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JackEx: the new digital manufacturing resource for optimization of Exoskeleton-based factory environments

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Abstract

The employment of Exoskeletons for manual handling work in manufacturing industries aims at increased employment, productivity, safety and security at workplace. This paper highlights several challenges, current results and future steps of our work in optimization of Exoskeleton-based factory environments. "JackEx" is the enhancement of the standard digital humanoid "Jack" with concepts and elements of passive Exoskeletons. For the development of JackEx, a new digital manufacturing resource, the intimate coupling of the Exoskeleton digital model to the humanoid "Jack" components was realized. First the CAD model of the Exoskeleton was decomposed in its elementary compound parts, by creating its corresponding kinematic model. As the next step, the coupling of Exoskeleton digital models to the humanoid was a real challenge since the humanoid and Exoskeleton kinematics are heterogeneous and autonomous. In order to define a common kinematic model of humanoid with integrated Exoskeleton, complex calculus and tests were performed resulting in a new kinematic model. JackEx was deeper validated in a virtual and digital environment through real test cases simulations. The comparison between the simulation results with those performed for the same task but without integrated Exoskeleton, revealed from an ergonomically perspective the benefits of employing the Exoskeleton in manufacturing factories.

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1. Motivation

Innovative production technology should enable to efficiently use human and material resources in order to secure production locations. Ever shorter product life cycles conflict with the necessity of extended service life of the production systems required for manufacturing of complex products and their variants. Flexibly adaptable, reconfigurable as well as self-organizing equipment and workplaces represent the key to overcome this challenge. Humans with their specific and tacit technological know-how have to be integrated into production in a newly defined role. The objective of our activities is to develop innovative technologies for human-centered workplace design and optimization with integrated Exoskeletons [1], by focusing on manufacturing processes with high level of flexibility [2]. The automotive industry mainly faces a real challenge in dismantling or disassembling processes of the old and non-reliable vehicles [3]. In order to reuse some of the materials like steel, metal and plastics parts, these have to be disassembled with complex processes, in which automation and employment of robotics represent a great challenge due to different car architectures thus involving high deploying costs. During time vehicles suffer different damages and adjustments, which can be handled just with a high level of flexibility or by human operators [4, 5]. The disassembled and manipulated parts have often high weights, affecting the health of worker. Our work focused on dismantling operations of car wheels, battery, and bonnet with the biggest challenge on disassembling the driver seat. Since each of these parts weights about 15kg, the processes apply a great stress on the back muscle.

For the implementation of the Exoskeleton in industrial factories several studies have been performed, revealing that the health of the workers which are manipulating daily weights above 10kg is critically affected because of the repetitive liftings, producing the so-called "Musculoskeletal disorders (MSDs)". The Exoskeleton concept addresses these challenges, supporting the worker in manipulating tasks thus assuring the safety and security aspects, as well. The

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philosophy and motivation behind this concept is to employ the Exoskeleton in factories where the workers could suffer injuries because of high weights lifting and manipulation [5]. Our paper focuses on the development of the new digital manufacturing resource further on called "JackEx", by combining the name of "Jack" standard digital humanoid created by Siemens with the Exoskeleton developed in the framework of the European FP7 Project "Intelligent exoskeleton based on human-robot interaction for manipulation of heavy goods in Europe's factories of the future", Robo-Mate (http://www.robo-mate.eu/). As the Exoskeletons are mainly used in military applications, no results regarding modelling and simulation research are available. Their applications in medical area mainly focus rehabilitation activities which are validated in real time.

As the project is still ongoing, several prototypes of the Exoskeleton were designed and currently are in testing. In our previous paper, "Exoskeleton-centered process optimization in advanced factory environments" [1, 6] we described the coupling of the active Exoskeleton to the digital human Jack. The current Robo-Mate Exoskeleton has currently two prototypes, the active one, actuated by motors and the passive model actuated through springs. The passive prototype is working under the Steadicam concept [8]. Different challenges were faced during the coupling of the standard digital humanoid Jack with the passive model of the Exoskeleton.

2. Design of the passive JackEx digital prototype

The employment of Exoskeleton in manufacturing industries started with a deep analysis of the industry requirements, searching for a suitable design in order to fit the needs of the automotive industry (assembly, disassembly and suppliers), thus protecting the health of the human operator. Various production areas from the automotive industry were studied and based on the resulted knowledge different prototypes were created and tested, reason why into the previous scientific paper "Exoskeleton-centered process optimization in advanced factory environments" we coupled the active part of the Exoskeleton. The current design consists of two modules, arms and trunk. This prototype enables the customization of the selected Exoskeleton variant which is composed of modules required for the realization of corresponding assembly/disassembly processes. Based on the industry requirements there is possible to use active and/or passive arms attached on the trunk module, thus there is the possibility of having both arms active/both arms passive [7,8,9].

The passive Exoskeleton design combines innovative the springs and the Steadicam concepts. The current design does not have an electrical part, eliminating a lot of risks, assuring the workers´ safety. Most of the possible failures are reduced through this design thus inducing reduced costs for maintenance, as well. The worker, based on his specific activities and executed tasks has the possibility to select between different levels of enabled support. The passive module of the Exoskeleton supports a range of 0,5kgs – 7,5kgs sustaining force/hand, adjusting this through elements 1 and 2 from Fig. 1. The second module (trunk module) is in particular designed to help the human operator in sustaining weight with knees and hips, these body parts being more capable of enduring loads. Lower part of the Exoskeleton is distributing the weights throughout the human body therewith sustaining it through the actuators. Fig.1 gives an overview of the current design and of the innovative idea behind it. The elements from Fig.1 marked with 1 represent the actuators and those marked with 2 the parts through which the worker receives a part of the load.

Fig. 1. Adjusting components (©Robo-Mate)

The above presented modules are prototypes which contain the core principles of the final design, further improvements and refinements will be realized into the final version, after the experimental tests will be performed. In our current work we used this version of design; when updates will be performed, the JackEx will be updated and adjusted accordingly [10].

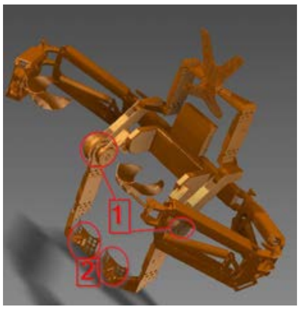

Fig. 2. Actuators and weight sustaining elements (©Robo-Mate)

The comprehensive behavior of the Exoskeleton requires additionally to the mechanical and hardware components a control algorithm for guiding the Exoskeleton movements, acting intimate with the digital human. Fig. show the Exoskeleton CADs coupled on the standard digital humanoid from Siemens, creating the innovative manufacturing resource, named JackEx.

3. Approach for Exoskeleton Modelling and Simulation

3.1. Employed methods and technologies

The employed modelling and simulation technology and system is Siemens Classic Jack. With the use of digital human models, planning and optimization of the workplace can be realized through modelling and ergonomics simulation, assuring that the comfort, safety and efficiency of the workplace will be realized as expected.

Several required capabilities for the realization of JackEx and the comprehensive modelling and simulation of the industry use cases are enabled by Classic Jack, as follows: