Detachable, Low-Cost Tool Holder for Grippers in Human-Robot Interaction

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Abstract. To hand over more than just pick & place tasks to an industrial collaborative robotic arm with a two-jaw gripper, the gripper must first be removed, and a new tool mounted. This tool change requires either human assistance or an expensive tool changer. The tools applied to the end-effector are often highly expensive and software system interfaces between different tools and robots are seldom available. Therefore, a holder was developed that allows the robot to pick up and operate a tool, such as an electric screwdriver, without having to demount the two-jaw gripper. Instead, the gripper's functionality is used to activate and deactivate the tool fixed to the holder. This paper presents the state-of-the-art of the underlying problem as well as the development process including simulations, the patented design, and the low-cost production of the tool holder. This detachable, low-cost tool holder enables a flexibilization of human-robot processes in manufacturing.

Keywords: Robot tools · Collaborative robots · Versatile production

1 Introduction

Industrial collaborative robotic arms (cobots) entered the market to enable physical human-robot interaction (HRI) in manufacturing. Due to their built-in force sensors, they allow safe interaction with human workers and employees on the shopfloor according to the applicable standards [10,15]. This is a novelty in comparison to classical industrial robots, which must be separated from workers' workplaces by additional safety measures such as walls, fences or specific safety skins. It is important to note that not only the safety of the robot arm plays a significant role, but the entire application, including the end effector, tools, workpieces, peripherals, software, etc., must be considered when checking the conformity against safety of the application. This safety aspect enables new ways of human-robot collaboration.

Cobot manufacturers usually sell the robot arm without the end-effector, i.e. the tool, as this must be adapted to the application. The robot arm is therefore generically designed for a large number of applications, while the end-effector

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must be individually adapted to a specific task. These cobot tasks are e.g., assembly, inspection, kitting, joining, packing, and pick & place tasks as well as machine tending, screwing, gluing, soldering, and grinding [2,6].

In theory, this multitude of possible tasks allows a very high degree of flexibility with regard to the use of cobots. However, the mentioned safety considerations and either time-consuming manual or costly automatic tool changes limit this flexibility in practice. This particularly concerns manufacturers with small and medium batch sizes, where a high flexibility is required [8]. We present a new and patented solution to this problem of tool changing as we have designed and developed a detachable, low-cost tool holder which allows the cobot to switch autonomously between the function of a two-jaw gripper and a screwdriver at lower investment costs. The functionality of the holder has been patented (AT523914, WO2022000011, IPC B25J 015/02 [17]). Our design allows a flexible alternation between the human and cobot in the use of the tool such as a screwdriver, without removing the primary tool (two-jaw gripper) from the cobot. In addition, the tool (commercially available screwdriver) deployed can also be used by the human, enabling further cost savings.

In this paper, we present a short overview of available solutions (Sect. 2). In Sect. 3, we present the development process of our solution followed by a detailed description of our detachable, low-cost tool-holder for cobot grippers in terms of design and functions (Sect. 4). We finish with a discussion (Sect. 5), and a conclusion with outlook (Sect. 6).

2 State-of-the-Art

The integration of a tool to the cobotic arm consists of two steps: the hardware and the software integration. In terms of hardware integration there are existing tool holders and changers patented. Examples of prior art are activating a gun type tool through special end-effectors [5,16], special fixtures with electrical I/O capabilities [3], or form-fitting membranes enclosing the tool [4].

Tooling solutions for cobots on the market are solutions from cobot manufacturers, solutions from third party manufacturers, and manufacturers of automated and manual tool changing systems for cobots. Cobot manufacturers such as Franka Emika and ABB offer tools for their cobots. Newer third party tool specialists have established themselves on the market such as Robotiq and onRobot, but there are also established (automation) companies such as Schunk, Festo, and Zimmer selling various tools for cobots. Other available solutions focus on automated and manual tool changing systems such as those manufactured by SmartShift, TripleA-robotics, and Nordbo-Robotics, where tools are stored on a rack, similar to tool changing systems used in automated metrology systems. Due to their price positioning, these specific tools for cobots are suitable for high volumes, but less suitable for smaller lot sizes. Additionally, these systems cannot be operated by a human as these tools are controlled directly by the cobotic arm's software.

Software integration is a complex, individual topic: It depends on the cobot, tool and software environment that are used. To enable flexible HRI in manufacturing, easy software interfaces are used to quickly (re-)program the cobot without text-based programming knowledge. Best case, the cobot's software allows the integration of tools. This is offered, for example, by some manufacturers such as Universal Robots, but also by integrators such as Drag&Bot where tools only have to be integrated and configured once. Depending on the system, the integration and configuration can take up to one working day. If the software environment does not support the tool, then tools must be programmed via input and output signals. This is relatively simple regarding two-jaw grippers, but is complex or impossible with other tools. To find a solution to these challenges, a multi-stage approach was chosen which is detailed in the following section.

3 Development Process

As part of a student thesis project [11] in our learning and teaching factory, a low-cost solution was designed and developed to how a cobot, equipped with a standard two-jaw gripper, can also take over the task of screwing. A tool change should be avoided as far as possible in order to save time, costs and interfaces. The boundary conditions are given by the existing robot incl. gripper (Franka Emika Panda) and inline screwdriver (AEG SE 3.6), as well as the FDM (fused deposition modeling) 3D-printing process. The following requirements for the tool holder were identified using the factorization technique by Feldhusen and Grote [7]:

1. Enable picking up and setting down the entire holder.
2. Enable operating the screwdriver through the cobot's gripper.
3. Design for assembly and customization, including optimization of assembly connections, planning of assembly, possibilities for customization, and simple alignment of components.
4. Allow fixating and removing the screwdriver in and out of the holder.
5. Enable centering of the screwdriver.
6. Do not exceed the max. payload of robot (1kg for Franka Emika Panda): screwdriver (534g) + holder (x) $\leq$ payload of robot.

A morphological box was used to compare the different concepts and select a solution. The tool holder was designed using CAD software and finite element analysis, e.g., for most stressed parts such as the edge of the lock. The components were 3D-printed in polylactic acid (PLA) using FDM, assembled, and mounted to the cobot's gripper to validate its functionality. The weight of the first prototype was 418g. The successful validation showed that the holder was able to hold and operate the screwdriver. The initial design was then optimized considering two aspects: weight and 3D printing design. Topology optimization was used to reduce the weight of the holder by 10%. The optimized prototype was 3D printed in PLA using FDM and successfully validated in practice.

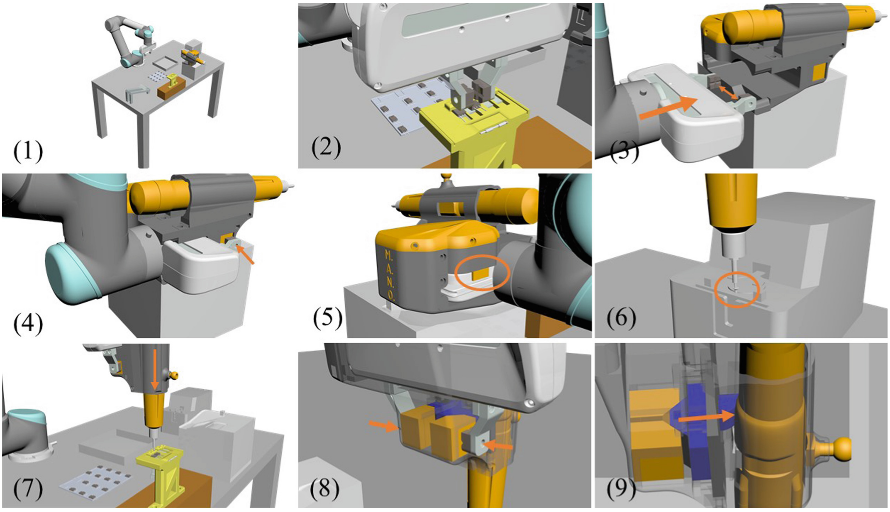

Fig. 1. (1) Full view of work table with cobot and latest holder prototype, (2) Pick & place function of the robot, (3) Screwdriver holder, (4) Holder fixation, (5) Holder locking, (6) Pick screw, (7) Positioning, (8) Screwdriver actuation, (9) Inside view of screwdriver actuation.

A process simulation illustrates the holder and its functionalities using the software "Autodesk 3ds Max®". The example scenario is a use case from the electronics industry, where a cobot assembles transistors on a heat sink. This requires the two-jaw gripper and the screwdriver holder. The operation consists of two parts, first a pick & place movement of the cobot in which it brings the heat sink and the transistors to a fixture, and then the tightening of bolts using the screwdriver. Therefore, the tool holder including the screwing tool has to be mounted to the gripper, then a bolt is magnetically attached to the tip of the screwdriver and screwed into the heat sink. Finally, the tool holder is removed from the gripper and set back into its initial resting position. Screenshots of the simulation (Fig. 1) illustrate the holder and its functionalities.

4 Detachable, Low-Cost Tool Holder for Robot Grippers

The design (screwing and manipulation module) and functions of the detachable, low-cost holder are described in the following. Figure 1 illustrates the simulations of the functions of the holder and Fig. 2 shows different views of the 3D-printed prototype. The screwing module was designed to incorporate a spring-loaded quick release system allowing for the fast and easy removal of the screwdriver. Pulling the release out, the screwdriver is removed. Letting go of the release causes the release to shoot back to its initial position. The design of the holster is individualized and only holds a specific screwdriver, but can be changed to accommodate different designs of inline tools. The cobot's gripper is fit into

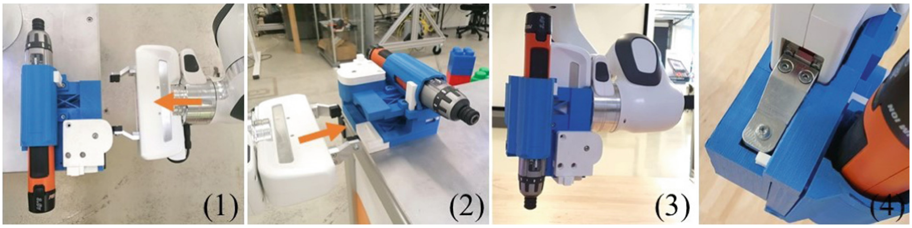

Fig. 2. (1–2) Tool holder fixation to the gripper, (3) side view of tool holder prototype mounted on a cobot, holding an inline screwdriver, and (4) screwdriver activation through two-jaw gripper.

a pocket in the manipulation module. The manipulation module contains the conversion mechanism, that converts the movement of the gripper's jaws to a force activating the screwdriver, consisting of two mirror-symmetric prisms and a counter-piece. When the jaws converge, the prisms converge toward each other causing the counter-piece to be pushed away, which in turn activates the initialization mechanism and subsequently the toggle switch of the screwdriver, see Fig. 1 (8–9). The gearbox houses the locking mechanism, which consists of a slider, gears, rack and pinion and the stop, responsible for blocking the locking mechanism. In its storage position, the slider is pushed inwards, until the gripper tool lifts the screwing tool, which causes the slider to move back into its initial position. The rack, which is mounted on the slider, causes the pinion to rotate, transferring force to the gears and subsequently to the lock, which is pushed forwards and thus secures the screwing tool to the gripper, see Fig. 1 (5).

To pick up the holder including the tool, the gripper's twin jaws are set to the maximum width position so that the jaws are guided into the holder (Fig. 1 (3)). In its initial position, the holder lies on an individualized stand, which through an extrusion keeps the locking mechanism deactivated by pushing the slider inwards. Once inside the screwing tool at the designated position, the jaws slowly converge until merely contact is made with the initialization mechanism (Fig. 1 (4)). The locking mechanism is activated to guarantee the fixation of the screwing tool to the gripper (Fig. 1 (5)). This mechanism is initiated by moving the gripper upwards and away from the stand, which causes the slider to fall outwards, and the locking mechanism to be activated, securely fixing the tool holder to the cobot gripper.

The operation of the screwdriver starts with picking up bolts through a magnetic tipped screwing bit and an automatic bolt feeding machine (Fig. 1 (6)). The cobot moves to the automatic bolt feeder, picks up a bolt and moves to the heat sink, placing the bolt into the threads of the previously placed transistor into the fixture (Fig. 1 (7)). In order for the bolt to twist itself into the threads, the screwdriver has to be activated. The gripper's jaws converge beyond the point of contact inside the pocket of the screwing tool, which causes the prisms inside the conversion mechanism to push against the counter-piece thus activating the toggle switch of the screwdriver (Fig. 1 (8–9)). Once the bolt has been tightened, the gripper's jaws diverge so that the screwdriver is deactivated. This process is repeated for the other bolts needed to complete the assembly.

In order to revert to pick & place sequences, the screwing tool has to be removed from the gripper of the cobot. This occurs analogue to the fixation of the tool. The tool is placed directly above the stand, so that the extrusion is directly underneath the slider. Once the holder is lowered so far that the slider is pushed upwards again, the lock is deactivated through the movement of the gears inside the locking mechanism. After the screwing tool has been set back onto the stand, the cobot can remove itself from the direct area of the screwing tool stand. The twin jaws diverge to the maximum width position, and the gripper backs out of the pocket of the screwing tool transversely. After successful removal, pick & place operations can be realized again.

5 Discussion

The described tool holder addresses the challenge of implementing cobot flexibility in terms of fast and flexible tool exchanges. The presented approach focuses especially on cobots as they are regarded to be used in very flexible environments with changing and rather small lot sizes. The cobot market volume is expected to grow up to 1B USD until 2023 and up to 8B USD until 2030 [9]. However, cobots are not seen as substitution to classical industrial robots, but as a new tool to open up new markets and applications. About 18,000 cobots were sold in 2019 in comparison to 363,000 industrial robots (5%) [9].

The potential price of the presented tool holder is positioned at the low-cost level of industrial tool holders. In terms of the envisaged costs of the system, the straightforward design, low-cost materials and the focus on off-the-shelf tools allows price ranges at about EUR 300–500, about 10% of the onRobot system which is considered as today's benchmark. The costs can be regarded as costs per function (such as screwdriving) as modules for the integration of further tools are under development. With the modular adaptability of the holster a similarly built tool could be used with an appropriate customized holster. Considering a growing market in robot usage in the industry grows naturally as the principal market for such a tool holder.

Against the mainstream of existing solutions, slight compromises of the needed availability and reliability are accepted at prototype level, but also regarding the final state. As the primary application area is HRI, this trade-off is actively accepted as long as a human co-worker may stand-in for the rapid problem-solving in low-threshold unforeseeable events (re-positioning, re-start, material replenishment for small lot sizes) [1].

As the solution today represents a technology readiness level of TRL5 (large scale prototype), further validation, integration and testing in different scenarios are necessary. The definition and approach of a considerable market poses a current two-sided challenge. First, the patented approach comprehensively covers robot/end-effector interfaces with a cutout/pocket such as the parallel jaw gripper (Fig. 2). Therefore, traditional interfaces are not covered by the presented solution. However, a significant share of cobot manufacturers offers solutions with a pre-assembled end-effector, usually a jaw gripper. Second, the presented solution stands in competition with existing tools and tool-changing systems. Therefore, regarding the commercialization, besides cobot and end-effector manufacturers, further potential partners such as automation companies, system integrators and tool manufacturers are investigated. In order to account for a significant market the prototype needs to be validated in terms of safety. Preliminary work on the conformity against safety of envisaged applications is considered within the SafeSecLab project [13].

6 Conclusion and Outlook

In this paper, we presented a new and patented tool holder that allows a cobot to switch autonomously between the function of a two-jaw gripper and a commercially available screwdriver, which can also be used by the human co-worker. This increases flexibility in terms of HRI and robot functionalities. The developed tool holder works around drawbacks of existing solutions such as automatic tool changers and specific tools for cobots by providing the robotic arm with a tool it can mount and remove independently, enabling it to switch between gripper and screwing tasks when required without manual tool installation through a worker. The existing prototypes were designed to operate in a controlled environment in the TU Wien Pilot Factory for Industry 4.0. For a broader use in industrial applications and environments the next step will include the transition from a prototype to a product. In this step different use cases will be validated and accordingly, business models will be created. Future work on the industrialization of the tool holder including an analysis of the production techniques is necessary. The general idea behind a tool holder is to improve the functionality of the robot in regard to different performable tasks. The more flexible a cobot can be used, the more different possible task allocations between human and machine become possible [14]. Thus, a direct positive impact on comprehensive work tasks and human factors, especially in terms of task load and adaptability is envisaged, contributing to more human-centered and even individualizeable work systems [12].

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