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DIGITAL TWIN ENABLED FRAMEWORK FOR INDUSTRIAL HUMAN-ROBOT COLLABORATION

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Industrial robots are systems used for manufacturing. Industrial robots allow for accomplishing automated tasks with high endurance, speed, and precision. However, industrial robots are typically enclosed within fences to guarantee human safety. A new generation of collaborative robots (cobots) is designed to collaborate with humans in an open workspace. Significant advances have regarded critical functional requirements and mechanisms for safety, collaboration variants and standardisations. As a result, cobots have become robust and suitable to be progressively introduced in manufacturing applications. Cobots are attractive for large, small and medium enterprises. Their capability to work alongside humans removes the requirement to confine them within a fenced space and makes them flexible manufacturing tools. In order to unlock the potential of cobots and speed up the exploitation of collaborative robotics in flexible manufacturing environments, research is needed to continue empowering cobots with ergonomic features, real-time sensing capabilities and controls, human-robot interfaces, and intuitive and task-driven programming. This work describes a framework being developed to facilitate the employment of human-robot collaboration in industrial assembly applications. Such a framework is enabled by a digital twin of the system.

Keywords: *cobots, robots, smart industry, digital twin*

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1. Introduction

The technological development can be partially reflected by the scope and level of mechanisation and automation in replacing humans for operations, and decision-making supports [1]. Robots have been widely applied to relieve humans from tedious, repetitive, and risky tasks. However, for most applications, robots are still not advanced enough, and human assistance is needed to tackle the changes in tasks and environmental factors. Humans have advantages over machines regarding intuitive decisions, responsiveness, agility, and adaptability. Therefore, a new generation of collaborative robots (cobots) has been developed to enable humans to work with robots. Typically cobots are industrial robots outfitted with several sensors. Cobots are meant to put humans at the centre of a manufacturing task and free workers from various tasks without difficulty, danger, or dullness. Humans do not disappear from production; Cobots work alongside operators rather than replacing them. Whereas traditional industrial robots have found significant application in large factories due to the required space and investments, cobots are potentially attractive for large and small and medium enterprises. Therefore the cobot sector is expected to proliferate in the upcoming years [2]. Humanity is witnessing technological and economic changes related to integrating innovations such as artificial intelligence (AI), blockchain, the Internet of Things, cryptocurrencies, automation tools, etc. Whereas the main problem of the fourth industrial revolution (Industry 4.0) is about adding autonomous behaviours to machines, the fifth industrial revolution (Industry 5.0) assumes synergy between people and autonomous machines. The fifth industrial revolution has been defined as the revolution that will return workers to production plants, combining human intelligence and creativity with the capabilities of machines to increase the efficiency of processes [3]. The current vision is that the autonomous workforce will be receptive and informed of human intentions and desires, resulting in an exceptionally efficient value-added production process, flourishing reliable autonomy, and reducing waste and production costs. Assembly tasks that require human intervention are widespread in industrial manufacturing. A typical future scenario could consist of a person working alongside one or more cobots on assembling a specific industrial product made of several parts. The human worker may start the task with the robotic system monitoring the process using one or multiple overhead cameras operating as system eyes. The human-robot system is also managed by a data acquisition and control unit that captures the camera frames, performs image processing, and examines patterns through machine learning algorithms. Such a system may simultaneously monitor the person and the environment and infers what assembly phase the operator is performing at any time, using an analysis of human intentions based on artificial intelligence. Besides traditional RGB vision and stereo cameras, functional near-infrared spectroscopy (FNIRS) [4] may also suitably monitor human intentions. While forecasting human intention with sufficient accuracy, the cobots could help the human actor complete the assembly task, increasing efficiency. The worker could perceive that as similar to how another person standing next to him/her may help and give clues. For example, once the system predicts that the human operator will use a specific component in the next step of the assembly task, it commands the cobot to take that part in advance and deliver it to a convenient position for the operator. The current research challenge consists in making the afore-described vision a reality and creating non-invasive work companions so that human workers can focus on their tasks, feeling helped out safely. This paper introduces the authors' ongoing work to establish a flexible and future-proof framework for human-robot collaboration in industrial assembly applications. Crucially, such a framework builds on top of a digital representation of a real-world system, and this foundation will enable the implementation of multiple Industry 5.0 paradigms.

2. Framework components

The cobot-assisted system for industrial assembly tasks is being developed according to the framework shown in Figure 1. A computer runs a bespoke modular software package comprising the module for real-time communication and control of the cobot, the module for controlling the robotic gripper, the sensor data processing, the artificial intelligence algorithms and the graphical user interface (GUI).

The GUI is also composed of multiple modules. A page is designed for the user to input all system settings (e.g. the parameters to connect to the cobot and the gripper, the preferred speed and acceleration of the robotic movements, the gripping power and the safe robot distances for approach and retraction movements). Another GUI module is dedicated to defining the initial composition of the stock of components (part identification numbers and quantities). The most extensive GUI module is the digital 3D environment developed to support the offline simulations of the real-world system and function as a digital twin when connected to the system. Such a digital environment may enable an Extended Reality (XR) modality in human-robot interaction. The digital environment is initially populated with the components the user defines on the component stock page, but the stock is updated

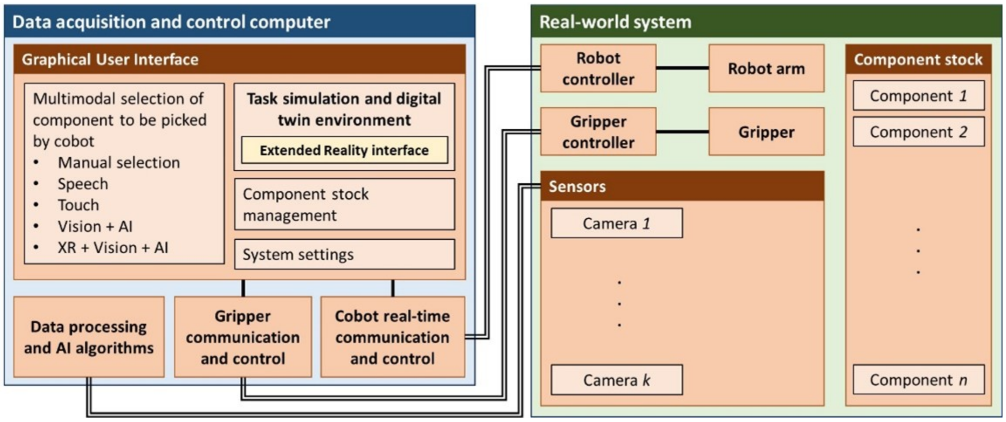

Figure 1: Proposed framework for industrial human-robot collaboration.

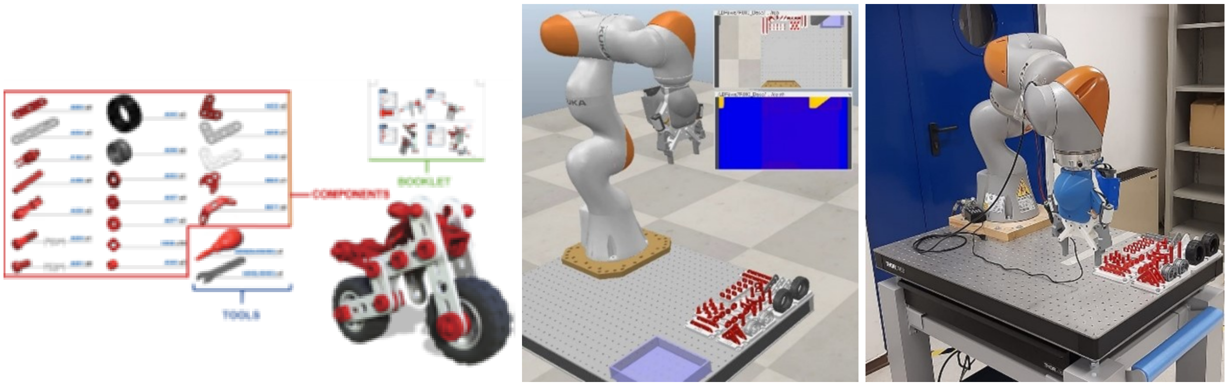

Figure 2: MECCANO toy kit (a), digital setup (b) and real-world setup (c).

during the execution of an assembly task to reflect the actual status of the real-world stock. Finally, the GUI comprises a multimodal approach to selecting the component the cobot needs to pick from the stock. The user can manually request a single component type by selecting its name or serial number and a specific number of units (via drop-down lists) or clicking on the component picture reproduced within the GUI. A user wishing to perform a manual selection can also trigger the robotic system to pick all the components required to complete a specific phase of the assembly task. Indeed, the assembly phases can be specified on the GUI setting page. Moving from manual selection towards more advanced triggering of the robotic system, the GUI will incorporate bespoke features to set up speech control, touch control, vision sensors, AI algorithms and XR interaction features. In turn, these features can be used to enable triggering the system through the worker's voice (him/her asking the system to pick a specific component), through the worker tapping the cobot wrist and through the autonomous inference of the worker's actions operated via the vision data, the AI algorithms and the XR interface.

3. The current state of the ongoing development

The system framework described above is a vision for which this paper's authors are working. Although most of the multimodal control features are still not developed, the underpinning digital simulation module, digital twin environment, and the communication links between the computer and the actual hardware have already been established and tested. The chosen application test case is based on a MEC-CANO toy kit. The kit contains all components required to assemble a toy model of a motorbike (see Fig. 2a). It is composed of 49 components with different shapes and sizes. Similarly to what happens in an industrial scenario, the subjects interact with tools such as a screwdriver and a wrench, as well as with tiny objects such as screws and bolts while executing a task involving sequential actions (e.g., take the wrench, tighten the bolt, put down wrench). Even though this scenario simplifies what can be found in real-world industrial settings, it is reasonably complex. Moreover, this is the same toy kit used by the authors of [5], where a benchmark to study human behaviour in an industrial-like scenario is proposed. Furthermore, the datasets generated in [5] are publicly available and may be used in the upcoming phases of this ongoing work. The robotic system used here is based on a KUKA iiwa 7 R800 collaborative robot and an in-house developed robotic gripper (consisting of a LEGO NXT Mindstorms controller, motors and gears [6] and 3D-printed body parts). Figure 2b-c shows the digital and real-world representation of the setup.

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