Digital Assembly Assistance System in Industry 4.0 era: a Case Study with Projected Augmented Reality

Marco Simonetto[1], Mirco Peron[1], Giuseppe Fragapane[1], Fabio Sgarbossa[1]

Abstract. Automation has increased more and more in manufacturing companies over the last decades. However, manual labor is still used in a variety of complex tasks and is currently irreplaceable, especially in assembly operations. Assisting and supporting the human worker during potentially complex assembly tasks is very relevant. Clear and easy-to-read assembly instructions, error-proofing methods, and an intuitive user interface for the worker have the potential to not only reduce the cognitive workload of the operator but also increase the productivity, improve the quality, reduce defects, and consequently reduce costs. Industry 4.0 technologies, in particular Augmented Reality and motion recognition sensors, can help companies in reaching these goals. However, there are currently only a few works that show how to implement these technologies with real case studies, especially with the Projected Augmented Reality (PAR). This is the reason why, in this paper an example of prototype of a smart workstation equipped with a Kinect-projector assistance system for manual assembly is presented.

Keywords: Digitalization, Assembly, Industry 4.0, Projector, Augmented Reality, Case study

1 Introduction

In the las few years, manufacturers are dealing with an increasingly demand for customized products (1). With such a market demand, the variety of products is increasing, dictating the necessity for more flexible and adaptable assembly lines in order to be responsive to the needs of individuals (2). Zhong and Ai (3) defined assembly lines as continuous production lines, consisting of materials and workstations combined by conveyor belts, contacting workers and machines closely and efficiently . These represent the last phase of production processes and are the place where the products are customized (4).

In assembly lines activities are still performed mainly by human operators due to their characteristics like flexibility, adaptability, decision-making skills, and creativity (5). Despite these qualities, humans workers can compromise the performance of an

[1] Marco Simonetto (✉), Mirco Peron, Giuseppe Fragapane, and Fabio Sgarbossa
Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, S P Andersens V 3, 7031 Trondheim, Norway
email: marco.simonetto@ntnu.no

assembly system due to the over-workload during the execution of the different assembly tasks (6). This over-workload can be high since the assembly tasks are growing in number due to the increased products varieties and they are getting highly demanded in terms of required skills (7).

In order to help human workers to reduce their workload during the executions of assembly tasks, new solutions have started being introduced thanks to the advent of Industry 4.0. Besides their effects on the human workload, these technologies can also increase the performance of the assembly lines and the quality of the products. An example of such solutions are the Augmented Reality (AR) instructions (8). These AR instructions compared to the traditional ones, such as paper-based and computer-assisted instructions (9,10), that can be used as assistance system to guide the human workers during the execution of assembly activities seems to be very promosing (11). Augmented Reality instructions can be presented to human workers through a screen, like a smartphone (12) or a tablet (13), throug head-mounted devices, like smart glasses, or through images projected directly in the working area (14). In the paper we will refer to this last possibility as Projected Augmented Reality (PAR). Despite the high attention that AR solutions have attracted in the last years among researchers and practitioners, the majority of these works are qualitative studies. In a perspective of implementation of such solutions, it is required to understand which is their impact on the execution of assembly activities in terms of task completition time, quality and mental workload. However, very few papers present quantitative studies, especially when dealing with PAR, despite the high interest that is recently gaining among companies. To fill this gap, in this paper, we presented a case study of a prototype of PAR solution, comparing its performances in terms of task completition time, quality, and mental workload with those of paper-based and computer-assisted instructions. The remainder of this paper is structured as follows. Section 2 provides a review of the existing literature on the AR solutions used to assist human workers. Section 3 introduces our case study, while Section 4 illustrates the results obtained from the case study. Finally, in Section 5 the results are discussed and the conclusions are drwan.

2 Literature review

In this section the results of a literature review carried out using Scopus database as search engine and limiting the research from January 2005 to August 2020 and English as language. Due to the need and importance of understanding and quantifying the impact of AR solutions on assembly operations, we considered only the papers reporting quantitative results.

Värno et al. (15) used AR to present the instructions to the assembly workers through a tablet. The parameters studied during the tests are the assembly time and the errors commited during the execution of the assembly tasks. The presented prototype is compared with paper-based instructions and resulted in better performing with respect to both the parameters. Koning et al. (16) presented an AR assistance system, with smart glasses and gloves, intended to assist an inexperienced worker during a manual assembly. They validate their solution through a user test that proved that the system is suitable for assisting in the manual assembly, reducing the number of errors respect to the case where AR is not used. Moreover, it provided a learning effect to its users while also offering a positive user experience. Two experiments with 50 partecipants were conducted in (9) to compared an animated AR system and the paper-based manual system. They studied the task completion time, the number of errors and the cognitive workload. The results of the experiments revealed how the AR system yielded better performances than the paper-based manual with respect to all the three considered parameters. The same parameters were also considered by Hou, Wang and Truijens (17), where the authors investigated how much improvement in assembly productivity and performance can be achieved by lowering cognitive workload via AR. AR instructions are presented through a screen and they are confronted with isometric drawings. A prototype developed based on the Ocolus Rift platform is presented and compared to paper-based instructions in Syberfeldt et al. (14). Contrarily to other works, paper-based instructions were characterized by better feedback from the human workers resulted in lower assembly time. The authors stated that this was due to the fact that the AR solution was perceived complex by the operators. A Cognition-based interactive Augmented Reality Assembly Guidance System (CARAGS) is benchmarched against a LCD screen-based digital documentation and a traditional AR assembly guidance system in (18). After the experiments, CARAGS has been shown to be the most intuitive, easy to use, and satisfactory guidance system among the three guidance systems based on the average values. It also gives the opportunities to complete the assembly tasks in less time respect to the other two solutions. The results in (19) demonstrated how the presented AR solution provides a more mental-relaxed solution to support the operators in an assembly task. This, even if the AR solution less performed in terms of assembly time with respect to the pape-based instructions, can bring an important advantage considering the highly customized products that are demanded nowaday. Two different sets of visual features through AR, concrete AR (CAR) and abstact AR (AAR) are presented and compared with paper-based instructions in (20). The experiments showed how AAR had the highest average error rates, as well as the longest average completion time, and that the paper-based instructions obtained the best results. However, both the AR solutions help operators in being more confident in performing assembly tasks. A system with AR together with data analytics is introduced by Lai et al. (21). The experimental results showed how this system, compared to the paper-based instructions, can reduce the assembly completion time and the number of errors committed during the assembly activities. Performance, ease of use and acceptance of two AR-based methods (mobile and spatial AR), are compared in (22). The results of the experiments demonstrated how participants were faster and made fewer error using the spatial AR solution. This solution gave the opportunity to project the assembly information of a puzzle directly on the workplace where the assembly activities were executed. The findings of Vanneste et al. (23) suggested that projection-based AR has the potential to cognitively support operators during assembly tasks and can hence contribute to better quality, a lower stress level, a higher degree of independence and a lower perceived complexity. A work with projection-based AR is presented in (24). Their tests indicate that this system is perceived as more helpful and more engaging compared with a similar system using AR smart glasses or an assembly station without assistance. However, they do not show any numerical results that demonstrate their results. Two examples of projected AR solutions to help impaired workers are introduced in (25,26). In both, the authors compared different solutions and showed how AR is able to help the impaired workers during the executions of the assembly tasks.

From the literature it emerges two facts. Fisrt, that AR instructions can be beneficial for the performance of an assembly line, and, second, that PAR solutions are scarcely investigated with quantitative studies. PAR can overcome the other AR instructions performances for example giving the opportunity to the human workers to not wear, or grab, any kind of devices to perform the assembly activities. These devices, like the smart glasses for example, can be uncomfortable and can create blind spots even for people that wear glasses daily (7). These reasons move us to create in the Logistic4.0 Lab the prototype of a smart workstation equipped with a Kinect-projector assistance system for manual assembly presented, with a case study, in the next chapter.

3 Case study description

To assess the potential of the assembly assistance system in terms of productivity and mental workload of the workers, the Logistics 4.0 Laboratory at the Department of Mechanical and Industrial Engineering at the Norwegian University of Science and Technology developed a smart assembly workstation. The smart assembly workstation consists of a Kinect-camera, motion recognition software, work-instruction program and a projector. While the cameras of the Kinect and the motion recognition software track the movement and trigger action in the work-instruction program, the projector can visualize neccessary information for the worker to pick and assemble a product (Figure1). This innovative, assistive work assembly process can be classiffied as Projected Augmented Reality (PAR). In most production environments paper-based manuals and workplace-mounted monitors provide work instructions. Therefore, the PAR was compared to paper-based and computer-assisted instruction method in times of productivity and and mental workload.

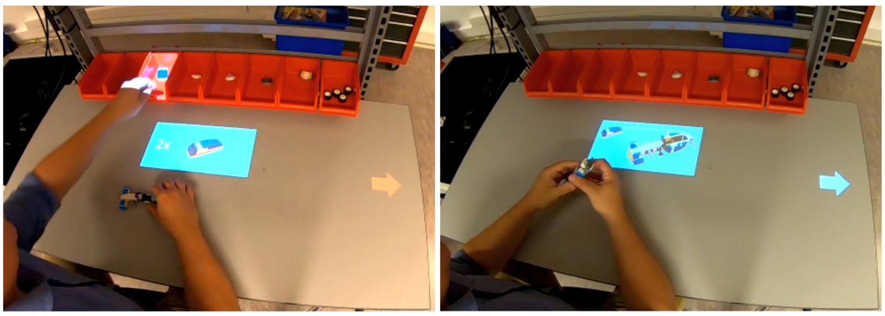

Fig. 1 The smart workstation with Projected Augmented Reality

The test population consisted of 15 participants, who carried out a series of assembly tests with different workstation configuration in the Logistics 4.0 Laboratory. The participants must assemble a LEGO model following the provided assembly information.

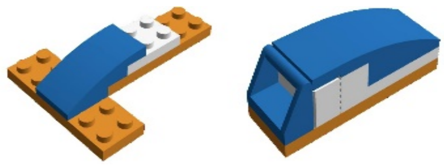

Fig. 2. The Front wing (on the left) and the Side pod (on the right)

In this paper, due to pages restriction, we are going to show only the results obtained from the assembly of two components (Front wing and Side pod, Figure 2) of a LEGO product These two components are characterized by different degrees of complexity: the Front wing has a lower degree of complexity (3 different parts, 4 work steps), while the Side pod has a higher degree of complexity (8 different parts, 8 work steps).

4 Results

In the experiment, we the first measured the time for completing the assembly tasks and the number of errors performed during the assembly. The results allowed to assess the performance and accuracy of the assistance system prototype. In the second part, after completing the assembly tests at the smart workstation, were asked to the particpants of the experiment to fill out an questionnaire.

The computer-assisted instructions achieved the best results in the Task Completion Times compared to the other alternatives (see Figure 3, left). The "Front wing" was assembled in 29.98 seconds with SD = 5.35 seconds and the "Side pod" in 46.19 seconds with SD of 6.79 seconds.

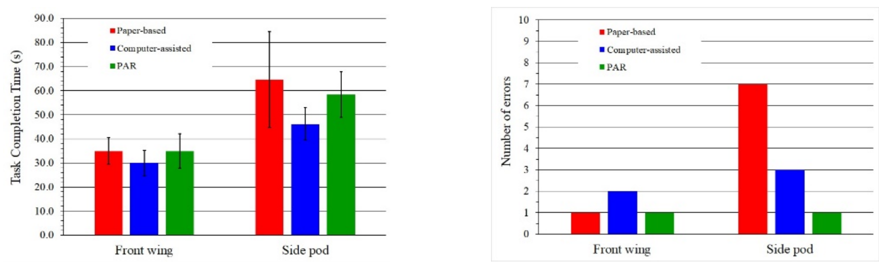

Fig. 3 Task Completition Time (left) and number of errors (right) of the the two assembled components

The quality of the assembly activities were measured by counting the number of assembly and picking errors (see Figure 3, right). The results show that the PAR system can reduce the possibility of committed errors during the especially for the more complex assembly task of the "Side pod".

The mental workload was measured thanks to the compilationof a simplified NASA-TLX questionnaire. The questionnaire asked the participants to give feedback on perceived enjoyment, frustration, perceived ease of use, effort, and mental demand for each work instruction method. The PAR system obtained the overall best resultsand scored especially high in perceived enjoinment (86.7%) and ease of use (86%).

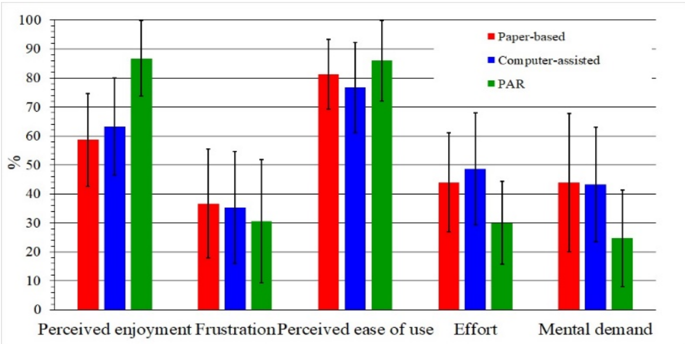

Fig. 4 Simplified NASA-TLX

5 Discussion and conclusion

In this paper, a prototype of a PAR system has been developed in order to quantify the benefits that an assembly line can obtain from its implementation. The results of the case study suggest that a PAR assistance system has several advantages over the paper-based and computers-assisted methods. Although PAR did not lead to the lowest Tasks Completion Time, Figure 3, the use of this solution can still be beneficial in situations where workers have to wear gloves or they have to use tools during the execution of the assembly tasks since with PAR they do not have to drag their finger on a touch screen or to move paper pages in order to move to the next assembly task. These operations can be problematic when workers have to wear gloves or they have to use tools during the execution of the assembly tasks. The PAR system can guarantee a higher quality of the final products since the numbers of mistakes maded by the human workers are lower, Figure 3. This means fewer products that need to be reassembled with a saving in time and money. Moreover, the results from the questionnaires showed how a PAR systems leads workers to do their work with less effort then the other two solutions, Figure 4. In such a way, workers' health can be preserved resulting in a higher productivity thanks to the reduced absenteeism related to sickness leaves.

Despite the just mentioned advantages, our solution is limited by some limitations, such as the inability to detect the correctness of the assembly operations. Another limitation that hinders our PAR from being the fastest solution is the fact that each task after being executes need to be confirmed, since there is not a system that can detect the execution of the assembly process step by step and understand when a task is over and the next has to start.

However, despite the two mentioned limitations that need to be solved in the future development of the system, the benefits provided by the PAR system are several. In order to study in more detail these benefits, as possible future work, our solutions can be tested in a real industry case study. Another future work can be the study of our solution in a business case point of view, comparing, for example, the costs of its implementation and maintenance with the same costs of the other two studied solutions in the case study (paper-based and computer-assisted instructions).

References

1. Battaïa O, Otto A, Sgarbossa F, Pesch E. Future trends in management and operation of assembly systems: from customized assembly systems to cyber-physical systems. Omega (United Kingdom). 2018;78:1–4.
2. Hu SJ, Ko J, Weyand L, Elmaraghy HA, Lien TK, Koren Y, et al. Assembly system design and operations for product variety. CIRP Ann - Manuf Technol. 2011;60(2):715–33.
3. Zhong Y guang, Ai B. A modified ant colony optimization algorithm for multi-objective assembly line balancing. Soft Comput. 2017;21(22):6881–94.
4. Akpinar S, Elmi A, Bektaş T. Combinatorial Benders cuts for assembly line balancing problems with setups. Eur J Oper Res. 2017;259(2):527–37.
5. Michalos G, Makris S, Spiliotopoulos J, Misios I, Tsarouchi P, Chryssolouris G. ROBO-PARTNER: Seamless human-robot cooperation for intelligent, flexible and safe operations in the assembly factories of the future. Procedia CIRP [Internet]. 2014;23(C):71–6. Available from: http://dx.doi.org/10.1016/j.procir.2014.10.079
6. Battini D, Calzavara M, Otto A, Sgarbossa F. Preventing ergonomic risks with integrated planning on assembly line balancing and parts feeding. Int J Prod Res [Internet]. 2017;55(24):7452–72. Available from: https://doi.org/10.1080/00207543.2017.1363427
7. Joundi J, Conradie P, van Den Bergh J, Saldien J. Understanding and exploring operator needs in mixed model assembly. CEUR Workshop Proc. 2019;2503:130–8.
8. Ong SK, Yuan ML, Nee AYC. Augmented reality applications in manufacturing: A survey. Int J Prod Res. 2008;46(10):2707–42.
9. Hou L, Wang X, Bernold L, Love PED. Using animated augmented reality to cognitively guide assembly. J Comput Civ Eng. 2013;27(5):439–51.
10. Watson G, Curran R, Butterfield J, Craig C. The effect of using animated work instructions over text and static graphics when performing a small scale engineering assembly. Collab Prod Serv Life Cycle Manag a Sustain World - Proc 15th ISPE Int Conf Concurr Eng CE 2008. 2008;44(0):541–50.
11. Van Krevelen DWF, Poelman R. A Survey of Augmented Reality Technologies, Applications and Limitations. Int J Virtual Real. 2010;9(2):1–20.
12. Bagamaspad AM, Caingles JI, Koa KA, Simeon JL, Ruiz C. A mobile augmented reality-based assembly guidance application for LEGO. MCCSIS 2018 - Multi Conf Comput Sci Inf Syst Proc Int Conf Interfaces Hum Comput Interact 2018, Game Entertain Technol 2018 Comput Graph Vis Comp. 2018;2018-July:237–44.
13. Servan J, Mas F, Menéndez JL, Ríos J. Assembly work instruction deployment using augmented reality. Key Eng Mater. 2012;502(February):25–30.

14. Syberfeldt A, Danielsson O, Holm M, Wang L. Visual Assembling Guidance Using Augmented Reality. Procedia Manuf [Internet]. 2015;1:98–109. Available from: http://dx.doi.org/10.1016/j.promfg.2015.09.068
15. Värno K, Mahmood K, Otto T, Kuts V. Development of a smart workstation by using ar technology. Ann DAAAM Proc Int DAAAM Symp. 2019;30(1):1061–7.
16. Konig M, Stadlmaier M, Rusch T, Sochor R, Merkel L, Braunreuther S, et al. MA2RA - Manual Assembly Augmented Reality Assistant. IEEE Int Conf Ind Eng Eng Manag. 2019;501–5.
17. Hou L, Wang X, Truijens M. Using augmented reality to facilitate piping assembly: An experiment-based evaluation. J Comput Civ Eng. 2015;29(1):1–12.
18. Wang X, Ong SK, Nee AYC. Multi-modal augmented-reality assembly guidance based on bare-hand interface. Adv Eng Informatics [Internet]. 2016;30(3):406–21. Available from: http://dx.doi.org/10.1016/j.aei.2016.05.004
19. Mourtzis D, Zogopoulos V, Xanthi F. Augmented reality application to support the assembly of highly customized products and to adapt to production re-scheduling. Int J Adv Manuf Technol. 2019;105(9):3899–910.
20. Radkowski R, Herrema J, Oliver J. Augmented Reality-Based Manual Assembly Support With Visual Features for Different Degrees of Difficulty. Int J Hum Comput Interact [Internet]. 2015;31(5):337–49. Available from: http://dx.doi.org/10.1080/10447318.2014.994194
21. Lai ZH, Tao W, Leu MC, Yin Z. Smart augmented reality instructional system for mechanical assembly towards worker-centered intelligent manufacturing. J Manuf Syst [Internet]. 2020;55(July 2019):69–81. Available from: https://doi.org/10.1016/j.jmsy.2020.02.010
22. Alves J, Marques B, Oliveira M, Araújo T, Dias P, Santos BS. Comparing Spatial and Mobile Augmented Reality for Guiding Assembling Procedures with Task Validation. 19th IEEE Int Conf Auton Robot Syst Compet ICARSC 2019. 2019;
23. Vanneste P, Huang Y, Park JY, Cornillie F, Decloedt B, Van den Noortgate W. Cognitive support for assembly operations by means of augmented reality: an exploratory study. Int J Hum Comput Stud [Internet]. 2020;143(October 2019):102480. Available from: https://doi.org/10.1016/j.ijhcs.2020.102480
24. Büttner S, Sand O, Röcker C. Extending the design space in industrial manufacturing through mobile projection. MobileHCI 2015 - Proc 17th Int Conf Human-Computer Interact with Mob Devices Serv Adjun. 2015;1130–3.
25. Korn O, Schmidt A, Hörz T. Augmented manufacturing: A study with impaired persons on assistive systems using in-situ projection. ACM Int Conf Proceeding Ser. 2013;
26. Funk M, Bächler A, Bächler L, Korn O, Krieger C, Heidenreich T, et al. Comparing projected in-situ feedback at the manual assembly workplace with impaired workers. 8th ACM Int Conf PErvasive Technol Relat to Assist Environ PETRA 2015 - Proc. 2015;