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Comprehensive modelling and simulation towards the identification of critical parameters for evaluation of exoskeleton-centred workplaces

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Abstract

Workers are key enablers of flexibility and productivity in Manufacturing, especially in processes where full automation is not feasible. Such workplaces are often characterized by manual manipulation of heavy loads, hazardous conditions and high level of vibrations. Exoskeletons, fusing flexibility, intelligence and human-centered control with the high payload, endurance, precision and sensor-based guidance represent enabling technologies to cope this challenge. In this paper critical parameters for the evaluation of exoskeleton-centered workplaces are identified, as core elements of the methodology for evaluating the exoskeleton-centered workplaces. Comprehensive modelling, simulation and analysis of ergonomics and process parameters represent the foundations of the methodology.

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1. Exoskeletons in Manufacturing

Daily movement of loads between 5 and 35 kg with a corresponding number of lifting operations leads to health risks for the worker [1]. The field of Exoskeleton application is broad and ranges from military applications to rehabilitation.
Looze et al. (2015) describes an exoskeleton as "…a wearable, external mechanical structure that enhances the power of a person. Exoskeletons can be classified as 'active' or 'passive'. An active exoskeleton comprises one or more actuators that augments the human's power and helps in actuating the human joints. A strictly passive system does not use any type of actuator, but rather uses materials, springs or dampers with the ability to store energy harvested by human motion and to use this as required to support a posture or a motion" [2].

The exoskeleton technology will be found more and more frequently in production plants in Europe in the future. Here the evaluation of this exoskeleton technology is particularly important to point out the benefits as well as possible challenges. Various critical parameters are required to evaluate the technology. This work examines various critical parameters, which were obtained with the help of simulation software, with regard to their usability. The examined and valid parameters will be used in a later work for an evaluation model.

1.1. Challenges in Manufacturing

Globally, costs are rising sharply combined with increasing cost pressure, especially in the case of manufacturing

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companies. This development is particularly strong to observe in high-wage countries [2].

Workers are key enablers of flexibility and productivity in Europe's industry, especially in manufacturing processes where full automation is not feasible due to small lot sizes, large product variety, and layout constraints. Such workplaces are often characterized by manual manipulation of heavy loads, hazardous conditions as well as high level of vibrations. Tasks taking place in these workplaces require increased cognitive efforts in order to maintain sustained levels of vigilance, leading to higher levels of mental fatigue, which in turn have a negative impact on both workers and workplaces, and contribute to jobs being lost or relocated outside Europe, therefore affecting European manufacturing as a whole. 26% of all lost work days in Germany are caused by musuloskeletal disorders (MSD) [3].

The negative impact at the Worker level is mainly attributed to work-related health problems. For example, the biggest Europe-wide occupational health survey found that 46% of European workers report back pain, with 43% experiencing painful shoulder, neck and upper limb muscles [4].

The most frequently reported work-related health problem by workers in the age group between 55 to 64 in 2013 was musculoskeletal disorders (MSDs). Around 62% of workers of this age group who reported having a work-related health problem indicated suffering from MSD. This percentage has increased since 2007 (when it was around 59%) [5].

In particular, the use of hand-held power tools can affect the blood circulation in the fingers. This is known as vibration-induced white finger [6] and can cause painful and disabling disorders of the blood vessels, nerves and joints [7]. Such conditions can lead to life-long Hand-Arm Vibration disorders (HAV) or Whole Body Vibration disorders (WBV).

The negative impact at the Workplace level is due to the reduced quality of the working environment (defined by the OECD Job Quality Index), which prevents workers from performing well in a sustainable manner, while fulfilling their ambition and feeling appreciated by the society. Research shows that heavy job demands and lack of adequate resources can lead to job strain and poor health [8].

In addition, automation of workplaces grows higher as a driver to job loss. The risk appears high in sectors, such as transportation and storage (56%), manufacturing (46%) and wholesale and retail (44%) [9]. Jobs that are most at risk are those, which "are on some level routine, repetitive and predictable."

At European manufacturing level, these issues have led to extra cost (e.g. total annual cost of MSD in excess of 240 billion euro, or circa 2% of GDP of the European economy) and contribute to the 3.5 million manufacturing jobs lost between 2008 and 2014 [10].

This is a serious challenge, especially in the context of the recent Joint Declaration for an ambitious EU industrial strategy, which was signed by 125 industrial associations representing the European manufacturing industry. The aspiration is to reindustrialize Europe and by 2020 increase the contribution of industry to the European GDP to 20% [11].

Industrial manipulators are assisting workers in lifting. However, in most cases this does not reduce the forces exerted by workers in horizontal load movement, does not absorb vibrations and does not eliminate hazardous conditions.

Intelligent solutions for human-robot collaboration, which are highly flexible and can be scaled up in production, with long and arduous programming effort and worker training.

A solution could be wearable exoskeletons combining the advantages of both industrial manipulators and human-robot collaboration, by fusing the flexibility, intelligence and human-centered control of human-robot systems with the high payload, endurance, precision and sensor-based guidance of exoskeletons.

1.2. Reasons for a methodology for evaluating the exoskeleton-centered workplaces

Exoskeletons aim to improve manufacturing workplace conditions. Thus there is no method yet to evaluate the use of the exoskeleton technology in manufacturing workplaces. Data must be collected before a method can be developed.

In order to evaluate the exoskeleton technology as accurately as possible for industrial use, critical parameters must first be identified. These parameters serve later as a basis for the evaluation method.

Among other parameters, the method will include the parameters discussed in this paper. In the next publications further parameters will be identified, validated and integrated into the method.

The second chapter discusses modeling and simulation with the integrated technology. After the requirements analysis the modelling is explained. The actual simulation project is then presented and the chapter is concluded with an analysis. In the following chapter critical parameters, which were found with the help of the simulation, are shown for the evaluation of the technology. After that the paper concludes with the conclusion and future work.

2. Modelling and Simulation of workplaces with integrated Exoskeletons

Simulations make it possible to carry out virtual experiments, which are often not feasible for various reasons. A prerequisite for this is a suitable, often mathematical, model.

Advantages:

- Models can be simulated in any number of scenarios;
- In the simulation, things can be observed that are not accessible in the experiment. For example, the forces acting on people;
- Changes can be introduced and tried out quickly.

Disadvantages:

- Models first have to be elaborately created;
- The results of the simulation depend on the accuracy of the models and simulations can take a very long time.

It is important to digitally model, simulate and analyze the workstations. Tools such as "Jack 9.0" [12] offered by Siemens can be used to understand the advantages and disadvantages of the technology. The following subchapters generally describe the procedure for successfully generating data that is important for the future evaluation of technologies.

Our method for digital workplace design and exoskeleton evaluation can be divided into two phases.

The first phase is the "as it is" situation. In this phase, the workplace is modelled, simulated and analyzed holistically without the exoskeleton. In the second phase of the "As it should be" situation, the workplace is examined again with the integrated exoskeleton.
Various different key performance indicators are compared and correlated. In the future, a method will be used to evaluate a wide variety of key performance indicators and results in order to select the optimum technology.

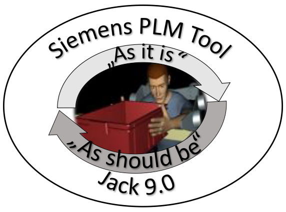

Fig. 1: The method with the two phases for exoskeleton evaluation.

Fig. 2: Siemens jack model with coupled exoskeleton. ©RoboMate

2.1. Requirements analysis

In order to get a realistic simulation and to verify the implementation of the Exoskeleton in the selected test cases, a requirement analysis has been conducted.

The following requirements have been identified in order to be able to create a simulation: production data, production resources, parts, used tools, the factory layout and actual cycle time and other timings; CAD models of the manufacturing objects (manufacturing resources, parts, compound parts, tools, devices) if exist; weight and other relevant data of the manipulated parts and specific workplace details. To round it all off videos of specific processes done by the workers detailed pictures of the stations are used.

On the basis of this information, the modeling of the workstation according to its real model can be started. The following steps were done with the Siemens Jack 9.0 Software. Siemens Jack 9.0 [12] is an independent product offering from Siemens PLM Software for Human Ergonomic Analysis. The software and its tools focus on Human Jack. Siemens Jack 9.0 software was used because it was not possible to create a coupling between Human Jack and the exoskeleton in Siemens Process Simulate or other software. In addition, Jack 9.0 and Siemens Process Simulate use the same inverse kinematic model for Jack, the human model. Process Simulate focuses on the simulation of industrial processes and Classic Jack on the ergonomics of the human model. Jack 9.0 has several add-on modules such as 3D Body Scan, Occupant Packaging Toolkit or in our case the Task Analysis Toolkit. Several tools from this toolkit are described in chapter 2.4. These kits were used for ergonomics analysis.

Previous publications describe the modeling and simulation in detail, in particular the procedure for coupling the exoskeleton with the digital model [13, 14, 15].

2.2. Modeling

The modeling phase is used to convert the model into a simulation model. For example, the visualization is used in the form of a true-to-scale graphical representation of the system topology (layout) and the individual model components [16].

The model is developed with the purpose in mind and does not contain all the characteristics of the real model. It is abstracted, so to speak, to create it as pragmatically and efficiently as possible. For example Figure 2 shows a model of the Human model “Jack” from Siemens coupled with an exoskeleton. This model will be used for the “As it should be” simulation.

2.3. Simulation

According to VDI 3363 [17], simulation is the reproduction of a system with its dynamic processes in a model that can be experimented in order to arrive at findings that can be transferred to reality. In particular, the processes are developed over time. In simulation, all resources, data, CAD models and so on are connected and related.

The most important thing is to focus on the relevant aspects and not to create too many unnecessary relationships. Many tests are used to determine whether the simulation matches the real environment and whether the timing fits. If everything fits, the analysis starts.

2.4. Analysis

After modelling and simulating the digitally recreated workstations, they were analysed using various tools provided by the program. The various used analyses are briefly explained below. With the software different ergonomic analyses could be carried out, which delivered different results [12].

- Lower back analysis: possibility of evaluating spinal forces acting on the lower back by using a complex biomechanical low back model.
- Fatigue Analysis: shows if given taks includes enough recovery time required for a job and compares it with the available rest time.
- Rapid upper limb assessment (RULA): analyses the workers exposure to the possibility of upper limb disorders.
- Static strength prediction (SSP): Calculates the percentage of overall worker population that has the strength to perform a task based on the posture and exertion requirements. Includes also wrist strength calculations.
- Ovako Working posture Assessment. System (OWAS)a: Shows the risk of injury level related to the posture taken. The tool presents four levels that suggest the urgency to modify the workplace.

National Institute for Occupational Safety and Health (NIOSH): Evaluates symmetrical and asymmetrical lifting task although taking into account the frequency of the task.

There are many other analyses with the software, but these were the most used.

3. Critical parameters for the evaluation of Exoskeletons centred workplaces

The evaluation of the simulation results is particularly important as not only the quality of the simulation results, but also their interpretation will determine the quality of the conclusions and the measures derived from these [17].
For the analysis, different analysises and parameters were used. It is important to consider as many goal-oriented parameters as possible for the evaluation.

An important part of the validation is an exhaustive examination of the input data. In many cases the data of the planners differ from the statements of the operators. Often it is also necessary to make an estimate of the statistical factors (e.g. certain mathematical distributions) to describe the input data [17].

In order to use the results of the simulation for a future evaluation model, various results and parameters were examined and checked for their usability.

The cycle time is a very good parameter to evaluate exoskeletons in simulations before introducting them in a real life shop floor. In our simulations we had workstations where the cycle time was reduced by exoskeletons and extended in others.

This clear parameter immediately showed whether the technology could have a future in the various simulated workplaces. Nevertheless, further parameters based on the cycle time would make sense to evaluate the use of this technology. Other time-critical parameters are the take-on and take-off time of the exoskeleton.

Ergonomic parameters were also very helpful for validating exoskeletons. The simulation allowed us to perform various ergonomics analyses and to assess the status before and after the use of the exoskeleton technology.

The lower back analysis was able to show directly with its traffic light criteria to what extent the workplace is harmful for the lower back area and to what extent an optimization of the workplace should be made.

The fatigue analysis showed that employees were less tired and exhausted after their shift due to the use of exoskeletons. This can have an indirect influence on the quality of the products, the reject rate and other parameters. Unfortunately it is not possible to receive these parameters directly with this software. This must be investigated in the next simulations and maybe enhanced with another solution.

The different parameters must be weighted differently and must be included in the upcoming evaluation model.

In future, even more temporal, qualitative and process-related parameters should be included in the analysis. For example, a failure rate or malfunction of the technology would be a parameter that could make the evaluation more valid. For this purpose another software has to be used.

4. Conclusion and future work

The paper shows with what parameters we can evaluate the exoskeleton with the help of simulation tools. The two phases of the simulation "As it is" and "As it should be" are important to validate different exoskeletons. After all the most critical parameters are shown for the evaluation. These critical parameters were all we could discover with the simulation tool so far. The future work will implement the identified critical parameters, as well as potential future upcoming discovered parameters in the simulation and from other sources, in a method. Based on this method, a software tool is created that will evaluate the exoskeleton technology based on the identified and selected parameters in the certain workplaces.

References

[1] Weidner R. Wissensbasierte Planung und Beurteilung von Montagesystemen in der Luftfahrtindustrie. Aachen (32).

[2] De Looze M, Bosch T, Krause F, Stadler K, O'Sullivan L. Exoskeletons for industrial application and their potential effects on physical work load. Journal of Ergonomics, Volume 59 (5). P 671 – 681 (2015).

[3] Westkämper, Engelbert: Towards the Re-Industrialization of Europe. A Concept for Manufacturing for 2030. Berlin, Heidelberg: Springer Berlin Heidelberg: Berlin, Heidelberg (9783642385025) (2014).

[4] European trade union institute. Musculoskeletal Disorders. Available at: https://www.etui.org/Topics/Health-Safety-working-conditions/Musculoskeletal-disorders; 2018.

[5] European Comission – Fact Sheet – Facts and figures: Healthy Workplaces Campaign for All Ages 2016 – 17. Available at: http://europa.eu/rapid/press-release_MEMO-16-1421_en.htm. 2018.

[6] Health and Safety Executive 2017. Available at: Hand arm vibration at work. http://www.hse.gov.uk/vibration/hav/index.htm. 2018.

[7] Health and Safety Executive 2017. Whole body vibration. Available at: http://www.hse.gov.uk/vibration/wbv/exposure.htm. 2018.

[8] OECD. OECD Employment Outlook 2014. OECD Publishing, Paris. Available at: http://dx.doi.org/10.1787/empl_outlook-2014-6-en. 2018.

[9] PwC, UK Economic Outlook March 2017, Available at: https://www.pwc.co.uk/economic-services/ukeo/pwc-uk-economic-outlook-full-report-march-2017-v2.pdf. 2018.

[10] European Agency for Safety and Health at Work. Work-related musculoskeletal disorders: Prevention report. Available at: https://osha.europa.eu/en. 2018.

[11] Joint Declaration on EU Industrial Strategy. Available at: http://www.acea.be/news/article/joint-declaration-for-an-ambitious-eu-industrial-strategy. 2018.

[12] Siemens Jack 9.0 – Available at: https://www.plm.automation.siemens.com/media/store/de_de/4917_tcm1023-4952_tcm38-1992.pdf. 2018.

[13] Constantinescu C, Popescu D, Muresan P, Stana S. Exoskeleton-centered process optimization in advanced factory environments, Proceedings of the 48th CIRP Manufacturing Systems – CIRP CMS 2015.

[14] Constantinescu C, Popescu D, Muresan P, Todorovic O. Optimisation of advanced manufacturing environments with integrated intelligent Exoskeletons, International Conference on Production Research – Africa, Europe and the Middle East – 2016.

[15] Constantinescu C, Muresan P, Simon G. JackEx: the new digital manufacturing resource for optimization of Exoskeleton-based factory environments - Proceedings of the 26th CIRP Design Conference – CIRP CMS 2016.

[16] VDI-Richtlinien – VDI 3633 – Blatt 11, Simulation von Logistik-, Materialfluss- und Produktionssystemen Simulation und Visualisierung. 2003.

[17] VDI-Richtlinien – VDI 3633 – Blatt 1, Simulation von Logistik-, Materialfluss- und Produktionssystemen Simulation und Visualisierung. 2014.