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Human – Industrial Robot Collaboration: Application of simulation software for workstation optimisation

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Abstract

The simulation possibilities of Human – Industrial Robot Collaboration (HIRC) are limited in commercial software and published research. In order to meet this a demonstrator software has been developed. This paper presents the combination of the quantitative output from the software (measuring operation time and biomechanical load) together with existing optimisation techniques used to design the optimal HIRC workstation. An industrial case is used as an example where the optimal geometric handover position between robot and human is found. From the simulation software metamodels were created in order to represent the investigated workstation. The model was used in a multi-objective optimisation problem and resulted in a trade-off chart between operation time and biomechanical load. The result shows one example of the possibilities to combine the quantitative results from the simulation with optimisation in order to get the best solution to a HIRC design problem.

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1. Introduction

In order to stay competitive in the globalised world there is a need for manufacturing companies to steadily increase their productivity. Industrial robots have been introduced in industry in the last 50 years and have assisted in huge productivity improvements since then. One way to future improvements is to let humans and robots work closer together. By removing the fences surrounding the industrial robots of today, production systems can be designed that combine the robot's strength and repeatability with the human's tactile sense and flexibility [1]. The best utilisation of these systems can be achieved by introducing robots in today's manual workstations [2]. Compared with manual stations, this should not only increase productivity [3] but also improve human ergonomics [4]. These systems imply that it is possible to work in manufacturing industries for a long time without injuries, thus meeting the demographic change that is a reality in developed countries [5, 6].

These fences surrounding industry robots may be physical or in the form of certified optical systems. They exists to ensure that no human gets in the way of a moving robot. Major current research efforts in Human – Industrial Robot Collaboration (HIRC) focus on developing systems that prevent the human from getting injured by the robot in a fenceless environment. Less research is found on design and simulation of HIRC systems. In order to meet this gap a demonstrator software has been developed [7, 8]. The software provides the possibility to analyse operation time and human biomechanical load in HIRC assembly workstation design tasks. These evaluations are connected to the proposed benefits of higher productivity and lower ergonomic load. The quantitative results can, together with the exact geometrics of both the product and the workstation, open up possibilities to use mathematical

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optimisation techniques to design the most favourable workstation [9].

Optimisation techniques have been used in workstation design research for many years. The general objective has for any company always been to optimise profit, and in workstation design that has resulted in operation time optimisation, such as in the design system EMMA [10]. In that system, ergonomic considerations are included, in addition to the time, in the workstation design problem. Manual evaluation of the solutions are however demanded.

Ben-Gal et al. [11] present a method to find the optimal layout considering economic and ergonomic goals by including the statistical technique Response Surface Methodology. In total four objectives are considered and a weight is put on each of them in order to find one optimised result. The same kind of weights on the optimisation objective are set in [12], but also include the digital human modelling tool.

The aim of this research paper is to present a method for applying existing optimisation techniques together with the HIRC demonstrator software to create productive and healthy workstations. These HIRC workstation design problems can be formulated as different optimisation problems. The software analyses both operation time and biomechanical load and the optimal solution must consider both. Thus the task can be describes as an multi-objective optimisation problem. As a proof of concept, this method is applied to optimise a real industrial workstation design case.

2. Method

The optimisation method use the developed HIRC simulation demonstrator software to create virtual simulation of a human and industrial robot collaborative workstation. This quantitative input and output data from the simulation are used to find the input which can lead to optimal workstation design, by using metamodel based multi-objective optimization approach. This process is described in detail by applying it on an industrial case in the following chapters.

2.1 HIRC simulation software used

The demonstrator software [7, 8] was used to generate the HIRC simulation used in this study. It combines a digital human modelling tool that evaluates biomechanical load with an industrial robot simulation tool. In this demonstrator software a HIRC work system can be designed, visualised, and evaluated. The evaluation is performed to analyse operation time and biomechanical load in these systems.

Operation time of the robot task is calculated by the simulation software, using robot and environmental data. Human operation time is also calculated by the software using a predetermined time system called SAM [13], based on the MTM (Methods-Time Measurement) system [14]. A predetermined time standard is used to analyse a standard time to perform a manual task. The MTM system was developed in the US in mid 1940’s and is one of the most widespread standards [13].

Biomechanical load is analysed with RULA (Rapid Upper Limb Assessment). It is an observational based posture, force, and muscular assessment tool used to evaluate the risk factors connected with work tasks [15]. It is developed in beginning of the 1990’s and consists of an assessment worksheet that is a method used to analyse individual human poses within a work task. It focuses on the positions of individual limbs of the human body and grade them according to the assessment worksheets. The tool quantifies the risk of musculoskeletal injuries on a human posture on a scale from one to seven, where a high score represents a high risk of future injuries.

2.2 Industrial case description

In this study an assembly workstation at a heavy vehicle manufacturer was optimised. It is a flywheel cover assembly station in the engine assembly plant. In this station the flywheel cover, with a weight of up to 60 kilograms and a diameter of 0.6 metres, is assembled on the engine block. The assembly is currently done by a human using an overhead conveyor system and a pneumatic lifting device.

Five operations are performed at the station. Figure 1 shows the workstation layout and the five operations. First, the assembly process starts as the flywheel cover is fetched from a rack of incoming material. Second, the cover is placed in the silicone applying machine, where a small silicone string is applied. Third, the cover is placed at the assembly position on the engine block. In the fourth operation, the flywheel cover is secured on the engine block by 12 screws, using an electric nut runner. The assembly process is then finished as the robot returns to its home position and a new cycle begins with a new product being fetched from the racks.

2.3 HIRC optimisation problems

Multi-objective optimisation aims at seeking a set of optimal trade-off solutions with respect to multiple conflicting objectives [16]. The input data (factors) in the model are assigned to be either parameters (that are chosen to be stable) or variables (that are to be optimised), in order to present the output of the experiment (the response) [17].

The multi-objective optimisation of the HIRC simulation presented is based on two objectives: to minimise the operation time and to minimise the biomechanical load. This HIRC

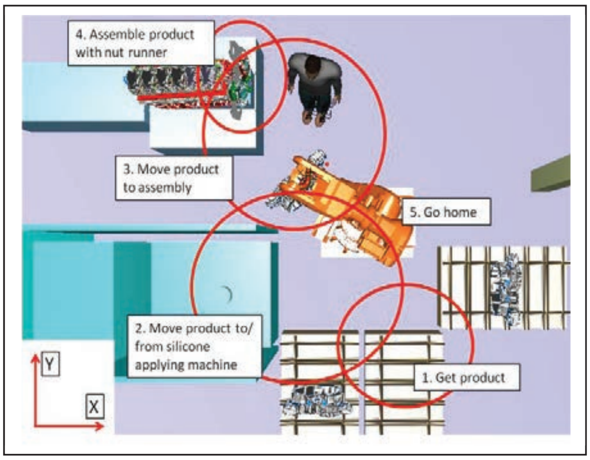

Fig. 1. Layout of the HIRC assembly station of flywheel cover, with five operations of interest.