Sensor-based control of a collaborative robot

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Flexible and reactive control of interaction between humans and robots will allow a closer cooperation in all service and industrial tasks, that require the adaptability skills of humans to be merged with the high performance of robots in terms of precision, speed and payload [2]. For this reason, recent research strives for intuitive human-robot cooperation, avoiding explicit clarification dialogue and commands.

We believe that sensor-based methods, such as visual servoing, provide better solutions, for intuitive HRI, than planning techniques requiring a priori models of the environment and agents. To our knowledge, few works [2 - 4] have explicitly dealt with HRI using sensor-based control approaches. Our objective is similar: we aim at enabling intuitive interaction between human and robot, in the context of an industrial scenario, where the two must collaborate to realize a task. The robot must be able to infer the human intentions during the task, using only sensed data.

The objective of this work is to enable a robot to aid a human operator in a screwing operation (see Fig. 1). Human and robot are operating on the opposite sides of a flank, where a series of screws must be inserted. The required operations are respectively:

- for the human: to insert the screws in the holes,
- for the robot: to tighten a bolt on each inserted screw.

To realize the proposed operation, we utilize two sensors: a Microsoft Kinect that observes the work scene from a fixed pose, and a camera rigidly linked to the robot end effector. These sensors are respectively dedicated to predicting the human intention, and to detecting new non-tightened screws.

To realize the proposed task, we apply a multimodal strategy, where the four modes are each related to a subtask. The four modes are:

- *Hand approaching*. If the human operating hand is detected by the Kinect, the robot is moved so that the camera has a good view of the area where it is operating.
- *Screw approaching*. Once a non-tightened screw is detected in the camera image, a 2 1/2 D visual servo controller [6] moves the robot tool in front of it.
- *Collaborative tightening*. If the robot is sufficiently near, the tool is placed on the screw to conclude the task[1].
- *Halting*. If neither the hand nor the screws are detected, the robot stops.

To properly activate these modes, we utilize a simple state machine. The transitions between modes are activated by perceived information (by the Kinect and camera) or by successful tightening.

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More details on this work are given in [1].

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[1]For the moment, this operation is executed in open-loop within our framework, since no sensed feedback is available at this stage. In future work, we plan to integrate force control for this subtask.

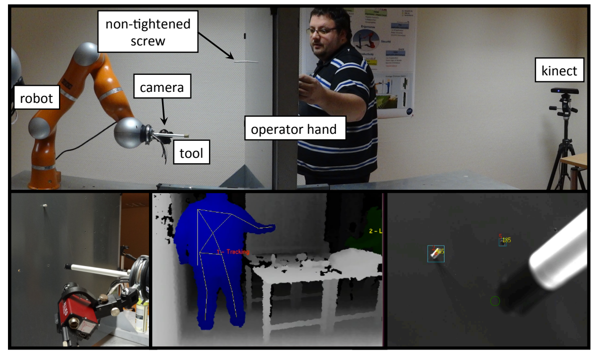

Fig. 1. Top: experimental setup. Bottom left: view of the camera and effector. Bottom center: Kinect image. Bottom right: camera image.

Except for the halting mode, the three other modes are realized with a unified formalism, the task Jacobian controller [7]. For the experiments, we use a lightweight KUKA LWR IV robot. Since this robot is redundant with respect to the tasks, we use the remaining degree of freedom to guarantee joint limit avoidance.

Since a tightening tool is not currently mounted on our end effector, we have validated our approach by verifying if the robot could successfully touch new, non-tightened screws with its tool. This task requires high accuracy, since the screw and tool diameters are respectively 4 and 14 mm. We have run a series of experiments, where screws have been successfully touched by the effector, so we are confident that with a tightening tool the approach will also work. A typical experiment is shown in the video located at http://youtu.be/P8wfQ5tOa5E.

In summary, we have presented a marker-less solution for human intention recognition and human-robot collaboration, and intuitive communication between the two agents, realized through action (specifically, screw inserting).

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