Multi-objective Optimization of Ergonomics and Productivity by Using an Optimization Framework

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Abstract. Simulation technologies are widely used in industry as they enable efficient creation, testing, and optimization of the design of products and production systems in virtual worlds, rather than creating, testing, and optimizing prototypes in the physical world. In an industrial production context, simulation of productivity and ergonomics helps companies to find and realize optimized solutions that uphold profitability, output, quality, and worker well-being in their production facilities. However, these two types of simulations are typically carried out using separate software, used by different users, with different objectives. This easily causes silo effects, leading to slow development processes and sub-optimal solutions. This paper reports on research related to the realization of an optimization framework that enables the concurrent optimization of aspects relating to both ergonomics and productivity. The framework is meant to facilitate the inclusion of Ergonomics 4.0 in the Industry 4.0 revolution.

Keywords: Ergonomics · Digital human modeling · Productivity · Simulation · Optimization

1 Problem Statement

Simulation technologies are widely used in industry because they enable efficient creation, testing, and optimization of the design of products and production systems in virtual worlds, rather than creating, testing, and optimizing prototypes in the physical world. This saves time and money and facilitates more thorough investigation of the solution space. Thus, simulation is used to design workstations from a productivity perspective. Simulation is also used to assess ergonomics in the design of workstations by using digital human modeling (DHM) software [1]. However, these two types of simulations are typically carried out using separate software, used by different users, with different objectives. This can cause silo effects, leading to slow development processes and sub-optimal solutions.

N. L. Black et al. (Eds.): IEA 2021, LNNS 223, pp. 374–378, 2022.
https://doi.org/10.1007/978-3-030-74614-8_46

Research has shown that productivity and ergonomics often go hand in hand [2], since improving workers' conditions often improves productivity [3, 4]. Sometimes, however, productivity and ergonomics objectives may be in conflict. Companies need to find and realize solutions in their production facilities that uphold profitability, output, and quality, as well as worker well-being. Hence, companies need to consider both productivity and ergonomics when using simulation tools to improve factories. Previous studies have considered these aspects at the design level of a workstation [5]. However, there is a lack of frameworks that can handle an overall perspective, treat productivity and ergonomics within one tool, and assist production engineers and ergonomists to find optimal solutions taking both ergonomics and productivity into account. This paper reports on research related to the realization of an optimization framework that enables the concurrent optimization of ergonomics and productivity. The framework is meant to facilitate the inclusion of Ergonomics 4.0 in the Industry 4.0 revolution [6, 7].

2 Method

In information systems research, the design and creation methodology defines the steps involved in developing and evaluating an artifact, which may be a construct, model, method, instantiation, or framework [8]. In this paper, design and creation methodology is applied to the development of a framework to enable concurrent optimization of ergonomics and productivity using a simulation-based multi-objective optimization approach.

3 Results

The proposed framework (Fig. 1) presents a workflow to perform optimizations using DHM tools so that multi-objective simulation-based optimizations of ergonomics and productivity can be carried out. This workflow can be used both with manual optimization methods and automatic methods. The flow can be followed either by a user performing design improvements manually or with the support of optimization algorithms. The workflow of the framework can be divided into three parts: (1) problem definition and creation of the optimization model, (2) optimization process, and (3) presentation and selection of results.

3.1 Part 1 - Problem Definition and Creation of the Optimization Model

The first step in the workflow of the framework is to define the problem (Fig. 1). The problem can be either a productivity issue, an ergonomics issue, or both, and it must be capable of being represented in a DHM tool. After defining the problem, the requirements of the expected result are defined so that ergonomics and productivity targets are defined as well as the way to assess them and the conditions to end the optimization. These targets have to be measurable in the simulation results of the DHM tool, such as results from ergonomics evaluation methods and cycle times, and must represent the needs of the engineers/ergonomists.

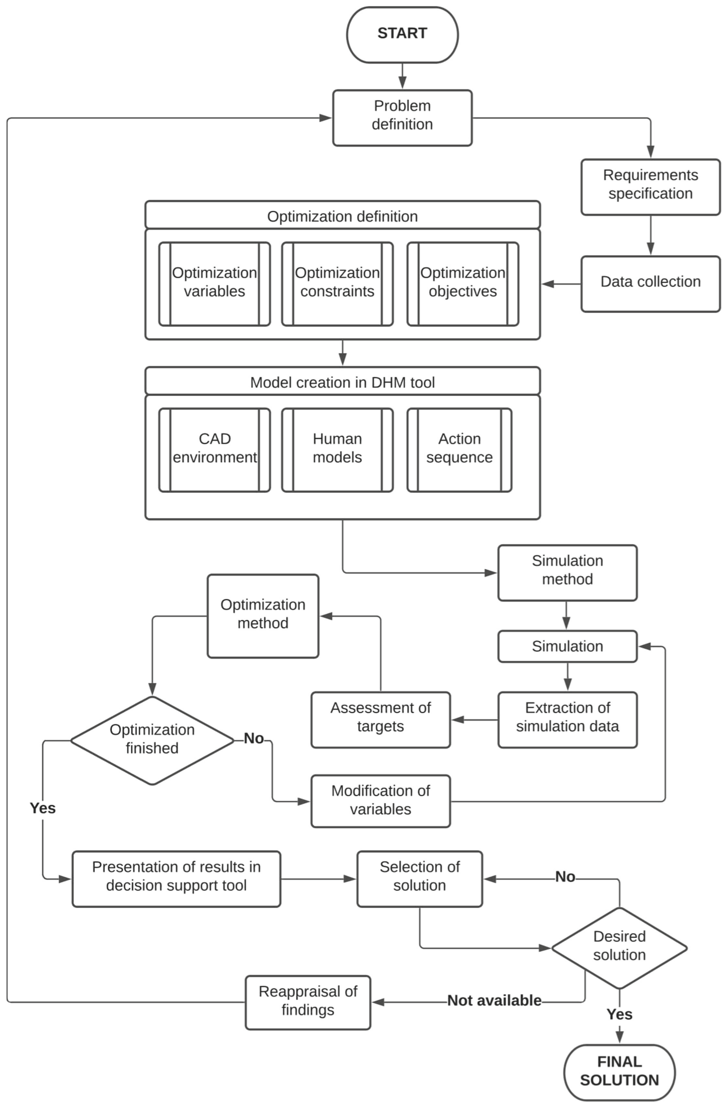

Fig. 1. Proposed optimization framework for optimization using DHM tools.

The next step is to collect data to define the optimization and create the model in the DHM tool. The optimization variables, constraints, and objectives of the ergonomics or productivity factors are defined based on the collected data. The DHM model containing the CAD environment, the human models, and the sequence of actions is then created. The CAD environment is made up of different elements depending on the case. For example, in an industrial case, the CAD environment can contain the factory layout, the resources/tools needed for production, and the product. The human models are defined so that diversity in the user group is represented. In the industrial case, this corresponds to representing diversity in the workforce. The action sequence represents the motions of the simulation. In an industrial case, the action sequence represents the actions that the workers perform to complete the tasks and other motions in the CAD environment, such as the motions of conveyor belts and robots.

3.2 Part 2 - Optimization Process

Once the model has been created, an iterative process is started to perform the optimization, following a circular generation-evaluation pattern. The simulation method defines the different settings for the subsequent simulations, such as collision avoidance and the motion generation solver (e.g., quasi-static or dynamic), and triggers the simulation (Fig. 1). The simulation data is extracted, and the targets are assessed by using the previously defined requirements. These requirements could be related to productivity (e.g., cycle time and other production metrics) and/or ergonomics (e.g., criteria of ergonomics evaluation methods). The assessed targets are input into the optimization method to calculate the optimization objectives. In manual optimizations, the optimization method and the requirements specification will define whether the optimization is finished; otherwise, only the optimization method (the optimization algorithm) will determine the end of the optimization. If the optimization has not met the requirements, the optimization method provides new variable values that modify the simulation input, and further iterations are run until the optimization is finished.

3.3 Part 3 - Presentation and Selection of Results

Once the optimization is finished, the results are presented (Fig. 1). The user then starts an iterative process of selecting solutions using a decision support tool and checking the solution results to evaluate whether the desired solution has been attained. The optimization objectives are displayed in the decision support tool to help obtain a good balance between ergonomics and productivity targets. Once a solution has been chosen, the optimization process is finished, and a final solution is defined as the result of the framework.

If no acceptable solution is available among the solutions, the findings need to be reappraised. This can lead to modifications of the previous steps, such as changes in the problem definition, requirements specification, data collection, optimization definition, or the model definition.

4 Discussion

The presented framework allows multi-objective optimizations of ergonomics and productivity using various DHM tools. The optimizations can be done by a user performing design improvements manually, or they can be done automatically using optimization algorithms. Using optimization algorithms to find optimized workstation designs allows exploring the solution space by performing a strategic search through feasible solutions without manually processing each of all possible configurations. However, results from the presented framework are sensitive to the accuracy of the virtual model. To obtain reliable results, the virtual model must appropriately represent the real world. Digitalization of the real-world industry and the workers could improve the accuracy of the simulation models. Such digitalization is one of the objectives of Industry 4.0 and Ergonomics 4.0. The most mature digitalization level is a digital twin of the factory, including both the environment and the workers. This digital twin could increase the accuracy of the results by creating more accurate models using new technologies, for example, motion capture systems could capture human motions and 3D scanning could capture the environment [9, 10].

Acknowledgment. This work has been supported by ITEA3 in the project MOSIM, the Knowledge Foundation and the associated INFINIT research environment at the University of Skövde, within the Virtual Factories with Knowledge-Driven Optimization (VF-KDO) research profile and the Synergy Virtual Ergonomics (SVE) project, and by the participating organizations. Their support is gratefully acknowledged.

References

1. Scataglini, S., Paul, G.: DHM and Posturography. Elsevier Academic Press, New York (2019)
2. Falck, A.-C., Örtengren, R., Högberg, D.: The impact of poor assembly ergonomics on product quality: A cost–benefit analysis in car manufacturing. Hum. Factors Ergon. Manuf. Serv. Ind. **20**, 24–41 (2010). https://doi.org/10.1002/hfm.20172
3. Vink, P., Koningsveld, E.A.P., Molenbroek, J.F.: Positive outcomes of participatory ergonomics in terms of greater comfort and higher productivity. Appl. Ergon. **37**, 537–546 (2006). https://doi.org/10.1016/j.apergo.2006.04.012
4. Widana, I.K., Sumetri, N.W., Sutapa, I.K.: Ergonomic work station design to improve workload quality and productivity of the craftsmen. J. Phys. Conf. Ser. **953**, 012091 (2018). https://doi.org/10.1088/1742-6596/953/1/012091
5. Battini, D., Faccio, M., Persona, A., Sgarbossa, F.: New methodological framework to improve productivity and ergonomics in assembly system design. Int. J. Ind. Ergon. **41**, 30–42 (2011). https://doi.org/10.1016/j.ergon.2010.12.001
6. Gašová, M., Gašo, M., Štefánik, A.: Advanced industrial tools of ergonomics based on Industry 4.0 Concept. Procedia Eng. **192**, 219–224 (2017). https://doi.org/10.1016/j.proeng.2017.06.038
7. Kadir, B.A., Broberg, O., Conceição, C.S.D.: Current research and future perspectives on human factors and ergonomics in Industry 4.0. Comput. Ind. Eng. **137**, 106004 (2019). https://doi.org/10.1016/j.cie.2019.106004
8. March, S.T., Smith, G.F.: Design and natural science research on information technology. Decis. Support Syst. **15**, 251–266 (1995). https://doi.org/10.1016/0167-9236(94)00041-2
9. Greco, A., Caterino, M., Fera, M., Gerbino, S.: Digital twin for monitoring ergonomics during manufacturing production. Appl. Sci. **10**, 7758 (2020). https://doi.org/10.3390/app10217758
10. Havard, V., Jeanne, B., Lacomblez, M., Baudry, D.: Digital twin and virtual reality: a co-simulation environment for design and assessment of industrial workstations. Prod. Manuf. Res. **7**, 472–489 (2019). https://doi.org/10.1080/21693277.2019.1660283