Human-Robot Collaboration for Complex Draping Processes of Carbon-Fibre-Reinforced Polymers for Aerospace Parts

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***Abstract*—This paper addresses the idea of a work place where heavy industrial robots are operating side by side with a highly skilled human to support him during manual manufacturing of complex aircraft parts made of Carbon-Fibre-Reinforced Polymers (CFRP), *i.e.*, draping and preforming of dry material cut pieces. The system is controlled by the human in intuitive ways of communications - gestures and voice - and takes care of all process steps not related to the core of the process - the manual draping. The paper discusses one of three use cases in the project Drapebot alongside with the technologies developed and integrated into large robotic cell. The description of the setup, safety implementations and the current status and results are discussed providing basis for safe and efficient human robot collaboration with industrial robots in manufacturing environment.**

***Index Terms*—human-robot collaboration, CFRP, frame, aircraft, industrial robots**

I. INTRODUCTION

The utilization of Carbon-Fibre-Reinforced Polymers (CFRP) in aircraft manufacturing is characterised by small batch production where the manufacturing rate is low in comparison to the automotive industry. Moreover, the part design is often complex, highly optimised and imposes highest requirements regarding to quality. For large structures like fuselage parts with lesser curvatures and bigger radii, novel manufacturing technologies like automated fibre placement are more and more common. However, smaller parts with more complex geometry are still manufactured in manual labour by highly skilled humans who are draping the CFRP material by hand. Also, for some parts, the specific technical or economic properties can imply to the use soft dry CFRP materials. Such manufacturing processes are difficult or even impossible to be fully automated because of the complexity of the necessary tools, challenges in handling of the material [1], lack of required flexibility or too high invest for small batch production. This gives a chance to semi-automated process, where the human operator can benefit from his highly efficient skills while being unburdened from exhausting and tedious supporting tasks. To develop a human-centred process for CFRP draping, where robots are helping at pace given by the human is the main goal of the project Drapebot which has now entered its final stage. The result of the project will be a set of technologies that make it possible to set up draping processes for various use cases where an industrial robot cell is used for multi-step processes where a human in the cell can take on the difficult actions in a leading and flexible way. This differentiates the automation approach from previous automation projects for draping CFRP in aircraft manufacturing [2], [3] and is characterised by a number of innovations, such as a very flexible process design, intuitive and human-friendly support for complex manual tasks and safe human-robot collaboration in CFRP production with heavy industrial robots compared to established manufacturing processes.

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II. USE CASES AND PROCESSES

The aim of the project Drapebot is to develop and combine technologies which enable efficient, flexible and safe implementation for a variety of environments and use cases. This includes different materials, sizes and shapes, geometries - especially complex curvatures - layup sequences and draping strategies. Drapebot addresses three sophisticated use cases where aerospace, automotive and maritime parts are manufactured. For the demonstrations, two robotic cells with different setup and technology platforms (KUKA and ABB) are available and utilize the developed technologies in its own specific ways. In each of the use cases, the manual draping by the human worker is central part of the process and is performed in the immediate vicinity to the robot or the robotic tool. Some of the process steps require even the system to support the human by direct collaboration during the draping or the transport of the material.

This publication focuses on the aerospace use case. It is provided by the Center for Lightweight Production Technology, a part of the German Aerospace Center (DLR) based in Augsburg, and focuses on manufacturing of structural frames for commercial aircraft like A350 Airbus. The part itself is generic but follows the best practices for the design of corresponding parts. The frame is component of circumferential stiffening structure of the fuselage with radius of 3 metres and length more than 4 metres The layup consists of 28 cut pieces with sizes varying from 40 by 20 centimetres (strengthening patches) up to 48 by 425 centimetres for long structural plies. The layup has predefined placing sequence, where most of the cut pieces must by placed and draped in particular order. Such processes are usually done in manual labour due to the high complexity of the preform and high requirements for quality of the draping. The draping strategy differs for the sizes of the material: the short patches are draped from the middle point (seed point) to the outer parts, the longer cut pieces (up to 1.5 metre) are placed on the mould and draped successively for multiple seed points whereas for the long cut pieces up to (4 metres) the draping starts from the middle point towards one end and is repeated for the second half of the cut piece. This is very challenging process, due to the fragility of the material and strong curvature of the mould. The material used for the part is unidiectional, biaxial with two directions (-45°\+45°and +45°\-45°) and triaxial with -45°\90°\+45°and +45°\90°\-45°respectively. Such materials are particularly difficult to drape by automated tools due to high forces necessary for the dislocation of the fibres over the entire length of the cut piece. Each of the materials is dry fabric but equipped with standard thermoplastic binder material used to join layers by melting the binder between the layers. The aerospace use case is set up on the Technology Readiness Cell (Technologierprobungszelle, TEZ) at the Center for Lightweighttechnology in Augsburg which consist of two KUKA210 R3100 ultra KR C4 industrial robots on common, 8 meters long gentry. The process will be developed over the full course of the project. The major challenges are support of the human during the manual draping and material logistics by the system. The worker leads through the process and is responsible for the quality assurance after draping of the cut piece while he can decide if quality assurance methods have to come to action or the process is to be carried out with successive cut pieces.

III. TECHNOLOGY COMPONENTS

In course over the first two years of the project, several technologies crucial for each process in three use cases of project Drapebot have been developed. The focus were put on the universality of each technology because of the severe differences between the use cases: the variety of materials, the size of the cut pieces, the cell layout and safety requirements, the processes and above all the robot platforms: KUKA (in case of aerospace use case) and ABB (in case for the other two use cases). In the following the key technology components will be described in greater detail with focus on their implementation at the TEZ for the aerospace use case only.

A. Human recognition

The human perception system analyses data provided by a network of visual sensors (*i.e.*, RGB-D cameras) by means of several AI-based algorithms to provide a thorough understanding of the people inside the robot work cell, such as their posture [4] and the volume occupied [5]. Body pose estimation algorithms provide information about the position of the people in the scene and their movements (e.g., the position of each human limb), while body parts segmentation algorithms provide information about the size and volume of each human limb. The estimated human poses are then further analysed by a human action recognition (HAR) module, which monitors the human worker's actions during the collaborative draping process [6]. An example for the outputs gained by the human perception is shown in Figure 1.

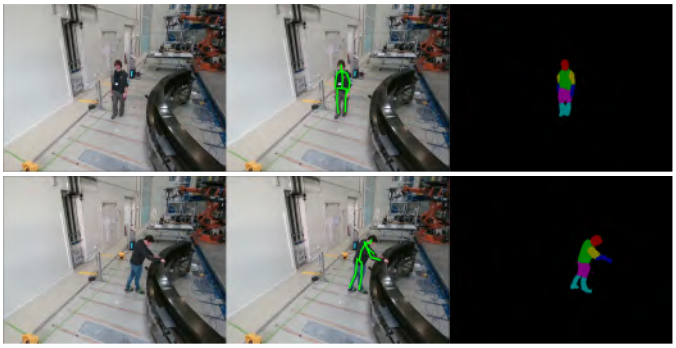

Fig. 1. Example of the human perception outputs. From left to right: input RGB image from one of the cameras; body pose estimation output; body parts segmentation output.

In particular, the human perception system is based on a network of RGB-D sensors (*i.e.*, Intel Realsense Depth D455 camera). Each camera is connected to a PC running single-view human perception software, which detects people inside the work cell and estimates their poses (*i.e.*, skeletons). A central "Master" PC combines the detections from the cameras in the network and outputs 3D people skeletons with respect to the work cell reference frame [4]. The use of a camera network allows one to monitor human workers inside the work cell without occlusions. In the case of TEZ at DLR, the area to be monitored is limited to the area in front of the mould, where the actual human-robot interaction takes place. A camera network of four cameras has been designed to monitor the area, placing the cameras at their corners to maximize coverage and the overlap between the cameras' field of view; the final camera network layout proposed and tested in the TEZ is shown in Figure 2. The camera network has been calibrated using an automatic hand-eye calibration procedure [7]. In particular, a known pattern (i.e., checker board) is mounted on the robot (as shown in Figure 2), and the robot moves the pattern in several positions while acquiring images from all the cameras. An optimization algorithm based on re-projection error minimization then computes the pose of each camera in the network with respect to the robot base frame by means of the acquired images and the robot kinematics.

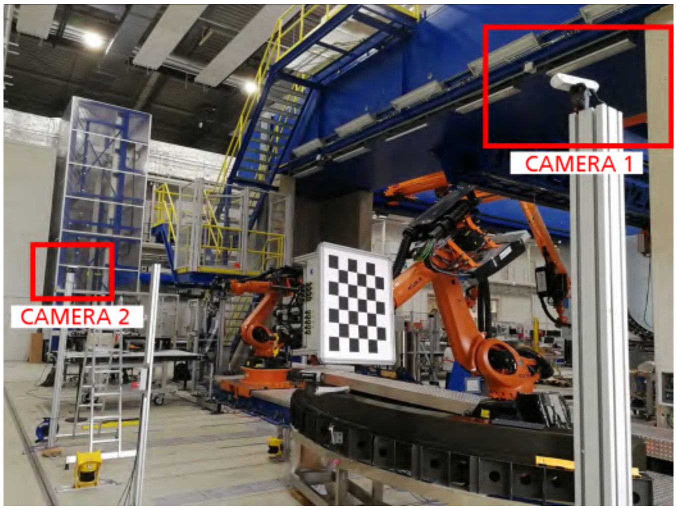

Fig. 2. Overview of the camera network installed in the TEZ in DLR.

The action recognition system is based on a deep learning classifier which takes as input sequences of 3D skeletons provided by the human perception system [6]. By using skeletons, the action classifier can focus on sequences of body poses that only describe human movements to learn a more general and robust representation of the actions of interest, which is independent from the viewpoints and unaffected by the scene clutter such as external objects, illumination, and the people appearance, like clothes or skin colour.

The TEZ work cell developed at DLR involves the use of gestures to provide a simple and intuitive way for the human operator to interact with the robots, such as to signal the start of the draping process or to request robot assistance with specific tasks (*e.g.*, take a picture of the ply for draping quality verification). Therefore, the actions to be recognized consist mainly of short-duration gestures to trigger parts of the draping process (*e.g.*, cut piece detection) so that the person is always in control of which step the robot is performing. Other gestures are used to easily communicate the worker's intentions to the robot, such as to stop the robot's execution to allow the inspection of the status of the ply during draping by the worker safely. Figure 3 provides some examples of the collaborative gestures selected:

1) "cut piece detection", by clapping hands above the head, triggers the localization of the next carbon fibre ply;
2) "take picture", by pointing at a desired location on the mould with a straight arm, triggers the acquisition of an image of the current status of the draping process;
3) "drape start", defined by making an horizontal circle (clockwise) with the right hand, triggers the robot to start the draping process.

The complete list of actions of interest includes also an "interrupt" gesture (raising one hand above head) to stop the current robot execution, or a "drape next" gesture to signal the robot to move to the next draping point.

B. *Motion planner*

The Motion Planner [8] module is crucial in generating accurate robot trajectories, which are essential for facilitating collaborative tasks between humans and robots within a Human-Robot Collaboration setting. This collaboration is particularly important during the transport and draping phases of manufacturing, where both robots and human operators work in close proximity, requiring a high degree of coordination and safety. The Motion Planner is designed to enhance safety and collaborative efficiency by incorporating real-time data on human presence in the work cell, ensuring smooth human-robot interaction. To achieve this, the module integrates real-time location data of operators to adapt robot trajectories, especially during high-risk tasks such as transporting large materials or precise draping activities. The human perception module (III-A) supports this, providing dynamic data to the trajectory planner, allowing it to respond to the changing collaborative environment. Additionally, safe zones [8] and a trajectory deformation volume [9] are established to ensuring the safety of human operators. In scenarios involving dual robots, such as in the DLR use case, motion planning must account for the simultaneous actions of both robots in overlapping workspaces. This includes synchronous tasks, where robots cooperatively transport materials, and asynchronous tasks, requiring distinct objectives yet concurrent operation within the workspace.

C. *Low level control*

The low-level control architecture designed for the TEZ aims to control industrial robots during the draping task. The complexity of the task, the dynamic environment, and the operator's presence are imposed using a general and flexible control architecture that can be easily interfaced with external

i) `Cut piece detection‘ gesture

ii) `Take picture‘ gesture

iii) `Drape start‘ gesture

Fig. 3. Example of the skeletons provided by the human perception system in the TEZ at DLR for different gestures considered in the collaborative draping process.

advanced control algorithms and smart sensors. To this aim, the control architecture in Figure 4 is based on three main blocks. A central management node (highlighted in green in Figure 4), embedding a Task&Motion Planner (TAMP), in charge of task scheduling and dynamic planning based on the evolution of the planning scene [10]. The second block (highlighted in light blue in Figure 4) exploits the ROS environment on a Linux PC to easily integrate advanced control algorithms and sensors, such as perception systems [11]. This block receives the nominal trajectory from the motion planner, modifies the trajectory based on external inputs, and can generate microinterpolated trajectories for the robot controller. An example is the possibility of trajectory velocity scaling on the operator's base and the robot's position in the cell workspace. The third block (highlighted in orange in Figure 4), running on a soft PLC (i.e., Twincat), is in charge of the low-level communication with the robot controller, receiving a microinterpolated trajectory and sending the trajectory to the robot controller. The choice of a robot open controller, such as the KUKA RSI real-time interface, allows an external trajectory planner to bypass the internal one. The use of the soft PLC guarantees real-time performance for robot communication. The driver running on the soft PLC is a robot brand-specific, and in case of robot brand change, is the only part of the architecture that must updated [12].

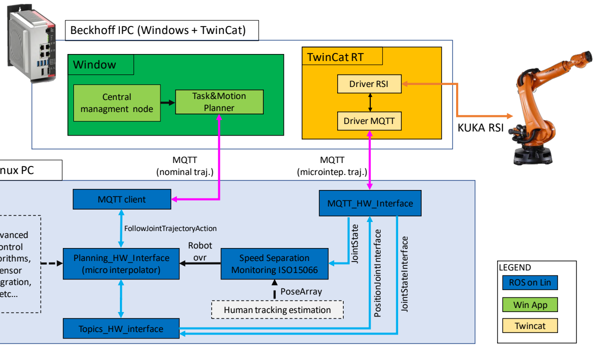

Fig. 4. TEZ control architecture based on two different PC (i) an industrial PC (i.e., Beckhoff IPC) running Windows and a soft PLC (i.e., Twincat), and a standard Linux PC running ROS. Three main blocks constitute the architecture (i) a central management node (highlighted in green), (ii) a group of ROS modules (highlighted in light blue), and (iii) a brand-specific low-level communication driver (highlighted in light orange) running a as soft PLC real-time task.

D. *Task planner*

Task and Motion Planning (TAMP) represents an integrative framework that combines high-level logical reasoning with low-level geometric feasibility, fostering a cohesive approach to robotic decision-making. At its core, TAMP involves two primary components: the logical reasoning determines the optimal sequence of actions a robot must execute to achieve a specified goal, and the geometric feasibility ascertains the physical realizability of these actions by the robot. Figure 5 depicts the first version of the framework proposed by Gottardi et al. in [8] for industrial applications.

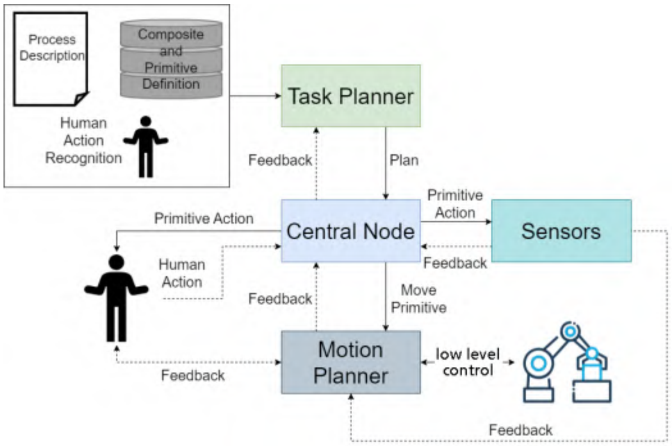

Fig. 5. Dynamic Human-Aware TAMP framework [8].

The Task Planner module [13] is an essential component of Human-Robot Collaboration in industrial settings. It specifically addresses the complexities of the draping process, which is a critical component in manufacturing where human expertise significantly influences quality outcomes. The core functionality of this module is to create adaptive, sequential action plans that align with immediate tasks and flexibly accommodate human inputs and unforeseen changes. This ensures a seamless work flow and maintains a safe operational environment through well-defined recovery actions. A hierarchical structure mixed with a Direct Acyclic Graph is essential for achieving a balance between adaptability, operational efficiency and industrial requirements from the process.

The process was broke down into two kind of activities called primitive action and composite action. The first - primitive actions - are the smallest activity steps while the latter are action sequences where primitive actions are combined due to the logical structure of the process. Each primitive action or action sequence can be addressed by the Task Planner via Central Node as described in Sections 5 and III-E and thus called upon by worker. For the aerospace use case primitive actions are: Cut Piece Detection (CPD), generating a robot trajectory, executing robot trajectory, moving suction unit on gripper up and down and toggling the suction on and off. A pick&place action sequence contains the CPD, generating robot path, moving the robot and extracting and switching on of the suction modules without waiting for the trigger given by the human between each step because of the logic chain of events. Another example of action sequence is "take picture" (and "inspect") where the worker calls for an picture or fibre angel measurement by triggering the action and pointing with stretched arm at the area in question on the mould. It consists of estimation the position of the human and the position of his right shoulder and wrist, calculation the position to be photographed on the mould by estimating the intersection between the shoulder-wrist straight and the top plane of the mould, calculating the path for the robot, moving the robot and finally triggering either the camera or fibre angle measuring device (FScan).

E. Central node

The framework introduces a Central Node [8], [13] to streamline communication between Task and Motion Planner modules in industrial settings, overcoming the challenge of managing extensive data. This Central Node not only orchestrates the execution of plans but also oversees the activities of various primitive actions while continuously monitoring the work cell through environmental sensors and systems for human perception and action recognition. This setup allows the Central Node to adapt to unplanned human gestures, triggering necessary actions not initially anticipated in the plan.

F. Interaction modes

The system can interact with the human using three communication channels:

- gestures, as described in Section III-A by preforming physical gestures defined and affiliated with action
- voice commands, by stating a phrase which is tied to an action. This phrase can be build up as free sentence containing a description of the action with key words and additional parameters. The Automatic Speech Recognition Engine (ASR) is used in SNIPS environment [14] to match the spoken language with pre-defined intent and action.
- augmented reality via HoloLens and input hardware can be used to make annotations to the digital model of the part and to present information to the human. It also can be used - but was not implemented in the use case - to trigger actions equal to the gesture and voice mode.

G. Robotic tools

Both robots are equipped with robotic tool designed, constructed and built by Abele Ingenieure GmbH, one of the partners in project Drapebot. The design for the aerospace variants consists of four suction units which can be extracted and retracted separately and suction force generated by Coanda-effect can be switched on and off. This ensures the strong grip for all cut pieces from the plybook for the use case. Although, the layout of the suction and fixation units is identical for both grippers, each is sporting additional equipment: camera and light for CPD and fibre angle measurement sensor (FScan) on one of the grippers and industrial camera for "take picture" action on the other gripper. Figure 6 shows the one of the grippers.

Fig. 6. One of the grippers provided by Abele Abele Ingenieure GmbH. You can see the four suction units (yellow), the fibre angle sensor (blue) and the camera for "take picture" action (red)

IV. AEROSPACE USE CASE

The aerospace use case provided by German Aerospace Center take on the manufacturing of standard frame as used for CFRP-heavy commercial aircraft. In the aimed scenario, one human acts inside a robotic cell with two industrial robots and preforms the CFRP made frame with dry material. The process covered in the scenario starts with the human worker entering the cell and supervising the delivery of the material.

Small patches and short cut-pieces are delivered on table using autonomously guided vehicle (AGV) from the cutter to the cell while the long cut pieces are provided manually on long pick-up tables next to the linear axis. The human triggers the begin of the preforming process by requesting the first cut piece. The system is checking for the position of the cut piece on the table and calculating the griping position of grippers which makes the process flexible regarding to the initial position of the cut piece on the table. The system moves the robot (or both robots in case of non-patch size cut pieces) to the pick-up movement, grasps the cut piece and transfers it to the mould. Depending on the size of the cut piece following scenarios are available:

1) a patch is placed on the mould and one of the suction units lowers on the seed point, providing support to human who now can utilize both hands for draping. This is shown in Figure 7.
2) for long cut-pieces both grippers are transporting the cut piece to the mould until the central point of the mould and the cut piece are in contact and both of the ends of the cut piece are still held by the grippers at each end of the mould giving the human just right amount of the material to drape a small part in the central area of the mould. After successful draping of the central part, human moves towards one end of the mould. Upon request by the human, the Central Node lowers the holding gripper down and moves it towards the end of the mould giving the operator more material for draping. After one side of the mould is finished, worker drapes (again from the centre of the mould to its end) the second part of the cut piece. Here again, the central node waits for the request by human and moves the second gripper into right position, giving the operator the right amount of material to drape.

Fig. 7. Draping of small patch. One suction unit is holding the material firm on the mould, while the human can use both hands for precise draping.

After the draping of the cut piece, system moves the gripper to the joining positions and by using the build-in fixation units it melts the binder on the backside of the material providing sufficient tack to fixate the cut pieces in place and preventing it from moving or displace during the process. At this point, the human responsible for the quality of the part has the opportunity to check the quality of the cut piece placed and draped. Depending on his judgement he can request a fibre angle measurement or high quality pictures for documentation of freely selectable areas on the web of the part. If equipped with augmented reality wearables he can place comments on the model of the part or compare the stored data with reality. If the operator is ready for the next step, he requests the subsequent cut piece and the process starts over from the detection and pick&place of the next ply.

The process flowchart first scenarios is shown in the Figure 8 and has been demonstrated in December 2023. The results are discussed in more detail in Section V-A.

A. Setup and safety

For the purpose of the project Drapebot, usual hard fence encapsulating the cell operating area from the surrounding space was exchanged for laser fences with direct connection to the cell safety resulting in immediate emergency stop in case of interrupting the laser fence at any place surrounding the cell. However, for the aerospace use case a human operator is present within the operating and works in the close vicinity of one or both robots. This requires additional sensors inside the cell and safety measures to make the operation of human safe. The key elements of the safety concepts are:

- **definition of areas for permissible robots speeds**
  The operational area of the cell is divided in three sub-areas: the safe area, where the human operator is intrinsically safe by being out of the distance from maximal range of the robots (including the tools mounted). If the worker is present in the safe area, the robots are allowed to move at full speed.
  The working area is defined in the front of the mould where the operator and the robots are working together. Because the robots can now reach the worker, the process taking place in this area was assessed under the aspects of the work safety, in particular to be compliant to the EU Directive on machinery [15] and the industrial norm DIN ISO/TS 15066 on robots and robotic devices [16]. This results for example in reduced speed of the robots (set by configuration of the cell properties) if the human is detected in working area.
  The third area excludes the presence of the human entirely and whenever the human can't be detected in the previous two areas, he is considered to be in the forbidden area and KUKA SafeOperation triggers emergency stop of the cell. The presence of the worker in the first two zones is monitored by three SICK laser scanner mounted on the floor and connected to SafeOperation architecture. The areas are shown in Figure 9. As described in Section III-C, this setup can be used to influence the speed of the process. To increase the speed of the robots, *i.e.*, for the long pick-up movement, human operator can leave the working area by stepping back into the safe area and thus allowing the robots to move faster.
- **making the cell and tool architecture inertly safe**
  The tools on the robots are design to ensure, that the

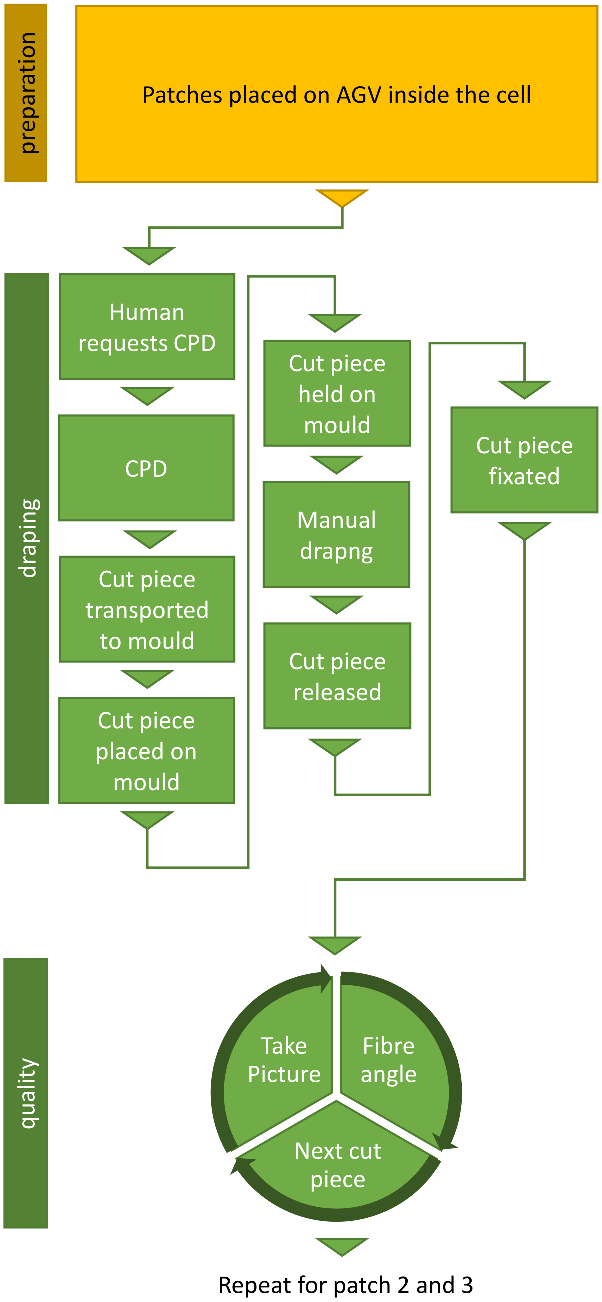

Fig. 8. Process for aerospace use case (scenario 1) showed at the demonstration in December 2023.

risk to cause harm to human is minimized (according to the [15] for robot speed allowed in working area). This includes the design of the mechanical parts of the gripper in order to reduce the risk of bruising or squeezing of human body parts. Also a number of emergency stop buttons are distributed within the cell, on the mould and on the robotic tools.

- **restriction of the robot's operational area**
  Using KUKA SafeOperation, the space where the robot can operate can be restricted. In the case of this scenario, robots movement is allowed only higher than the height of the mould creating a safe space for the human where he can retreat by going into squat position or lying down on the floor.
- **using position of human while creating robotic paths**
  The Motion Planner, Section III-B, takes the current position of the human within the cell (delivered by the Human Recognition, Section III-A) into the generation of the robot trajectories. This reduces the risk of collisions between human and moving robots. However, due to the lack of real-time comparison of path and moving human position, as for now, the adjustment or recalculation of the path is not implemented yet.

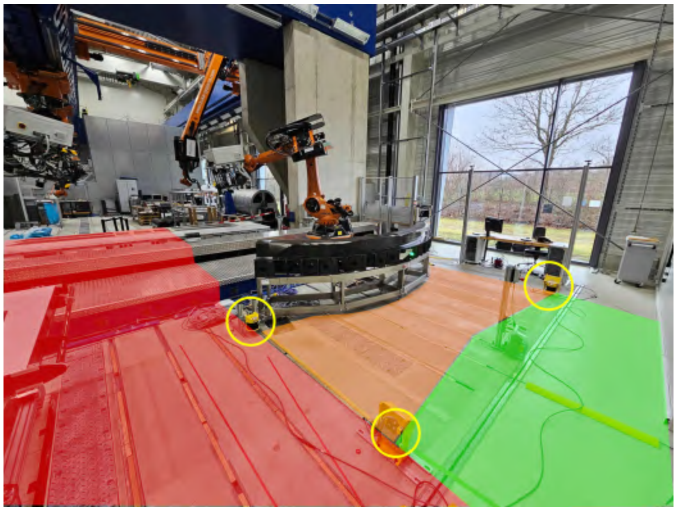

Fig. 9. Defined safety areas for aerospace use case at TEZ: GREEN = safe area, ORANGE = working area, RED = forbidden area. Yellow circles are marking the SICK laser scanner to localise human within the areas.

The safety architecture has been assessed by the safety officer at DLR and opened to service as laboratory setup.

V. RESULTS AND DISCUSSION

This paper summarises the results after 3rd year of the project up to the technical review in January 2024. Short outlook towards the end of the project in December 2024 will be presented in Section VI

A. *Technical results*

The process as shown in Figure 8 was presented for three patches in continuous run during the demonstration in December 2023. All components mentioned before have been implemented at the TEZ and used during the process run. The process flow was directed by human via voice commands except for the "take picture" and "inspect" actions, where the position of the joints (straight right arm pointing at area on the mould, see Figure 3 ii)) was detected and used for the calculation of the photo coordinates. After the draping of the cut piece, the actions "take picture" and "inspect" actions were executed multiple times and each run was finished by "drape next" command.

B. User studies

The collaborative robot work cell was evaluated in terms of usability and task load. Experiments were performed with 20 participants, 17 males and 3 females, ages ranging between 21 and 57 with median age 36. 13 participants reported to have experience working with industrial robots. Each participant performed ten collaborative draping tasks, where the robot retrieved a cut piece at the pick-up table and held it at a position along the top the of the mould. Once the robot had come to a stop the participant could approach from the safe area to finish draping along the edges of the mould. Once finished and returned to the safe area, the participant would signal the robot to retrieve the next cut-piece. During the ten collaborative draping tasks in the first session, this was done using a button mounted to the participant's hip, named the non-natural user interface (NoNUI) condition. For the two subsequent sessions we had participants signal the robot using one of two natural user interfaces (NUI) in counter-balanced order. One NUI used voice commands to signal the robot, and the other used gesture recognition where participants had to lift their hand toward the robot. For these two sessions the robot did not retrieve cut-pieces. Once the signal to continue was received the robot would make a movement from side to side in response.

After each session the participants rated the robot work cell in terms of usability using the Standard Usability Scale (SUS) [17] and Usability Metric for User Experience (UMUX) scales [18]. The NASA Task-Load index (TLX) [19] was administered at the end of the experiment, and participants were told to rate their experience with the collaborative work cell as a whole. The usability scores are shown in Figure 10 and the NASA TLX rating are shown in Figure 11. The results show high usability scores and low task load overall. The user studies and the evaluation framework are described in full in a paper by Hald & Rehm [20] (accepted).

VI. FUTURE WORK

In the next months until the final demonstration, major effort will be put to setup the second scenario for the long cut-pieces (Section IV, Scenario 2). This will be utilised for further user studies where a greater extent of the direct collaboration between human and both robots during draping of long cut pieces will be investigated. Optimisation of the process regarding to performance in speed and quality will be addressed to almost every aspect of the process.

VII. CONCLUSION

In this paper the early result of the project Drapebot are presented. An industrial robotic cell with two heavy robots have been adapted for safe human-robot collaboration for aerospace use case where a human is draping dry CFRP material. The robots are supporting him in safe and intuitive way using natural communications channels, *i.e.*, voice commands and gestures. Necessary technologies like human detection and pose estimation, path planner for both robots, task planner, central node for task distribution and low-level-control for robot movement execution have been developed and integrated on the TEZ. The aerospace use case has been set up and demonstrated in compliance with the regulations regarding work safety. The setup was also used to preform studies on usability and user experience.

The results show feasibility of safe and flexible human-robot collaboration with industrial robots and provide sound basis for concepts and discussion on human-robot-collaboration-based work environment in complex industrial context.

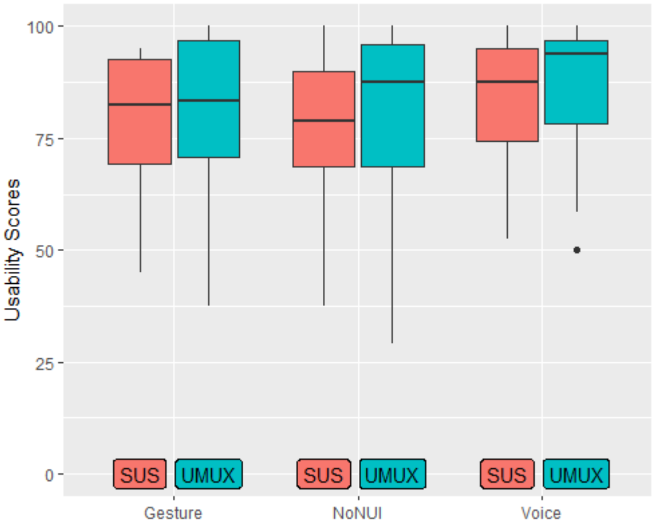

Fig. 10. The distributions of the SUS and UMUX scores between UI conditions.

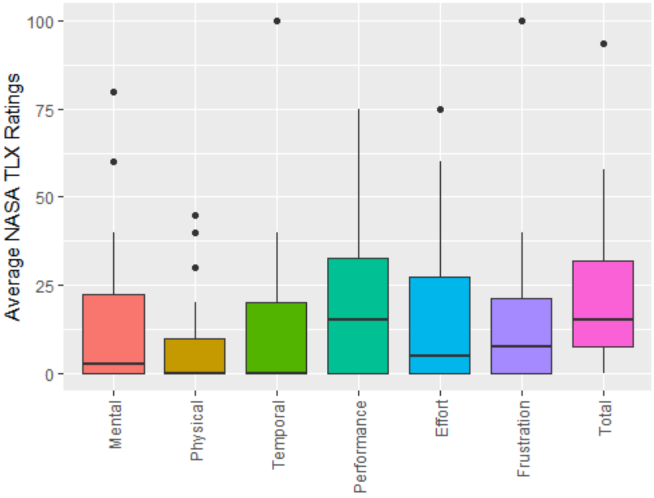

Fig. 11. Distribution of NASA TLX scores.

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