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Augmented reality system for operator support in human–robot collaborative assembly

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ABSTRACT

This paper presents the design and implementation of an augmented reality (AR) tool in aid of operators being in a hybrid, human and robot collaborative industrial environment. The system aims to provide production and process related information as well as to enhance the operators' immersion in the safety mechanisms, dictated by the collaborative workspace. The developed system has been integrated with a service based station controller, which is responsible for orchestrating the flow of information to the operator, according to the task execution status. The tool has been applied to a case study from the automotive sector, resulting in an enhanced operator's integration with the assembly process.

1. Introduction

In many industries, the assembly process is mainly performed by human resources, due to the fact that the operations require a human like sensitivity. The materials handled vary and often showunpredictable behaviour (upholstery, rubber, fabric, etc.) and every so often, more than one operators are active in order to perform cooperative or parallel operations in each station [1,2]. Industries need to increase quality levels in terms of precision and repeatability, to reduce throughput time in assembly stations, to enable traceability of the performed operations and to reduce operators' ergonomic stress (e.g. by reducing the applied physical strength). This can be done with the introduction of automation systems to the assembly lines. Nevertheless, surveys by the European Business Test Panel (EBTP), across 90 European companies, have identified the poor acceptance of robots (61% use 1–10 robots, 32% use 11–50 robots) [3]. The main reasons for that are estimated by theInternational Federation of Robotics and involve challenges for the adoption of new technologies. Moreover, especially when the manufacturing process can be partially automated, the lack in advanced safety systems for the supervision of human robot collaborative workspace leads to a human resource assignment.

Augmented reality (AR), as an interactive technology, has increasingly gained public interest during the last few years. The AR approach is related to a general concept of mixed reality (MR) that merges real and digital information into the user's view in such a way so as to appear as they were one and only environment [4,5]. Research in AR applications focuses towards mobility that is either for commercially available products or for custom designed applications [6–8]. Despite the progress in AR, made in the last two decades [9], potential AR manufacturing applications are still in exploratory and prototyping stages. With significant improvements in tracking algorithms [10,11] and faster response time of hardware [12], much information can be visualized effectively in near real-time. As a result, AR can be used in factory [13,14] and assembly planning [15], in assembly guidance [16–19], in product design [17,20] and others. Nevertheless, apart from some small scale experimental installations where humans have a more active role, many of the above applications have not reached the production site.

This paper presents the implementation of an AR system in aid of the operators in a human robot collaborative assembly environment. Section 2 provides a description of the proposed approach. Section 3 describes the system's implementation and Section 4 presents a case study. Finally, in Section 5, conclusions are drawn together with an outlook for future research.

2. Approach

Our approach includes an AR solution that supports the operators in the assembly process, by providing immersive assembly instructions in their field of view along with production data when needed. This application also aims at increasing operator's "safety feeling" and acceptance when working close to large industrial robots by visualizing data coming from a robot's controller and by displaying visual alerts to increase their awareness for a potentially hazardous situation. The functionalities covering the above objectives are orchestrated by a central execution control system, into which the AR application is integrated and the appropriate information is visualized when required without intervening with the operator's work. The functionalities provided by the AR solution are: assembly process information provision, robot workspace and trajectory visualization, audio/visual alerts and production data.

The manufacturing schedule contains all the data, stored into the repository of the execution controller, which is required by the resources. These include the task sequence, the robot programmes to be run, as well as the information to be visualized such as the

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trajectory, the 3D CAD files of the assembly models, etc. This system also orchestrates the execution of the tasks by sending to and receiving from the robot and the AR operator support application, appropriate signals.

Finally, an application on an Android smartwatch was created in order to help the operator to both inform the manufacture scheduler when an operation is completed and activate the production data functionality in his/her AR glasses. The above functionalities are analysed in the following subsections.

2.1. Operator support – assembly process information

The aim of this functionality is to assist operators in the assembly process by visualizing all the parts or components (for example screws, tools, glue, etc.) that will be used and their corresponding position with the real object. For example, in Fig. 1, are visualized a drum's 3D model, four bolts and the way they should be placed onto the real object (axle).

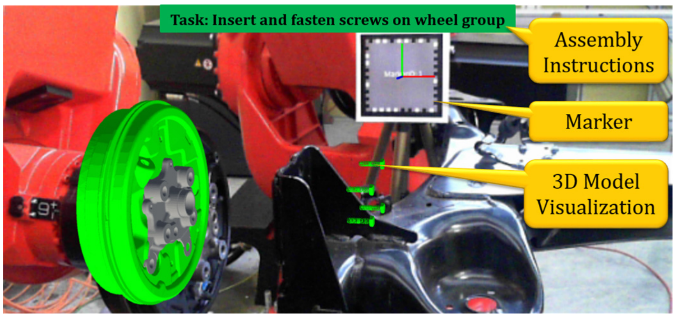

Fig. 1. Digital components superimposed over real objects.

2.2. Robot motion and workspace visualization

The second functionality targets at increasing the operators' acceptance of working on hybrid, human–robot collaborative, industrial environments. This is achieved by visualizing information deriving from a robot's controller such as a robot's trajectory and the safety zones. As it is shown in Fig. 2 a red line visualizes the robot's end effector trajectory even before the robot starts moving. In Fig. 3, there is a display of two safety areas (red and green area) called interference regions. The red area represents a part of the robot's working space and aim at preventing the operator from entering it, while the green one is a part of the operator's working area and it is safe for him/her to work inside. It should be mentioned that the above functionalities are for informational purposes only and are not safety certified. In other words, if the operator enters the red area or the robot's trajectory path, the augmented reality system will not sense it.

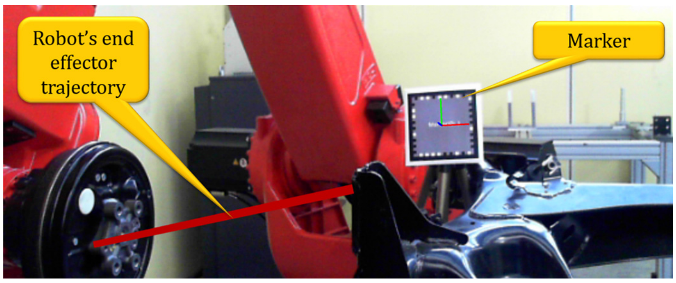

Fig. 2. Robot's end effector trajectory.

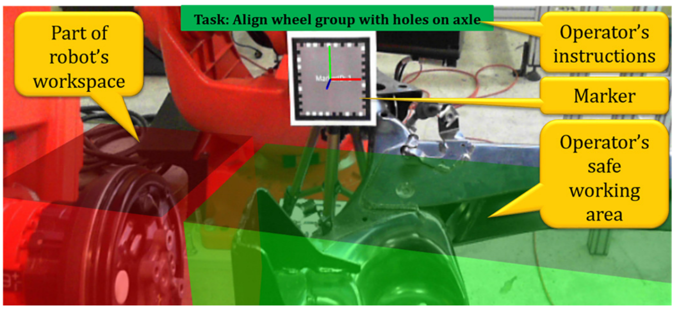

Fig. 3. Safety volume (green cube) and robot's working area (red cube).

2.3. Visual alerts

The third functionality has a supplementary role as to the previous one. It refers to visual alerts that inform the operator about potential hazards at the shopfloor in order to increase the operator's awareness. These alerts contain messages originating from the execution control system and may refer to robot movements, devices that operate in the cell and potentially can harm the human (such as hot glue dispensing devices) and any other general alert designated by the process planner. An example of this functionality is displayed in Fig. 4.

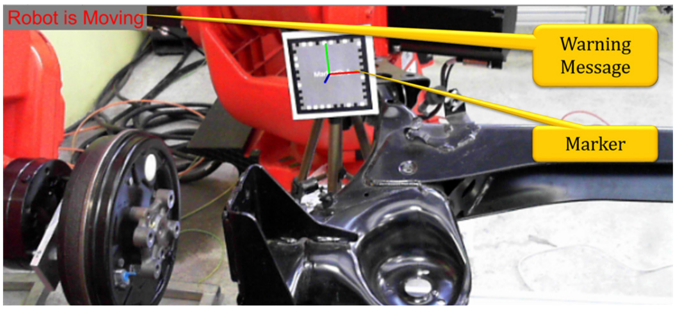

Fig. 4. Warning messages.

2.4. Production data

Finally, the last functionality, aims at informing the operator about the shopfloor status, without interfering with his/her work, upon his/her request. These messages contain information about the current and the next model to be assembled, the average remaining cycle time to complete current operation and the status of the successfully completed operations versus the targeted ones (Fig. 5). These messages are refreshed automatically through the execution system and are displayed in the operator's field of view, using the corresponding button on the smartwatch.

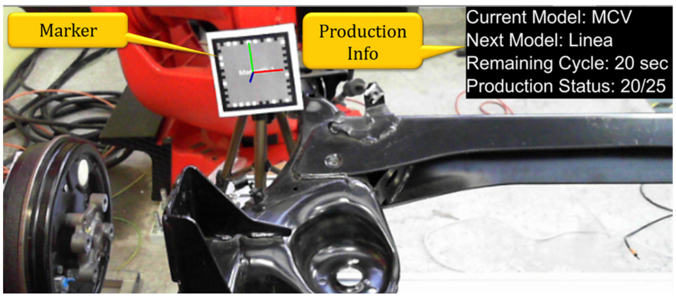

Fig. 5. Production information messages.

3. Implementation

The AR application has been implemented using the Unity3D, which handles the 3D models, the network communication and message exchange with the execution system, via scripts developed in C#. The application's AR capabilities are added through the Qualcomm's Vuforia library that offers quick and multiple marker recognition. Last but not least, some custom scripts have been created for the execution of the following tasks:

- the model, trajectory and safety area's correct visualization,
- the representation of production data and warning messages,
- the connection with ROS for message exchange,