"I see you": safe and effective human-robot interaction based on vision system

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***Abstract*—The interaction between humans and robots is becoming more and more common in several applications, from industrial to service scenarios. To obtain a productive interaction, robots must be able to adapt their trajectories to the human partners' movements. Different kinds of sensors, such as vision systems or wearable IMUs, can be used to track the motion of the operators. Results achieved in the development of online motion planning algorithms based on vision systems, useful for human-robot interaction, are here presented. A multiple depth sensor layout based on Microsoft Kinect is utilized to track human's position and gesture. The algorithms are implemented on a collaborative robot UR3 to show their effectiveness in different real scenarios.**

Keywords—collaborative robotics, collision avoidance, hand-over, vision system

I. INTRODUCTION

The industrial world is facing important changes and it is entering in a new phase of its history, the so called "Industry 4.0". Collaborative robotics will have an important role in this transition. In fact, the main characteristics of collaborative robotics are the easiness of programming and the possibility to have robots in the factories without the need of physical fences. These aspects let humans and robots work side by side. They permit to exploit the precision and adaptability of robotic systems and the flexibility of human operators in new working paradigms, where humans and robot share simultaneously tasks in one single workspace. Furthermore, they make also possible to partially automate processes that were previously entirely manual with improved ergonomic features. Not the least, they make robotics affordable also for the small and medium-sized enterprises (SMEs).

The interaction between humans and robots can be possible in several scenarios, both industrial and service ones. Based on [1], the International Federation of Robotics defined four different types of human-robot interaction (HRI): *coexistence*, *sequential collaboration*, *cooperation* and *responsive collaboration*, from the weaker to the closer interaction (cf. Fig. 1).

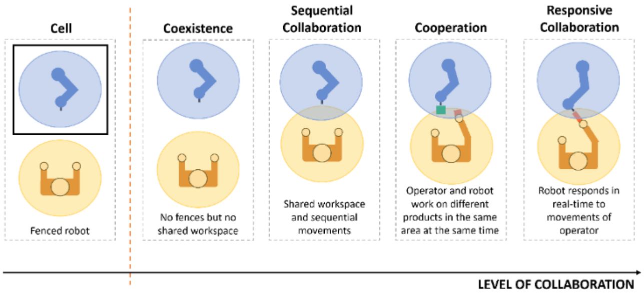

Fig. 1: The four types of HRI (on the right) and the case without HRI (on the left).

Regardless of the type of HRI, to make the interaction between human and robot effective, it is important to develop control algorithms to adapt robot trajectories to the movements of the human operator. Several sensors based on different technologies can be used to track the operator's movements, such as vision systems or wearable IMUs. In this work, vision sensors have been used as tracking system. In this way, the operator does not have to wear any sensors, that could limit his/her movements.

A brief review of authors' results in the field of HRI research are here presented. Two online control algorithms will be shown in the following: 1) collision avoidance algorithm, that can be used to ensure the safety of the human operator in every type of HRI; 2) hand-over algorithm, that permits human and robot to hand objects to one other. Besides, experimental results carried out on a demonstrative set up are shown in the accompanying video.

II. VISION SYSTEM AND EXPERIMENTAL SETUP

The movements of the human operator are acquired by two RGB-D camera Microsoft Kinect v2. Two Kinect are used to avoid problems related to the occlusions of a sensor. The data given by the two Kinect (skeleton representation of the human operator and 3D point cloud of operator and environment) are collected and properly combined. Further information about the data fusion process are reported in [2] for the skeleton and in [3] for the point cloud.

A schematic representation of the experimental setup is shown in Fig. 2. It consists of three PCs, the two Kinect, a UR3 robot from Universal Robots and a router. The control algorithms take advantage of the data recorded by the vision system to calculate the joint velocities sent to the controller of the robot. The hardware architecture tested permits to control the UR3 robot with a frequency of 62.5 Hz. Further information related to the experimental setup and the control architecture are given in [4, 5].

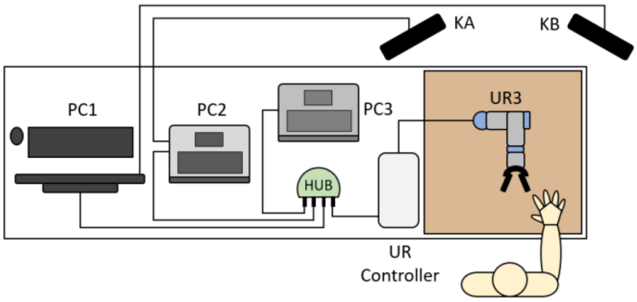

Fig. 2: Scheme of the experimental setup.

III. COLLISION AVOIDANCE

To ensure a safe collaboration between the human operator and the robot, the ISO/TS 15066:2016, which regulates collaborative robotics, proposes the so called “space and separation monitoring” approach. This approach implies that the collaboration is considered to be safe if a protective separation distance is satisfied [6]. This means that the robot and the human can move within the same workspace, as long as they keep a protective distance. For this reason, collision avoidance becomes fundamental in collaborative robotics.

Since the human is observed by Kinect sensors as a point cloud or a skeleton, two different approaches have been investigated. The first considers the raw data, i.e. the human point cloud which can be made of thousands of points, as the human volume. The second take the skeleton, i.e. the human body approximated to 25 joints, as the reference signal. Both the approaches have pros and cons. The point cloud is more precise and allows to see in details the human body, but it requires more processing time for data fusion and distance calculation. To face these aspects, the point cloud can be opportunely down sampled and denoised [3]. On the other hand, the skeleton is less expensive in terms of computational load but suffers from tracking errors due to registration methods; thus, optimization problems are required to obtain a more robust skeleton [2]. The results show that it is possible to obtain either point cloud or skeleton optimized data within 1/30 s, i.e. Kinect sample time.

Once the human is tracked, the robot must be controlled so that it is able to react by keeping the separation distance. In particular, it is required that the robot avoids the human with each link, so a multiple-link collision avoidance algorithm has been developed [7]. The method is based on artificial potential fields and repulsive velocities. For each link, the minimum distance from the human body is computed; then the distance is used to produce a repulsive velocity, which is a vector in the cartesian space, on the robot link. The advantage of this approach is that, if the robot moves according to the task, it is possible to generate the repulsive effect by simply adding the repulsive velocity vector to the task velocity vector. Then, by using the inverse kinematic algorithm based on inverse Jacobian, one can compute the joint velocity vector. The proposed technique is fast and can produce the control input vector in less than 5 ms.

The collision avoidance algorithms have been preliminary implemented on a UR3 robot by using Optritrack sensor to trace the human hand [8]. The results show that the robot is able to online react to obstacles with a frequency of 62.5 Hz by smoothly adjust the trajectory according to the task. Currently, authors are working on the experimental validation of the human-robot collision avoidance based on point cloud and skeleton tracking. The results are promising and are shown in the accompanying video.

IV. HAND-OVER

Hand-over is the action of exchanging objects between two subjects, in this case between human and robot. This type of interaction can be useful both in service applications (for example handing food or medicines to patients in hospitals) and in industrial ones (e.g. assembly or boxing operations). The hand-over is an example of responsive collaboration because the robot has to respond in real-time to the movements of the human worker.

To obtain a fluent and effective hand-over action, the control algorithm must have the following features: 1) the hand-over has to be bidirectional, in order to have both human-to-robot and robot-to-human hand-over; 2) the operator must be able to choose the object transfer point (the point in the robotic workspace in which the hand-over is performed) that he/she prefers or is more ergonomically suitable. For this reason the robot has to be able to follow a dynamic target, both in position and in orientation; 3) the waiting time for the operator, that is the time the worker has to wait before the hand-over action is completed, must be short.

The control algorithm that authors have developed accomplished the aforementioned features as described in [4, 5]. The control algorithm is based on the artificial potential fields method, that permits to control online the behavior of the robot and to follow dynamic target. Given the position of the hand of the operator, the distance from the tool center point of the robot is obtained. This distance is used to calculate an attractive velocity vector that pushes the robot towards the object transfer point. In this way the operator can change the position of the hand and the control algorithm calculates the proper attractive velocity. In addition, in [5] the concept of virtual hand is introduced, to obtain a safe and fluent hand-over and to consider the dimensions of the object to exchange. To reduce the waiting time, the skeleton data are given as input to a Kalman filter, that is used to predict the position of the virtual hand so to anticipate the approaching movement of the robot to the object transfer point. The main experimental results for hand-over tasks are presented and discussed in [5] and shown in the accompanying video.

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