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ScienceDirect

Procedia Manufacturing 11 (2017) 124 – 131

Procedia MANUFACTURING

27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, 27-30 June 2017, Modena, Italy

Interactive simulation of human-robot collaboration using a force feedback device

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Abstract

In this paper, we demonstrate the use of interactive simulation as a tool for workcell validation and optimization. The proposed technique uses real-time physics simulation to immerse the design engineer or production planner inside a responsive virtual model of the factory. The user can interact with components and tools, as well as with the robots performing their assigned tasks, including collaborative steps. The hand guiding function of sensitive lightweight robots can be simulated using force feedback devices. Future application scenarios can be directly tested in the assembly process simulation. Thanks to this first-person 3D experience, a better understanding of the risks, complexity and potential improvements can be reached. With this knowledge, it is possible in early planning stages to define the first working and protection areas for safety programming. These are necessary for the human-robot collaboration to be safe. In addition to safety, the process reliability can be optimized in the simulation, too.

Peer-review under responsibility of the scientific committee of the 27th International Conference on Flexible Automation and Intelligent Manufacturing

Keywords: Interactive simulation; collaborative robotics; manufacturing ergonomics; modelling and simulation; force feedback; human factors; smart manufacturing

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Peer-review under responsibility of the scientific committee of the 27th International Conference on Flexible Automation and Intelligent Manufacturing
doi:10.1016/j.promfg.2017.07.210

1. Introduction

The role of robots in manufacturing processes is undergoing a revolution. Robotic applications in the final assembly can create age-appropriate jobs. The assembly workers are supported in physically demanding activities and the ergonomics in the workplace is improved. Furthermore, tremendous gains in productivity and flexibility can be achieved by removing the fences and letting humans and robots work together in the same work area to fulfill a common task. [1] This approach is called human-robot collaboration (HRC) [2]. Both collaboration partners can make optimal use of their specific abilities. The safety of the assembly worker is ensured, for example, by power and force limiting by inherent design or control. [3, 4] The new functions of sensitive lightweight robots are based on force sensors and a new control mode, the so-called impedance mode. However, new risks have to be addressed, and new means of optimization are necessary [5]. Through the use of collaborative robotic systems in the final assembly, also the demands on the methods and tools of the digital factory, especially the simulation, are increasing. Physics-based simulation is becoming very important for future robot simulation. New tools for work-cell design, validation and optimization are required.

2. State-of-the-art

Physics-based interactive simulation has been a subject of research and development for several decades, starting with the work on VPS at BOEING in the early 1990s [6], one of its main applications being the validation of assembly tasks for the industry [7]. The main technical challenge consists in updating the state of the virtual environment according to the laws of physics, or to a simplification of them, not slower than the user's own perception of time. If the goal is to provide force feedback to the user, the real-time requirements are even stronger because, according to control theory, the maximum achievable stiffness is a function of the update frequency squared. In practice, the typical update rates are far above the requirements of visual feedback alone, and close to 1 kHz.

Due to that constraint, most of the research work has been concentrated on the difficult problem of collision detection, and the interactive simulation of robots has received little attention [8]. Some effort has been recently deployed for the simulation of humans in real-time, for the purpose of ergonomic assessment [9]. The simulation of specific mechanical constraints has been proposed by some authors as a way to simplify some assembly tasks; in [10], the constraints must be selected actively by the user in order to affect the simulation behavior, whereas in [11], they provide a help to the user for the alignment of the assembly movement proper.

The combination of robotic systems and interactive constraints was introduced by Blake Hannaford in the late 1980s as "shared control" [12], in the domain of tele-manipulation, and it still generates a lot of interest for safety-sensitive tasks today [13]. In the case of industrial applications, the strong separation of workspaces between humans and robots, due to safety regulations, prevented any kind of physical interaction until the emergence of the concept of "service robots", and more specifically the development of the "lightweight robot" by DLR [14].

In the last few years, several teams have successfully combined the simulation of human operators with robots, for the purpose of the ergonomic design of collaborative robots [15, 16]. However, the complexity of such simulations is still too high for achieving a level of performance compatible with real-time interactivity, so that they cannot provide a first-person, hands-on experience of the task to be performed. In the field of industrial assembly validation and ergonomics assessment, simulation methods are already being used that precisely meet these requirements [17]. A real use case from the automotive industry is used to check whether these methods are also suitable for the work-cell design and optimization of human-robot collaboration.

3. Description of the use case

In the automotive industry, there is a very high variety of variants, so the final assembly is largely done by manual work. This results in a large number of non-ergonomic activities on the vehicle chassis by handling heavy components or tools above the head or above the shoulders. One way to improve the ergonomics is to turn the entire vehicle on its side by means of a complex conveyor system so that the above-mentioned activities can be carried out in a pleasant working height. However, this is not an adequate solution, because it would lead to very high