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Survey: The Evolution of the Usage of Augmented Reality in Industry 4.0

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Abstract. The usage of Augmented Reality (AR) in industrial and modern manufacturing is more and more growing since the fourth industrial revolution. Using AR boost the digitization of the industrial production lines, gain time and money and improve maintenance tasks as well as the human-machine interaction. This paper is a literature review of the use of AR in industries including the use cases in different type of application such as design, simulation, maintenance, remote assistance, human-robot interaction and robot programming.

1. Introduction

Nowadays, the industrial landscape is being transformed its fourth revolution thanks to the rise of the internet of things, collaborative/autonomous robots, cyber-physical systems, internet of services. This transformation, also known as Industry 4.0, is the new area where the internet of things interconnects with cyber-physical systems. It makes a mixture of software, sensor, processor and communication technologies. Thus, it plays a huge role in making objects able to feed information into the network and eventually adds value to manufacturing processes. Industry 4.0 ultimately aims to construct an open and smart manufacturing platform for industrial-networked information applications based on a range of technologies cited in Figure 1. This concept is best described as ”smart factory” which aims to merge virtual and real worlds together [2].

Industrial robots play an important role in the Industry 4.0. They have been involved considerably in the last decades. They are becoming more collaborative, productive, flexible, safer, and versatile and they have a huge capability to interact with each other and work safely side by side with humans. Programming industrial robots in large manufacturing, as well as small and medium-sized enterprises, requires a lot of time. Thus, a new method of programming industrial robots that came out with this revolution is Augmented Reality (AR).

AR is a way of transforming and visualizing digital information as pictures or videos. AR has been used for industrial tasks for more than 20 years [3], e.g. it can be used only for visualization of information or even for interaction. With the last few years, AR was involved widely in different fields and activities.

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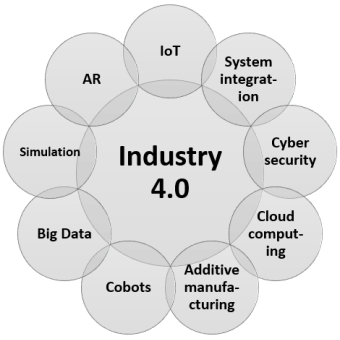


Figure 1. Technologies related to industry 4.0 [1].

Notably, it is being involved in education by enhancing the student's motivation to learn [4] and training teachers to become more effective [5]. It also boosts the digitization of the industry production lines or maintenance tasks [6, 7].
This paper reviewed AR-based industrial applications that appears alongside the fourth industrial revolution such as maintenance, assembly, remote assistance as well as human-robot interaction and robot programming. It is organized as follows. Section 2 is about the general usage of AR in industry 4.0 including the definition of AR and the selection criteria. Section 3 summarizes the usage of AR for visualization applications such as simulation, design, maintenance, assembly and disassembly. Section 4 discussed remote communication usage such as remote assistance and remote maintenance. Section 5 analyzed AR usage for robotics: human-robot interaction (HRI), robot manipulation and robot path planning. Finally, the conclusion in section 6.

2. Usage of Augmented Reality in industry 4.0

All along the appearance of industry 4.0, digitalization and smart factories, many manufacturers start exploring the benefits that AR can offer in a smart industrial environment.
AR is the integration of virtual objects in the real world [8]. Therefore, it enhances the reality by appearing virtual objects alongside the real ones. Professor Paul Milgram is the first who introduced the concept of the reality-virtuality. Mixed Reality Continuum, shown in Figure 2., is a one-dimensional array between the Real and the Virtual Environments [9].



Figure 2. Milgrams Mixed Reality Continuum [9].

After that, as a compliment of Milgram's Mixed Reality, Mann [10] presented the concept of Mediated Reality shown in Fig. 3 for modifying the real view instead of just adding to it.

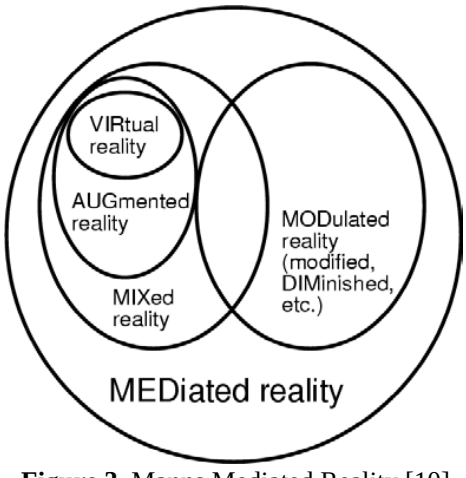


Figure 3. Manns Mediated Reality [10].

2.1 Selection criteria

This review includes the recent projects that used AR in industry 4.0. In the last period, the usage of AR in the smart factories has involved and took a different kind of interventions. Before 2014, most of the use cases of AR was for data visualization either to assist the employees [11] or to improve maintenance tasks [12]. After that, it was developed to assist employees thanks to the remote assistance and/or maintenance [13]. Furthermore, it starts to be used for the human-robot interaction [14] and collaboration, robot programming [15] and robot trajectories planning [8]. Figure 4. illustrates how AR is being implemented in industry 4.0 based on analyzing most of the projects realized since 2012.

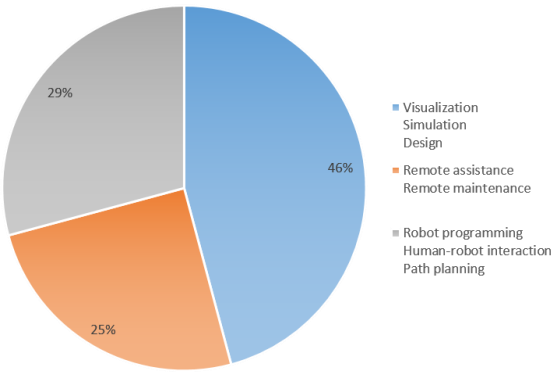


Figure 4. AR implementation in industry 4.0.

3. Visualization usage

3.1. Data visualization, simulation and design

Data displaying and simulation is one of the basic application of AR in general and in manufacturing in special. As its name said, it is just projection of information from a database to a user interface for different usage.

In 2012 A. Nee sited in [16] a list of design applications using AR in addition to some other industrial applications and then a year after, J. Novak-Marcincin [11] suggested a similar model that enables a user to visualize information related to the manufacturing process, additional text and acoustic information related to the work environment, conditions and objects.

In 2014, HC Fang presented in [14] an HRI AR-based interface that aims to assist users when interacting with a virtual robot in a real work environment. He adopted for that an AR Tool Kit-based hand-held device tracking method which was a marker-cube attached with a probe and virtual robot registration. It allows users to interact with spatial information of the working environment. It can be used to guide the virtual robot to intervene in the path planning and end-effector (EE) orientation planning processes. The actual working environment, the virtual robot model, the trajectory information, as well as the interaction processes are visualized through a monitor-based display. In the same year, V. Paelke also presented a similar application [17].

Another concrete system was presented in [18] in the same year. Lofvendah worked together with ABB to build an android application that displays an ABB industrial robots SafeMove coordinates using AR [19]. It was designed to help engineers verify the SafeMove settings. First, a user enters the coordinates in SafeMove that will create an area and then create its virtual model. Then, they need to track the robot in order to place the virtual model of the safety zone. They placed several fiducial markers[20] around the real robot to know where to place the model. A function was added to allow the adjustment of the safety zone. Next, a calibration is required to integrate the virtual model with the real one. Finally, the last communication between the robot and the application is needed. To use the application, a user have to hold a tablet and point it towards a robot then he will see on the screen the augmented objects with the virtual safety zone as well as the possible movements and reachable areas of the robot. In the end, they tested their application with ABB employees. They faced a problem by holding the device all the time. Thus a solution was based on replacing the tablet with a wearable device such an AR head-mounted device.

In [21], an AR interactive space has been presented in 2015 in Italy. It aims to visualize and interact with virtual objects and models.

In the same context, a CNC aid machine was developed by J. Chardonnet based on AR [22] in 2017. It projects on a tablet or wearable device personalized information about process status and a real-time 3D simulation of the machine. S. Suto [23] has presented in the same year an AR-based simulation application for human-robot collaboration. His main idea is to digitize the human gestures using a Kinect sensor to simulate the collision in the virtual space in order to avoid it in the real one. Furthermore, it is also able to generate a collision-free trajectory for the robot.

As a common application, D. Mourtzis [24] has developed recently an AR-based computer aided manufacturing system that delivers informative texts, safety zones in the area, step-by-step instructions and some other indications as shown in Figure 5.

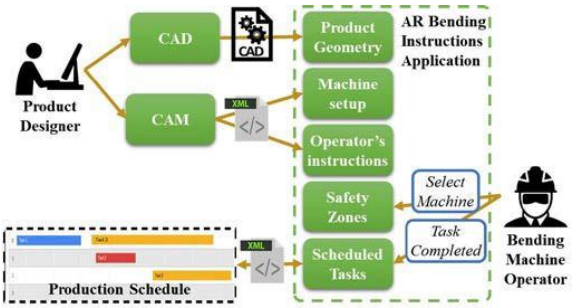


Figure 5. The architecture of Mourtzis's proposed approach [24].

This system promotes the efficiency of considering and resolving appearing problems.

A design and touch-based interaction interface was pre- sented also in 2018 in [25] to enhance the human-machine interaction. The prototype enables users to design their own object's shapes and products to be transferred to a G-code and then printed.

This application, as well as all presented prototypes and systems, prove the performance of this technology on making the simulation of models, visualization of virtual objects and the interaction with them as easy as it is real.

3.2 Maintenance

Maintenance counts around 60 to 70 % from the core activity of the production life-cycle [12]. Since unexpected machine breakdown could be time-consuming and this can directly influence the productivity, AR has arisen as an enabling technology for handling the increasingly complex maintenance processes.

R. Palmarini [26] has distinguished in his systematic literature review (SLR) several implementations of AR in maintenance applications. Figure 6. represents the fields of the application being used AR in maintenance throughout 30 studies. Dini [27] also came out with the same results. The mechanical field is the highest area of application, as mentioned in Figure below, and it includes the maintenance activities in different sectors such as aviation, automotive and military... In the same SLR, Palmarini has mentioned as well the percentage of the maintenance operations which are: 33% of dis-assembly and assembly operations, 26% repair activities, 26% Inspection and diagnosis and 15% training operations.

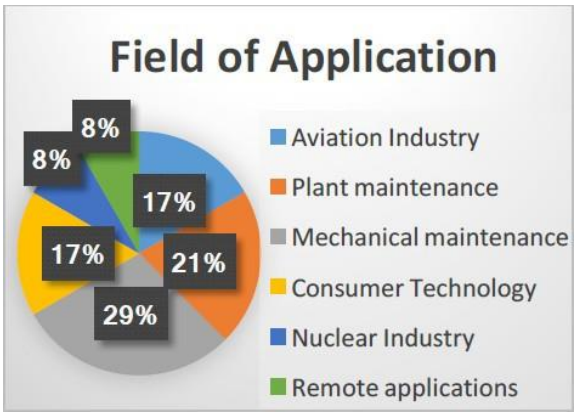


Figure 6. Field of application of AR for maintenance reported by R. Palmarini [26].

Later, he presented an AR-based method for maintenance [28]. His innovative system aims to support the maintenance tasks by guiding the employee to determine the requirements and the constraints for every different operation. The method is to develop a list of questions that helps for the point directly on the problem.
Webel defines training as the process that aims to transfer maintenance skills to technicians [29]. He developed a novel method for multimodal AR-based training of maintenance skills.
Mourtzis proposed in [30] a Product-Service System platform for tele-maintenance support using AR. This platform enables technicians and manufacturer experts to communicate maintenance instructions and exchange data and feedback reports. Figure 7. details the proposed architecture of this solution. It is composed by three steps that are executed every time which are:(i) malfunction report composition, (ii) diagnosis and AR maintenance instruction generation and, (iii) mainte- nance and evaluation. First, the system registers a report of the set of features for a scheduled maintenance or unexpected malfunction and then send it to the maintenance support provider. After viewing the report, it creates an enhanced failure report containing a cloud-based feedback mechanism to be sent to the manufacturer in a short time. If needed, the expert assists the technicians by giving them AR instructions. The hardware design of their system uses three main devices: a set of optical see-through Augmented Reality goggles, a laptop PC and a mobile device [31].

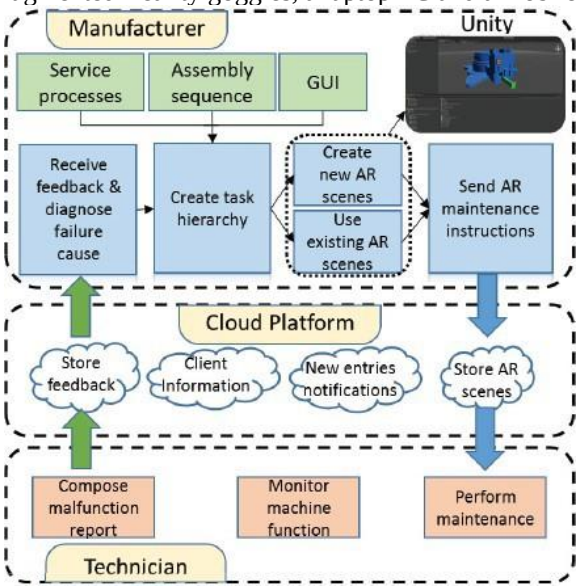


Figure 7. Architecture of the developed solution by Mourtzis.

For a hand-free vision system, they used as an AR head-mounted device. Then, the computer is the element responsible for executing the AR application and the communication handler. The third element is the mobile device that considers the interface of communication between the operator and the AR application.
Many examples and utilization of AR in maintenance could be pointed out. Previous literature [32-34] cited different applications of maintenance and repair tasks. All previous research and industrial projects prove the same result that the AR usage in maintenance reduce the machine breakdown time and improve the employee's abilities to fix and point faster on the problem.

3.3 Assembly/Dis-assembly
Assembly and/or disassembly are unavoidable and critical processes for any product's lifecycle. X. Wang [35] has published a very detailed review of AR assembly research. He defined assembly as the operation of grouping altogether some parts in order to form the desired product with good added value. Furthermore, he explained how AR resolved the two major problems in the assembly which are: 1) users need to identify technical specifications and constraints such as the mating surfaces, axes and edges which could be a very complex task, 2) 3D software does not help the user to interact directly with the parts neither manually manipulate them. However, AR came up to build up a pragmatic synergy between the user and the product by merging all together augmented and real objects along with making the manipulation of the pieces possible.
ARDIS is an AR-guided application for products dis-assembly proposed by M.Chang [36]. ARDIS generates the information automatically without any external/human intervention. Therefore, it makes the disassembly

process more intuitive and efficient. It proves that this application has a big impact on the re-manufacturing operation as well.
MotionEAP [37] is another AR industrial assembly interface developed in Germany. MotionEAP has many capabilities and options such as 1) It projects the instructions to the workers as well as all the steps, 2) It recognizes the worker's activities and the actual assembly step and 3) It is able to give visual feedback at different levels.
Another German AR assembly interface proposed by C.Kollatsch [31] and shown in Figure 8.

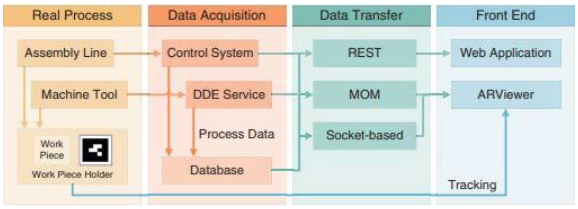


Figure 8. The monitoring concept of the AR-assembly applica- tion proposed Kollatsch [31].

It consists mainly of 4 stages. First, it starts from the real assembly line and real objects for the process data acquisition. After that, the system gathers all parts information and details to be first transferred and then stored in a database. Finally, is to project the necessary assistance to the user to accomplish the assembly operation. Kollatsch chose an Android device for the visualization of his assembly application. Most of the interviewed workers gave positive feedback for using such application during the assembly process.
Recently, Danielsson [38] has a similar approach but he replaced the handheld device by an AR head-mounted device that is an AR-glasses. In his work, he presented the results of the user's interview regarding the usage of this technology in an automotive assembly.
All presented AR-based systems offer assistance to the users all along of an assembly or disassembly process. It presents the proper information of an assembly process and step-by-step approach of the operation.

4. Remote assistance usage

The remote assistance, frequently called see-what-I-see remote cooperation, is the ability to hook up with an expert on-site anytime and anywhere. Whenever an urgent issue or complicated problem appears, workers in the workplace can easily connect with expertise from outside for a quick diagnose. This kind of AR application is a real-time shared interface in both sides.
Maintenance tasks in factories are very critical and though, thus they require fast and efficient interventions. D. Mourtzis [13] and M. Fiorentino [39] has roughly presented remote maintenance using AR. Then, Fiorentino made an evaluation of the efficiency of this aspect.
Almost alike, the ACAAR system presented in [40] enables a user to add digital information such as texts, pictures or computer-aided design (CAD) models. Furthermore, it can explain the contents regarding the required maintenance tasks.
F. Ferrise suggested in [41] an AR application for remote maintenance. It aims to enable the connection of an expert situated in a control room with an ordinary technician located on the promises.

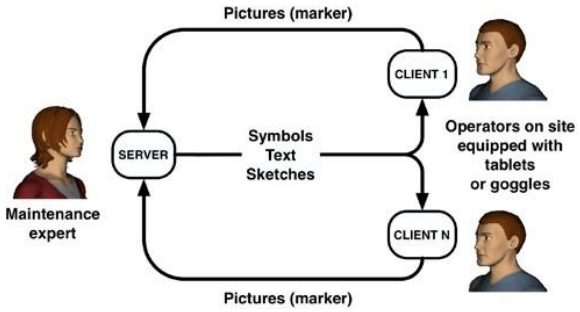


Figure 9. The system proposed by F. Ferrise [41].

The system presented in Figure 9. starts when one or more operator(s), called also a client, send pictures of the real scene to the expert, called server.

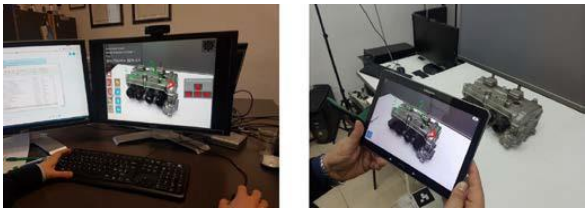


Figure 10. Real exemple of the system proposed by F. Ferrise [41].

As shown in the example in Figure 10., the expert indicates what and where the problem is by using symbols, text and some information.
In [42], a worker bears an AR device that records a real-time video stream of what he sees in addition to other data such as sensor information. The video has to be sent to an expert from outside and he can give an exact solution with additional information on real time, so he doesn't need to move to the factory to fix the problem.
It is been proved by all previous applications and industrial agents who tested this technology in their labs, that remote assistance reduced the machine downtime, saved money as well as time.

5. Robot programming usage

Programming industrial robots methods are increasing day after day in order to make it easier, faster and cheaper. Z. Pan detailed in his review in [15] the different programming methods for industrial robots. He discussed two of traditional programming methods: Online and Offline robot programming (OLP). During an online programming, the robot operator moves the robot manually to execute simple tasks. It's an efficient method but over-time it could not handle complex programs. OLP generates the programs using 3D CAD models. The operator can check and simulate the program before downloading it to the real robot such as safety zones, reachability and movements... it is even possible to use additional sensors in OLP. This method is more complex than the online programming and it requires more qualified engineers and more time. Recently, AR starts to be used for making robot programming that easy that any non-expert robot programmer would be able to setup any industrial application.
The main usage of AR on robot programming are HRI, robot manipulation and path/trajectory planning.

5.1 Human-Robot Interaction (HRI)

Industry 4.0 came up with the revolution of the human-robot collaboration and introduced collaborative robots where humans and robots work alongside together and also called "cobots". The cobots are becoming more adaptive and aware of their collaborators. This has come up with the research about the interaction and collaboration process. One of the most suggested and successful technologies was AR. It was used as: an interface for visualization and interaction like in [14], a third point of view for robot intentions visualizations as presented in [43], an application to support the HRI and cooperation such in [44] and [45], a teach pendant interface as defined in [46], or an interface for guiding users throughout an unfamiliar assembly operation just as demonstrated in [47].
Maly had an evaluation of the usage of AR interfaces for the human-robot interaction in [48]. After he developed an AR application for industrial robot visualization, highlighting parts of the robot and safe zone detection, he made an evaluation for his prototype. Six participants engaged in operating the system's features. All of them were satisfied with the data visualization and well confirmed that the hand gestures were fast except some gestures were not correctly detected which means the prototype wasn't 100% successful.
This section illustrated some AR-based HRI dedicated for visualization and human-robot collaboration operations but these are not its only application for robots. Recently, it started to be used for more than the only visualization but for robot programming as well.

5.2 Robot manipulation

The technological revolution aims to make objects more intelligent, thus human can easily communicate and deal with them. Using AR for robot manipulation is also aiming to make the human-robot interaction more easy even for non-expert operators and without the need of losing a lot of time in practicing how to move or to manipulate a robot especially with the important increase of numbers of cobots in factories. In 2016, Chryssolouris has proposed in [49] a robot programming method for robot manipulation using only body and hand gestures and without using any programming language.
The architecture of the system presented in Figure 11. lay-out the method used in this application.

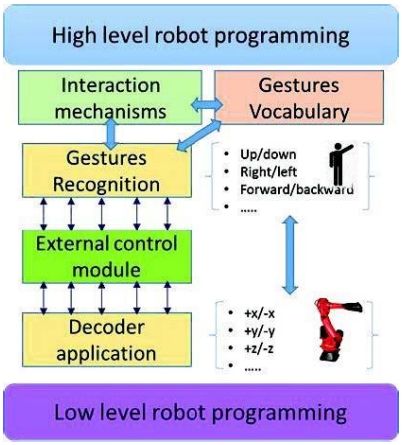


Figure 11. The system architecture proposed in [49].

The high-level robot programming is reached by using commands in the form of body and hand gestures vocabulary tracked by the intermediate of external device or sensors. The predefined gestures enable the user to control the robot movement on the 3 axis x, y and z. As an example, to move the robot on the direction +x, the user has to extend his right hand upwards and hold the left down. To move along the y-direction, the operator has to extend the right hand at the height of his shoulder and points to the left side. In the same year, another similar system was proposed in [50]. The idea is about an AR handheld device presenting a task-based interface for the robot control. They tested this approach with 19 industrial robot programmers where they confirm that it effectively reduced the mental demand of the programmers during the programming operation as well as required time.
A year after, L.Wang [51] worked on an application that virtually augments robot assembly commands and instructions. R.Matarneh [52] developed a voice control method for robotic assembly process models.
Recently in 2018, J.Wassermann [53] presented a com- pletely new approach which aims to manipulate a robot based on a cloud system. The main program generates the control instructions and then the AR simulation and the collision detection being created.
AR technology gave a lot of powerful features that assists un-expert workers during a robot programming tasks. Furthermore, it decreases the error risk during programming and increases the instructions' efficiency.

5.3 Path planning
Collaborative robot operations require a high level of accuracy and precision for paths and trajectory planning. One of the most difficult problems when programming a collaborative robot using AR technology is the teleoperation of the robot hence planning the robot's path [8]. The first proposed research in path planning and end-effector orientation using AR was in Singapore in 2012 [54]. The suggested approach, shown in Fig. 12, aims to create a path from a series of collision- free-volume (CFV). Then the path is optimized throughout a convex optimization method in order to get the best time- trajectory. Finally, a virtual robot and the planned trajectory are being simulated.

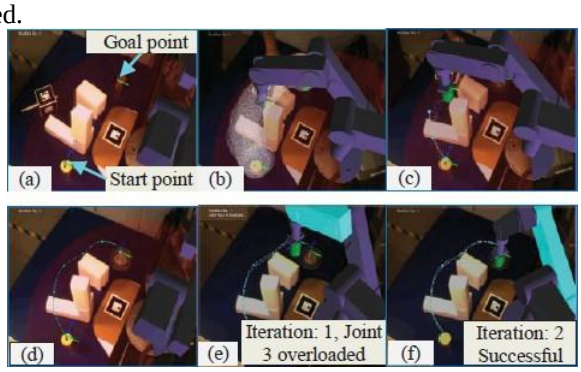


Figure 12. A case study of the proposed approach. (a) Task setup; (b) CFV generation; (c) Creation of control points; (d) Geometric path generation; (e) Trajectory simulation: unsuccessful trial; (f) Successful trajectory simulation.

Researchers tested this method for a pick and place task, as shown in Figure 12. (e) and (d), but this work is for virtual robots and not real ones.
Two years later, in 2014, the same research group presented a Euclidean distance-based method [55].

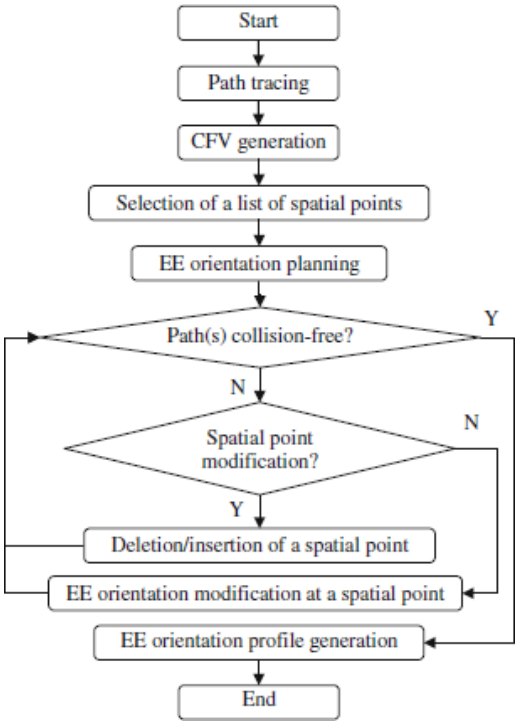


Figure 13. Procedures for the proposed AR-based path following operation [55].

Figure 13. illustrates the use of the CFV method in the suggested approach. First, a virtual sphere and a CFV area are created by recording the movement of the interaction device. Then, a parametric trajectory is being recorded by moving the interaction device. Later, the Euclidean distance-based method is used to the point of interest from the spatial points forming a collision-free trajectory. When the robot path is generated, the CFV verify if the EE of the robot still along the CFV during the movement. This approach gives also the possibility to get a collision-free trajectory for all the kinematic system of the robot. The experiment results of this approach for a pick-and-place task approve its benefits as a teach-in method and that it offers a bigger accuracy.
The next AR-based robot path planning was suggested in 2016 by C. Chu [56]. The proposed method aims to promote the robot path planning using AR for programming by a demonstration. First, the real objects are captured, analyzed and processed throughout an external vision device. Then, the results are combined with provided virtual objects. Last, the system launches a real-time visual information when detecting collision with an obstacle or an object.
In 2017, M. Tessarotto [57] presented an industrial robot path planning using AR. This method was especially focused on AR for offline more than online programming and, as all AR- based robot programming and path planning methods, it makes it feasible and easy even for inexpert operators. Record the trajectory is the first step of this method. An operator records the trajectory via the software interface or by an HTC Vives controller for an online robot programming. After recording the trajectory, it could be virtually displayed and modified throughout the program. The possible modifications are: ”Distance filtering” that removes some points from the trajectory to smooth out the movements, ”Flattening” to change every point of the path to smooth it itself, ”Offset” to move a trajectory in order to be used in different context and ”Only reachable” that enables the specification of whether the trajectory must contain all the points or to exclude the points not reachable by the robot. Later, a series of ’position/time’ or ’position/speed’ trajectory forms couples are required in order to create the robot program to be sent to the controller.
Recently in 2018, the ”ARTool Zero” framework [58] was presented to support users during a trajectory planning. It also enables the generation as well as the simulation of the part- program that guides a touching

probe to identify the necessary geometric features. ARTool Zero displays the coordinates throughout a mobile device to the machine using markers that aims to convert the 2D plane into a 3D plane in the space.
Most of the existing robot path planning methods are time-consuming and may require sophisticated software tools which means expert engineers to develop the programs. New user- friendly AR-based path planning features are making this operation easier and possible for even inexpert workers. The majority of the presented works use AR for visualization of the suggested paths and collision-free trajectories. Quite a few, but increasing, number of AR-based path planning programs that allow efficiently and easily program trajectories all-alongside simple human intervention.

6. Conclusion

This literature review discusses the evolution of the use of AR in industrial factories since 2012. Based on the projects presented in this paper, several areas of applications were using AR technology. However, the type of utilization was evolving over time. At the outset, almost all the applications were for data visualization including simulation and design which means visualization of 3D products or special information related to real objects. Then it was used to support workers during maintenance operations or assembly/dis-assembly where the AR system displays assistant information generated by the system itself. In the meanwhile, remote assistance operations have appeared to remotely assist technicians on site by expert engineers located far from the factory. Remote assistance is used mainly for maintenance tasks and unexpected machine breakdown. Besides, along with the increasingly existence of collaborative robots, AR is being used for human-robot interaction. Similarly, it starts for visualization tasks, then human assistance. Until recently, AR went forward in industry 4.0 by being used in robot manipulation and trajectories planning. Although its recent implementation for robot programming, AR-based features still can be more powerful and requires development in this area. Moreover, all along the advancement of collaborative robots and their important role in factories, HRI and tasks operation should be feasible by any worker and as easy as possible. This will decrease the costs and the time of programming the robots as well as increase the efficiency and effectiveness as well. Thus, more research still needs to be done in this context.

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References

[1] M. A. K. Bahrin, M. F. Othman, N. H. N. Azli, and M. F. Talib, J. Techno (2016)
[2] B. Bunse, GTIA, (2013)
[3] G. Kipper, J. Rampolla, Augmented Reality: an emerging technologies guide to AR, (Elsevier, 2012)
[4] A. Balog and C. Pribeanu, Handbook of Research on 3-D Virtual Environments and Hypermedia for Ubiquitous Learning, 537-554, (IGI Global, 2018)
[5] P. O'Shea and C. Campbell, Virtual and Augmented Reality: Concepts, Methodologies, Tools, and Applications, 1644-1658 (2018)
[6] D. Andersen, V. Popescu, M. E. Cabrera, A. Shanghavi, B. Mullis, S. Marley, G. Gomez, and J. P. Wachs, *Military medicine,* 182, 310–315 (2017)
[7] K. J. Carlson and D. J. Gagnon, *Clinical Simulation in Nursing*, 12, 123–127 (2016)
[8] M. Billinghurst, A. Clark, and G. Lee, *Foundations and Trends in HumanComputer Interaction*, 8, 73–272 (2015)
[9] V. Krevelen, D. W. F., and R. Poelman, J. of VR 9.2 (2010)
[10] S. Mann and W. Barfield, J. of HCI, 15, 205– 208 (2003)
[11] J. Novak-Marcincin, J. Barna, M. Janak, and L. Novakova-Marcincinova, *Procedia Computer Science*, 25, 23–31 (2013)
[12] D. Mourtzis, E. Vlachou, N. Milas, and N. Xanthopoulos, *Procedia CIRP*, 41, 655– 660 (2016)
[13] D. Mourtzis, V. Zogopoulos, and E. Vlachou, *Procedia CIRP*,63, 46–51, (2017)
[14] H. C. Fang, S. K. Ong, and A. Y. Nee, *Advances in Manufacturing*, 2, 275–288 (2014)
[15] Z. Pan, J. Polden, N. Larkin, S. Van Duin, and J. Norrish, ROBOTIK (2012)
[16] A. Nee, S. Ong, G. Chryssolouris, and D. Mourtzis, *Manufacturing Technology*, 61, 657–679 (2012)
[17] V. Paelke, ETFA (2014)
[18] B. Lo¨fvendahl, Augmented Reality Applications for Industrial Robots, 167, (2014)
[19] I. L. Madar, M. Smith, and P. Knackfuss, LNICST, 150, 151–156 (2015)

[20] M. Fiala, TPAMI (2010)
[21] G. Caruso, M. Carulli, and M. Bordegoni, *Computer-Aided Design and Applications*, 12, 86–95 (2015)
[22] J.R. Chardonnet, G. Fromentin, and J. Outeiro, *Multimedia Tools and Applications* (2017)
[23] S. Su¨to, Z. Forgo´, and F. Tolvaly-Roca, *Procedia Engineering*, 181, 503–508 (2017)
[24] D. Mourtzis, V. Zogopoulos, I. Katagis, and P. Lagios, *Procedia CIRP* (2018)
[25] Y. Zhang and T.-H. Kwok, *Procedia Manufacturing*, 26, 1278–1286 (2018)
[26] R. Palmarini, J. Erkoyuncu, R. Roy, and H. Torabmostaedi, *Robotics and Computer-Integrated Manufacturing*, 49, 215–228 (2018)
[27] G. Dini and M. D. Mura, *Procedia CIRP*, 38, 14–23 (2015)
[28] R. Palmarini, J. A. Erkoyuncu, and R. Roy, *Procedia CIRP*, 59, 23–28 (2017)
[29] S. Webel, U. Bockholt, T. Engelke, N. Gavish, M. Olbrich, and C. Preusche, *Robotics and Autonomous Systems*, 61, 398–403 (2013)
[30] D. Mourtzis, V. Zogopoulos, and E. Vlachou, *Procedia CIRP*, 63, 46–51 (2017)
[31] C. Kollatsch, M. Schumann, P. Klimant, V. Wittstock, and M. Putz, *Procedia CIRP*, 23 (2014)
[32] A. W. Yew, S. K. Ong, and A. Y. Nee, *Procedia CIRP* (2017)
[33] D. Aschenbrenner, M. E. Latoschik, and K. Schilling, ACM VRST '16 (2016)
[34] C. Hub, D. Hub, K. Base, and F. O. R. Managers, *Service in industry HUB* (2017)
[35] X. Wang, S. K. Ong, and A. Y. Nee, *Advances in Manufacturing* (2016)
[36] M. M. Chang, S. K. Ong, and A. Y. Nee, *Procedia CIRP* (2017)
[37] M. Funk, T. Kosch, R. Kettner, O. Korn, and A. Schmidt, i-KNOW (2016)
[38] O. Danielsson, A. Syberfeldt, M. Holm, and L. Wang, *Procedia CIRP* (2018)
[39] M. Fiorentino, A. E. Uva, M. Gattullo, S. Debernardis, and G. Monno, *Computers in Industry* (2014)
[40] J. Zhu, S. K. Ong, and A. Y. Nee, J. Comp. Integ. Manuf. 28, 213–225 (2015)
[41] R. Masoni, F. Ferrise, M. Bordegoni, M. Gattullo, A. E. Uva, M. Fiorentino, E. Carrabba, and M. Di Donato, *Procedia Manufacturing*, 11, 1296–1302 (2017)
[42] J. Rambach, A. Pagani, M. Schneider, O. Artemenko, and D. Stricker, *Computers*, 7, 6 (2018)
[43] E. Ruffaldi, F. Brizzi, F. Tecchia, and S. Bacinelli, *Augmented Reality, Virtual Reality, and Computer Graphics* (2016)
[44] G. Michalos, P. Karagiannis, S. Makris, O¨ . Tokc¸alar, and G. Chrys- solouris, *Procedia CIRP*, 41, 370–375 (2016)
[45] S. Makris, P. Karagiannis, S. Koukas, and A. S. Matthaiakis, *CIRP Annals - Manufacturing Technology*, 65 (2016).
[46] S. Galen, D. Liedtke, and D. Schilberg, *Human Interface and the Management of Information*, 10273, 161–169 (2017)
[47] O. Danielsson, A. Syberfeldt, R. Brewster, and L. Wang, *Procedia CIRP*, 63, 89–94 (2017)
[48] P. Leit, I. Mal, and D. Sedl, *Industrial Informatics (INDIN)*, 14, 176–181 (2016)
[49] P. Tsarouchi, A. Athanasatos, S. Makris, X. Chatzigeorgiou, and G. Chryssolouris, *Procedia CIRP*, 55, 1–5, (2016)
[50] S. Stadler, K. Kain, M. Giuliani, N. Mirnig, G. Stollnberger, and M. Tscheligi, RO-MAN (2016)
[51] H. Liu and L. Wang, *Procedia Manufacturing*, 11, 22–30 (2017)
[52] S. Maksymova, R. Matarneh, V. V. Lyashenko, and N. V. Belova, J. of Comp. and Comm., 05, 1–15, (2017)
[53] J. Wassermann, A. Vick, and J. Kru¨ger, *Procedia CIRP*, vol. 76, pp. 161–166, (2018)
[54] H. C. Fang, S. K. Ong, and A. Y. Nee, *Procedia CIRP*, 3, 191–196 (2012)
[55] H. C. Fang, S. K. Ong, and A. Y. Nee, J. Inter. Des. and Manuf., 8, 33–42 (2014)
[56] P.-c. Li and C.-h. Chu, A-DEWS, 1–5 (2016)
[57] M. Tessarotto, Trajectories Programming for Industrial Robots Through Augmented Reality (2017)
[58] M. Ragni, M. Perini, A. Setti, and P. Bosetti, *Computers and Industrial Engineering* (2018)