Picking up and assembling watch components: an ongoing challenge for collaborative robots

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***Abstract*—Collaborative robots (cobots) offer increased interaction capabilities at relatively low cost. However, in contrast to their industrial counterparts, they inevitably lack in precision. The latter can generally be improved but it comes at the expense of time-consuming calibrations that need to be performed regularly. In addition, modeling errors at the task level rapidly accumulate as tasks change and robots are re-programmed, adding to the robots' own kinematic and dynamic errors. These aspects strongly limit the application of cobots in tasks that require high precision. We discuss this challenge in the context of the COB'HOOK project that considers the use of cobots for the watch-making industry. We present the use case of picking up and assembling watch parts and discuss a solution combining high-precision laser sensing and an optimal control formulation that is used to plan relative trajectories.**

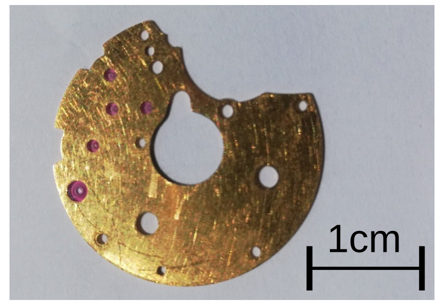

Fig. 1. Watch component used for pick up and assembly in the COB'HOOK project.

I. Introduction

Despite being more and more ubiquitous in industrial contexts, collaborative robots still have a limited presence in the watch-making industry. As small watch components need to be handled, most collaborative robots, despite their high repeatability, do not have the accuracy required to perform tasks that require sub-millimeter precision. The COB'HOOK project studies the problem of picking up and assembling watch components using collaborative robots such as the 7-axis torque-controlled Panda robot by Franka Emika. Watch components are usually diverse in their shape and size, with insertion points changing from one part to another, see Fig. 1. One typical solution for this problem is to rely on visual servoing [2]. However, common cameras often require structured environments, where watch components have to be carefully placed in ways that are convenient for being picked and placed. Similarly, cameras moving with the robot (eye-in-hand) can become occluded by the watch components that the robot needs to handle. Hence, even if picking up the part can be done successfully, subsequently performing an assembly is not straightforward. In order to alleviate the precision problem, we propose a dual-arm robotic solution relying on a combination of laser scanning and model predictive control (MPC). The approach consists of having one robot arm moving a laser scanner to build a point cloud of the watch component and another component of interest (e.g. the end-effector, for pick up, or another watch component, for assembly). Subsequently, using point cloud registration techniques we propose to find the poses of the watch component and the other relevant object with sub-millimeter precision. Finally, knowing the final desired pose of the watch component, we use MPC to plan a relative trajectory that ensures the pick-up/assembly. The technique shares connections with position-based visual servoing, however, in our case the flexibility given by having a separate scanning arm circumvents the need to constrain sensing to one specific pose.

II. Proposed Approach

Aiming to improve cobot precision for handling watch components, we propose an approach that combines laser sensing and MPC to plan an end-effector trajectory between components that ensures a correct assembly. For the purpose of the explanation, we will say that the *first arm* is responsible for performing the assembly while the *second arm* scans the parts.

A. Laser scanning

We assume to know a desired pose for the robot end-effector which is close to the one necessary for pick up/assembly. This can be easily obtained in torque-controlled cobots by having a controller compensating the robot gravity and kinesthetically moving the arm to the pose of interest. Using a laser scanner with μ-meter resolution, attached to the second arm, we can obtain a point could containing the components of interest (see Fig. 2 for an example of a watch component point cloud). Using point cloud registration, for example the iterative closest point method [1] we can identify the poses of both components with sub-millimeter precision.

B. Planning a relative trajectory

Having identified the component poses, we propose a formulation based on model predictive control (MPC) to plan a relative trajectory that aligns the two components for either pick-up or assembly. For a time horizon T, MPC solves the

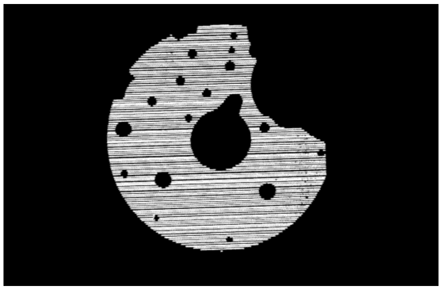

Fig. 2. Point cloud of the watch component in Fig.1, obtained from laser scanner.

problem

$$\min_{\boldsymbol{u}} \sum_{t=1}^{T} (\boldsymbol{\mu}_t - \boldsymbol{x}_t)^\top \boldsymbol{Q}_t (\boldsymbol{\mu}_t - \boldsymbol{x}_t) + \boldsymbol{u}_t^\top \boldsymbol{R}_t \boldsymbol{u}_t, \qquad (1)$$

subject to linear dynamics $\boldsymbol{x}_{t+1} = \boldsymbol{A}\boldsymbol{x}_t + \boldsymbol{B}\boldsymbol{u}_t$ where $\boldsymbol{x}_t$ and $\boldsymbol{u}_t$ are the system state (in this case position and velocity of the robot end-effector) and control command at t, $\boldsymbol{A}$ and $\boldsymbol{B}$ are matrices that describe the system, $\boldsymbol{\mu}_t$ is the desired state at t and $\boldsymbol{Q}_t$, $\boldsymbol{R}_t$ regulate the tracking precision and the amplitude of control commands. By setting $\boldsymbol{Q}_t$ and $\boldsymbol{\mu}_t$ properly, one can ensure that the planned trajectory will pass through desired key-points to perform the assembly. Moreover, it permits the generation of efficient control commands by taking into account the allowed variations in the task. Consider, for example, the case where the assembly task is invariant around an axis of rotation. This formulation can be exploited, for example, to allow the robot trajectory to be less precise along the invariant degree of freedom, by setting a low value for the corresponding entry in $\boldsymbol{Q}_t$, while being precise along the remaining ones. The robot then relies on the relative trajectory to ensure a successful assembly.

III. Conclusion

We proposed a possible solution to address the problem of cobot precision during assembly of watch components. It relies on high-precision laser scanning and MPC. Evaluating the robustness of the approach can be done using popular benchmarks such as the NIST task board #1 [3] and is part of future work. If results prove promising, the approach shows potential to be combined with learning from demonstration, where learned policies can be refined using sensor information. One possible way is to rely on the fusion of controllers (see e.g. [4]) to consider one MPC as a nominal task plan and another one for refining the trajectory, with the fusion being regulated by the associated uncertainties.

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