A Smart Workcell for Human-Robot Cooperative Assembly of Carbon Fiber Parts

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***Abstract*—The production of carbon fiber parts is currently mainly performed by human operators, due to the complexity of the process. When large parts are involved, more operators are needed. The DrapeBot project aims at developing a human-robot cooperative system capable of assisting one single operator working on large parts. This requires environment perception in the workcell, intelligent robot task and motion planning, and the understanding of the production process. This paper outlines the track proposed to create such an intelligent cooperative workcell.**

***Index Terms*—Human-robot cooperation, cooperative production, behavior recognition, body pose estimation, robot task and motion planning.**

I. Introduction

Draping is one of the most complex operations in carbon fiber manufacturing. It is carried out by transporting the carbon fiber fabric onto the preform and adapting its shape. This process is usually performed by human operators. When it comes to large components, usually two or more highly skilled operators are needed—one usually controlling the process, and the other(s) acting as a support. This is, at the same time, expensive and unneeded, because one single skilled operator could manage the draping process, while the task of the additional operators could be carried out by an automatic system capable of following the indications provided, as exemplified in Figure 1. This means to better exploit the skills of the human operator who acts as the leader of the draping process, guiding the whole process and assessing its quality, while, at the same time, employing robots for executing the more trivial but heavy duties.

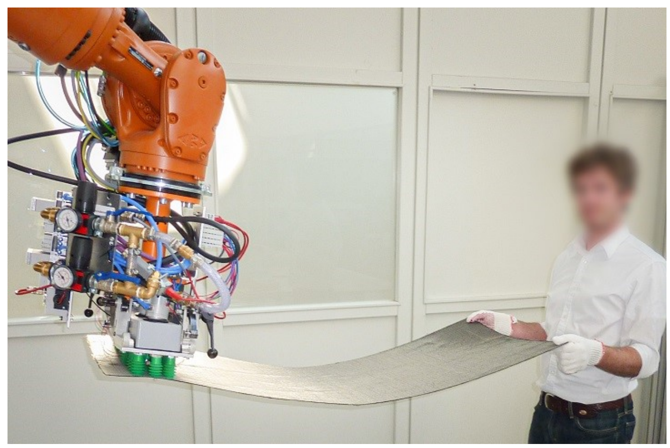

Fig. 1. A human operator cooperates with a robot for carbon fiber transportation.

A. Human-Robot Interaction for Carbon Fiber Parts Manufacturing

The European project DrapeBot (www.drapebot.eu) has the goal of developing a novel human-robot interaction technology capable of supporting one single human operator handling large carbon fiber parts. This is based on cutting edge AI tools, both at the perception and the action stage. In such context, a thorough understanding of the scene is needed to properly feed the AI systems that are in charge of determining the robot action and motion in real-time. Also, understanding the human intention is crucial to analyze whether the human-robot interaction is ergonomically correct and safe.

B. The Smart Workcell

The workcell developed in DrapeBot is smart because it is aware of the processes that take place inside the workspace, thanks to the sensors and the artificial intelligence modules that equip the cell. Understanding human behavior starts from perceiving the human body posture, involving Action Recognition [1], people re-identification [2] and human-computer interaction—a typical output of a body pose estimation system

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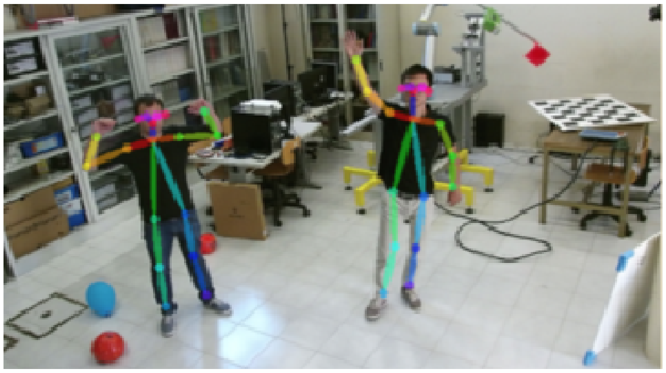

Fig. 2. Example of body pose estimation system, a key element of the smart workcell.

is shown in Figure 2. In recent years, several efforts have been done to obtain fast and reliable human motion estimates in real-time. Several works, like [3], focused specifically on employing image processing techniques to gain knowledge about the human pose in real-time. In some cases, filtering has been also applied to provide smoother results [4].

An intelligent reaction from the robot, however, depends not only on the perception of human behavior but also on the current status of the workcell. For example, similar gestures may have different meanings depending on the current status of the workcell (e.g. the presence or absence of fabric on the mould). The most flexible approach to understand the environment is semantic segmentation. This method is capable of classifying elements of the scene and it commonly runs on 2D images. Nowadays, however, Deep Neural Networks (DNNs) and Convolutional Neural Networks (CNNs) are boosting semantic segmentation of 3D images.

II. Workcell Environment Understanding

Focusing on the perception stage, DrapeBot aims at enhancing the state of the art and the industrial practice by combining visual sensors with inertial sensors to obtain a fast and accurate perception of how human workers move in the workcell. This will be accompanied by a semantic interpretation of the environment. In this way, the system will ensure a smooth and reliable interaction with the human(s), that will not be blocked nor slowed down due to temporary perception failures caused, for example, by an occlusion preventing the vision system to perceive the human operator. Such high-end perception systems will be employed to provide a thorough understanding of the working environment and the body pose of the person(s) present in the working area of the robot. A probabilistic model for human body pose estimation will be derived, capable of taking advantage of both visual and inertial sensors, enhancing the detection when both are available but capable of working when only one sensory system is working. An important element of the project will be the definition of the sensing accuracy needed to meet the safety requirements of the robotic workcell.

The semantic environment perception equipping the workcell will be a key element for detecting in detail the current status of the workcell, because it can provide a high-level description of the components of the environment, enabling automatic evaluation of the current status of the production process, possible misalignments, and possible risks when workers are in proximity of dangerous moving elements.

The DrapeBot project will enhance the state of the art and the industrial practice by deploying an integrated layered framework where the Task and Motion Planning (T&MP) and the low-level control will be jointly designed to work in full synergy. The T&MP will manage human and context information to do both: reason on the user model and interpret several sensorial information. Sensor data will come from the robotic system and the human perception system, that will include an AI-based human action and intention understanding module. This will enable optimization of task sharing between humans and robots and selecting the processing areas to minimize human interference. The low-level control will exploit the estimated human intention control dealing with the compensation of the model inaccuracies, and allowing a continuous adaptation on the best task and motion plan computed by the T&MP module.

Considering the T&MP layer, the core advancement will consist in the deployment of modules designed for efficient online computation of a sub-plan after performing each action. Thus, exploiting at each iteration updated sensory readings, it implicitly takes into account unexpected changes in the estimated state due to previous sensors and actuators failures, or environment re-configurations. This framework will integrate a human-aware motion planner that will generate a collision-free trajectory provided in real-time leveraging on a data-driven approach (e.g, a Deep Reinforcement Learning framework) to improve the planning effectiveness.

III. Conclusions

In this paper, the design of a smart workcell for cooperative processing of large carbon fiber parts was presented. The workcell can actively support the human operators in the production process thanks to accurate and redundant sensory information that are integrated with the robot task and motion controller.

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