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New Challenges for Human-Robot Collaboration in an Industrial Context: Acceptability and Natural Collaboration

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Abstract— **In this paper, we focus on two challenges to enable human-robot collaboration in factories. The first challenge is to evaluate the acceptability of an operator to work with a robot on a new collaborative task. Comparing physical and virtual situation, we highlight notions related to acceptability which can be evaluated using virtual reality. This will able us to evaluate future collaborative scenarios before their setting-up on supply chains.**

The second challenge is to provide a natural collaboration between the robot and the operator. We chose to study gesture recognition to enable a smooth collaboration. With this method, the robot should be able to understand its environment, adapt its speed and be synchronized with the operator.

We used two use cases to test our frameworks, to evaluate them and to highlight possible improvements.

I. INTRODUCTION

The development of robots has been common in our society, and also in our industries. Social robots have already been useful in various contexts: guide in museum, stimulation for autistic children or assistant for elderly people for example. In an industrial context, robots are also present. Until a few years ago, industrial robots evolved in specific areas, away from operators. Nowadays, collaborative industrial robots are progressively incorporated in supply chains. These robots are used to help the operator with complementary skills (strength, precision,..). Operator and robot can work side by side on different tasks, *i.e.* in copresence, or on a common task, *i.e.* in collaboration.

Interaction between operators and industrial collaborative robots raise new questions about human-robot interaction. The first one is to ensure the operator security. When the industrial robots were in closed areas, any intrusion in these parts of the supply chain automatically stopped the robots. This option is no longer available in the context of a human-robot interaction. During the past years, new technologies provided ways to make the robot understand its environment. Depth-cameras, laser sensors, and inbuilt sensors, like force sensors or tactile sensors, enable robots to be safe and to be able to react accordingly if there is a contact with an operator.

A second question is acceptability. Will operators, who were taught to stay away from robot, accept to work every day with a robot as a co-worker? The question of acceptability has been well studied in the case of social robots were communication can occur between a robot and a human. In industrial context, the question is different: the kind of robots and the interaction modes are different. To evaluate the acceptability, some factors can be common (robot appearance or movement), but other can be specific of the industrial context (spatial or temporal distribution).

A third question is about the collaboration, how to make it natural? By natural, we mean a smooth and efficient collaboration. The robot needs to adapt its speed and to respond fluidly to the operator needs at the appropriate time.

In this paper, we present frameworks to answer the two last questions. The organization of the paper is the following. In Section II, we present related work on human-robot collaboration in the industry. In Section III, we describe two use cases we used in our study. In Section IV, we focus on the framework to evaluate the acceptability using virtual reality. In Section V, we present our method to enable a natural collaboration using gesture recognition. Finally, we provide a conclusion and perspectives in Section VI.

II. RELATED WORK

Human-robot interaction is becoming more and more present in our everyday life. Social robots are already used to help elderly people [7] or to guide visitors in a museum [5]. But human-robot collaboration implies more interaction by reaching a common goal [2]. An efficient collaboration can be made by coordinate the participants actions in time and space [6]. Preferences and needs of the human can be taking into account while a robot is performing its tasks [1].

In factories, new collaborative robots are designed to be intrinsicly safe and to provide complementary skills to human co-workers like the Kuka LWR [11] and the Universal Robot UR [12]. Robot apparence [4], manipluator's movments [10] or different robot arms and movement profiles [8] have been studied to see if they have an impact on the acceptability of human-robot collaboration.

Simple task sharing between a robot and an operator have also been studied, like holding the same table [9], but in most the majority of the cases the robot is working alone on low added value tasks [3]. Smooth collaboration is still a challenge to enable an expension of these collaborative robots in factories.

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III. USE-CASES

In this Section, we will present two use-cases: a copresence scenario and a collaborative scenario.

A. *Use case 1: Scenario of copresence*

For this use case, the operator and the robot work side by side, sharing the same area, but working on different tasks. This use case is inspired from concrete operations on car doors. The robot role on the door is to fix a sealing sheet on the door. To do this, it applies a caster on the edge of the sheet to stick it definitively. In car plants, this operation is currently done by a human but it can lead to muskulo-skeletal disorders, especially on the wrist of the operator. That is why a robot was chosen to perform this task while operators are concentrated on other operations next to the robot, see Fig. 1.

Fig. 1. Use-case to study a human robot copresence

B. *Use case 2: Scenario of collaboration*

For this use case, the operator and the robot are working on a common task, in collaboration. The task is inspired from the assembly of motor hoses on supply chain. Presently, the assembly process of motor hoses has some drawbacks: the worker has to find the appropriate parts of the motor hoses among other motor parts, which is a lack of time and increase the cognitive load of the worker. In this collaborative scenario, the robot is giving the appropriate piece to the operator. The assembly of motor hoses requires the worker to take two hose parts respectively on left and right side, join them, screw them, take a third part from left, join it, screw it, and finally place the mounted motor hose in a box. The actions performed by the robot are giving a piece with the right claw and giving a piece in the left claw. The operator and the robot are facing each other and are separated by a preparation table, see Fig. 2.

IV. AXIS 1: DEFINING THE CONDITION OF ACCEPTABILITY USING VIRTUAL REALITY

A. *Protocole*

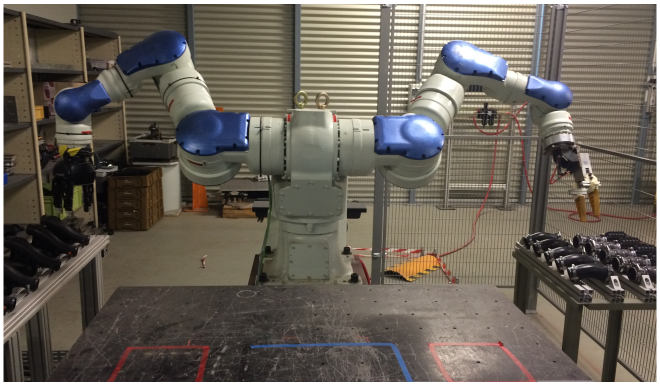

Fig. 2. Use-case to study a human robot collaboration

We want to know how a human-robot interaction can be accepted by an operator. Many parameters have to be evaluated; virtual reality can be an interesting tool to perform tests on new human-robot interaction configurations. We want to establish which notions, related to acceptability, can be evaluated in virtual situation.

For both use cases presented below in Section III we created a similar virtual environment, see Fig. 3 and Fig. 4. User studies have been performed to gather subjective impressions through questionnaires and more objective measures were taken thanks to physiological measures, both in physical and virtual environment. The results of this study will be used to test, in a virual environnemnt, futur industrial human-robot collaboration scenarios.

B. *Use case 1*

The aim of this study is to gather operators' subjective impression when working side by side with a collaborative robot. We compared different proximity configurations: one far and one close. On each configuration, operators had to complete 4 cycles of 4 doors, both in virtual and physical environment. Physiological measures to gather information on stress and physical effort were taken at the end of each cycle. Questionnaires were asked at the end of each configuration to evaluate several notions : usability, safety, robot skills, impression and acceptability.

Fig. 3. Physical and virtual environment on the copresence use-case

Globally the far configuration has been preferred to the close configuration. Through the questionnaires, operators found that the far configuration is more usable, safer and more acceptable.

The same trend can be observed in both physical and virtual environment. The operator's subject impressions can be correlated in both situations. But, in the virtual environnemnt, operators felt less constraints and less physical effort. Also, the virtual robot was more accepted that the real one.

C. *Use case 2*

With this study, we wanted to compare different levels of interaction with the robot. We used three scenarios with increasing interaction. For the first scenario, the robot puts the motor pieces on the table where the operator can grab them. On the second scenario, the robot gives directly the pieces to the operators. And finally, in the third scenario, with more interaction, the robot maintains the main part while the operator assembles the other parts and screws them. For each scenario, two configurations were designed: a manual configuration and an automatic configuration. For the manual configuration, the operator uses buttons to indicate to the robot to do the next action (to free a piece from its claws, or to change the orientation of the main part for the third scenario). In the automatic configuration, there is no more buttons, an external person pressed the buttons to simulate a smooth interaction where the robot reacts accordingly the operators' actions. On each combination of configuration (manual and automatic) and scenario, the operators had to complete 3 cycles of assembly.

Like for the first use case, we used questionnaires and physiological measures. Questionnaires were asked after each configuration, while physiological measures were taken after each cycle.

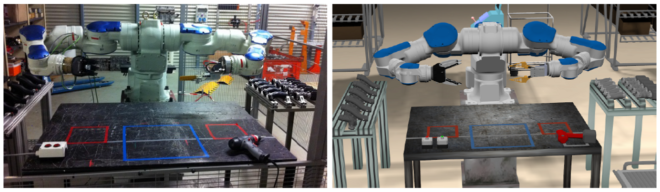

Fig. 4. Physical and virtual environment on the collaboration use-case

For this use case, a good correlation was found between the physical and virtual results. With the increase of interaction, the physical effort of the operator decreased. Moreover, the operator preferred the automatic configuration than the manual configuration. Indeed, removing the buttons decreased the cognitive load of the worker during the task and allowed a smooth collaboration.

D. *Conclusion Axis 1*

A good correlation has been found on the notions of usability, perceived utility and perceived efficiency of a human-robot collaboration system in virtual and physical situations. For hedonist components of acceptability (perceived safety, perceived relaxation and satisfaction) the results from the questionnaires were correlated while a gap was found for the skin conduction level in physical and virtual situations. The users seem less sensitive to stress in a virtual environment.

Virtual reality appears to be an efficient tool to perform user studies on acceptability on human-robot collaboration when dealing with subjective notions. Moreover, the results of the second use case show that operators prefered an automatic situation rather pressing on buttons, because the collaboration was smoother. This highlights the need for robots to be more intelligent and to be able to understand their environment.

V. AXIS 2: INTELLIGENT ROBOT WITH PERCEPTION TO UNDERSTAND ITS ENVIRONNEMNT

We investigate the recognition of technical gestures performed by the operator to enable a smooth collaboration between the robot and the operator. With gesture recognition, the robot can understand which task is being performed, can anticipate on a future task and adapt its speed. Furthermore, during the study described subsection in IV-C, the operators expressed a preference for the automatic mode, where the robot automatically reacts to the worker action.

A. *Use case 1*

On the use case of copresence, we used inertial sensors carried by the operators. We determined a set of gestures to be recognized and we tested two types of sensors: a jacket equipped of 12 inertial sensors located at the operator joints, and a set of two sensors affixed to each of the operator hands. Both these technologies are unaffected by occlusions and they provide a rotational representation of the gestures. The 4 gestures we want to recognize are: to remove a protective paper on the sealing shit, to fit on door the sealing sheet, to pre-fix the sealing sheet on the door and to fit the window sealing strip. These gestures are illustrated in Fig. 5.

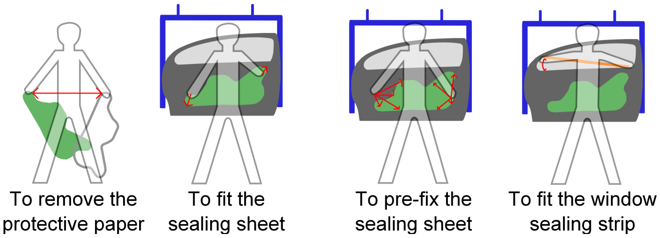

Fig. 5. Gestures on the copresence use case

We obtain 96% of correct recognition using the jacket and 86% of correct recognition using the set of two sensors. Even if these results are good, we observed that the inertial sensors could disturb the operators during their task performance, non-intrusive sensors should be prefered for an industrial context.

B. *Use case 2*

On the use case of collaboration, we decided to use non-intrusive sensors to prevent the operator to be hindered by additional equipment. We used a depth camera with a top view to minimize the possible hands occlusions while the operator is performing his assembly task. We also equipped the tools with inertial sensors, the screwing gun in this use case. We chose 5 gestures to recognize: to take a part in the robot right claw, to take a part in the robot left claw, to join two parts together, to screw and to put the final motor hose in a box. These gestures are illustrated Fig. 6.

We process the data from the depth camera by tracking the operator hands in the depth map. Using only data from

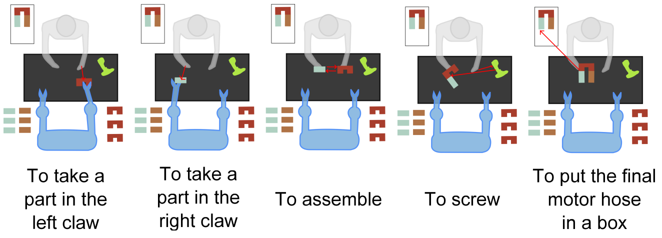

Fig. 6. Gestures on the collaboration use case

the depth camera, we reach 80% of correct recognition, and with late fusion of data from the depth camera and the inertial sensor on the screwing gun we obtain 94% of correct recognition. We implemented this solution on the robot from the second use case. Its claws open automatically when an operator wants to take a piece. This enables smooth and natural human-robot collaboration.

C. Conclusion Axis 2

This two use cases highlighted the challenges to enable natural human-robot collaboration in the industry. The choice of sensors is restricted to prevent any hindrance for the operator. Also, the choice of gestures must be done to efficiently synchronize the robot to the operator. Moreover, the system of gesture recognition should be robust to prevent any false recognition which could lead the robot to a misunderstanding of its environment. However, this method enables smooth human-robot collaboration close to a human-human collaboration, which could help the operator efficiency during his tasks performance.

VI. CONCLUSION

In this paper, we presented two frameworks dealing with new challenges for human-robot collaboration in supply chain. These two challenges can be expressed as: will the operator accept to work with a robot as a partner and how to make the collaboration natural?

We first presented two use cases, a co-presence scenario and a collaborative scenario. We used these use cases to evaluate our frameworks.

To evaluate the acceptability of an operator to work with a robot on a new collaborative task, we decided to use virtual reality. Each use case was designed in a physical and in a virtual environment. We compared results, from questionnaires and physiological measures, in both situations. We conclude that virtual reality can be helpful to evaluate subjective notions on acceptability. The conception of a new scenario in a virtual environment, before its installation on supply chain, could enable testing these notions and adapt the new collaborative task to improve the operators' acceptability. Moreover, this work highlights the operators' preference for a smooth collaboration with a robot.

To enable a natural collaboration, we studied technical gesture recognition to help the robot to be synchronized with the operator. We used two types of sensors: inertial sensors held by the operator for the first use case, depth camera and inertial sensors on tools for the second use case. Gesture recognition with inertial sensor on the operator led to good recognition results, but is too intrusive to be used in an industrial context. With the depth camera, a first step to extract information, hands location, from the depth map is necessary. Using hands locations and data from the inertial sensor on the screwing-gun, we obtained recognition rate equivalent to those obtained on the first use case with the intrusive set-up. However, a more robust system without any false recognition, should be necessary to prevent the robot from any misunderstanding of its environment.

These two frameworks enable us to propose solutions to evaluate the acceptability of an operator on a new collaborative task and to provide a smooth collaboration. Improvement can be made, and new technologies in a near future will certainly lead to new answers for these challenges.

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