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A Smart Workcell for Cooperative Assembly of Carbon Fiber Parts Guided by Human Actions

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***Abstract*—The production of carbon fiber parts is a complex process mainly performed by human operators. For small parts, high dexterity and skilled operators are needed while for large parts many people are often needed to transport the material without damaging it. The DrapeBot project aims at developing a human-robot cooperative system capable of assisting an operator working on carbon fiber parts. This requires environment perception in the workcell, intelligent robot task and motion planning, and the understanding of the production process. In particular, the project focuses on realizing a safe and effective collaboration where the operator can interact with the robot in an intuitive manner by means of gestures. This paper outlines the track proposed to create such an intelligent workcell.**

***Index Terms*—Human-robot cooperation, cooperative production, behaviour recognition, body pose estimation, human action recognition.**

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 [1].

The European project DrapeBot[1] has the goal of developing a novel human-robot interaction technology capable of supporting one single human operator handling large carbon fiber parts. Among the various use cases envisioned in DrapeBot there are the automotive and aerospace sectors. In the former case, the project addresses the production of complex components of an automotive sport car, like the front hood or the side panels with dimensions up to 2-3 meters. In the latter case, the project addresses the production of parts of the structural framework of an aircraft fuselage, mostly skin stiffening elements such as spars and ribs. The typical size of a rib is 5 meters and consists of up to 20 layers of material.

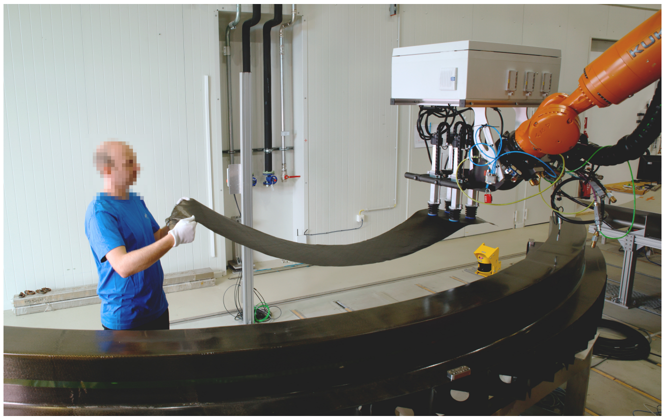
Fig. 1. An example of the draping process of an aerospace carbon fiber parts. The human operator cooperates with a robot holding the material.

The DrapeBot project proposes the development of two robotic workcells shown in Figure 2, specialized for different carbon fiber parts production processes. A medium size workcell is designed for supporting the human operator in the production of small and medium carbon fiber parts such as components in the automotive industry (e.g., car's hood); such workcell has a footprint of approximately 3×5 meters in size and equipped with an industrial robot arm which assists the human partner during material transportation phases, or by placing directly and precisely small patches of material leaving to the operator to adapt the material in high curvature points.

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[1] www.drapebot.eu

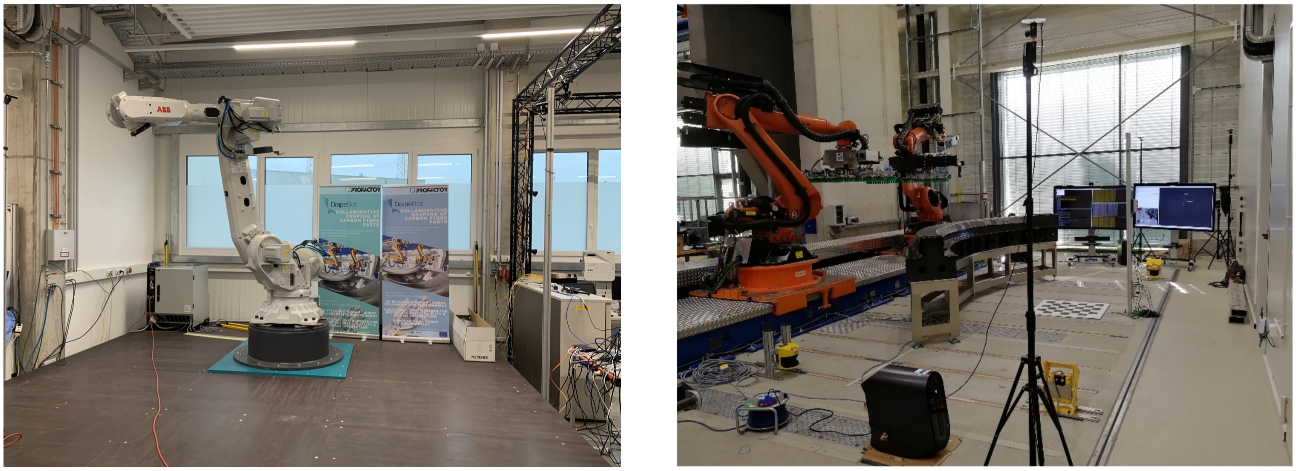

Fig. 2. The two workcells developed in the DrapeBot project. On the left, a workcell for the production of small and medium parts such as in automotive industry; on the right a workcell for large carbon fiber parts production as in the aerospace industry. Both workcells are equipped with a network of cameras.

For production processes involving large carbon fiber parts instead, a large size workcell (i.e., with a footprint of 6.5×8.5 m) equipped with two industrial robot is proposed; the two manipulators are moved in coordination to assist the human operator during the material transportation to prevent large patches from being deformed or ruined by too high tensions.

Both workcells are 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.

II. WORKCELL PERCEPTION SYSTEM

The workcells developed in DrapeBot are smart because they are aware of the processes that take place inside the workspace, thanks to: i) prior knowledge of the production processes being performed; ii) a complex sensory system capable of observing the workcell under different viewpoints, using different sensor technologies and with a certain degree of redundancy, and iii) AI modules capable of interpreting the sensory data to extract high-level information, with a special focus on human activities.

A. Human Perception

In terms of human perception, DrapeBot aims to improve the state of the art and industrial practice by combining different information to get a quick and accurate perception of workers' activities: where they are, what they do, and how they do it. Different perception modules are developed to understand human activities at multiple levels, namely: pose estimation, human parsing, human action recognition.

A probabilistic model for human body pose estimation is derived, capable of taking advantage of both visual [2] and inertial sensors [3], enhancing the detection when both are available but capable of working also when only one sensory system is working. Pose estimation provides a schematic representation of the human body made of links and joints, as depicted in Figure 3. The human parsing module [4] outputs a 3D human representation derived from body parts segmentation, which combines high-level semantic information (i.e., human body parts) and volume information. Human parsing and pose estimation outputs represent complementary information which are then combined together to obtain a complete and accurate estimation of the human movements and the workcell space taken by the human body, that is crucial to ensure safety.

Finally, the human perception system includes an AI-based human action and intention recognition module trained to recognize human behaviors from a predefined set of actions which can occur in a human-robot collaboration task. The list of actions includes common collaborative actions such as *transporting*, *picking an object* or gestures to give commands to the robot like *stop*, *move left/right*, as shown in Figure 3. Depending on the use case, the set of actions can be extended to include specific actions for the actual process; considering the automotive case, the actions considered are: i) adapt the carbon fiber patch to a desired shape; ii) press the patch in some key position to fine-tune the shape adaptation in the previous step; iii) remove a film in order to expose an adhesive layer – this is an action that is required to attach the current patch to the next one. Such actions are very specific for carbon fiber production (they are key production steps); however, the actions performed by the human operators are rather generic and limited to pressing, holding and pulling a carbon fiber patch. This makes it possible to tackle complex tasks related to carbon fiber production using an action recognition system trained to recognize rather generic actions. The gap between a general action (like "pull an object") and the special meaning that such action has in the specific production process relies in: a) knowledge on the production environment and the objects involved in the actions; b) a priori knowledge of the production process being performed, which is available to the system.

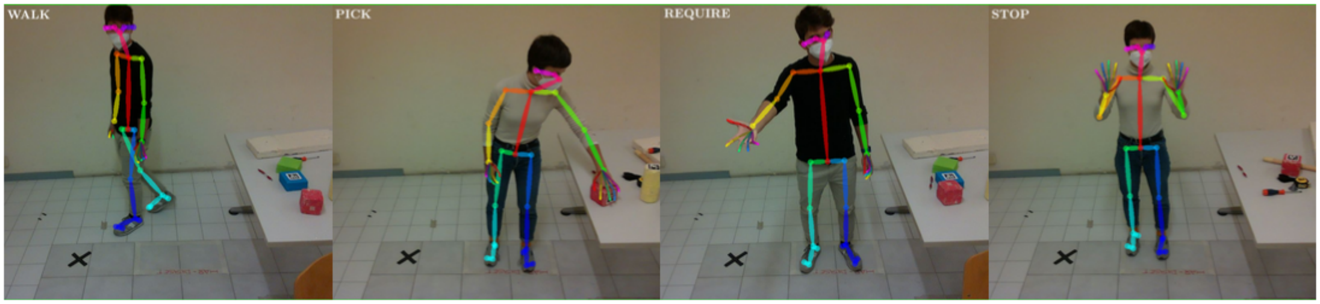

Fig. 3. An example of possible action during a human-robot collaboration task. From left to right: *walking*, *picking an object*, *requiring an object* and gestures to give commands to the robot like *stop*.

B. Environment Understanding

The semantic environment perception module is 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. Indeed, an intelligent reaction from the robot depends not only on the perception of human behavior but also on the current status of the workcell. Moreover, 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 is commonly based on Deep Neural Networks (DNNs) [5].

Thanks to semantic segmentation it is possible to monitor the current status of the workcell and to recognize particular conditions of the material handled during the collaboration, such as if the material is too tight or too loose. Moreover, the semantic segmentation of the environment is helpful to improve the understanding of the human actions, for example which objects the operator is using in a given moment.

III. HUMAN-ROBOT COLLABORATION

The human perception system provides a complete understanding of the human behaviour, involving the human pose and the recognized human actions and intentions. This high-level information can be used to optimize task sharing between humans and robots and to select the processing areas to minimize human interference. In particular, a task planner module coordinates the robot activities based on the current sequence of human actions: such module is responsible for creating a continuously updated plan that serves as a guideline for the robot workflow, composed of a sequence of robot actions to achieve a given task. Moreover, human intentions are also taken into account by the task planner to dynamically adapt the robot behaviour to the human needs during the collaboration. The robot low-level control will exploit the estimated human intentions to better assist the human partner during collaborative transportation tasks, dealing with the compensation of the inaccuracies (e.g., human unexpected movement), and allowing a continuous adaptation of the best robot motion trajectory. (e.g., during material transportation, if the human worker slows down the robot adapts its movements not to pull the material too much).

During collaboration the human operator can trigger specific actions by the robot through the use of gestures (e.g., inspect a specific location on a carbon fiber part). In such a case, the gesture is recognized by the human perception system prompting the motion planner module to generate a collision-free trajectory to move the robot in the requested position.

IV. 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. Special emphasis is placed on achieving effective and intuitive collaboration for the human operator through gesture recognition and intention estimation; by knowing human intention is indeed possible to program the robot actions such that they are perceived the more natural as possible by the human partner.

REFERENCES

[1] Matheson, E., Minto, R., Zampieri, E. G., Faccio, M., Rosati, G. (2019). Human–robot collaboration in manufacturing applications: A review. Robotics, 8(4), 100.

[2] Cao, Z., Simon, T., Wei, S. E., Sheikh, Y. (2017). Realtime multi-person 2d pose estimation using part affinity fields. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 7291-7299).

[3] Paulich, M., Schepers, M., Rudigkeit, N., Bellusci, G. (2018). Xsens MTw Awinda: Miniature wireless inertial-magnetic motion tracker for highly accurate 3D kinematic applications. Xsens: Enschede, The Netherlands, 1-9.

[4] Terreran, M., Barcellona, L., Evangelista, D., Ghidoni, S. (2021, December). Multi-view Human Parsing for Human-Robot Collaboration. In 2021 20th International Conference on Advanced Robotics (ICAR) (pp. 905-912). IEEE.

[5] Chen, L. C., Zhu, Y., Papandreou, G., Schroff, F., Adam, H. (2018). Encoder-decoder with atrous separable convolution for semantic image segmentation. In Proceedings of the European conference on computer vision (ECCV) (pp. 801-818).