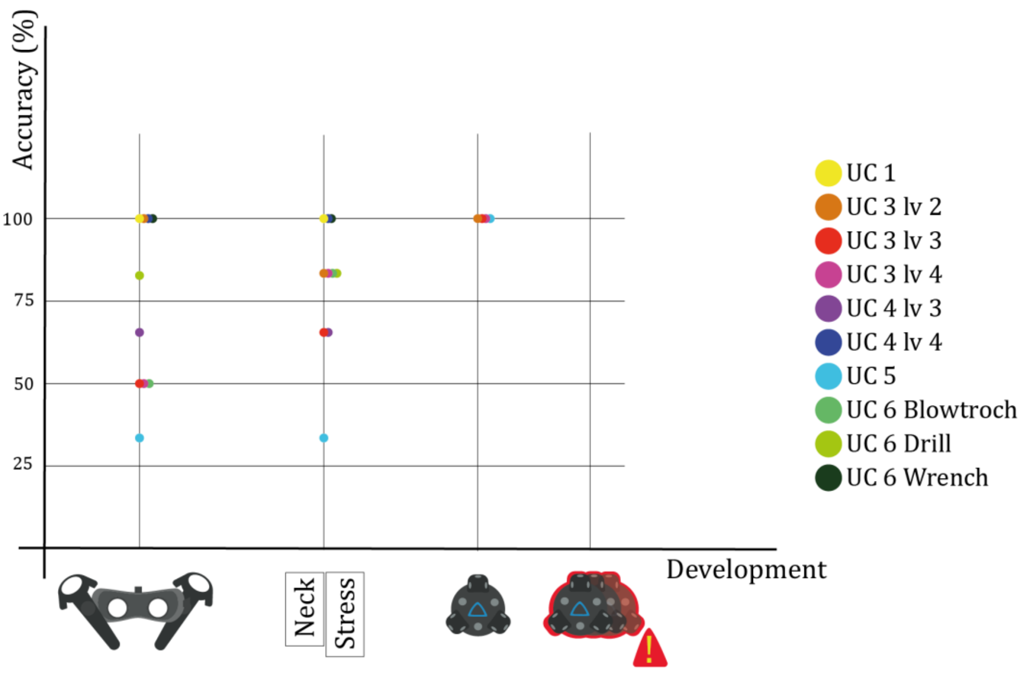

Figure 17. Accuracy vs development of the strategy

The % of accuracy obtained in the comparison between the project strategy and EPP is shown in the first vertical gridline of development. Then, the next gridline shows the % of accuracy if the neck misinterpretation would be fixed and if the 'work postures imparting stress in hips/knees' wouldn´t be counted' and finally, in the last two gridlines, if the chest tracker and the chest and legs trackers were added. This last gridline of full-body MoCap is saved for future studies, as it is only useful to study with use cases that involve lower limbs work. The data used for these approximations are shown in Table 6.

Use cases	Fix neck and stress issues	New accuracy	Add more trackers	New accuracy
1	No change in general RULA scores (3 in both key-frames). However, the individual neck score would be exact	100%	No need	
3 (shelf level 2)	RULA score in P2 would be 3 (same accuracy), but in P3 would be 4 (less accuracy. It is missing the trunk bending)	83%	Add chest tracker	100%
3 (shelf level 3)	RULA score in P2 would be 3 (same accuracy), but in P3 would be 4 (more accuracy. It is still missing the trunk bending)	67%	Add chest tracker	100%
3 (shelf level 4)	RULA score in P2 would be 4 (more accuracy), and in P3 would be 6 (more accuracy, but still missing the trunk bending)	83%	Add chest tracker	100%
4 (drawer level 3)	RULA score in P2 would be 4 (same accuracy), as well as in P3 (same accuracy. It is because of the mispositioning of the wrists)	67%	No need	
4 (drawer level 4)	RULA score in P2 would be 3 (same accuracy), and in P3 would be 4 (same accuracy). However, the scores of Group B would be more accurate	100%	No need	
5	RULA score in P2 would be 5 (same accuracy), as well as in P3 (same accuracy). It is missing the chest tracker	33%	Add chest tracker	100%
6 Blowtorch	RULA score in P2 would be 4 (same accuracy), but in P3 would be 5 (more accuracy). It is missing a proper positioning of the hands	83%	No need	
6 Drill	RULA score in P2 would be 3 (same accuracy), and in P3 would be 4 (same accuracy). It is missing a proper positioning of the arms	83%	No need	
6 Wrench	RULA score in P2 would be 4 (same accuracy), as well as P3 (same accuracy)	100%	No need	

Table 6. Assumptions taken to calculate the hypothetical %approach.

3.2.9 PHASE 10: Output the strategy guideline

A strategy diagram (Figure 18) has been created to explain how the strategy works. It can be used as a guideline to the user to carry out the assessment correctly. Each step is roughly explained, and in the case of further information needed, it is recommended to read the complete report.

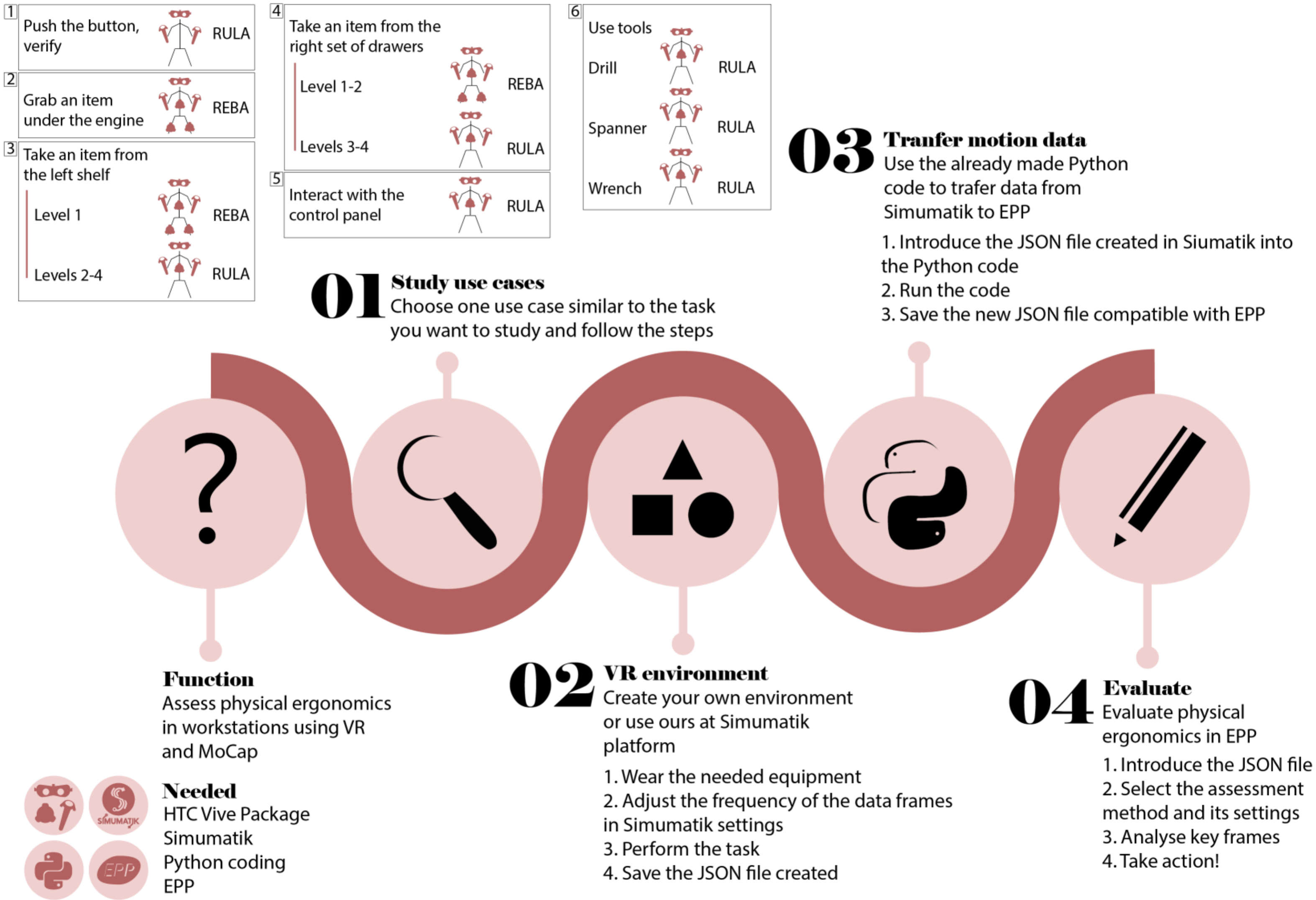

Figure 18. Strategy diagram

Some media content was created to show the results of the strategy and uploaded online:

- A video showing the different steps of the strategy and explaining its functioning for the users. It has the format of a commercial video (Figure 19).

Figure 19. Strategy commercial video https://youtu.be/6rWmaYQgLSg

- A video showing the strategy's performance divided into three steps: MoCap, Simumatik, and EPP (Figure 20).

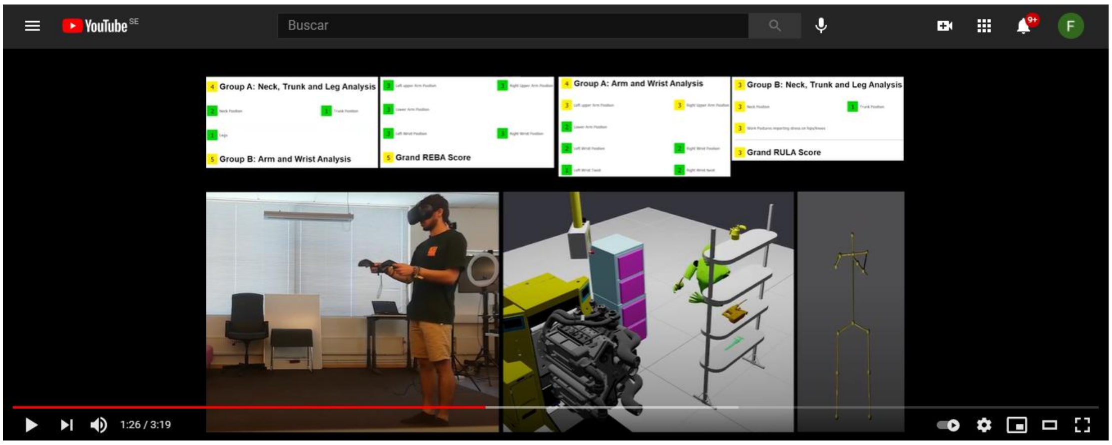

Figure 20. Steps of the strategy at simultaneous time https://youtu.be/6rWmaYQgLSg

4 Discussion and conclusions

Nowadays, the industry faces many issues. Companies have started to think about the physical ergonomics of their workstations, concerning the distribution of the components and the physical human-machine interaction. Usually, workstations are designed and built before ergonomics assessments are carried out, and therefore it´s late to implement major changes in its design. In this study, the physical ergonomics of workers are targeted through the creation and assessment of a strategy. This strategy is also born from the idea that ergonomics evaluations should be available for all companies, independently of their size and resources. This means that every company should be able to take care of the health of their workers in an easy and economically manageable way.

This strategy was designed to assess workstation ergonomics using virtual models of production. It had predefined limitations such as using HTC Vive as MoCap and VR device, Simumatik as DHM software, and EPP as ergonomics evaluation platform.

To start with the HTC Vive system, it was easy and intuitive to use. Controllers and headset followed the movements smoothly, and the possibility of adding more trackers to different body parts made it interesting for future studies, where more accurate predictions could be carried out. However, each extra tracker added up more budget to the overall assessment, and therefore, it would be needed to find a balance between economics and accuracy needed by the company using it. According to the industrial supervisor, Mikel, the general HTC Vive package (headset and two controllers) had a cost of approximately 500 €; meanwhile, each extra tracker cost 100 €. This would mean increasing the initial budget by 20% if one tracker was added or by 60% if three trackers were added. Therefore, this investment is remarkable and needs to be studied to decide the cost-effectiveness of adding the trackers in the strategy and decide what is best for users.

Simumatik platform is designed for the virtual emulation of production systems and robot logic. However, as a DHM modeling software, it has still a lot to develop. Throughout the process of implementing the strategy and carrying out the experiments, many obstacles with the platform, related to malfunctioning of the manikin movements or crashes of the platform were found. This is normal, as it is still in the development phase and it hasn´t been refined yet. It can be pointed out some great features of the platform though:

- Simumatik worked great to create new components and work with them, resulting in an easy interface for users to create their environments without previous knowledge in programming.
- The movement of the manikin (when it worked) was smooth and it had a great grip to grab objects and interact with the environment. However, the manikin didn´t have controllable fingers and it could be great to allow the user to see more accurate visuals of the hands, as future work for the strategy.
- The steps needed to carry out the use cases and record the movement data were fairly simple and could be carried out by a single person. This would allow the own worker/user to evaluate himself without the need for an evaluator or other worker.

The transfer of information from Simumatik to EPP was carried out with Python code. This was created considering some restrictions and assumptions that led to fairly accurate body movements' prediction: the spine was a single, straight segment that went from the neck to the pelvis. The legs were also straight and attached to the spine and, therefore, rotated with them. This rough estimation was dependant on the number of trackers available for the MoCap and was thought the easiest and most accurate way to do it. However, as it can be studied in the results of the use cases, most of the tasks involve the rotation of the trunk: bending or twisting. These movements couldn´t be tracked nor predicted in Python with the setting of trackers available. The same problem arises for the legs; no trackers can capture their rotation or flexion, so they are just attached to the trunk, making it impossible to perform the tasks that involve close to the floor movements, such as squatting.

EPP was a useful tool to perform physical ergonomics assessments. It takes as input a large list of joints and segments of the body, but that list was reduced to the available ones. Some of these were needed to be introduced for the correct functioning of the software, and therefore, they needed to be roughly predicted or just be positioned in the same location as others. EPP offered two basic assessment methods: RULA and REBA. For the scope and aim of this project, they were fairly enough, as it was just targeted a rough assessment that delivered basic recommendations for users. For future studies, it would be interesting to dig deeper into more complex assessments and evaluate if the strategy is worth it economically.

It was achieved an overall accuracy of the strategy of 73,3%, compared with IPS IMMA. This % represents the similarity of the strategy results to the ones of IPS IMMA. However, as IPS IMMA is not a perfect physical ergonomics evaluator, this % of accuracy is not the comparison with the exact RULA evaluation, considered the manual RULA evaluation. The main idea of the evaluation phase was to compare the project strategy, which involves a series of steps, with software that could perform all of those steps together at the same time. Therefore, IPS IMMA and Jack were the tools chosen. Manual calculations of RULA scores would mean skipping the MoCap and DHM steps, as keyframes would be evaluated straight from the drawings of the use cases or with video recordings of users performing the tasks, and it would be more of a straightforward evaluation, not a strategy.

As mentioned before, IPS IMMA is also a piece of software under construction, and sometimes it showed some minor mistakes when calculating the RULA scores. The neck bending and twisting were especially affected. Throughout the process of comparing the results of the project strategy, the positioning of the manikins in IPS IMMA was changed several times, as the RULA scores were far from the ones of the use cases represented. RULA scores calculated manually were roughly studied as well to support IPS IMMA.

It is important to state that the project strategy involved MoCap of a real human, while IPS IMMA allows the user to place the body parts wherever the user wants, and therefore the project strategy probably shows an idea of a task closer to the reality than the other DHM software. IPS has also been previously used for MoCap (Garcia Rivera et al., 2020), where the software displayed the VE. In this experiment, ergonomics evaluation was carried out in a different piece of software and then implemented online in the VE of IPS. Although this approach seems similar to the project strategy, it doesn´t include the DHM phase, as there is no manikin in the VE in IPS represented. It also uses a double system of trackers: HTC Vive to interact with the VE, and smart textiles to perform the ergonomics evaluation. This is reduced to just the HTC Vive system in the project strategy, which is found enough because the evaluation was offline. Future work could study this duality of MoCap.

Problems were faced in all strategy steps, and it was needed to reiterate them: calibration of HTC Vive was done several times to ensure bigger workspace, Simumatik environment was changed several times to adapt it to real industry background, Python code was tested through try and failure, etc. This process of reiteration is really common when working with ill-defined problems, and it is mainly connected to Product Development Processes. According to the results, the main issues found are presented in Table 5. The ones concerning calculation issues (neck problems and work imparting stress) were taken into account in Figure 17, showing the actual accuracy of the strategy if these issues were solved. Therefore, the accuracy of the strategy should be understood as if those issues were solved, being 80%. The initial accuracy % obtained in the use cases is not realistic, as some of the RULA scores in IPS IMMA and the project strategy match because of luck. Also, adding another tracker in the chest would be more difficult, time-consuming, and resource-consuming for the company, and although it shows that the accuracy % could be close to 100% in most of the use cases, it´s a hypothetical situation and further study would be needed.

In conclusion, the strategy created offers a cheap and straightforward way to assess physical ergonomics. However, all the different steps that compose the strategy are being developed individually and have individual mistakes. Therefore, connecting all of these steps, with their mistakes, results in more complex mistakes. Simumatik has problems with the movement of the manikin, the Python code interpretation of the data has problems with the bending of the neck, and EPP with the twisting of it, as well as it counts other scores that aren´t needed for the overall evaluation (work imparting stress on hips/knees). However, even after facing those problems, the overall accuracy (73,3%) was good and that through further development, this strategy could become stronger and more robust, offering their users more liability with all kinds of use cases. Product Development designers could use the strategy to test industrial machinery and equipment as well, although the main users would be all kinds of companies with an industrial production background that want to study physical ergonomics and can´t spend a huge amount of resources in that.

5 Recommendations

From the understanding and insights of the strategy developed and tested, some recommendations could be introduced in future research:

- Implement more trackers: the results showed that adding a tracker to the chest in most of the use cases could increase the accuracy. The company already bought extra trackers, but they didn't have time to prepare the platform to add them. Therefore, this improvement could be carried out in a short time.
- Fix the neck misinterpretation: from the study of the scores in EPP, it was discovered that in the standard standing position, the neck segment appeared to be leaning forward. There are two solutions:
    - Study if the measurement taken to calculate the forearm was the right one. Fix if not.

    - Fix the position of the head in Python code or in EPP, moving it a bit backward. As well, fix the neck twist in EPP, establishing the rotation angle between the spine and the head.
- Implement the study of the lower limbs: initially, it was decided to study the full-body, but as it happened with the chest tracker, the company Simumatik didn't have ready their platform, and these trackers couldn't be implemented either. REBA method couldn't be properly used either, as its main difference with RULA is that it covers the full body assessment.
- Compare results with JACK: the results of our strategy were compared with IPS IMMA. However, it could be useful to have a second comparison, to strengthen the accuracy of our strategy.

Similar strategies studied throughout the project came up with some recommendations for future development. They are valid for the project, and they cover different levels of difficulty.

- Display ergonomics assessment results back in the VE: for the strategy, it could be useful to introduce back the results of EPP into Simumatik. This could be done by displaying a report once the task was finished or performing real-time assessments. Some projects showed just warning signals (Jayaram et al., 2006), which warned the user about immediate changes to make; however, it could also be improved with some simple manikin sketch-up displayed. Including this manikin with coloured body parts was found to be easier to understand (Iriondo et al., 2019). Garcia Rivera et al. 2020 introduced a screen recording of an ergonomics evaluation tool into VR with software specifically developed for that purpose and was found efficient and reliable as well.
- Study the effects of anthropometry on subjects: Plantard et al., 2017 suggested testing the strategy with different subjects to see if anthropometry affected the result. The project´s experiments were just carried out with one user and it could be good research to study boundary cases and analyse how different measures affect the performance of the strategy or if any misinterpretations arise.
- Study if the strategy democratizes ergonomics assessments: evaluate the costs of the resources needed for the strategy vs the average available resources of small companies. As well as analyse the benefits for the companies. Sultan-Taïeb et al. (2017) propose analysing if ergonomics assessments are worth it from an economic point of view. This means if the benefits, such as reduction of resources spent on WRMSD and improvement of workstation productivity because of redesign, surpass the expenses of the ergonomics assessments.

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7 Appendix A: Ergonomics evaluation methods

Reference	Experiment	Posture data input	Assessment method used	Conclusions
(Jayaram et al., 2006)	Try out two methodologies: develop ergonomics assessments (RULA) in DHM tools or connect DHM tools to ergonomic assessment toolkits (Jack)	1. Sensors in the head (HMD), lower arms, torso, lower legs 2. CyberGlove for the right hand	RULA	1. Implementing ergonomic assessment tools into DHM is the best in terms of fluency of data and easiness. Synchronization accuracy needed for real-time assessments is hard to reach when connecting DHM tools and assessment toolkits 2. Introducing tools with weights in VE helps in the immersion
(Alexopoulos et al., 2013)	Design of ErgoToolkit	1. Virtually in DHM software 2. Static and dynamic snapshots	1. Posture definition and recognition 2. Stress screening with Automotive assembly worksheet (AAWS): posture score sheet, material handling sheet, and action forces sheet	1. Powerful app for design issues 2. Introduction of data manually and automatically 3. Easy interface 4. Easy to adapt to companies 5. Could implement time and cost assessments as a recommendation
(Vignais et al., 2013)	Assess ergonomics in real-time and delivers feedback in an HMD, with visual and audio signals. It is tested in 4 manufacturing tasks	1. 7 IMU´s: one on each upper arm, one on each forearm, one on the HMD, one on the chest, and one on the pelvis 2. Goniometers on wrists	RULA	1. No extra time needed to finish the task 2. Less exposure to dangerous RULA scores

(Battini et al., 2014)	Assess ergonomics in real-time and delivers feedback on a screen on the user´s arm. It is tested in two warehouses	17 IMUs	1. RULA 2. OCRAS 3. OWAS 4. Lifting index (LI) 5 Hands positions 6. Hip movements	1. Uses a colour scale to display real-time feedback to the user 2. Displays information about limitations for each method so the user can choose 3. Increases workers´ productivity and well-being
(Plantard et al., 2015)	Study MoCap with Kinect with virtual input data. Develop a software tool to evaluate the efficiency of Kinect for MoCap in real environments	MoCap with Kinect	RULA	This tool is used with Kinect to: 1. Avoid occlusions 2. Test different camera placement 3. Test difficult postures 4. Mimic real-world situations and overcome its constraints
(Plantard et al., 2017)	Study Kinect with a new occlusion-resistant update: compare MoCap with Kinect with actual movements, in the laboratory, and compare RULA scores provided by Kinect MoCap with expert ones, in a cluttered workstation	MoCap with Kinect	RULA	1. Needs manual and automatic introduction of data 2. Kinect can help ergonomists to evaluate at 30 Hz but can´t substitute them 3. Achieves more accurate results with the occlusion-resistant update
(Iriondo et al., 2019)	Create a software tool to manage posture data	1. Sensors MoCap 2. Virtually in DHM software	1. RULA 2. REBA 3. EAWS	1. Focuses on the users: individual vs. group of workers´ needs for assessment functions; non-expert vs. ergonomists interface design 2. Feedback is given by a virtual or human coach

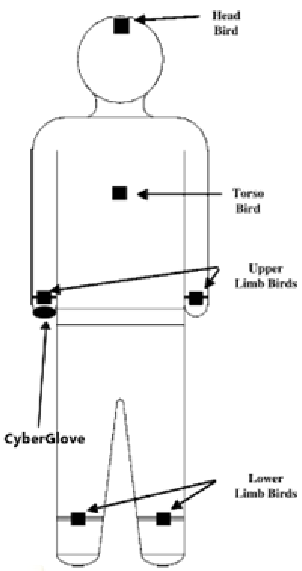
Table 7. Survey of previous experiments

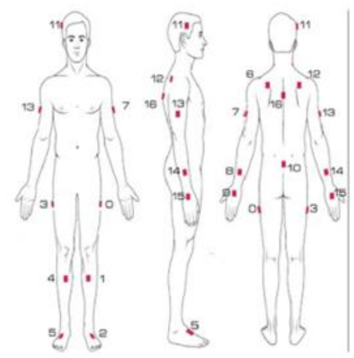
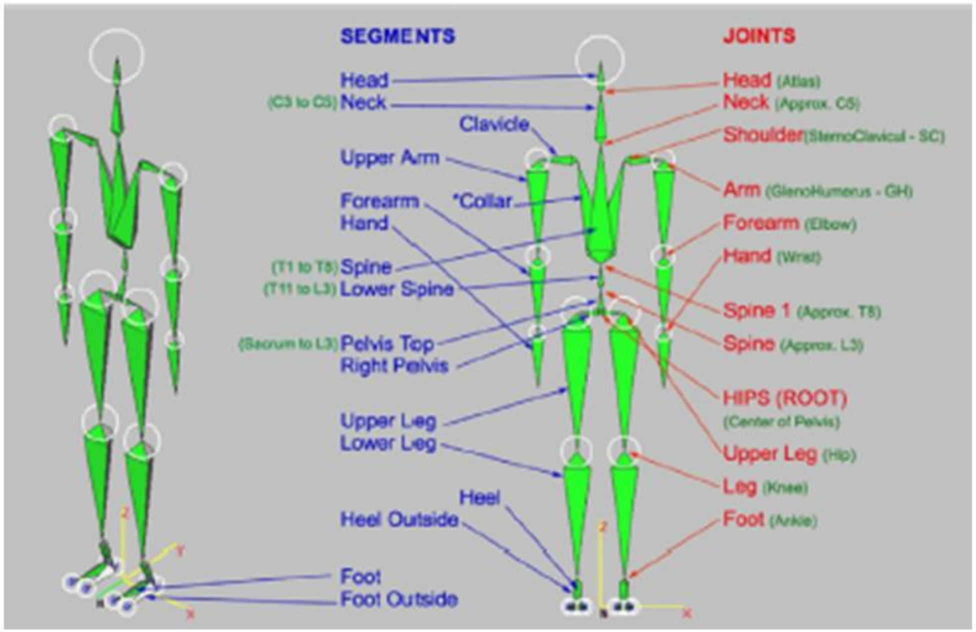
Method	Parts of the body assessed	Posture	Load	Frequency	Duration	Recovery	Material and tests used	Reasons to implement it	Reference
Rapid Upper Limb Assessment (RULA)	Upper body and limb	X	X	X			RULA worksheet with scores for upper body parts and a general score for the posture	(+) Easy (+) Quick assessment (-) Subjective	(Vignais et al., 2013) (Jayaram et al., 2006) (David, 2005) (Iriondo et al., 2019)
Rapid Entire Body Assessment (REBA)	Whole-body	X	X	X			REBA worksheet with scores for upper and lower body parts and a general score for the posture	(+) Easy (+) Quick assessment for dynamic tasks (+) Covers the whole body (-) Subjective	(David, 2005) (Hignett & McAtamney, 2000)
Ovako Working Analysis System (OWAS)	Whole-body (4 basic body portions)	X	X					(+) Time sampling for body posture and force (+) Frequency and time studied (+) Fast (-) No detail on upper limb	(David, 2005) (Battini et al., 2014)
Strain index	Upper limb	X	X	X	X		Upper limb repetitive movement equation. The combined index of six exposure factors	(+) Repetitive movements	(Battini et al., 2014) (David, 2005)

Occupational Repetitive Action (OCRA)	Upper limb	X	X	X	X	X	Upper limb repetitive movement checklist. Assessment scores	(+) Repetitive movements	(Battini et al., 2014) (David, 2005)
Snook and Ciriello	Involve in lifting, in general (back, neck, upper and lower limb) Manual handling						Tables with maximum forces and weights	(+) Manual lifting movements	(Battini et al., 2014)
National Institute of Occupational Safety and Health (NIOSH)	Involve in lifting, in general (back, neck, upper and lower limb) Manual handling	X	X	X	X	X	Lifting equation that defines recommended weight limit (RWL)	(+) Manual lifting equation (+) Assess risk factors	(Battini et al., 2014) (David, 2005)
BORG SCALE								(+) Intensity levels (+) Study of efforts	(Battini et al., 2014)
PLIBEL	Various body parts	X	X				Checklist evaluating different body regions	(+) Risk factors	(David, 2005)
QEC	Upper body and limb	X	X	X	X		Workers responses and scores for the intervention	(+) Study in dynamic and static tasks	(David, 2005)
Manual Handling Guidance, L23	Manual handling	X	X	X	X	X	Checklists for task, environment, equipment, and individual risk factors	(+) Risk factors in manual handling	(David, 2005)

Table 8. Ergonomics assessment methods

8 Appendix B: Experimental studies

Reference	Specs and positioning	Calculation and prediction	Method	Recommendations
(Jayaram et al., 2006)	V-8 helmet, CyberGlove, Flock of Birds hardware devices Total number: 7 	Uses torso tracker to calculate the positions of the rest through forward and inverse kinematics. Transformation matrices orientate body parts according to VE. Upper arms and upper legs are untracked. Torso tracker is used to position shoulder joints, as it defines the orientation of the whole torso. Transformation matrices are used for this. Then, the lower arm tracker is used to calculate the elbow joint with similar equations. The upper arm vector (UA) goes from shoulder to elbow. To draw the lower arm there were two options: 1. Attached to the upper arm at the elbow, using the orientation of the lower arm tracker; 2. Using the global coordinates of the lower arm tracker. Option 1 provided better visual display, as there was no possible gap between lower and upper arm sections, but hand positioning was a bit offset, while option 2 offered better hand positioning although lower and upper arm sections were a bit split at some positions, due to the complexity of the shoulder joint. Option 2 was chosen for better accuracy. Angles of the upper arm for RULA are calculated projecting the UA in the coordinate system related to the torso. L is the reference frame coordinate axis. $\theta = \cos^{-1}(\vec{UA} \cdot \vec{L})$ The lower arm vector goes from the elbow to the palm and its angle is calculated in the same way. Lower body parts are similarly calculated.	RULA	Due to the complexity of the human body, more trackers would be needed. (+) A good setting to track wrist angles and lower arm location and angles, because there is a tracker in the lower arm. (-) A bad setting for back bending. Add more trackers to fix this.

(Battini et al., 2014)	IGS-180i (IMU with magnetic compensation). Trackers have 6 degrees of freedom and work at 500Hz. All are connected to a multi-processing unit that sends data to a computer via Wi-Fi. Total number: 17 	Uses pipeline procedure to determine all body parts' positions and orientations. Prediction is not needed. The biomechanical model used: 	OWAS, OCRA, RULA, LI, hands positioning, distance travelled, hip movements	Enough sensors. Add light sensors for electromyography (EMG) to measure muscle use.

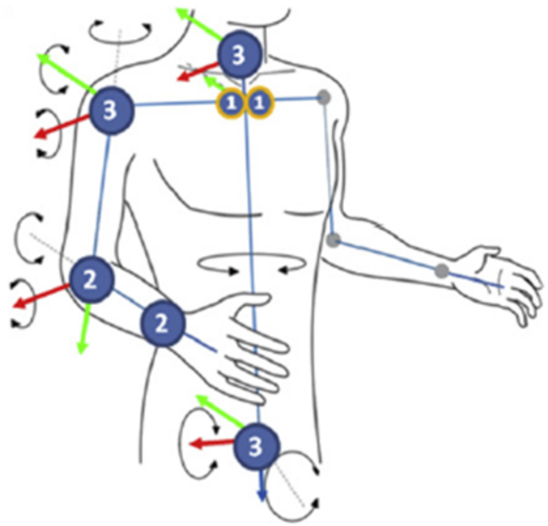
(Vignais et al., 2013)	Wireless Colibri IMUs. Trackers have a tri-axial accelerometer, a tri-axial gyroscope, and a tri-axial magneto-inductive magnetic sensor. Work at 100 Hz. Total number: 7 Bi-axial SG65 goniometers. Record flexion/extension, radial/ulnar deviation of wrist. Total number: 2  	The biomechanical model is composed of 10 rigid parts (trunk, clavicles, upper arms, forearms, hands, and head) connected to restricted articulations (pelvis, neck joint, sternoclavicular joints, shoulder, elbows, and wrists). In total, this model has 20 degrees of freedom: 3 in the pelvis, 3 in the neck, 1 in the clavicle, 2 in the shoulder, 2 in the elbow, and 2 in the wrist. Rotation axes of body parts are presented orthogonal to the model. Calibration process: height of the subject is taken as input and each segment length is derived from that. The position of IMUs to the body segments is directly measured on the human. IMUs are orientated through two postures: standing and forward bending, plus using accelerations and magnetic measurements. Angles of body parts are obtained using the IMUs data with Kalman filters. Trunk, pelvis, and head positions are estimated from the IMUs data and the rotations of the neck and pelvis are calculated with differential rotations. Using chest orientation and data from the arms IMUs, shoulder, and elbows are estimated. 	RULA	Add video signals to overcome magnetic disturbances.

Table 9. Trackers and body parts prediction study

Method	Case studied	DHM tool (1) IPS-IMMA (2) Jack	Scores (1) IPS-IMMA (2) Jack	Result of posture case
RULA	Kneeling right		4 Group A: Arm and Wrist Analysis 2 Left Upper Arm Position 2 Right Upper Arm Position 3 Lower Arms Position (Worst Arm) 2 Left Wrist Position 2 Right Wrist Position 1 Left Wrist Twist 1 Right Wrist Twist 1 Group B: Neck, Trunk and Leg Analysis 1 Neck Position 1 Trunk Position 1 Work postures imparting stress 3 Grand RULA score	Posture doesn´t represent a big danger if it is not held for a long time. It would be a good posture as part of a use case, as it results in a medium RULA score What makes it a 3?

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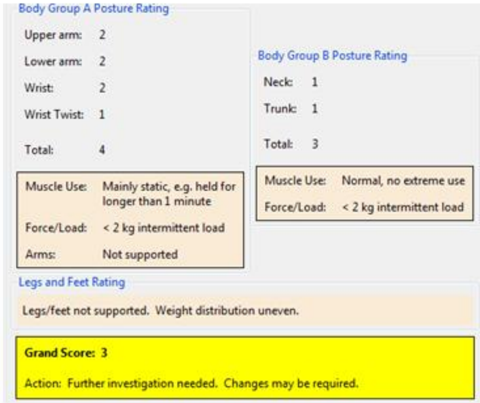
<td>
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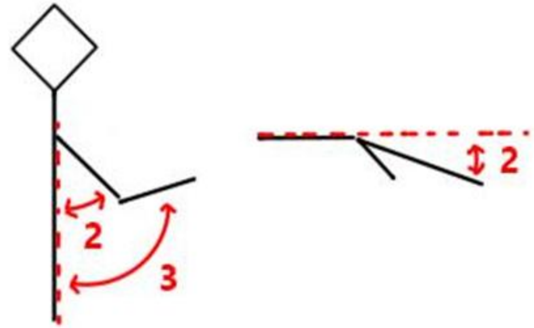
<td>
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<tr>
<td></td>
<td>Standing</td>
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</td>
<td>Posture is fairly simple, doesn’t represent any danger. It´s a good posture for a start of a use case</td>
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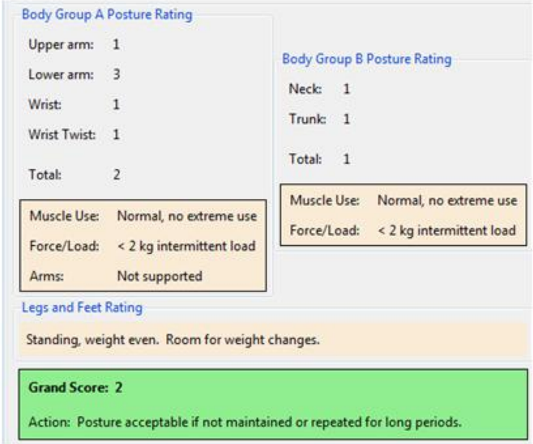
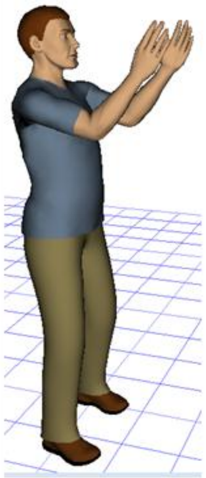
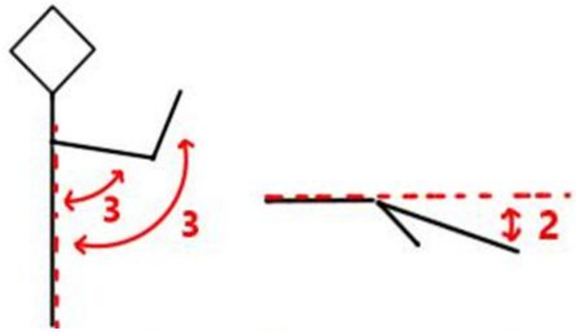
<tr><td></td><td></td><td></td><td>
</td><td></td></tr>
<tr><td></td><td>High work</td><td></td><td>
</td><td>Posture represents a danger of WRMSD. The main posture to focus in a use case

What makes it a 5?</td></tr>
</table>

				 Trunk should have a RULA score of 1. Possible errors of positioning (trunk bending that was not the intention) or software malfunction. If the trunk was properly scored, the final RULA score would be 3

In Jack, scores are usually greater because it takes into account manual input: muscle use and load, for both group A and B, as well as deeper data of feet and legs positioning. Through these data, their estimated scores are more accurate.

Table 10. RULA and REBA assessments in Jack and IPS-IMMA (Fraunhofer Chalmers, 2021; Siemens, 2021)

9 Appendix C: Use cases

A. Mount a [part] into the engine	B. Hammer a [part] into the engine, with rotation	C. Spray the engine, with rotation
1. The worker is in a static position waiting for the AGV to place the engine to be processed right in front of him	1. The worker is in a static position waiting for the AGV to place the engine to be processed right in front of him	1. The worker is in a static position waiting for the AGV to place the engine to be processed right in front of him
2. The worker has in a box at waist height a toolbox: a drill, a wrench, and a spray of oil for greasing. At the head height on the right side, there is a shelf with the new coupling parts for the engine, as well as screws	2. The worker is provided with a toolbox at hip height on the right side. In the toolbox, there is a hammer with silicone heads to avoid damaging the engine structure. At the same level, but on the left side, there is [part] that needs to be hammered into the engine	2. The worker is provided with a spray gun of rust inhibitor fluid at rib level in the right position
3. The worker with his right arm takes the drill and makes a small hole in the engine	3. The engine is rotated 90º for better positioning of the holes where this [part] will be introduced. A button on the right side of the AGV is pressed for this	3. The worker grabs the spray gun
4. The worker leaves the drill in its corresponding box (waist height) and decides to take the new part that will be attached to the engine	4. The worker takes the [part] and places it in its position	4. The worker sprays the entire engine in a sideways motion while the engine is rotating 360 degrees
5. He places the piece with both hands in its new position and fits in the previous hole	5. The worker takes the hammer and beats the [part] until it´s completely inside its position	5. The activity ends and the engine is moved to another workstation

6. With the help of the wrench, the worker tightens the screws of the new piece, leaves the wrench, and takes the oil spray to grease the new joints	6. The activity ends and the engine is moved to another workstation	6. The worker waits for a new engine to repeat the operation
7. The activity ends and the engine is moved to another workstation	7. The worker waits for a new engine to repeat the operation	7. The worker completes the operation in 30 seconds
8. The worker waits for a new engine to repeat the operation	8. The worker completes the operation in 1 minute	
9. The worker completes the operation in 1 minute and 20 seconds		

Table 11. Initial use cases

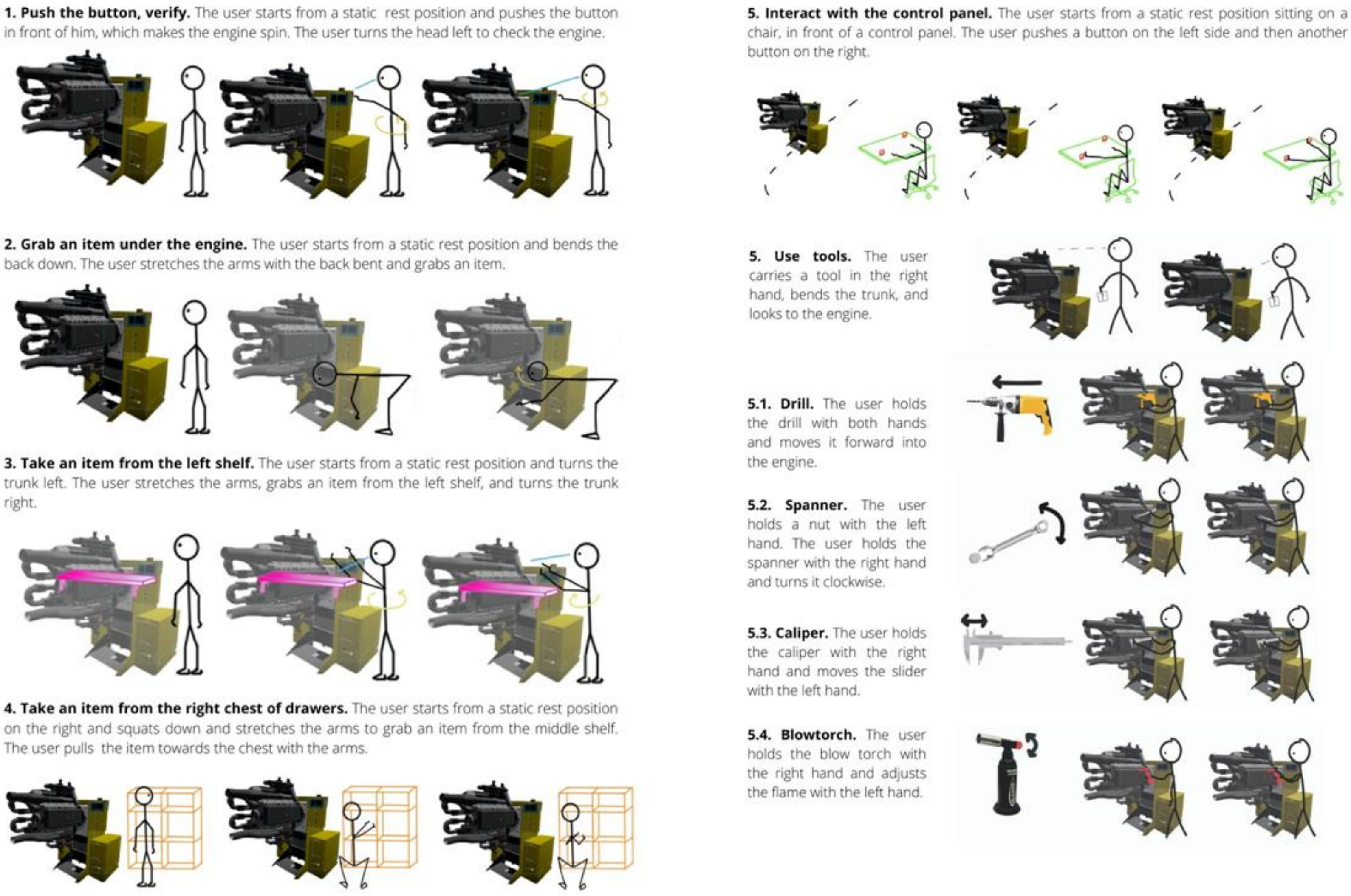


Figure 21. Final use cases

10 Appendix D: Body parts data

	Limitations (rad)		
Joints	Degrees of freedom	Lower	Upper
Neck	3 (rx,ry,rz)	-0.5 -0.5 -1	0.5 0.5 1
Shoulder	3 (rx,ry,rz)	-1.5 -0.5 -1.5	1.5 0.5 1.5
Elbow	1 (rx)	-1	0
Wrist	2 (ry,rz)	-0.5 -0.5	0.5 0.5

Table 12. Limits in the movement of the manikin joints

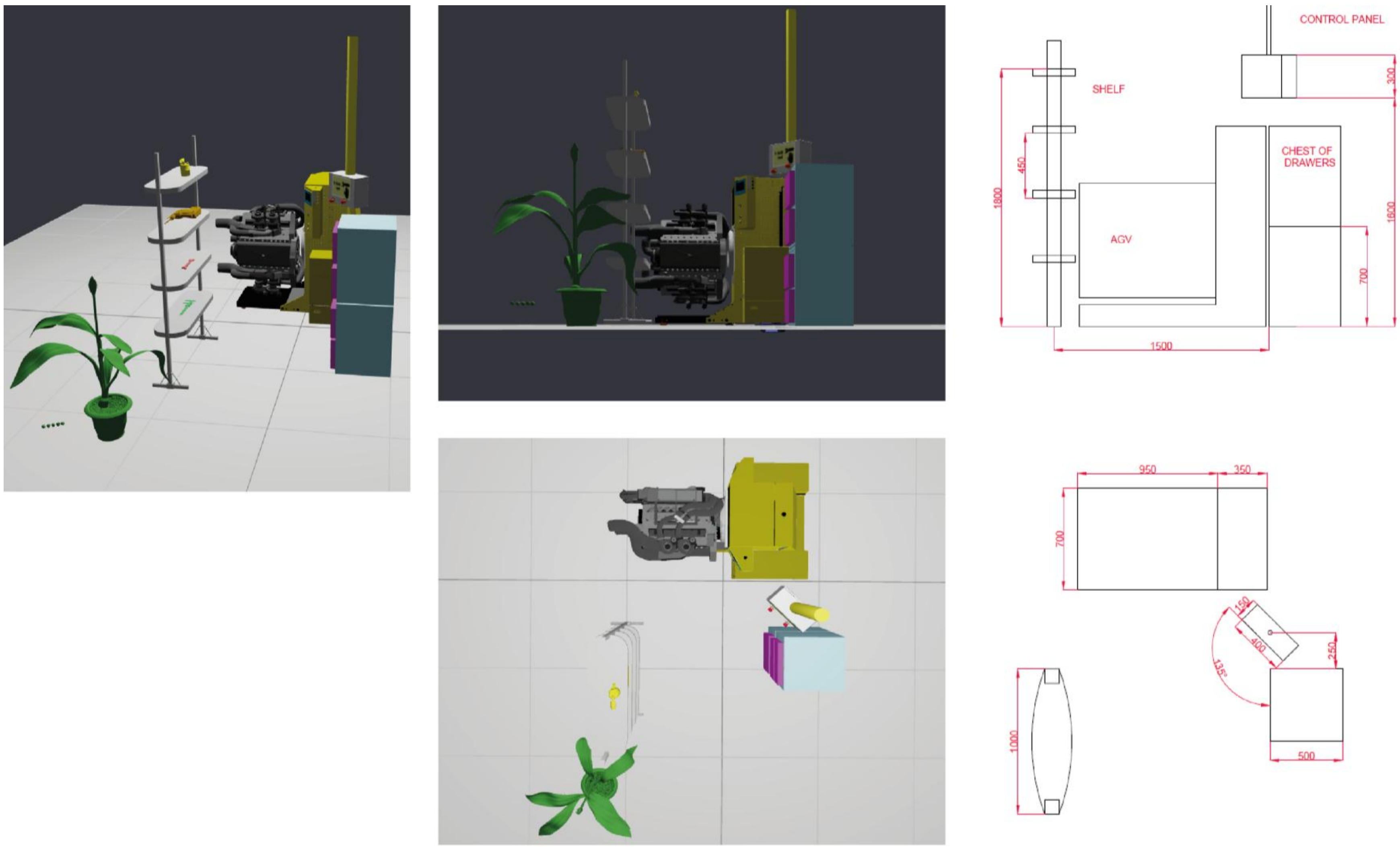


Figure 22. Draft of the workstation created

Body parts	References
L5S1	f(x,y,z) = T6T7(x,y, z-0.8)
L3L4	f(x,y,z) = T6T7(x,y, z-0.4)
T12L1	f(x,y,z) = T6T7(x,y, z-0.2)
T6T7	Middle point between both shoulders
T1T2	Middle point between both shoulders
C6C7	f(x,y,z) = T6T7(x,y, z+0.02)
C4C5	f(x,y,z) = T6T7(x,y, z+0.04)
Atlanto_Axial	Head
Eyeside	Head
LeftHip & RightHip	f(x,y,z) = Shoulder(x,y, z-0.9)
LeftKnee & RightKnee	f(x,y,z) = Shoulder(x,y, z-0.13)
LeftAnkleRot & RightAnkleRot	f(x,y,z) = Shoulder(x,y, z-0.17)
LeftAnkle & RightAnkle	f(x,y,z) = Shoulder(x,y, z-0.17)
LeftToes & RightToes	f(x,y,z) = Shoulder(x,y, z-0.17)
LeftAC & RightAC	Shoulder
LeftGH & RightGH	Shoulder
LeftShoulderRotation & RighShoulderRotation	Shoulder
LeftElbow & RightElbow	Elbow
LeftWristRotation & RightWristRotation	Wrist
LeftWrist & RightWrist	Wrist
Left_MiddleCarpal & Right_MiddleCarpal	f(x,y,z) = Wrist(x,y,z+0.05)
Left_MiddleProximal & Right_MiddleProximal	f(x,y,z) = Wrist(x,y,z-0.05)
Left_IndexProximal & Right_IndexProximal	f(x,y,z) = Wrist(x,y+0.1,z)
Left_IndexCarpal & Right_IndexCarpal	f(x,y,z) = Wrist(x,y+0.1,z)
Left_PinkyProximal & Right_PinkyProximal	f(x,y,z) = Wrist(x,y,z-0.05)

Table 13. References and calculations performed to obtain the positioning data needed in EPP

11 Appendix E: Python code

```
import math
import json
from matplotlib import pyplot
from mpl_toolkits.mplot3d import Axes3D
def callJSON (file):
    f = open(file)

    data = json.load(f)
    # Iterating through the json
    # list
    k = 0

    ''' head,chest,left_arm,right_arm,left_forearm,right_forearm,left_hand,right_hand '''
    partes = [[], [], [], [], [], [], [], []]
    tiempo = (data['time_stamps'])
    for i in data:
        if i != 'time_stamps':
            objeto = (data[i])
            for j in objeto:
                # print(j,":", objeto[j])
                partes[k].append(objeto[j])
            # print(partes[k])
            k += 1
    f.close()
    return (partes,tiempo)
def q_conjugate(q):
    w, x, y, z = q
    return (w, -x, -y, -z)
def q_mult(q1, q2):
    w1, x1, y1, z1 = q1
    w2, x2, y2, z2 = q2
    w = w1 * w2 - x1 * x2 - y1 * y2 - z1 * z2
```

```
    x = w1 * x2 + x1 * w2 + y1 * z2 - z1 * y2
    y = w1 * y2 + y1 * w2 + z1 * x2 - x1 * z2
    z = w1 * z2 + z1 * w2 + x1 * y2 - y1 * x2
    return w, x, y, z
def qv_mult(q1, v1):
    q2 = (0.0,) + v1
    return q_mult(q_mult(q1, q2), q_conjugate(q1))[1:]
def norm (v):
    m=math.sqrt((v[0]**2)+(v[1]**2)+(v[2]**2))
    a=v[0]/m
    b = v[1] / m
    c = v[2] / m
    return (a,b,c)
def vecX (q):
    o=(1,0,0)
    q = qv_mult(q,o)
    return norm(q)
def vecY (q):
    o=(0,1,0)
    q = qv_mult(q,o)
    return norm(q)
def vecZ (q):
    o=(0,0,1)
    q = qv_mult(q,o)
    return norm(q)
def point (q,p,d,a):
    if a=='x':
        vf=vecX(q)
    elif a=='y':
        vf = vecY(q)
    elif a == 'z':
        vf = vecZ(q)
    a=d*vf[0]
    b=d*vf[1]
    c=d*vf[2]
    x=a+p[0]
```

```
    y = b + p[1]
    z = c + p[2]
    return (x,y,z)
def midP (p1,p2):
    v=[0,0,0]
    v[0] = p2[0] - p1[0]
    v[1] = p2[1] - p1[1]
    v[2] = p2[2] - p1[2]
    m = math.sqrt((v[0] ** 2) + (v[1] ** 2) + (v[2] ** 2))
    v=norm(v)
    a=v[0]*(m/2)
    b = v[1] * (m / 2)
    c = v[2] * (m / 2)
    x = a+p1[0]
    y = b + p1[1]
    z = c + p1[2]
    return (x,y,z)


def cL5S1 (MidS):
    valores = [[], [], []]
    for i in range(len(MidS[0])):
        valores[0].append(MidS[0][i])
        valores[1].append(MidS[1][i])
        valores[2].append(MidS[2][i] -0.8)
    return valores
def cL3L4 (MidS):
    valores = [[], [], []]
    for i in range(len(MidS[0])):
        valores[0].append(MidS[0][i])
        valores[1].append(MidS[1][i])
        valores[2].append(MidS[2][i] - 0.4)
    return valores
def cT12L1 (MidS):
    valores = [[], [], []]
    for i in range(len(MidS[0])):
```

```
        valores[0].append(MidS[0][i])
        valores[1].append(MidS[1][i])
        valores[2].append(MidS[2][i] - 0.2)
    return valores
def Elbow (arm):
    valores=[[],[],[]]
    for i in range(len(arm[0])):
        p = list()
        q = list()
        p.append(arm[0][i])
        p.append(arm[1][i])
        p.append(arm[2][i])
        q.append(arm[6][i])
        q.append(arm[3][i])
        q.append(arm[4][i])
        q.append(arm[5][i])
        np= point(q,p,0.15,'y')
        valores[0].append(np[0])
        valores[1].append(np[1])
        valores[2].append(np[2])
    return valores
def Shoulder (arm):
    valores=[[],[],[]]
    for i in range(len(arm[0])):
        p = list()
        q = list()
        p.append(arm[0][i])
        p.append(arm[1][i])
        p.append(arm[2][i])
        q.append(arm[6][i])
        q.append(arm[3][i])
        q.append(arm[4][i])
        q.append(arm[5][i])
        np= point(q,p,-0.15,'y')
        valores[0].append(np[0])
        valores[1].append(np[1])
```

```
        valores[2].append(np[2])
    return valores
def Wrist (hand):
    valores=[[],[],[]]
    for i in range(len(hand[0])):
        p = list()
        q = list()
        p.append(hand[0][i])
        p.append(hand[1][i])
        p.append(hand[2][i])
        q.append(hand[6][i])
        q.append(hand[3][i])
        q.append(hand[4][i])
        q.append(hand[5][i])
        np= point(q,p,-0.1,'y')
        valores[0].append(np[0])
        valores[1].append(np[1])
        valores[2].append(np[2])
    return valores
def Fingers (hand):
    valores=[[],[],[]]
    for i in range(len(hand[0])):
        p = list()
        q = list()
        p.append(hand[0][i])
        p.append(hand[1][i])
        p.append(hand[2][i])
        q.append(hand[6][i])
        q.append(hand[3][i])
        q.append(hand[4][i])
        q.append(hand[5][i])
        np= point(q,p,0.1,'y')
        valores[0].append(np[0])
        valores[1].append(np[1])
        valores[2].append(np[2])
    return valores
```

```
def SideTopHand (hand):
    valores=[[],[],[]]
    for i in range(len(hand[0])):
        p = list()
        q = list()
        p.append(hand[0][i])
        p.append(hand[1][i])
        p.append(hand[2][i])
        q.append(hand[6][i])
        q.append(hand[3][i])
        q.append(hand[4][i])
        q.append(hand[5][i])
        np= point(q,p,0.05,'z')
        valores[0].append(np[0])
        valores[1].append(np[1])
        valores[2].append(np[2])
    return valores
def SideBottomHand (hand):
    valores=[[],[],[]]
    for i in range(len(hand[0])):
        p = list()
        q = list()
        p.append(hand[0][i])
        p.append(hand[1][i])
        p.append(hand[2][i])
        q.append(hand[6][i])
        q.append(hand[3][i])
        q.append(hand[4][i])
        q.append(hand[5][i])
        np= point(q,p,-0.05,'z')
        valores[0].append(np[0])
        valores[1].append(np[1])
        valores[2].append(np[2])
    return valores
def MidShoulder (s1,s2):
    valores=[[],[],[]]
```

```
    for i in range(len(s1[0])):
        p1 = list()
        p2 = list()
        p1.append(s1[0][i])
        p1.append(s1[1][i])
        p1.append(s1[2][i])
        p2.append(s2[0][i])
        p2.append(s2[1][i])
        p2.append(s2[2][i])

        valores[0].append(midP(p1,p2)[0])
        valores[1].append(midP(p1,p2)[1])
        valores[2].append(midP(p1,p2)[2])
    return valores

def cC6C7 (MidS):
    valores = [[],[],[]]
    for i in range(len(MidS[0])):
        valores[0].append(MidS[0][i])
        valores[1].append(MidS[1][i])
        valores[2].append(MidS[2][i] + 0.02)
    return valores
def cC4C5 (MidS):
    valores = [[], [], []]
    for i in range(len(MidS[0])):
        valores[0].append(MidS[0][i])
        valores[1].append(MidS[1][i])
        valores[2].append(MidS[2][i] + 0.04)
    return valores
def Hip (Shoulder):
    valores = [[], [], []]
    for i in range(len(Shoulder[0])):
        valores[0].append(Shoulder[0][i])
        valores[1].append(Shoulder[1][i])
        valores[2].append(Shoulder[2][i] - 0.9)
    return valores
```

```
def Knee (Shoulder):
    valores = [[], [], []]
    for i in range(len(Shoulder[0])):
        valores[0].append(Shoulder[0][i])
        valores[1].append(Shoulder[1][i])
        valores[2].append(Shoulder[2][i] - 1.3)
    return valores
def Ankle (Shoulder):
    valores = [[], [], []]
    for i in range(len(Shoulder[0])):
        valores[0].append(Shoulder[0][i])
        valores[1].append(Shoulder[1][i])
        valores[2].append(Shoulder[2][i] - 1.7)
    return valores
'''def Toes (L5S1): #no lo estoy usando
    valores = [[]]
    for i in L5S1:
        valores[0][i] = (L5S1[0][i] + 0.2)
        valores[1][i] = (L5S1[1][i]+ 0.2)
        valores[2][i] = (L5S1[2][i] - 0.9)
    return valores'''
def draw ():
    fig = pyplot.figure()
    # fig = plt.figure()
    # ax = fig.add_subplot(111, projection='3d')
    ax = Axes3D(fig)
    '''xs=(-0.489,-0.465,-0.294,-0.0475)
    ys=(0.2602,0.006304,0.0336,0.08799)
    zs=(1.196,1.2451,1.000,1.042)

    xl=(-0.489,-0.51267,-0.3133,-0.100,0.06665,-0.0438,0.0098)
    yl=(0.2602,0.51413,0.511,0.447,0.4644,0.45255,0.4594)
    zl=(1.196,1.1480,0.923,0.983,1.0921,1.080,0.9959)

    xc=(-0.307,-0.489299,-0.4892,-0.48929,-0.48929,-0.489)
    yc=(0.275,0.260217,0.260,0.260217,0.2602,0.260)
```

```python
zc=(1.494,1.23663,1.216,0.9966,0.79663,0.3966)

xp=(-0.489,-0.512679,-0.5126,-0.5126)
yp=(0.260,0.51413,0.514130,0.514130)
zp=(0.3966,0.248083,-0.15191,-0.551)
ax.plot(xs, ys, zs)


import time
#time.sleep(5)
ax.plot(xl, yl, zl)
ax.plot(xc, yc, zc)
ax.plot(xp, yp, zp)'''
ax.set_xlabel('X')
ax.set_ylabel('Y')
ax.set_zlabel('Z')
ax.set_xlim3d([-2, 2])
ax.set_ylim3d([-2, 2])
ax.set_zlim3d([0, 2])

def Column(Atlanto_Axial, C4C5, C6C7, T12L1, L3L4, L5S1, i):
    valores = [[], [], []]  # lista de tres listas con X,Y y Z de cada partes de la columna. i es la iteración.
    valores[0].append(Atlanto_Axial[0][i])
    valores[1].append(Atlanto_Axial[1][i])
    valores[2].append(Atlanto_Axial[2][i])

    valores[0].append(C4C5[0][i])
    valores[1].append(C4C5[1][i])
    valores[2].append(C4C5[2][i])

    valores[0].append(C6C7[0][i])
    valores[1].append(C6C7[1][i])
    valores[2].append(C6C7[2][i])

    valores[0].append(T12L1[0][i])
    valores[1].append(T12L1[1][i])
```

```
        valores[2].append(T12L1[2][i])

        valores[0].append(L3L4[0][i])
        valores[1].append(L3L4[1][i])
        valores[2].append(L3L4[2][i])

        valores[0].append(L5S1[0][i])
        valores[1].append(L5S1[1][i])
        valores[2].append(L5S1[2][i])

        return valores

    def RArm(T6T7, RightAC, RightElbow, RightWrist, Right_IndexCarpal, Right_MiddleCarpal, Right_MiddleProximal, i):
        valores = [[], [], []]  # lista de tres listas con X,Y y Z de cada partes del brazo derecho. i es la 
iteración.
        valores[0].append(T6T7[0][i])
        valores[1].append(T6T7[1][i])
        valores[2].append(T6T7[2][i])

        valores[0].append(RightAC[0][i])
        valores[1].append(RightAC[1][i])
        valores[2].append(RightAC[2][i])

        valores[0].append(RightElbow[0][i])
        valores[1].append(RightElbow[1][i])
        valores[2].append(RightElbow[2][i])

        valores[0].append(RightWrist[0][i])
        valores[1].append(RightWrist[1][i])
        valores[2].append(RightWrist[2][i])

        valores[0].append(Right_IndexCarpal[0][i])
        valores[1].append(Right_IndexCarpal[1][i])
        valores[2].append(Right_IndexCarpal[2][i])

        valores[0].append(Right_MiddleCarpal[0][i])
```

```python
    valores[1].append(Right_MiddleCarpal[1][i])
    valores[2].append(Right_MiddleCarpal[2][i])

    valores[0].append(Right_MiddleProximal[0][i])
    valores[1].append(Right_MiddleProximal[1][i])
    valores[2].append(Right_MiddleProximal[2][i])

    return valores

def LArm(T6T7, LeftAC, LeftElbow, LeftWrist, Left_IndexCarpal, Left_MiddleCarpal, Left_MiddleProximal, i):
    valores = [[], [],
               []]  # lista de tres listas con X,Y y Z de cada partes del brazo izquierdo. i es la iteración.
    valores[0].append(T6T7[0][i])
    valores[1].append(T6T7[1][i])
    valores[2].append(T6T7[2][i])

    valores[0].append(LeftAC[0][i])
    valores[1].append(LeftAC[1][i])
    valores[2].append(LeftAC[2][i])

    valores[0].append(LeftElbow[0][i])
    valores[1].append(LeftElbow[1][i])
    valores[2].append(LeftElbow[2][i])

    valores[0].append(LeftWrist[0][i])
    valores[1].append(LeftWrist[1][i])
    valores[2].append(LeftWrist[2][i])

    valores[0].append(Left_IndexCarpal[0][i])
    valores[1].append(Left_IndexCarpal[1][i])
    valores[2].append(Left_IndexCarpal[2][i])

    valores[0].append(Left_MiddleCarpal[0][i])
    valores[1].append(Left_MiddleCarpal[1][i])
    valores[2].append(Left_MiddleCarpal[2][i])
```

```
        valores[0].append(Left_MiddleProximal[0][i])
        valores[1].append(Left_MiddleProximal[1][i])
        valores[2].append(Left_MiddleProximal[2][i])

        return valores

    def RLeg(L5S1, RightHip, RightKnee, RightAnkle, i):
        valores = [[], [],
                   []]  # lista de tres listas con X,Y y Z de cada partes de la pierna derecha. i es la iteración.
        valores[0].append(L5S1[0][i])
        valores[1].append(L5S1[1][i])
        valores[2].append(L5S1[2][i])

        valores[0].append(RightHip[0][i])
        valores[1].append(RightHip[1][i])
        valores[2].append(RightHip[2][i])

        valores[0].append(RightKnee[0][i])
        valores[1].append(RightKnee[1][i])
        valores[2].append(RightKnee[2][i])

        valores[0].append(RightAnkle[0][i])
        valores[1].append(RightAnkle[1][i])
        valores[2].append(RightAnkle[2][i])

        return valores

    def LLeg(L5S1, LeftHip, LeftKnee, LeftAnkle, i):
        valores = [[], [], []]  # lista de tres listas con X,Y y Z de cada partes de la pierna izq. i es la
iteración.
        valores[0].append(L5S1[0][i])
        valores[1].append(L5S1[1][i])
        valores[2].append(L5S1[2][i])

        valores[0].append(LeftHip[0][i])
        valores[1].append(LeftHip[1][i])
```

```
        valores[2].append(LeftHip[2][i])

        valores[0].append(LeftKnee[0][i])
        valores[1].append(LeftKnee[1][i])
        valores[2].append(LeftKnee[2][i])

        valores[0].append(LeftAnkle[0][i])
        valores[1].append(LeftAnkle[1][i])
        valores[2].append(LeftAnkle[2][i])

        return valores

    for i in range(len(Atlanto_Axial[0])):
        c, = ax.plot(Column(Atlanto_Axial, C4C5, C6C7, T12L1, L3L4, L5S1, i)[0],
                     Column(Atlanto_Axial, C4C5, C6C7, T12L1, L3L4, L5S1, i)[1],
                     Column(Atlanto_Axial, C4C5, C6C7, T12L1, L3L4, L5S1, i)[2], color='green')
        RA, =ax.plot(RArm(T6T7, RightAC, RightElbow, RightWrist,
Right_IndexCarpal,Right_MiddleCarpal,Right_MiddleProximal, i)[0],RArm(T6T7, RightAC, RightElbow, RightWrist,
Right_IndexCarpal,Right_MiddleCarpal,Right_MiddleProximal, i)[1],RArm(T6T7, RightAC, RightElbow, RightWrist,
Right_IndexCarpal,Right_MiddleCarpal,Right_MiddleProximal, i)[2],color='green')
        LA, =ax.plot(LArm(T6T7, LeftAC, LeftElbow, LeftWrist, Left_IndexCarpal, Left_MiddleCarpal,
Left_MiddleProximal, i)[0],LArm(T6T7, LeftAC, LeftElbow, LeftWrist, Left_IndexCarpal, Left_MiddleCarpal,
Left_MiddleProximal, i)[1],LArm(T6T7, LeftAC, LeftElbow, LeftWrist, Left_IndexCarpal, Left_MiddleCarpal,
Left_MiddleProximal, i)[2],color='green')
        RL, =ax.plot(RLeg(L5S1, RightHip, RightKnee, RightAnkle, i)[0],RLeg(L5S1, RightHip, RightKnee, RightAnkle,
i)[1],RLeg(L5S1, RightHip, RightKnee, RightAnkle, i)[2],color='green')
        LL, =ax.plot(LLeg(L5S1, LeftHip, LeftKnee, LeftAnkle, i)[0],LLeg(L5S1, LeftHip, LeftKnee, LeftAnkle,
i)[1],LLeg(L5S1, LeftHip, LeftKnee, LeftAnkle, i)[2],color='green')
        pyplot.pause(0.1)
        c.remove()
        RA.remove()
        LA.remove()
        RL.remove()
        LL.remove()

    '''ln, =ax.plot((1,2), (2,3), (4,5))
```

```
    pyplot.pause(3)
    ax.plot((2,7), (1,1), (4,5))
    ln.remove()
    pyplot.pause(3)
    ax.plot((2,5), (4,4), (4,5))'''

    pyplot.show()

def zerolistmaker (n):
    listofzeros=[0]*n
    return listofzeros

def convert():
    data= {
       "Operation sequence" : "Tryout0",
       "Simulation name" : "Tryout0",
       "Simulation settings" :
          {
             "Time stamps" : tiempo,
             "Operation Sequence actors" : ["Family 1"],
             "Family 1" :
                {
                   "Actions" : ["Start"]
                }
          },
       "Manikin family" :
             {
                "Name" : "Family 1",
                "Manikin names" : ["Female_w=65_s=1674"],
                "Type" : "IMMA",
                "Female_w=65_s=1674" :
                   {
                      "Name" : "Female_w=65_s=1674",
                      "Anthropometrics" :
                         {
                            "Measurements vector" : ["Body mass (weight)", "Stature (body height)", "Eye height",
```

"Shoulder height", "Elbow height", "Iliac spine height, standing", "Crotch height", "Tibial height", "Chest depth, standing", "Body depth, standing", "Chest breadth, standing", "Hip breadth, standing", "Sitting height (erect)", "Eye height, sitting", "Cervicale height, sitting", "Shoulder height, sitting", "Elbow height, sitting", "Shoulder-elbow length", "Elbow-wrist length", "Shoulder (biacromial) breadth", "Shoulder (bideltoid) breadth", "Elbow-to-elbow breadth", "Hip breadth, sitting", "Lower leg length (popliteal height)", "Thigh clearance", "Knee height", "Abdominal depth, sitting", "Thorax depth at the nipple", "Buttock-abdomen depth sitting", "Hand length", "Palm length perpendicular", "Hand breadth at metacarpals", "Index finger length", "Index finger breadth, distal", "Foot length", "Foot breadth", "Head length", "Head breadth", "Face length (nasion-menton)", "Head circumference", "Sagittal arc", "Bitrageon arc", "Wall-acromion distance", "Grip reach (forward reach)", "Elbow-grip length", "Fist (grip axis) height", "Forearm-fingertip length", "Buttock-popliteal length (seat depth)", "Buttock-knee length", "Neck circumference", "Chest circumference", "Waist circumference", "Wrist circumference", "Thigh circumference", "Calf circumference"],
"Measurements" :
{
"Body mass (weight)" : 65,
"Stature (body height)" : 1674,
"Eye height" : 1553,
"Shoulder height" : 1359,
"Elbow height" : 1042,
"Iliac spine height, standing" : 933,
"Crotch height" : 796,
"Tibial height" : 407,
"Chest depth, standing" : 238,
"Body depth, standing" : 252,
"Chest breadth, standing" : 328,
"Hip breadth, standing" : 387,
"Sitting height (erect)" : 892,
"Eye height, sitting" : 766,
"Cervicale height, sitting" : 639,
"Shoulder height, sitting" : 575,
"Elbow height, sitting" : 238,
"Shoulder-elbow length" : 341,
"Elbow-wrist length" : 278,
"Shoulder (biacromial) breadth" : 357,
"Shoulder (bideltoid) breadth" : 425,
"Elbow-to-elbow breadth" : 490,

```
        "Hip breadth, sitting" : 428,
        "Lower leg length (popliteal height)" : 454,
        "Thigh clearance" : 147,
        "Knee height" : 522,
        "Abdominal depth, sitting" : 235,
        "Thorax depth at the nipple" : 160,
        "Buttock-abdomen depth sitting" : 250,
        "Hand length" : 180,
        "Palm length perpendicular" : 103,
        "Hand breadth at metacarpals" : 79,
        "Index finger length" : 67,
        "Index finger breadth, distal" : 16,
        "Foot length" : 243,
        "Foot breadth" : 92,
        "Head length" : 189,
        "Head breadth" : 147,
        "Face length (nasion-menton)" : 115,
        "Head circumference" : 556,
        "Sagittal arc" : 0,
        "Bitrageon arc" : 0,
        "Wall-acromion distance" : 0,
        "Grip reach (forward reach)" : 758,
        "Elbow-grip length" : 346,
        "Fist (grip axis) height" : 743,
        "Forearm-fingertip length" : 474,
        "Buttock-popliteal length (seat depth)" : 478,
        "Buttock-knee length" : 594,
        "Neck circumference" : 318,
        "Chest circumference" : 962,
        "Waist circumference" : 788,
        "Wrist circumference" : 153,
        "Thigh circumference" : 599,
        "Calf circumference" : 363
    },
  "Ranges of motion vector" : ["None"],
  "Ranges of motion" :
```

```
                        {
                            "None" : 0
                        }
                    },
                "Motion" :
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                                        "Joints" : ["Translation", "Rotation", "L5S1", "L3L4", "T12L1", "T6T7",
"T1T2", "C6C7", "C4C5", "AtlantoAxial", "Eyeside", "LeftHip", "LeftKnee", "LeftAnkleRot", "LeftAnkle", "LeftToes",
"RightHip", "RightKnee", "RightAnkleRot", "RightAnkle", "RightToes", "RightAC", "RightGH", "RightShoulderRotation",
"RightElbow", "RightWristRotation", "LeftAC", "LeftGH", "LeftShoulderRotation", "LeftElbow", "LeftWristRotation",
"LeftWrist", "Left_IndexCarpal", "Left_IndexProximal",  "Left_MiddleCarpal", "Left_MiddleProximal",  "RightWrist",
"Right_IndexCarpal", "Right_IndexProximal",  "Right_MiddleCarpal", "Right_MiddleProximal", "Right_PinkyProximal",
"Left_PinkyProximal"],
                                        "Transformations" :
                                            {
                                                "Translation" :
                                                    {
                                                        "tx" : L5S1[0],
                                                        "ty" : L5S1[1],
                                                        "tz" : L5S1[2],
                                                        "r1x" : zerolistmaker(len(tiempo)),
                                                                        "r1y" : zerolistmaker(len(tiempo)),
                                                                        "r1z" : zerolistmaker(len(tiempo)),
                                                                        "r2x" : zerolistmaker(len(tiempo)),
                                                                        "r2y" : zerolistmaker(len(tiempo)),
                                                                        "r2z" : zerolistmaker(len(tiempo)),
                                                                        "r3x" : zerolistmaker(len(tiempo)),
                                                                        "r3y" : zerolistmaker(len(tiempo)),
                                                                        "r3z" : zerolistmaker(len(tiempo)),
                                                                    },
                                                "Rotation" :
                                                    {
                                                        "tx" : zerolistmaker(len(tiempo)),
                                                        "ty" : zerolistmaker(len(tiempo)),
                                                        "tz" : zerolistmaker(len(tiempo)),
                                                        "r1x" : zerolistmaker(len(tiempo)),
```

```
                                        "r1y" : zerolistmaker(len(tiempo)),
                                        "r1z" : zerolistmaker(len(tiempo)),
                                        "r2x" : zerolistmaker(len(tiempo)),
                                        "r2y" : zerolistmaker(len(tiempo)),
                                        "r2z" : zerolistmaker(len(tiempo)),
                                        "r3x" : zerolistmaker(len(tiempo)),
                                        "r3y" : zerolistmaker(len(tiempo)),
                                        "r3z" : zerolistmaker(len(tiempo)),
                                    },
"L5S1" :
    {
        "tx" : L5S1[0],
        "ty" : L5S1[1],
        "tz" : L5S1[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                        "r1y" : zerolistmaker(len(tiempo)),
                                        "r1z" : zerolistmaker(len(tiempo)),
                                        "r2x" : zerolistmaker(len(tiempo)),
                                        "r2y" : zerolistmaker(len(tiempo)),
                                        "r2z" : zerolistmaker(len(tiempo)),
                                        "r3x" : zerolistmaker(len(tiempo)),
                                        "r3y" : zerolistmaker(len(tiempo)),
                                        "r3z" : zerolistmaker(len(tiempo)),
                                    },
"L3L4" :
    {
        "tx" : L3L4[0],
        "ty" : L3L4[1],
        "tz" : L3L4[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                        "r1y" : zerolistmaker(len(tiempo)),
                                        "r1z" : zerolistmaker(len(tiempo)),
                                        "r2x" : zerolistmaker(len(tiempo)),
                                        "r2y" : zerolistmaker(len(tiempo)),
                                        "r2z" : zerolistmaker(len(tiempo)),
                                        "r3x" : zerolistmaker(len(tiempo)),
```

```
                                        "r3y" : zerolistmaker(len(tiempo)),
                                        "r3z" : zerolistmaker(len(tiempo)),
                                   },
                    "T12L1" :
                       {
                          "tx" : T12L1[0],
                          "ty" : T12L1[1],
                          "tz" : T12L1[2],
                          "r1x" : zerolistmaker(len(tiempo)),
                                        "r1y" : zerolistmaker(len(tiempo)),
                                        "r1z" : zerolistmaker(len(tiempo)),
                                        "r2x" : zerolistmaker(len(tiempo)),
                                        "r2y" : zerolistmaker(len(tiempo)),
                                        "r2z" : zerolistmaker(len(tiempo)),
                                        "r3x" : zerolistmaker(len(tiempo)),
                                        "r3y" : zerolistmaker(len(tiempo)),
                                        "r3z" : zerolistmaker(len(tiempo)),
                                   },
                    "T6T7" :
                       {
                          "tx" : T6T7[0],
                          "ty" : T6T7[1],
                          "tz" : T6T7[2],
                          "r1x" : zerolistmaker(len(tiempo)),
                                        "r1y" : zerolistmaker(len(tiempo)),
                                        "r1z" : zerolistmaker(len(tiempo)),
                                        "r2x" : zerolistmaker(len(tiempo)),
                                        "r2y" : zerolistmaker(len(tiempo)),
                                        "r2z" : zerolistmaker(len(tiempo)),
                                        "r3x" : zerolistmaker(len(tiempo)),
                                        "r3y" : zerolistmaker(len(tiempo)),
                                        "r3z" : zerolistmaker(len(tiempo)),
                                   },
                    "T1T2" :
                       {
                          "tx" : T1T2[0],
```

```
        "ty" : T1T2[1],
        "tz" : T1T2[2],
        "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
                        "r2y" : zerolistmaker(len(tiempo)),
                        "r2z" : zerolistmaker(len(tiempo)),
                        "r3x" : zerolistmaker(len(tiempo)),
                        "r3y" : zerolistmaker(len(tiempo)),
                        "r3z" : zerolistmaker(len(tiempo)),
                  },
"C6C7" :
    {
        "tx" : C6C7[0],
        "ty" : C6C7[1],
        "tz" : C6C7[2],
        "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
                        "r2y" : zerolistmaker(len(tiempo)),
                        "r2z" : zerolistmaker(len(tiempo)),
                        "r3x" : zerolistmaker(len(tiempo)),
                        "r3y" : zerolistmaker(len(tiempo)),
                        "r3z" : zerolistmaker(len(tiempo)),
                  },
"C4C5" :
    {
        "tx" : C4C5[0],
        "ty" : C4C5[1],
        "tz" : C4C5[2],
        "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
```

```
                                    "r2y" : zerolistmaker(len(tiempo)),
                                    "r2z" : zerolistmaker(len(tiempo)),
                                    "r3x" : zerolistmaker(len(tiempo)),
                                    "r3y" : zerolistmaker(len(tiempo)),
                                    "r3z" : zerolistmaker(len(tiempo)),
                                },
"AtlantoAxial" :
    {
        "tx" : Atlanto_Axial[0],
        "ty" : Atlanto_Axial[1],
        "tz" : Atlanto_Axial[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                    "r1y" : zerolistmaker(len(tiempo)),
                                    "r1z" : zerolistmaker(len(tiempo)),
                                    "r2x" : zerolistmaker(len(tiempo)),
                                    "r2y" : zerolistmaker(len(tiempo)),
                                    "r2z" : zerolistmaker(len(tiempo)),
                                    "r3x" : zerolistmaker(len(tiempo)),
                                    "r3y" : zerolistmaker(len(tiempo)),
                                    "r3z" : zerolistmaker(len(tiempo)),
                                },
"Eyeside" :
    {
        "tx" : Eyeside[0],
        "ty" : Eyeside[1],
        "tz" : Eyeside[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                    "r1y" : zerolistmaker(len(tiempo)),
                                    "r1z" : zerolistmaker(len(tiempo)),
                                    "r2x" : zerolistmaker(len(tiempo)),
                                    "r2y" : zerolistmaker(len(tiempo)),
                                    "r2z" : zerolistmaker(len(tiempo)),
                                    "r3x" : zerolistmaker(len(tiempo)),
                                    "r3y" : zerolistmaker(len(tiempo)),
                                    "r3z" : zerolistmaker(len(tiempo)),
                                },
```

```
"LeftHip" :
    {
        "tx" : LeftHip[0],
        "ty" : LeftHip[1],
        "tz" : LeftHip[2],
        "r1x" : zerolistmaker(len(tiempo)),
                              "r1y" : zerolistmaker(len(tiempo)),
                              "r1z" : zerolistmaker(len(tiempo)),
                              "r2x" : zerolistmaker(len(tiempo)),
                              "r2y" : zerolistmaker(len(tiempo)),
                              "r2z" : zerolistmaker(len(tiempo)),
                              "r3x" : zerolistmaker(len(tiempo)),
                              "r3y" : zerolistmaker(len(tiempo)),
                              "r3z" : zerolistmaker(len(tiempo)),
                         },
"LeftKnee" :
    {
        "tx" : LeftKnee[0],
        "ty" : LeftKnee[1],
        "tz" : LeftKnee[2],
        "r1x" : zerolistmaker(len(tiempo)),
                              "r1y" : zerolistmaker(len(tiempo)),
                              "r1z" : zerolistmaker(len(tiempo)),
                              "r2x" : zerolistmaker(len(tiempo)),
                              "r2y" : zerolistmaker(len(tiempo)),
                              "r2z" : zerolistmaker(len(tiempo)),
                              "r3x" : zerolistmaker(len(tiempo)),
                              "r3y" : zerolistmaker(len(tiempo)),
                              "r3z" : zerolistmaker(len(tiempo)),
                         },
"LeftAnkleRot" :
    {
        "tx" : LeftAnkleRot[0],
        "ty" : LeftAnkleRot[1],
        "tz" : LeftAnkleRot[2],
        "r1x" : zerolistmaker(len(tiempo)),
```

```
                                        "r1y" : zerolistmaker(len(tiempo)),
                                        "r1z" : zerolistmaker(len(tiempo)),
                                        "r2x" : zerolistmaker(len(tiempo)),
                                        "r2y" : zerolistmaker(len(tiempo)),
                                        "r2z" : zerolistmaker(len(tiempo)),
                                        "r3x" : zerolistmaker(len(tiempo)),
                                        "r3y" : zerolistmaker(len(tiempo)),
                                        "r3z" : zerolistmaker(len(tiempo)),
                                    },
                        "LeftAnkle" :
                           {
                              "tx" : LeftAnkle[0],
                              "ty" : LeftAnkle[1],
                              "tz" : LeftAnkle[2],
                              "r1x" : zerolistmaker(len(tiempo)),
                                        "r1y" : zerolistmaker(len(tiempo)),
                                        "r1z" : zerolistmaker(len(tiempo)),
                                        "r2x" : zerolistmaker(len(tiempo)),
                                        "r2y" : zerolistmaker(len(tiempo)),
                                        "r2z" : zerolistmaker(len(tiempo)),
                                        "r3x" : zerolistmaker(len(tiempo)),
                                        "r3y" : zerolistmaker(len(tiempo)),
                                        "r3z" : zerolistmaker(len(tiempo)),
                                    },
                        "LeftToes" :
                           {
                              "tx" : LeftToes[0],
                              "ty" : LeftToes[1],
                              "tz" : LeftToes[2],
                              "r1x" : zerolistmaker(len(tiempo)),
                                        "r1y" : zerolistmaker(len(tiempo)),
                                        "r1z" : zerolistmaker(len(tiempo)),
                                        "r2x" : zerolistmaker(len(tiempo)),
                                        "r2y" : zerolistmaker(len(tiempo)),
                                        "r2z" : zerolistmaker(len(tiempo)),
                                        "r3x" : zerolistmaker(len(tiempo)),
```

```
                                                "r3y" : zerolistmaker(len(tiempo)),
                                                "r3z" : zerolistmaker(len(tiempo)),
                                        },
"RightHip" :
   {
      "tx" : RightHip[0],
      "ty" : RightHip[1],
      "tz" : RightHip[2],
      "r1x" : zerolistmaker(len(tiempo)),
                                                "r1y" : zerolistmaker(len(tiempo)),
                                                "r1z" : zerolistmaker(len(tiempo)),
                                                "r2x" : zerolistmaker(len(tiempo)),
                                                "r2y" : zerolistmaker(len(tiempo)),
                                                "r2z" : zerolistmaker(len(tiempo)),
                                                "r3x" : zerolistmaker(len(tiempo)),
                                                "r3y" : zerolistmaker(len(tiempo)),
                                                "r3z" : zerolistmaker(len(tiempo)),
                                        },
"RightKnee" :
   {
      "tx" : RightKnee[0],
      "ty" : RightKnee[1],
      "tz" : RightKnee[2],
      "r1x" : zerolistmaker(len(tiempo)),
                                                "r1y" : zerolistmaker(len(tiempo)),
                                                "r1z" : zerolistmaker(len(tiempo)),
                                                "r2x" : zerolistmaker(len(tiempo)),
                                                "r2y" : zerolistmaker(len(tiempo)),
                                                "r2z" : zerolistmaker(len(tiempo)),
                                                "r3x" : zerolistmaker(len(tiempo)),
                                                "r3y" : zerolistmaker(len(tiempo)),
                                                "r3z" : zerolistmaker(len(tiempo)),
                                        },
"RightAnkleRot" :
   {
      "tx" : RightAnkleRot[0],
```

```
        "ty" : RightAnkleRot[1],
        "tz" : RightAnkleRot[2],
        "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
                        "r2y" : zerolistmaker(len(tiempo)),
                        "r2z" : zerolistmaker(len(tiempo)),
                        "r3x" : zerolistmaker(len(tiempo)),
                        "r3y" : zerolistmaker(len(tiempo)),
                        "r3z" : zerolistmaker(len(tiempo)),
                    },
"RightAnkle" :
    {
        "tx" : RightAnkle[0],
        "ty" : RightAnkle[1],
        "tz" : RightAnkle[2],
        "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
                        "r2y" : zerolistmaker(len(tiempo)),
                        "r2z" : zerolistmaker(len(tiempo)),
                        "r3x" : zerolistmaker(len(tiempo)),
                        "r3y" : zerolistmaker(len(tiempo)),
                        "r3z" : zerolistmaker(len(tiempo)),
                    },
"RightToes" :
    {
        "tx" : RightToes[0],
        "ty" : RightToes[1],
        "tz" : RightToes[2],
        "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
```

```
                                    "r2y" : zerolistmaker(len(tiempo)),
                                    "r2z" : zerolistmaker(len(tiempo)),
                                    "r3x" : zerolistmaker(len(tiempo)),
                                    "r3y" : zerolistmaker(len(tiempo)),
                                    "r3z" : zerolistmaker(len(tiempo)),
                                },
"RightAC" :
    {
        "tx" : RightAC[0],
        "ty" : RightAC[1],
        "tz" : RightAC[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                    "r1y" : zerolistmaker(len(tiempo)),
                                    "r1z" : zerolistmaker(len(tiempo)),
                                    "r2x" : zerolistmaker(len(tiempo)),
                                    "r2y" : zerolistmaker(len(tiempo)),
                                    "r2z" : zerolistmaker(len(tiempo)),
                                    "r3x" : zerolistmaker(len(tiempo)),
                                    "r3y" : zerolistmaker(len(tiempo)),
                                    "r3z" : zerolistmaker(len(tiempo)),
                                },
"RightGH" :
    {
        "tx" : RightGH[0],
        "ty" : RightGH[1],
        "tz" : RightGH[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                    "r1y" : zerolistmaker(len(tiempo)),
                                    "r1z" : zerolistmaker(len(tiempo)),
                                    "r2x" : zerolistmaker(len(tiempo)),
                                    "r2y" : zerolistmaker(len(tiempo)),
                                    "r2z" : zerolistmaker(len(tiempo)),
                                    "r3x" : zerolistmaker(len(tiempo)),
                                    "r3y" : zerolistmaker(len(tiempo)),
                                    "r3z" : zerolistmaker(len(tiempo)),
                                },
```

```
"RightShoulderRotation" :
    {
        "tx" : RightShoulderRotation[0],
        "ty" : RightShoulderRotation[1],
        "tz" : RightShoulderRotation[2],
        "r1x" : zerolistmaker(len(tiempo)),
                              "r1y" : zerolistmaker(len(tiempo)),
                              "r1z" : zerolistmaker(len(tiempo)),
                              "r2x" : zerolistmaker(len(tiempo)),
                              "r2y" : zerolistmaker(len(tiempo)),
                              "r2z" : zerolistmaker(len(tiempo)),
                              "r3x" : zerolistmaker(len(tiempo)),
                              "r3y" : zerolistmaker(len(tiempo)),
                              "r3z" : zerolistmaker(len(tiempo)),
                         },
"RightElbow" :
    {
        "tx" : RightElbow[0],
        "ty" : RightElbow[1],
        "tz" : RightElbow[2],
        "r1x" : zerolistmaker(len(tiempo)),
                              "r1y" : zerolistmaker(len(tiempo)),
                              "r1z" : zerolistmaker(len(tiempo)),
                              "r2x" : zerolistmaker(len(tiempo)),
                              "r2y" : zerolistmaker(len(tiempo)),
                              "r2z" : zerolistmaker(len(tiempo)),
                              "r3x" : zerolistmaker(len(tiempo)),
                              "r3y" : zerolistmaker(len(tiempo)),
                              "r3z" : zerolistmaker(len(tiempo)),
                         },
"RightWristRotation" :
    {
        "tx" : RightWristRotation[0],
        "ty" : RightWristRotation[1],
        "tz" : RightWristRotation[2],
        "r1x" : zerolistmaker(len(tiempo)),
```

```
                                      "r1y" : zerolistmaker(len(tiempo)),
                                      "r1z" : zerolistmaker(len(tiempo)),
                                      "r2x" : zerolistmaker(len(tiempo)),
                                      "r2y" : zerolistmaker(len(tiempo)),
                                      "r2z" : zerolistmaker(len(tiempo)),
                                      "r3x" : zerolistmaker(len(tiempo)),
                                      "r3y" : zerolistmaker(len(tiempo)),
                                      "r3z" : zerolistmaker(len(tiempo)),
                                 },
"LeftAC" :
    {
        "tx" : LeftAC[0],
        "ty" : LeftAC[1],
        "tz" : LeftAC[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                      "r1y" : zerolistmaker(len(tiempo)),
                                      "r1z" : zerolistmaker(len(tiempo)),
                                      "r2x" : zerolistmaker(len(tiempo)),
                                      "r2y" : zerolistmaker(len(tiempo)),
                                      "r2z" : zerolistmaker(len(tiempo)),
                                      "r3x" : zerolistmaker(len(tiempo)),
                                      "r3y" : zerolistmaker(len(tiempo)),
                                      "r3z" : zerolistmaker(len(tiempo)),
                                 },
"LeftGH" :
    {
        "tx" : LeftGH[0],
        "ty" : LeftGH[1],
        "tz" : LeftGH[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                      "r1y" : zerolistmaker(len(tiempo)),
                                      "r1z" : zerolistmaker(len(tiempo)),
                                      "r2x" : zerolistmaker(len(tiempo)),
                                      "r2y" : zerolistmaker(len(tiempo)),
                                      "r2z" : zerolistmaker(len(tiempo)),
                                      "r3x" : zerolistmaker(len(tiempo)),
```

```
                                "r3y" : zerolistmaker(len(tiempo)),
                                "r3z" : zerolistmaker(len(tiempo)),
                            },
        "LeftShoulderRotation" :
            {
                "tx" : LeftShoulderRotation[0],
                "ty" : LeftShoulderRotation[1],
                "tz" : LeftShoulderRotation[2],
                "r1x" : zerolistmaker(len(tiempo)),
                                "r1y" : zerolistmaker(len(tiempo)),
                                "r1z" : zerolistmaker(len(tiempo)),
                                "r2x" : zerolistmaker(len(tiempo)),
                                "r2y" : zerolistmaker(len(tiempo)),
                                "r2z" : zerolistmaker(len(tiempo)),
                                "r3x" : zerolistmaker(len(tiempo)),
                                "r3y" : zerolistmaker(len(tiempo)),
                                "r3z" : zerolistmaker(len(tiempo)),
                            },
        "LeftElbow" :
            {
                "tx" : LeftElbow[0],
                "ty" : LeftElbow[1],
                "tz" : LeftElbow[2],
                "r1x" : zerolistmaker(len(tiempo)),
                                "r1y" : zerolistmaker(len(tiempo)),
                                "r1z" : zerolistmaker(len(tiempo)),
                                "r2x" : zerolistmaker(len(tiempo)),
                                "r2y" : zerolistmaker(len(tiempo)),
                                "r2z" : zerolistmaker(len(tiempo)),
                                "r3x" : zerolistmaker(len(tiempo)),
                                "r3y" : zerolistmaker(len(tiempo)),
                                "r3z" : zerolistmaker(len(tiempo)),
                            },
        "LeftWristRotation" :
            {
                "tx" : LeftWristRotation[0],
```

```
                "ty" : LeftWristRotation[1],
                "tz" : LeftWristRotation[2],
                "r1x" : zerolistmaker(len(tiempo)),
                                 "r1y" : zerolistmaker(len(tiempo)),
                                 "r1z" : zerolistmaker(len(tiempo)),
                                 "r2x" : zerolistmaker(len(tiempo)),
                                 "r2y" : zerolistmaker(len(tiempo)),
                                 "r2z" : zerolistmaker(len(tiempo)),
                                 "r3x" : zerolistmaker(len(tiempo)),
                                 "r3y" : zerolistmaker(len(tiempo)),
                                 "r3z" : zerolistmaker(len(tiempo)),
                         },
    "LeftWrist" :
          {
                "tx" : LeftWrist[0],
                "ty" : LeftWrist[1],
                "tz" : LeftWrist[2],
                "r1x" : zerolistmaker(len(tiempo)),
                                 "r1y" : zerolistmaker(len(tiempo)),
                                 "r1z" : zerolistmaker(len(tiempo)),
                                 "r2x" : zerolistmaker(len(tiempo)),
                                 "r2y" : zerolistmaker(len(tiempo)),
                                 "r2z" : zerolistmaker(len(tiempo)),
                                 "r3x" : zerolistmaker(len(tiempo)),
                                 "r3y" : zerolistmaker(len(tiempo)),
                                 "r3z" : zerolistmaker(len(tiempo)),
                         },
    "Left_IndexCarpal" :
          {
                "tx" : Left_IndexCarpal[0],
                "ty" : Left_IndexCarpal[1],
                "tz" : Left_IndexCarpal[2],
                "r1x" : zerolistmaker(len(tiempo)),
                                 "r1y" : zerolistmaker(len(tiempo)),
                                 "r1z" : zerolistmaker(len(tiempo)),
                                 "r2x" : zerolistmaker(len(tiempo)),
```

```
                                "r2y" : zerolistmaker(len(tiempo)),
                                "r2z" : zerolistmaker(len(tiempo)),
                                "r3x" : zerolistmaker(len(tiempo)),
                                "r3y" : zerolistmaker(len(tiempo)),
                                "r3z" : zerolistmaker(len(tiempo)),
                            },
        "Left_IndexProximal" :
            {
                "tx" : Left_IndexProximal[0],
                "ty" : Left_IndexProximal[1],
                "tz" : Left_IndexProximal[2],
                "r1x" : zerolistmaker(len(tiempo)),
                                "r1y" : zerolistmaker(len(tiempo)),
                                "r1z" : zerolistmaker(len(tiempo)),
                                "r2x" : zerolistmaker(len(tiempo)),
                                "r2y" : zerolistmaker(len(tiempo)),
                                "r2z" : zerolistmaker(len(tiempo)),
                                "r3x" : zerolistmaker(len(tiempo)),
                                "r3y" : zerolistmaker(len(tiempo)),
                                "r3z" : zerolistmaker(len(tiempo)),
                            },
        "Left_MiddleCarpal" :
            {
                "tx" : Left_MiddleCarpal[0],
                "ty" : Left_MiddleCarpal[1],
                "tz" : Left_MiddleCarpal[2],
                "r1x" : zerolistmaker(len(tiempo)),
                                "r1y" : zerolistmaker(len(tiempo)),
                                "r1z" : zerolistmaker(len(tiempo)),
                                "r2x" : zerolistmaker(len(tiempo)),
                                "r2y" : zerolistmaker(len(tiempo)),
                                "r2z" : zerolistmaker(len(tiempo)),
                                "r3x" : zerolistmaker(len(tiempo)),
                                "r3y" : zerolistmaker(len(tiempo)),
                                "r3z" : zerolistmaker(len(tiempo)),
                            },
```

```
"Left_MiddleProximal" :
   {
      "tx" : Left_MiddleProximal[0],
      "ty" : Left_MiddleProximal[1],
      "tz" : Left_MiddleProximal[2],
      "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
                        "r2y" : zerolistmaker(len(tiempo)),
                        "r2z" : zerolistmaker(len(tiempo)),
                        "r3x" : zerolistmaker(len(tiempo)),
                        "r3y" : zerolistmaker(len(tiempo)),
                        "r3z" : zerolistmaker(len(tiempo)),
                   },
"RightWrist" :
   {
      "tx" : RightWrist[0],
      "ty" : RightWrist[1],
      "tz" : RightWrist[2],
      "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
                        "r2y" : zerolistmaker(len(tiempo)),
                        "r2z" : zerolistmaker(len(tiempo)),
                        "r3x" : zerolistmaker(len(tiempo)),
                        "r3y" : zerolistmaker(len(tiempo)),
                        "r3z" : zerolistmaker(len(tiempo)),
                   },
"Right_IndexCarpal" :
   {
      "tx" : Right_IndexCarpal[0],
      "ty" : Right_IndexCarpal[1],
      "tz" : Right_IndexCarpal[2],
      "r1x" : zerolistmaker(len(tiempo)),
```

```
                                  "r1y" : zerolistmaker(len(tiempo)),
                                  "r1z" : zerolistmaker(len(tiempo)),
                                  "r2x" : zerolistmaker(len(tiempo)),
                                  "r2y" : zerolistmaker(len(tiempo)),
                                  "r2z" : zerolistmaker(len(tiempo)),
                                  "r3x" : zerolistmaker(len(tiempo)),
                                  "r3y" : zerolistmaker(len(tiempo)),
                                  "r3z" : zerolistmaker(len(tiempo)),
                              },
"Right_IndexProximal" :
    {
        "tx" : Right_IndexProximal[0],
        "ty" : Right_IndexProximal[1],
        "tz" : Right_IndexProximal[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                  "r1y" : zerolistmaker(len(tiempo)),
                                  "r1z" : zerolistmaker(len(tiempo)),
                                  "r2x" : zerolistmaker(len(tiempo)),
                                  "r2y" : zerolistmaker(len(tiempo)),
                                  "r2z" : zerolistmaker(len(tiempo)),
                                  "r3x" : zerolistmaker(len(tiempo)),
                                  "r3y" : zerolistmaker(len(tiempo)),
                                  "r3z" : zerolistmaker(len(tiempo)),
                              },
"Right_MiddleCarpal" :
    {
        "tx" : Right_MiddleCarpal[0],
        "ty" : Right_MiddleCarpal[1],
        "tz" : Right_MiddleCarpal[2],
        "r1x" : zerolistmaker(len(tiempo)),
                                  "r1y" : zerolistmaker(len(tiempo)),
                                  "r1z" : zerolistmaker(len(tiempo)),
                                  "r2x" : zerolistmaker(len(tiempo)),
                                  "r2y" : zerolistmaker(len(tiempo)),
                                  "r2z" : zerolistmaker(len(tiempo)),
                                  "r3x" : zerolistmaker(len(tiempo)),
```

```
                        "r3y" : zerolistmaker(len(tiempo)),
                        "r3z" : zerolistmaker(len(tiempo)),
                    },
"Right_MiddleProximal" :
   {
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      "ty" : Right_MiddleProximal[1],
      "tz" : Right_MiddleProximal[2],
      "r1x" : zerolistmaker(len(tiempo)),
                        "r1y" : zerolistmaker(len(tiempo)),
                        "r1z" : zerolistmaker(len(tiempo)),
                        "r2x" : zerolistmaker(len(tiempo)),
                        "r2y" : zerolistmaker(len(tiempo)),
                        "r2z" : zerolistmaker(len(tiempo)),
                        "r3x" : zerolistmaker(len(tiempo)),
                        "r3y" : zerolistmaker(len(tiempo)),
                        "r3z" : zerolistmaker(len(tiempo)),
                    },
                "Right_PinkyProximal":
                    {
                        "tx": Right_MiddleProximal[0],
                        "ty": Right_MiddleProximal[1],
                        "tz": Right_MiddleProximal[2],
                        "r1x": zerolistmaker(len(tiempo)),
                        "r1y": zerolistmaker(len(tiempo)),
                        "r1z": zerolistmaker(len(tiempo)),
                        "r2x": zerolistmaker(len(tiempo)),
                        "r2y": zerolistmaker(len(tiempo)),
                        "r2z": zerolistmaker(len(tiempo)),
                        "r3x": zerolistmaker(len(tiempo)),
                        "r3y": zerolistmaker(len(tiempo)),
                        "r3z": zerolistmaker(len(tiempo)),
                    },
                "Left_PinkyProximal":
                    {
                        "tx": Left_MiddleProximal[0],
```
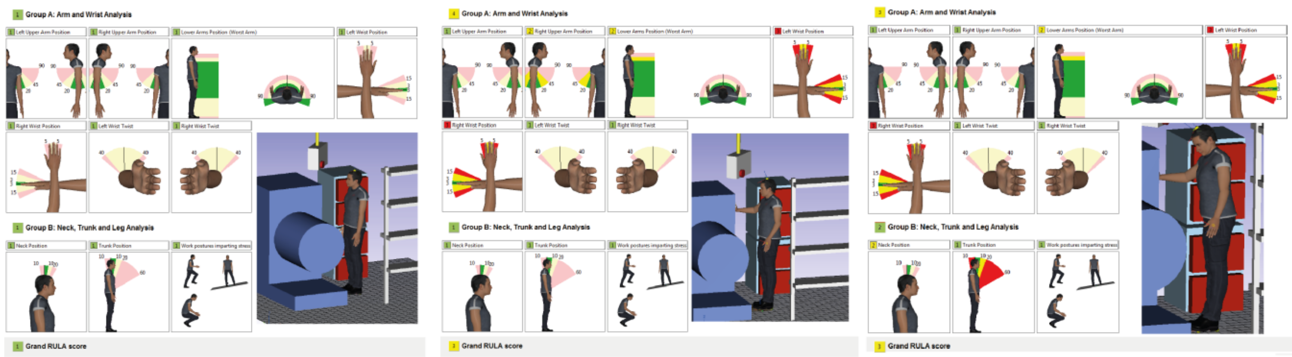
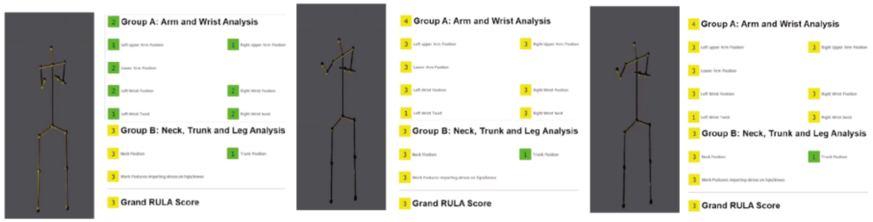

```
                    "ty": Left_MiddleProximal[1],
                    "tz": Left_MiddleProximal[2],
                    "r1x": zerolistmaker(len(tiempo)),
                    "r1y": zerolistmaker(len(tiempo)),
                    "r1z": zerolistmaker(len(tiempo)),
                    "r2x": zerolistmaker(len(tiempo)),
                    "r2y": zerolistmaker(len(tiempo)),
                    "r2z": zerolistmaker(len(tiempo)),
                    "r3x": zerolistmaker(len(tiempo)),
                    "r3y": zerolistmaker(len(tiempo)),
                    "r3z": zerolistmaker(len(tiempo)),
                },

                                                        }
                                                }
                        }
                }
        }
    with open('data.txt', 'w') as outfile:
        json.dump(data, outfile, indent=2)

[partes,tiempo]=callJSON('VR_data 12_59_06.json')

RightElbow=Elbow(partes[3])#
LeftElbow=Elbow(partes[2])#
RightAC=Shoulder(partes[3])#
RightGH=RightAC
RightShoulderRotation=RightAC
LeftAC=Shoulder(partes[2])#
LeftGH=LeftAC
LeftShoulderRotation=LeftAC
RightWristRotation=Wrist(partes[7])#
RightWrist=RightWristRotation
LeftWristRotation=Wrist(partes[6])#
LeftWrist=LeftWristRotation
Left_IndexCarpal=Fingers(partes[6])#
```

```
Left_IndexProximal=Left_IndexCarpal
Left_MiddleProximal=SideBottomHand(partes[6])#
Left_MiddleCarpal=  SideTopHand(partes[6])#
Right_IndexCarpal=Fingers(partes[7])#
Right_IndexProximal=Right_IndexCarpal
Right_MiddleProximal=SideBottomHand(partes[7])#
Right_MiddleCarpal=  SideTopHand(partes[7])#
T6T7 =MidShoulder(RightAC, LeftAC)#
T1T2=T6T7
C6C7=cC6C7(T6T7)#
C4C5=cC4C5(T6T7)#
L5S1=cL5S1 (T6T7)#
L3L4=cL3L4 (T6T7)#
T12L1=cT12L1 (T6T7)#
Atlanto_Axial=partes[0]#
Eyeside=Atlanto_Axial
LeftHip=Hip(LeftAC)#
LeftKnee=Knee(LeftAC)#
LeftAnkleRot=Ankle(LeftAC)#
LeftAnkle=LeftAnkleRot
LeftToes=LeftAnkleRot
RightHip=Hip(RightAC)#
RightKnee=Knee(RightAC)#
RightAnkleRot=Ankle(RightAC)#
RightAnkle=RightAnkleRot
RightToes=RightAnkleRot

draw()
convert()
```

12 Appendix F: Comparison between IPS-IMMA & the project strategy

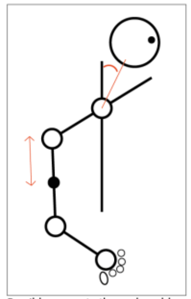
Use case 1





Improvements: this sequence of movements doesn´t need legs tracking. The key moves are the twist of the neck and the stretching of the arms.

Trackers change: No
New trackers:-



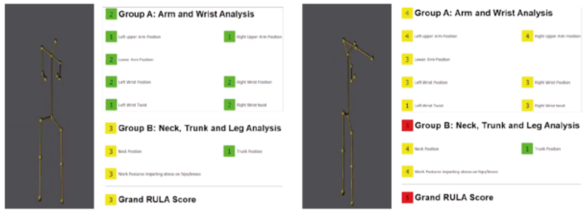
Possible reason to the neck problem

Comparison of scores: the main difference in this sequence is P1. It was supposed to have a RULA score of 1, however some body parts were misplaced: the forearms were left in 90º and the wrists were twisted. Therefore, it was decided to not count the P1 for the assessment, as it is was the starting point in all use cases and didn´t add any value.
The neck positioning had some issues as well, which can be seen throughout the whole sequence (high scores in our strategy). The neck was calculated using the position of both forearms. If the length of the forearms wasn´t the right one, the neck could be misplaced further from the head. This could be the reason why the neck is leaning forward in standard position. As well, it can be seen the problem explained before that the neck twist couldn´t be measure.
However, the arms and wrists analyses are pretty accurate, as well as the general RULA score.

P2 3 P3 3 Overall accuracy 100%

Figure 23. Comparison IPS IMMA-strategy: use case 1

Use case 3 lv. 2



Comparison of results: P2 differs slightly in the arms positioning between our strategy and IPS IMMA. The neck score of 3 comes from bending forward, but measures more than in IPS IMMA. IPS IMMA measures the twist of the neck as well. P3 is almost accurate in all its fields; trunk twisting can´t be measured with the trackers we had, and new ones should be added. Work postures imparting stress on kness/hips shouldn´t be counted in any of the use cases because we are not tracking the lower limbs.
The overall score is exact, but just because the posture was regarded as imparting stresses.

Improvements: this sequence of movements doesn´t need legs tracking. However the key moves are the arms stretching and the chest twisting. Because there wasn´t a tracker on the chest, it could´t be measured.

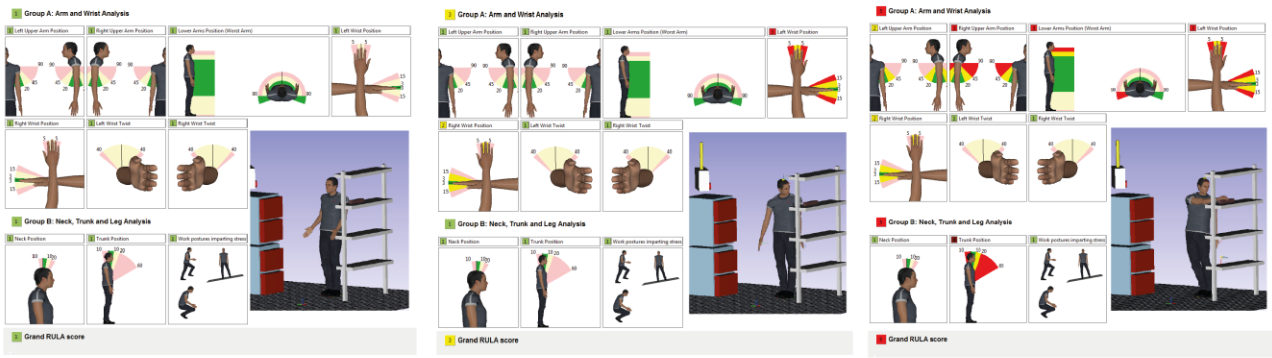
Trackers change: Yes

New trackers: 1x  in the chest

P2 3 P3 3 Overall accuracy 100%

Figure 24. Comparison IPS IMMA-strategy: use case 3 lv. 2

Use case 3 lv. 3



Improvements: this sequence of movements presents the same issue as the one carried out in level 2 of the shelf.

Trackers change: Yes

New trackers: 1x  in the chest

Comparison of scores: P2 differs slightly in the arms positioning between our strategy and IPS IMMA. P3 instead has a big difference in its scores. Because trunk twisting couldn´t be measured with our trackers, the RULA score drops to a 3, when in reality, in IPS IMMA, it shows it should be a 5. The overall RULA score, therefore, suffers a big inaccuracy. This coud be fixed adding more trackers. The neck issues can be seen in this sequence.

P2 3 P3 0 Overall accuracy 50%

Figure 25. Comparison IPS IMMA-strategy: use case 3 lv. 3

Use case 3 lv. 4

Improvements: this sequence of movements presents the same issue as the one carried out in level 2 of the shelf.

Trackers change: Yes

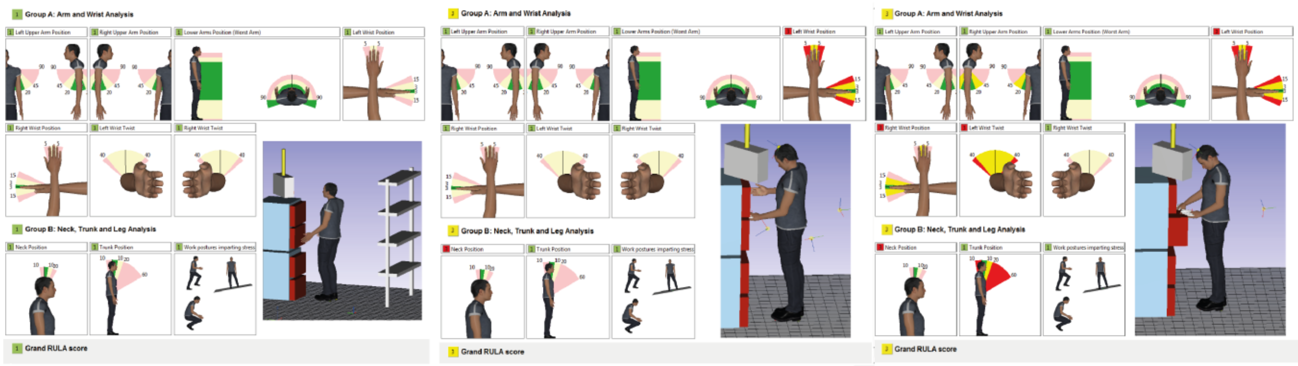
New trackers: 1x  in the chest

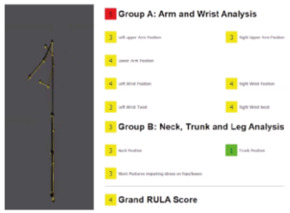
Comparison of results: P2 faces the same neck issues as previous use cases. However, in this case, because the head is looking upwards, the spine lines up with the head, and the neck looks like is not bending (that´s why it has a score of 1 in our strategy, when it should have a 4). The twist isn´t counted either. P3 has the neck and the trunk issue explained before.

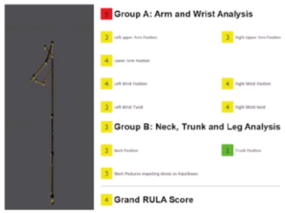
P2 2 P3 1 Overall accuracy 50%

Figure 26. Comparison IPS IMMA-strategy: use case 3 lv. 4

Use case 4 lv. 3







Improvements: this sequence of movements doesn´t need legs tracking. The key moves are the arms stretching, and the neck bending to look inside the drawer.

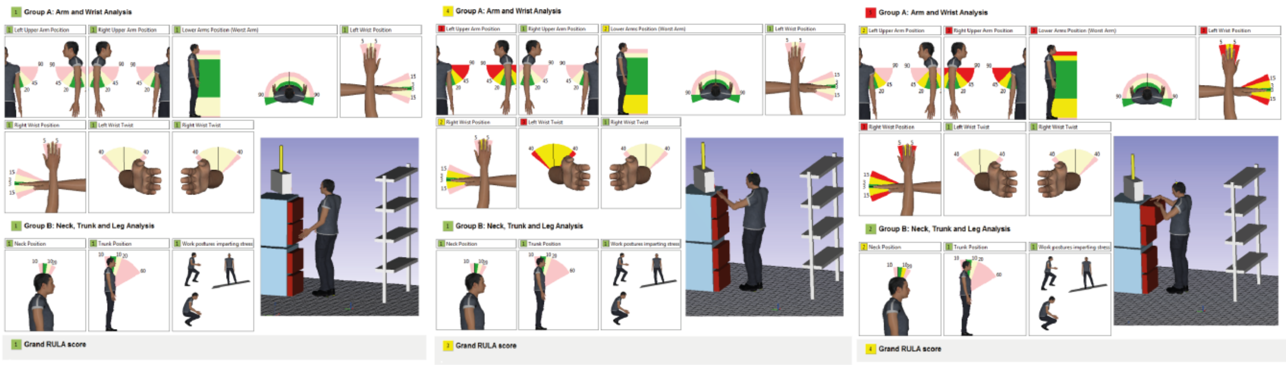
Trackers change: No
New trackers: -

Comparison of scores: P2 is not affected by the neck issue because there is a big bending of the neck and no twist. Apart from that, the arms positioning have higher scores in our strategy, probably because the movements were more natural in our strategy than with a manikin that needed to be positioned in IPS IMMA. In P3 the wrists have higher scores than IPS IMMA. The wrists' movements are difficult to replicate when doing use cases, and that could have influenced the experiment.

P2 2 P3 2 Overall accuracy 67%

Figure 27. Comparison IPS IMMA-strategy: use case 4 lv. 3

Use case 4 lv. 4



Improvements: this sequence of movements doesn´t need legs tracking. The key moves are the arms stretching and the neck bending to look inside the drawer. If the height of the user is >170 mm, chest bending is also involved. An additional tracker may be needed for the chest.

Comparison of scores: P2 and P3 face the same neck issues. However, they don´t have a big influence on the overall RULA scores, as neck bending is also involved in this use case. The height of the user could be an issue in this case, and it´s explained in the improvements.

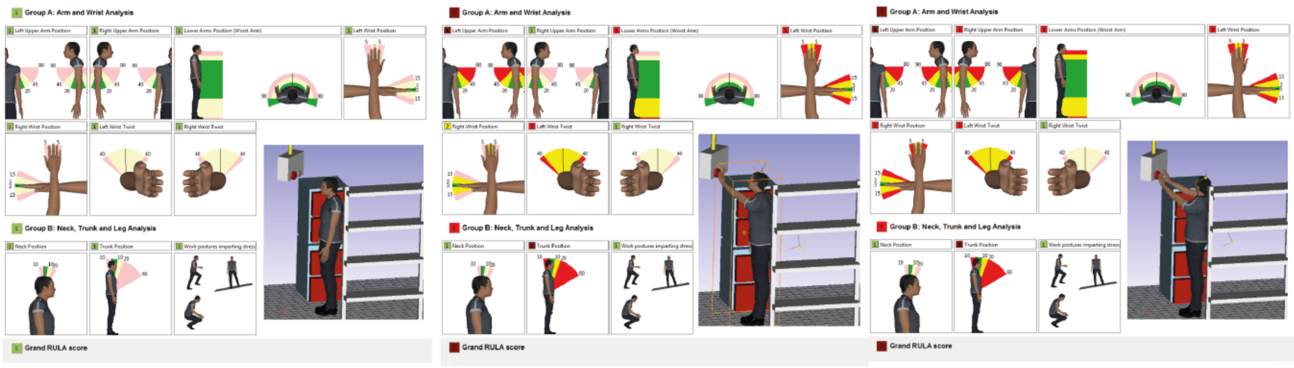
Trackers change: Yes if user´s height >170mm

New trackers: 1x  in the chest

P2 3 P3 3 Overall accuracy 100%

Figure 28. Comparison IPS IMMA-strategy: use case 4 lv. 4

Use case 5



Improvements: this sequence of movements doesn´t need legs tracking. However the key moves are the arms stretching and the chest twisting. Because there wasn´t a tracker on the chest, it could´t be measured.

Trackers change: Yes

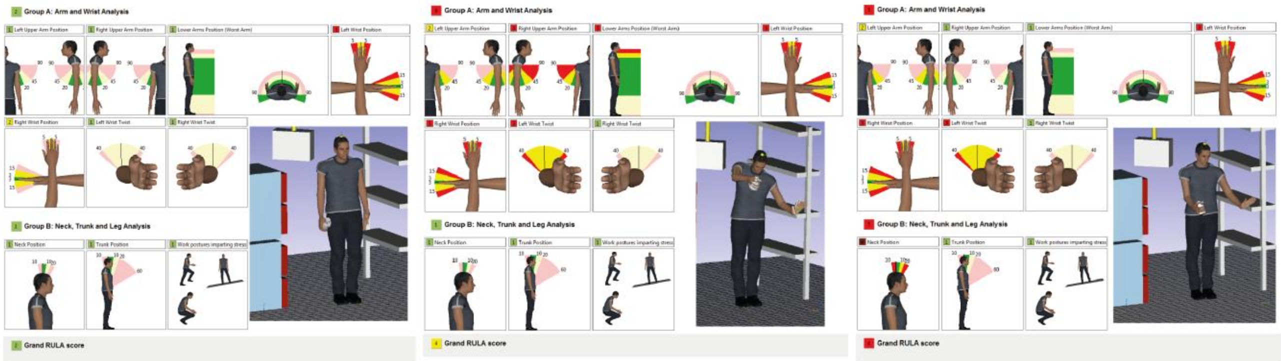
New trackers: 1x  in the chest

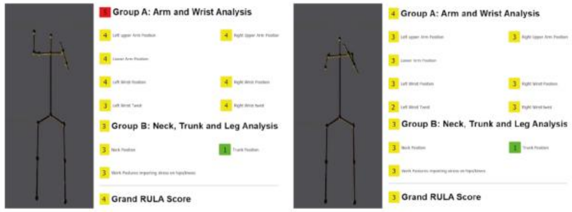
Comparison of scores: P2 and P3 face the trunk issue, so extra trackers would be needed to rise up the accuracy.

P2 1 P3 1 Overall accuracy 33%

Figure 29. Comparison IPS IMMA-strategy: use case 5

Use case tools: blowtorch





Comparison of scores: P2 faces the neck issues; however, the overall RULA score is not affected. In P3 there is a big influence of the neck positioning. Our strategy doesn´t change its score from P2 to P3, but in IPS IMMA it can be seen a difference of 2 points. This problem is probably caused by the user performing the task inaccurately: the neck had to be twisted to check the AGV.

Improvements: this sequence of movements was planned to be carried out with the help of an AGV that could adjust the height of the load to the user´s height. Therefore, it wouln´t be needed to bend the legs to complete the task. However, if the AGV couldn´t perform this adjustment, extra trackers would be needed.

Trackers change: Yes if AGV isn´t configurable

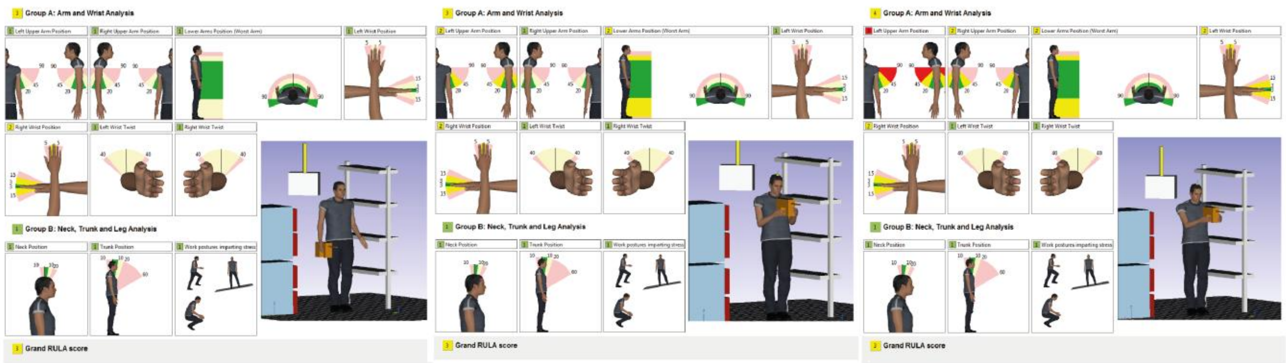
New trackers: 1x  in the chest

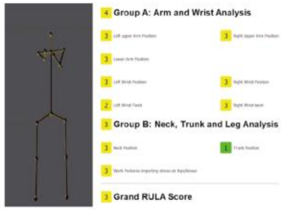
2x  one in each top ankle

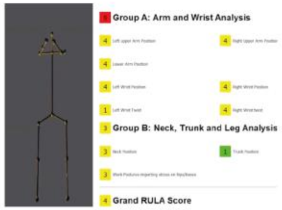
P2 3 P3 0 Overall accuracy 50%

Figure 30. Comparison IPS IMMA-strategy: use case blowtorch

Use case tools: drill







Improvements: this sequence of movements presents the same issue as in the previous case.

Trackers change: Yes if AGV isn´t configurable

New trackers: 1x  in the chest

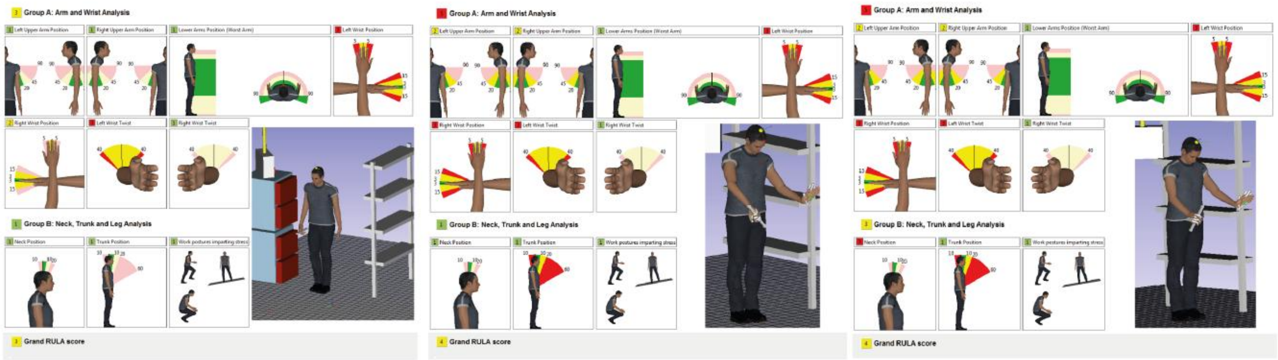
2x  one in each top ankle

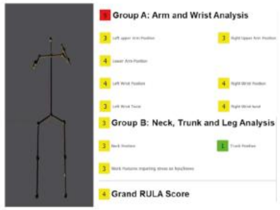
Comparison of scores: it can be seen the neck issue in both P2 and P3. P3 has a higher RULA score in our strategy because of the positioning of the arms. Probably the drilling was performed at a higher height by the user, and that caused the different scores.

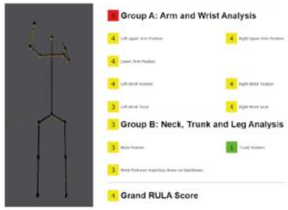
P2 3 P3 2 Overall accuracy 83%

Figure 31. Comparison IPS IMMA-strategy: use case drill

Use case tools: wrench







Comparison of scores: it can be seen the same issues with the neck that have been happening throughout all the use cases. However, the overall RULA scores are accurate.

Improvements: this sequence of movements present the same issue as in the previous case.

Trackers change: Yes if AGV isn´t configurable

New trackers: 1x  in the chest

2x  one in each top ankle

P2 3 P3 3 Overall accuracy 100%

Figure 32. Comparison IPS IMMA-strategy: use case wrench