Multi-sensor control framework for autonomous screwing

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***Abstract*—A framework is presented in this paper to control a semi-humanoid cobot and perform autonomously a task of screwing screws in panels. Our approach relies on the direct integration of the embedded sensors information into the control loop that uses a multi-task formalism. A hierarchy of constrained tasks is solved at each iteration of a closed-loop system. The considered constraints are joints limits, visual servoing feature, range and wrist joint desired position. Moreover, the solution is validated on a real setup and shows good robustness with respect to the uncertainties of the environment.**

***Index Terms*—Multi-sensor control, visual servoing, cobots**

I. Introduction

Interest in collaborative robots have grown significantly in the last few years. The evolution from classic automated manipulator to cobots with autonomous decision making capabilities raises new challenges in perception and control design. The idea of reactive architecture, in contrast to model-based or planning, allows a good consideration of the dynamic and uncertainty of the real-world without the need for complex models. In addition, the use of multiple sensors such as cameras, laser or force transducers in such architecture directly links perception and action in a very natural way.

In our research, we aim at allowing a cobot to perform autonomously a screwing task in a dynamic environment. To consider the uncertainty of the real-world while ensuring the completion of the task, the use of reactive methods seems crucial [1]. We use a strict hierarchical control framework for the completion of the task rather than the task fusion proposed in [2]. In our work we use the semi-humanoid robot Baxter from Rethink Robotics equipped with a 2D camera and an infrared range laser in the end-effector of each of its seven joints arms. An RGB-D sensor has been also mounted on the movable head in order to have a high-level view of the environment around the robot.

The article is organized as follow. First, in section II we briefly explain the initial step that analyse the environment. Then, in section III we describe our multi-task-priority framework for the completion of the screwing task. Finally, section IV reports experimental results and a conclusion.

II. Prepositioning the arm in front of the targets

In this section, we address the problem of detecting and analysing the workspace environment around the robot. We call *prepositioning* the process that will detect where the screwing task has to be performed and define if and how the robot can reach the targets. This process is divided in three steps.

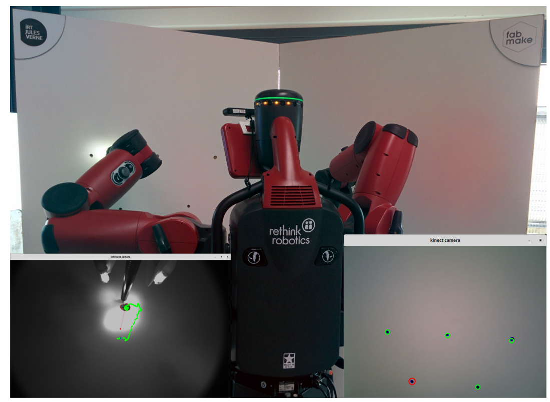

Fig. 1. Robot experimental setup. The kinect windows (right) shows the different holes detected. The reachable target are coloured in green and red otherwise. The left hand camera windows (left) shows the visual servoing task.

1) Plane detection: Detect the different plane surfaces in the environment where the screw holes are. To do so, we mounted an RGB-D camera on the head of the robot Baxter and use the RANSAC algorithm to estimate the different planes equation in a fixed frame of the robot.

2) Target detection: The goal of this step is to detect the different location of the screw holes in the planes. To do so, we use the 2D vision of the RGB-D camera. The main idea of the computer vision algorithm is to transform the image into a gray scale then into a binary image. Then, we can use an ellipse detection algorithm to detect the exact position of the targets in the image frame. Finally, the positions are translated into a fixed frame of the robot.

3) Virtual positioning: In order to define if the target can be reached by the manipulator we solve an inverse kinematic task. If we are able to find a solution we can say that the target is reachable, otherwise it means that no articular joint position can be found to put the effector in the desired pose. By doing so, we are able to first perform screwing on the reachable targets and then move the robot to consider the points left.

III. A task-priority framework for screwing

In this section we present a framework for the completion of the screwing task with Baxter arm manipulator.

A. Task-priority framework and quadratic formulation

The main challenge of screwing a screw is to perfectly align the screw held by the end-effector in front of the target, put the screw inside the hole and do the actual screw of the screw in the plane. By taking advantage of the arm redundancy, the screwing task can be separated in a set of different sub-tasks that correspond to a desired measurement for a sensor considered independent of other tasks.

Kanoun proposed in [3] an elegant task-priority framework based on a sequence of *quadratic problems*. In this framework, each task can be either an equality or an inequality. The task is linked to the joint velocities with its corresponding Jacobian. For instance, a control task can be only the minimal-norm solution to the quadratic problem: $\dot{\mathbf{q}} = \text{argmin } \|\hat{\mathbf{J}}\dot{\mathbf{q}} - \dot{\mathbf{e}}^*\|$ where $\dot{\mathbf{e}}^* = -\lambda(\mathbf{s}-\mathbf{s}^*)$ is the desired sensor feature variation. We can thus define a complex robotic task by a hierarchy of tasks $(\dot{\mathbf{e}}_i^*)$ and their corresponding Jacobians $(\hat{\mathbf{J}}_i)$.

B. Constrained sub-tasks

The screwing task is divided in four different priority quadratic problems constrained by their respective sensor task.

1) Level 1 Joint limits: We must ensure that the velocity commands does not exceed the velocity and position limits of each joint of the robot. In order to keep these values in their bound we define inequalities using a special weighting method. The key idea is to drastically increase the weight of the constraint when the velocity commands exceed a safe region close to the limits, which can be seen as repulsive field around the limits [2].

2) Level 2 Visual feature: The objective of the visual servoing task is to use the camera data in order to align the screw with the screw hole. Once the point (i.e. hole gravity center) is detected and tracked, its position is regulated directly into a desired position in the image frame. However, when the screw is perfectly aligned with the target, the camera cannot differentiate the screw and the hole. Therefore, the end of the task is performed in open-loop. During the alignment we estimate the point position in the world frame then we replace the tracking by this estimation.

3) Level 3 Range and wrist: The infrared sensor of the end-effector is used to control the distance of the end-effector with respect to the plane. The sensor provides a single distance measure and is used to determine if the screw is too far from the objective, aligned or inside the hole. Another third priority level constraint is what we call the fixed wrist constraint. We want the rotational joint of the wrist is in its limits from the left side, then we are ensured to have a maximum rotation to the right to screw the screw at best. To do so we define an equality constraint that set the wrist joint to its minimum position. At the end of the process the equality constraint is set to the maximum position of the joint to screw.

4) Level 4 Orientation: The last fourth priority constraint is the orientation. Indeed, the end-effector must be perfectly perpendicular to the plane. Since we know the orientation of the plane, if we can evaluate the orientation of the end-effector, we can define an orientation error to regulate. However, this task is performed in open-loop since no feedback on the real orientation of the end-effector is available. This last constraint has not shown robust results yet.

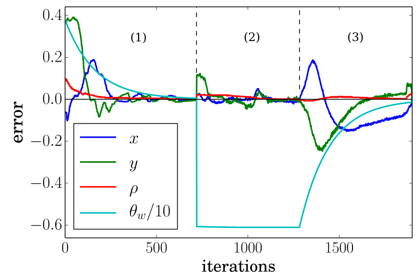

Fig. 2. General behavior of the different task on a screwing performance. We can notice the different step of the process: (1) correspond to the alignment of the screw with the hole, (2) is the insertion inside the hole and (3) the actual screwing of the screw.

C. Active set solver with Lagrange multipliers

The quadratic optimization problems have to be solved hierarchically at each iteration of the control loop. Since the control loop is running at 30Hz, a trade-off has to be made between quality of the solution and efficiency. We propose to use a solver based on the active set strategy with Lagrange multipliers [3].

IV. Results, conclusion and on-going work

A. Experimental results

Figure 2 shows result of the screwing task obtained with the designed framework. The experiments were performed with the semi-humanoid robot Baxter. It can be seen that every sub-task converged correctly to their desired position, note that the orientation has not been set for this experiment. During the experiment, the framework has shown good robustness with respect to the different uncertainties such as Baxter positioning accuracy. A video of the experiment is provided on the web [1].

B. Conclusion

We presented in this paper a framework to perform a screwing task with a robotic manipulator. We showed that the designed system is able to correctly perform the task. However, we showed limits in the orientation constraint. We believe that the multi-sensor based control designed is the correct way to perform such task in the context of a collaborative robots and we will continue to improve the framework with the following guideline: correct estimation of the end-effector orientation using the head camera, extension of the framework with 2D 1/2 visual servoing technique to ensure global convergence of the system and extensive testing of the proposition.

References

[1] A. Cherubini, R. Passama, A. Meline, A. Crosnier, and P. Fraisse, "Multimodal control for human-robot cooperation," in *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2013, pp. 2202–2207.

[2] O. Kermorgant and F. Chaumette, "Dealing with constraints in sensor-based robot control," *IEEE Transactions on Robotics*, vol. 30, no. 1, pp. 244–257, 2014.

[3] O. Kanoun, F. Lamiraux, and P.-B. Wieber, "Kinematic Control of Redundant Manipulators: Generalizing the Task-Priority Framework to Inequality Task." *IEEE Transactions on Robotics*, vol. 27, no. 4, pp. 785–792, 2011.

[1] experiment video: https://youtu.be/U_OlFQ8HatU