CIRP Annals - Manufacturing Technology 65 (2016) 61–64

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

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

Sotiris Makris (2)*, Panagiotis Karagiannis, Spyridon Koukas, Aleksandros-Stereos Matthaiakis

Laboratory for Manufacturing Systems and Automation, Department of Mechanical Engineering and Aeronautics, University of Patras, Patras 26500, Greece

ARTICLE INFO

Keywords:
Augmented reality
Hybrid assembly system
Robot

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.

© 2016 CIRP.

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

* Corresponding author.
E-mail address: makris@lms.mech.upatras.gr (S. Makris).

http://dx.doi.org/10.1016/j.cirp.2016.04.038
0007-8506/© 2016 CIRP.

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).

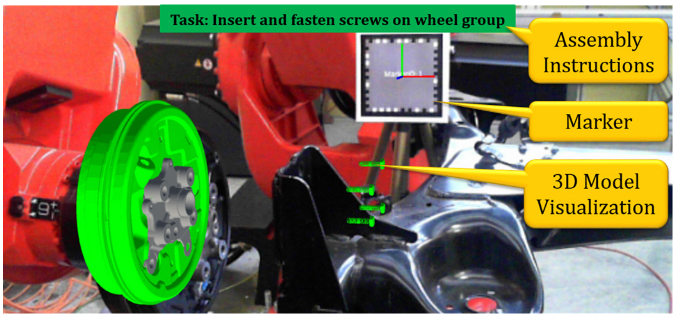


Fig. 1. Digital components superimposed over real objects.

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.

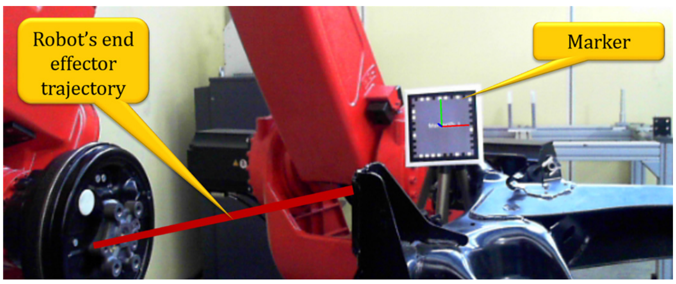


Fig. 2. Robot's end effector trajectory.

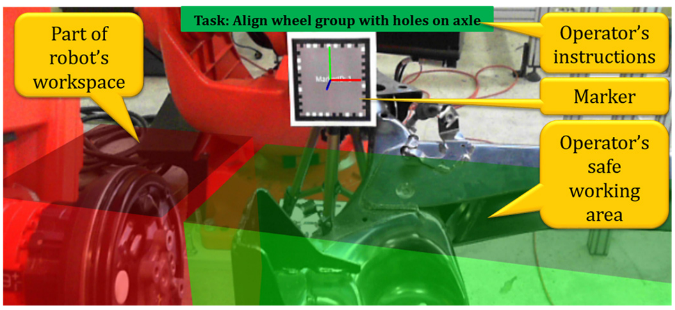


Fig. 3. Safety volume (green cube) and robot's working area (red cube).

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.

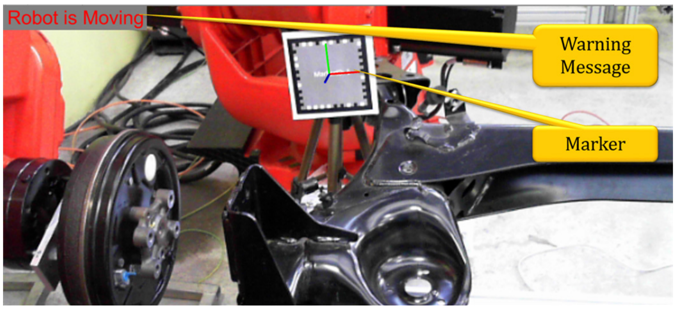


Fig. 4. Warning messages.

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.

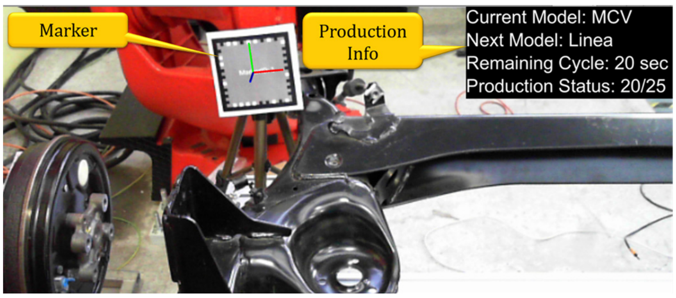


Fig. 5. Production information messages.

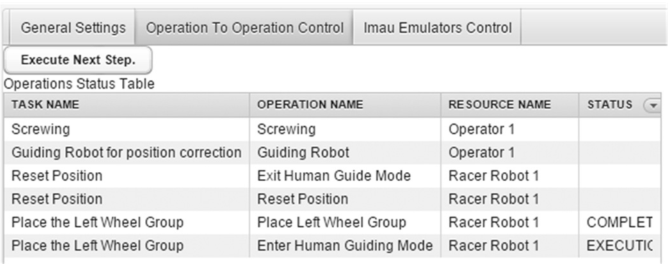
3. Implementation

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,

- the connection with the main repository for the downloading of the necessary data.

The execution control system is implemented as a java EE web application (Fig. 6) that also provides a user interface for accessing the data and executing the manufacturing schedule step by step. The execution control system utilizes ROS topics and services in order for the appropriate signals to be sent to the resources. The ROS-Java implementation of ROS is used for publishing topics and registering ROS services by the Java EE web application. Rosbridge provides a JSON API to ROS functionality for non-ROS programmes and the Rosbridge server exposes this API to the robot control system and the AR operator support system, allowing them to connect directly to the ROS master server via the ROS and WebSocket protocol. An advantage of using the Rosbridge protocol is that it enables the server to open only a single port, which is used by the Rosbridge server to allow for WebSocket connections. Using only the ROS protocol to integrate would require that all of the server machine's ports be open, thus the current configuration is safer and easier to fit into a real company's environment.


General Settings | Operation To Operation Control | Imau Emulators Control

Execute Next Step.

Operations Status Table

TASK NAME	OPERATION NAME	RESOURCE NAME	STATUS
Screwing	Screwing	Operator 1	
Guiding Robot for position correction	Guiding Robot	Operator 1	
Reset Position	Exit Human Guide Mode	Racer Robot 1	
Reset Position	Reset Position	Racer Robot 1	
Place the Left Wheel Group	Place Left Wheel Group	Racer Robot 1	COMPLET
Place the Left Wheel Group	Enter Human Guiding Mode	Racer Robot 1	EXECUTIC

Fig. 6. Web interface of the execution control system.

The manufacturing tasks are orchestrated at operation level, which is the minimum unit of work that the manufacturing schedule can contain. A task can contain one or more operations and it is considered completed when all of its operations have been executed. There are three kinds of scenarios for the execution of tasks:

- execution of human tasks,
- execution of robot tasks, and
- execution of collaborative human–robot tasks.

The orchestration of human operations starts when the execution controller notifies the AR system that a human operation is ready to be executed. The notification is always sent to a stationary robot and the operator can start working. The AR system automatically confirms the start of the execution but the operator has to signal when an operation's execution has finished using the smartwatch. After the execution controller has been informed of an operation's completion, it will proceed with the execution of the next one. This process continues until all operations have been completed.

The orchestration of a robot's operation starts when the command is sent to the AR system to indicate the trajectory to be followed by the robot in the next operation, while the robot is instructed to start the operation, by notifying the controller. Upon receiving the command, the AR system visualizes the trajectory. During the execution of the robot's operation the operator can see the robot moving along the visualized trajectory. Finally, the robot notifies the operation's completion and the execution controller notifies the AR system to hide the trajectory visualization (Fig. 7).

The orchestration of a collaborative human–robot operation starts by first setting the robot to the collaborative mode, named "Human Guidance Mode". In that mode, the robot is loaded with a programme that allows its manipulation by the operator. When the robot confirms having entered this mode, the AR system is signalled to show the interference regions and display textual instruction in order for the operator to start the operation's execution. Upon its completion, the robot is instructed to exit the

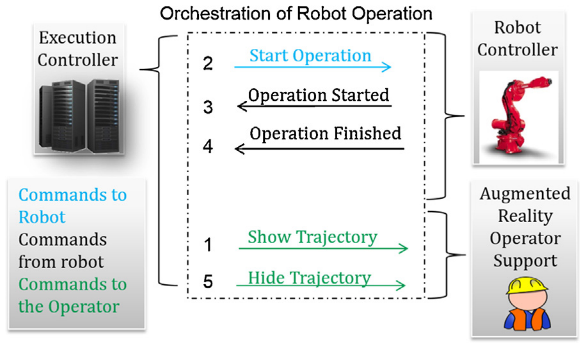


Fig. 7. Execution of robot operation sequence.

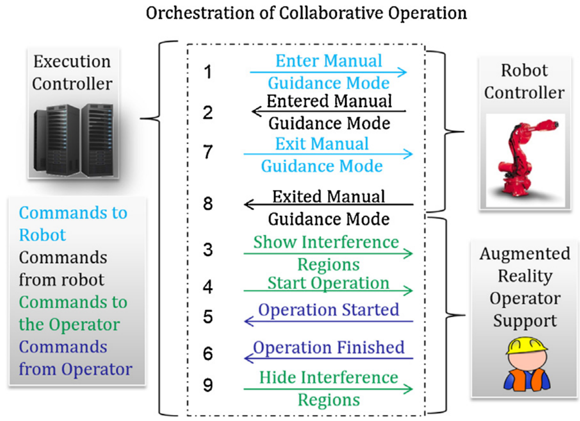


Fig. 8. Execution of collaborative operation sequence.

human guidance mode and the interference regions and the messages are hidden from the operator's field of view (Fig. 8).

The operator provides feedback to the execution system via an Android application installed on a smartwatch. This allows the operator to inform the central manufacturing system of a task's completion by the pressing of a button. This application is also connected to the Rosbridge server using the WebSocket protocol and sends/receives ROS commands. Furthermore, it allows the operator to activate/deactivate the visualization of production data information in the AR application. An overview of the different systems and their connections is shown in Fig. 9.

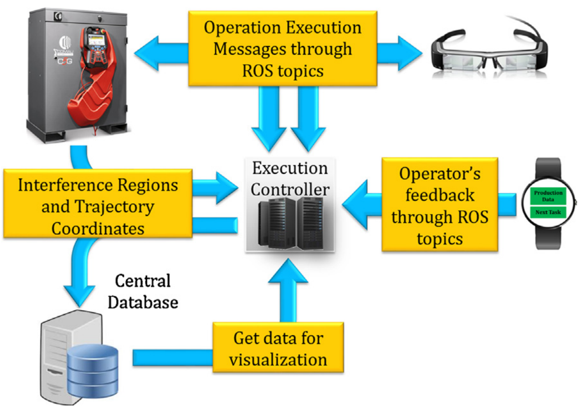


Fig. 9. System implementation.

4. Case study

The case study tested by this application derives from the automotive industry. As it is shown in Fig. 10, the application has been applied to a robotic cell, which contains a high payload robot (COMAU NJ 130), fixtures to support the parts, a car axle and a rear axle wheel group. The use of the robot is to load the axle, weighing around 25 kg, on the fixture and to load the rear wheel group, weighing around 11 kg. The operator, bare handed, adjusts the

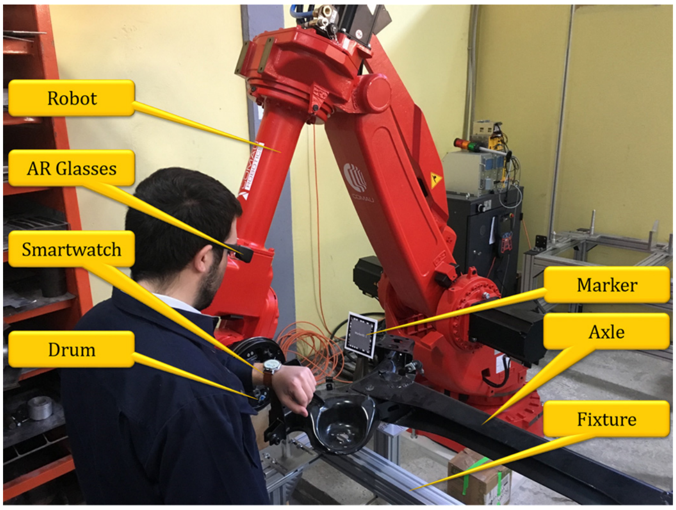


Fig. 10. The cell where the automotive scenario was tested.

parts' position and performs the assemble operations of the wheel group and the cables. Safety in the cell is implemented by the use of industrial 3D camera namely SafetyEye and following the safety principles discussed in [21].

The application minimizes, to milliseconds, the time required for the operators to access the necessary information and sends feedback to the system from their work posts. It also increases the operator's acceptance to work next to big industrial robots without safety fences. In addition to this, it decreases the stoppages and enhances the training process by offering better and more intuitive information directly to the production lines without paper signs for the provision of instructions. Lastly, the production's supervision is improved by tracking the task messages sent from the system to the operators and the robots.

5. Conclusions

The aim of this work is to develop a system helping human operators working in a hybrid, human and robot collaborative industrial environment, by providing them with immersive assembly instructions in their field of view along with production data when needed. The system should increase operators' "safety feeling" when working close to large industrial robots. An execution control system was also presented as an auxiliary to the above application. It used ROS topics and services to exchange messages with the resources. A web interface, implemented in Java, was used for the orchestration of the tasks in three different scenarios. The first was an execution of human tasks and operations, the second was execution of robot tasks and operations and the third was the execution of collaborative human–robot tasks and operations. Finally, an Android application, running on a smartwatch, was also presented and used by the operator as an input device to inform the execution control system of an operation's completion and when the operator would like to show/hide production data messages.

Further research should focus on the use of better AR glasses that meet industrial standards. In addition to this, the marker-less recognition should also be examined. This leads to better and more robust recognition since the correct visualization depends on the marker's recognition. Lastly, the extension of this application to other human–robot interaction industrial environments should be checked.

The case study demonstrated an enhanced human–robot interaction capability, enabled by the use of wearable devices, combined with data coming from the shop floor.

Acknowledgement

This research has been supported by the research project "ROBO-PARTNER – Seamless Human–Robot Cooperation for Intelligent, Flexible and Safe Operations in the Assembly Factories of the Future" (Grant Agreement: 608855) funded by the European Commission (www.robo-partner.eu).

References

[1] Chryssolouris G (2006) *Manufacturing Systems: Theory and Practice*, 2nd ed. Springer-Verlag, New York.
[2] Michalos G, Makris S, Papakostas N, Mourtzis D, Chryssolouris G (2010) Automotive Assembly Technologies Review: Challenges and Outlook for a Flexible and Adaptive Approach. *CIRP Journal of Manufacturing Science and Technology* 2(2):81–91.
[3] Eurostat's Portal on SMEs. Available from: http://ec.europa.eu/yourvoice/ebtp/consultations/2011/robotics/report_en.pdf (retrieved 15.09.14).
[4] Höllerer T, Feiner S (2004) Mobile Augmented Reality. in Karimi H, Hammad A, (Eds.) *Telegeoinformatics: Location-Based Computing Services*, Taylor & Francis Books Ltd..
[5] Milgram P, Kishino F (1994) A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information Systems* E77-D(12):1321–1329.
[6] Hakkarainen M, Woodward C, Billinghurst M (2008) Augmented Assembly Using a Mobile Phone. *Proceedings of 7th IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2008*, Cambridge, 167–168.
[7] Stutzman B, Nilsen D, Broderick T, Neubert J (2009) MARTI: Mobile Augmented Reality Tool for Industry. *Proceedings of 2009 World Congress on Computer Science and Information Engineering (CSIE2009)*, Los Angeles, USA, 425–429.
[8] Xin M, Sharlin E, Sousa MC (2008) Napkin Sketch – Handheld Mixed Reality 3D Sketching. *Proceedings of 15th ACM Symposium on Virtual Reality Software and Technology (VRST2008)*, Bordeaux, France, 223–226.
[9] Zhou F, Duh HBL, Billinghurst M (2008) Trends in Augmented Reality Tracking, Interaction and Display: A Review of Ten Years of ISMAR. *Proceeding of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, 193–202.
[10] Schmalstieg D, Langlotz T, Billinghurst M (2010) Augmented Reality 2.0. *Virtual Realities, Dagstuhl Seminar Series*, 13–37. (Chapter 2).
[11] Salzmann M, Fua P (2010) *Deformable Surface 3D Reconstruction from Monocular Images (Synthesis Lectures on Computer Vision)*, Morgon & Claypool Publishers978-1608455836.
[12] Korah T, Wither J, Tsai Y-T, Azuma R (2011) Mobile Augmented Reality at the Hollywood Walk of Fame. *Proceedings of Virtual Reality Conference (VR) IEEE*, 183–186.
[13] Pentenrieder K, Bade C, Doil F, Meier P (2007) Augmented Reality-Based Factory Planning – An Application Tailored to Industrial Needs. *IEEE and ACM International Symposium on Mixed and Augmented Reality*, 31–42.
[14] Nee AYC, Ong SK, Chryssolouris G, Mourtzis D (2012) Augmented Reality Applications in Design and Manufacturing. *CIRP Annals – Manufacturing Technology* 61(2):657–679.
[15] Ong SK, Pang Y, Nee AYC (2007) Augmented Reality Aided Assembly Design and Planning. *CIRP Annals – Manufacturing Technology* 56(1):49–52.
[16] Yuan ML, Ong SK, Nee AYC (2005) Assembly Guidance in Augmented Reality Environments Using a Virtual Interactive Tool. *Innovation in Manufacturing Systems and Technology*, .
[17] Sääski J, Salonen T, Hakkarainen M, Siltanen S, Woodward C, Lempiäinen J (2008) Integration of Design and Assembly Using Augmented Reality. Ratchev S, Koelemeijer S, (Eds.) *Micro-Assembly Technologies and Applications*, vol. 260. International Federation for Information Processing. 395–404.
[18] Makris S, Pintzos G, Rentzos L, Chryssolouris G (2013) Assembly Support Using AR Technology Based on Automatic Sequence Generation. *CIRP Annals – Manufacturing Technology* 62(1):9–12.
[19] Michalos G, Karagiannis P, Makris S, Tokçalar Ö., Chryssolouris G (2015) Augmented Reality (AR) Applications for Supporting Human–Robot Interactive Cooperation.48th CIRP Conference on Manufacturing Systems, Naples, Italy *Procedia*.
[20] Mourtzis D, Doukas M (2012) A Web-Based Virtual and Augmented Reality Platform for Supporting the Design of Personalised Products.45th CIRP Conference on Manufacturing Systems, Athens, Greece *Procedia* 234–241.
[21] Michalos G, Makris S, Tsarouchi P, Guasch T, Kontovrakis D, Chryssolouris G (2015) Design Considerations for Safe Human–Robot Collaborative Workplaces. *Procedia CIRP* 37:248–253.