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Brigida Bonino, Franca Giannini, Marina Monti

# Augmented Reality in manufacturing engineering

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Istituto di Matematica Applicata e Tecnologie Informatiche "*E. Magenes*" Consiglio Nazionale delle Ricerche Via Ferrata, 5/a 27100 PAVIA (Italy) Email: <u>reports@imati.cnr.it</u> <u>http://www.imati.cnr.it</u>

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Brigida Bonino Istituto di Matematica Applicata e Tecnologie Informatiche "E. Magenes" Consiglio Nazionale delle Ricerche Via De Marini,6 – 16149 Genova (Italy) E-mail: <u>brigida.bonino@ge.imati.cnr.it</u>

Franca Giannnini Istituto di Matematica Applicata e Tecnologie Informatiche "E. Magenes" Consiglio Nazionale delle Ricerche Via De Marini,6 – 16149 Genova (Italy) E-mail: <u>franca.giannini@ge.imati.cnr.it</u>

Marina Monti Istituto di Matematica Applicata e Tecnologie Informatiche "E. Magenes" Consiglio Nazionale delle Ricerche Via De Marini,6 – 16149 Genova (Italy) E-mail: <u>marina.monti@ge.imati.cnr.it</u>

#### Abstract.

The report provides an overview of the existing research works addressing the interaction with 3D models using Augmented Reality technologies. It also illustrates the results of our experiments both simply using HoloLens, Unity 3D and integrating Leap Motion. In the first case, only the built in tap gesture and voice commands have been used for the interaction with the digital elements. Whereas with Leap Motion additional gestures have been considered to easy the 3D digital object manipulation. The carried out experiments reveal the actual limitations of AR technologies for the effective use in real applications merging 3D virtual objects in real environments when digital elements have to be inspected and manipulated.

Keywords: Augmented reality, 3D object manipulation

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# Augmented Reality in manufacturing engineering

Brigida Bonino<sup>†</sup>, Franca Giannini<sup>†</sup>, and Marina Monti<sup>†</sup>

<sup>†</sup>Istituto di Matematica Applicata e Tecnologie Informatiche "Enrico Magenes", CNR Via De Marini 6, 16149 Genova, Italy

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## 1 Introduction

Manufacturing engineering consists of multiple activities, such as design and planning, training, assembly and maintenance. Due to the growing numbers of product variants, the process is very expensive, in costs and time, and any mistake could affect the quality of the final result.

In the last few years, to overcome these issues, digital manufacturing is becoming more popular. Recent researches aim to assist workers and to increase the manufacturing flexibility. The key technologies in this trend include Virtual Reality (VR) and Augmented Reality (AR). With these tools is possible to interact with a virtual model of the final product, simulate the manufacturing and assembly processes, compare assemblies and test if a part is usable in an assembly by virtually inserting it.

However, using VR is still limited in the design of the products and in the related production processes. In fact, user is immerse in a completely virtual world and any physical reference is lost. Even if the environment is modelled as much realistic and natural as possible, the interactions between the user and the virtual model are not fully realistic. Working only with virtual elements decreases the fidelity and credibility of the simulation and doesn't allow to evaluate the compliance of the product under development within the real environment where it is has to be inserted, such for instance the fitting of some different parts on the physical assembly. Using AR technologies, instead, seems to be the solution to overcome some of these limitations and facilitate mechanical assembly process. The user is in the real world and can manipulate both real and virtual components, placing them side by side and comparing them in a very realistic way.

In a previous work, we proposed a VR application exploiting the 3D space to group and organize the results of a 3D CAD assemblies retrieval system, inspect assemblies' components and evaluate their similarities [13]. The next step is to import all the results, or only some chosen assemblies, in a AR environment. The idea is to exploit HoloLens to improve user experience during the assemblies inspection and the evaluation of assemblies similarities and finally to make them usable in maintenance applications. In this context, there are several problems to face up to. It is necessary to analyze how to detect real-virtual objects collisions, how to realistically manipulate virtual objects with real hands and how to lean virtual objects against physical elements. It could be also useful to recognize a physical part and then augment it or highlight all the parts, belonging to an assembly, equal (or similar) to it. Moreover, allowing constraint-based interactions between real and virtual components looks useful to test the correct positioning of a part in an assembly.

This report, first, provide an overview of some recent works related to the use of AR in the industrial field, in particular for the manufacturing engineering. Then, our research on AR, focused on the use of the HoloLens, is described.

# 2 AR in manufacturing

AR is receiving an increasing attention by researchers in the industrial engineering field. The aim is to exploit this growing technology to provide tools that enhance the manufacturing process. By supporting human operators in different tasks, such as planning, assembly or maintenance, the costs and the time of the production could be reduced.

#### 2.1 Devices

To provide a compelling AR experience, it is important the choice of one device rather than another, depending on the purpose of the application developed.

There exist two main classes of devices: Hand Held Display (HHD) and Head Mounted Display (HMD). The first consists in devices that fit in user's hands. The device is equipped with a screen on which virtual content is displayed merged with the real environment, captured by a camera. HHDs mainly include smartphones and tablets. Thanks to their affordable price and common utilization in everyday life, these devices are very promising platforms for AR [4]. For example, AR smartphones

and tablets applications have been recently exploited for substituting paper instructions [10, 19] or for supporting maintenance and training tasks [11, 27]. However, HHDs are not suitable for all maintenance jobs due to the limited size of the screen and their need to be supported. HMDs, instead, are wearable optical see-through devices, like smart glasses and smart helmets. In the industrial field, this kind of hardware is generally superior than HHD since they free the operator's hands. In the last few years the spread of smart glasses grew rapidly and a vast range of similar products is now available on the market. To guide developers in the selection of the optimal HMD, a study [20] points out five key characteristics that smart glasses should have if used in manufacturing applications, such as a field of view as large as possible or being as light as possible. In general, HMDs could enhance different manufacturing operations. For examples, the use of smart glasses is exploited for improving human-robot collaboration [1], in assembly tasks [17] or workers training [29].

#### 2.2 Applications and Tasks

In this section we provide a collection of some of the most interesting and promising AR works of the last decade, dealing with manufacturing operations and CAD assembly tasks.

In literature, a lot of applications take advantage of AR devices to provide interactive instructions, instead of the paper based manuals. An example of HHD application is described in [19]: a procedure for the maintenance of a notebook is considered. Each step shows an operation and provide a short description of it; the next step is activated when a defined configuration of the object is achieved, relying on images or CAD models. The experiments show that users benefit from the AR tool, especially in the execution of the steps with almost no errors. Khuong et al. [9] used a Lego assembly task to evaluate context-aware instructions on HMDs (Figure 1(a)). They provide two visualization modes, one of them that displays guidance information directly overlaid on the physical model, and another one in which guidance information is rendered on a virtual model adjacent to the real model. Tests surprisingly show that the second visualization mode was preferable in every way to displaying information directly on the physical object. In [18] is presented an AR system that helps untrained workers to assemble products without any previous knowledge or training. In this works, instead of HMDs, projection-based techniques are used, trying to avoid FOV limitations. The system shows both picking information for the next part to assemble as well as assembly instructions in the physical work space of the user. Makris et al. [14] proposed an AR application for supporting workers in an assembly task. In particular, starting from CAD data and having as basis the assembly sequence of the specific product, the system is based on an algorithm that creates the virtual instructions and overlap them on the real object. In [2], then, different tools for presenting instructions are compared: smartphone, smart glasses or paper. The authors distinguish between in-situ and in-view implementations. The first consists of 3D instructions displayed in the target position, the latter shows 2D information in the field of view. Tests on a Lego assembly task point out that the use of AR glasses, combined with in-situ instructions, is overall helpful. In particular, even if time and cognitive load aren't improved, errors are significantly reduced.

Similarly, AR technologies play an important role in training tasks. It is proved that, in general, technicians supported by AR devices acquire new assembly skills in a more intuitive way and saving time. AR-based training researches for assembly tasks nevertheless requires improvements because scientific limitations in this field are still evident [28]. Liu et al. [12] promote the efficiency of assembly training and guidance by creating an information-enhanced AR assembly environment. In order to avoid a time-consuming and intensive training, [7] proposes an innovative system based on the interaction between a force sensor and an augmented reality (AR) equipment used to give to the worker the necessary information about the correct assembly sequence and to alert him in case of errors (Figure 1(b)). In [30] a combination of an AR interface with an Intelligent Tutoring System is shown. Authors aim to provide a robust and customized learning experience for each user. In particular, the intelligent AR system controls the ordering of the assembly steps and can make decisions about what material to present next based on the student's performance. The user study points out the proposed AR training significantly improves the learning outcome over traditional AR approaches. Werrlich et



(a) The two instruction visualization techniques provided by [9]: overlaid or adjacent to the real model

(b) Visual messages provided by [7]: suggesting the right position; error symbol; suggesting the error recovery

Figure 1: Examples of virtual instructions and messages visualization for training.

al. [29] introduce two slightly different HMD based software for information visualization in assembly training tasks. The first application consists of six features that can be selected by means of buttons. For example, user can chose between a superimposed augmented animation of the process, the visualization of text describing the current task or watching an augmented video where an expert performs the task. Moreover, different training levels are provided: the lower the level, the more detailed the instructions are. In the second application, a quiz mode is added. After assembling the object in the told training modes, user is required to virtually complete the procedure with the correct sequence with no errors. Tests conducted in a real engine assembly task shows that these applications help to increase the quality of the training and of the assembly procedure.

To provide reliable virtual training and instructions, the assembly sequence of the product should be determined and the CAD data of the model should be converted in a suitable format. However, no precise tools to automatically do these operations exist yet. As a consequence, some recent works have started to analyze these aspects. [15] proposes a method for the human-driven generation of an assembly sequence through different steps. First, an expert creates the instructions on a computer, arranging manually the components. Then, the information is forwarded to the AR application, where the expert can complete the instructions by adding the positional data. Once the sequence is finished and saved, it can be recalled by workers to be supported in their tasks. In [6] an algorithm for automatic disassembly sequence generation is described. In particular, different sequences are planned based on the object's geometrical and mobility constraints table. Depending on the sequence chosen as optimal, AR content, describing each step, is generated and linked to the corresponding task of the disassembly procedure. The augmented instruction are rendered automatically on the scene in real time.

Again in the field of AR industrial operations among the topics in assembly simulation and planning, several works focus on real-virtual interactions. On the one side the components' constraints and the possible interaction between real and virtual parts are studied, on the other the manipulation of a virtual object with human hands is addressed. Some examples of real-virtual collision and contact detection researches are the following. Valentini et al. [21] propose a system for manipulating and interactively assembling virtual objects. The user is immersed in an AR scene by means of aheadmounted display (HMD) and interact with the virtual components using sensor-based glove. The work focuses on the study of objects' constraints and the interpretation of user's grasp. Then an example about the simulation of the assembling of a cylindrical component into a hole is discussed. Wang et al. [24] provide a new AR assembly environment to facilitate assembly simulation and planning (Figure 2(a)). In particular, an ontology-based assembly information model is constructed from the assembly CAD model for modelling components contact relations, while a tool is used to move a chosen virtual object. The tool consists of a cube with two different markers applied on. One marker is a tracker to register the movement of the tool and consequently move the selected object, the other is the deselection object signal. This work aims to improve both physical-virtual components contacts detection and interactions between user and product. To enhance the efficiency of the assembly planning process, also [23, 26] take into account the assembly features (Figure 2(b)). Staring from



(a) Physical-virtual interaction in assembly process with the help of an interaction tool [24]



(b) Virtual parts constraint based interaction and barehand interaction in assembly process [26]

Figure 2: Examples of assembly simulation and planning processes.

the assembly CAD model, geometric constraints between components are extracted and stored. These should be recognized in the AR environment when two components come in contact, allowing a realistic merging. Both works then analyze the assembly manipulation in augmented reality through bare-hand interactions. By means of computer vision and stereo vision technologies, the main idea is to retrieve information about fingertips and render two spheres on the index and the thumb tips. A virtual object is grasped when both the spheres collide with it. Then, user can manipulate the object and simulate the assembly task.

Other works address mainly gestures recognition in AR and virtual objects manipulation. Wang et al. [25], for example, proposed a methodology for assembly panning with the use of a 3D bare-hand interaction tool. User can naturally manipulate virtual parts by pinching them with both his hands without distinction. Hands and fingertips are in fact recognized in the AR environment, and the right and left hands are differentiated as well as the thumb and the index fingertips. The 3D direct interaction of virtual objects is, then, achieved by comparing the hand pose between different frames. In [3] a marker based technique is proposed for natural bare-hand interactions. Only using Vuforia AR platform and no extra equipment, corresponding virtual fingers are created by the recognition of specific markers applied on real hand fingertips (Figure 3(b)). To provide realistic interactions, physical proprieties, such as forces, have been added both to virtual objects and virtual hands. The technique results successful for hand assembly of small parts. Compared with other methodologies using extra devices or hand recognition techniques, virtual fingers are very efficient in term of set up time, cost and natural feeling. In [5] the authors propose the use of bi-manual gestures to improve the



(a) Bimanual gestures with the Microsoft HoloLens [5]



(b) Virtual fingers superimposed on the real, by means of Vuforia marker recognition, allowing bare-hand interaction [3]



(c) Integration between Leap Motion and AR. Manipulation of virtual part with grasp pose [22]

Figure 3: Examples of gesture recognition in AR.

scale and rotation tasks on the HoloLens. In particular, five different techniques, both uni-manual and bi-manual, are developed and evaluated (Figure 3(a)). Results demonstrate that two-handed gestures are comparable to one-handed gestures in terms of accuracy and execution time. Furthermore, in spite of the limited field of view and the resulting hand tracking loss, most users prefer one of the suggested bi-manual technique. Then, in [8] ability to manipulate and modify holographic objects is provided by connecting the HoloLens to the Leap Motion by Wi-Fi. The latter detects hands position and recognizes gestures. The processed data are sent to HoloLens, where virtual hands are superimposed on real hands. The proposed interaction tasks include selection, grasp, scale, rotation and deformation. Tests concerning the manipulation of a cube find out that the accuracy of gestures detection is good and users succeed in the tasks with ease and in a short averaged time. Similarly, Valentini [22] discusses the integration between Leap Motion and an augmented reality architecture for assembly simulation. His challenge is to implement a virtual assembly methodology based on natural bare-hand interactions. Different grasp poses have been studied to assess a suitable recognition of the contact between real hand and virtual object, as well as a reliable and natural interaction (Figure 3(c)). Except for the uncomfortable field of view of the AR device, no remarkable difficulties in objects manipulation come out from the usability test. Some more problems arise in the imposing of mating constraints between virtual objects, but in general the methodology should be considered feasible and suitable for interactive AR application.

All the works we refer to in this subsection are collected in Table 2 a at the end of the report. The table summarizes the main tasks addressed, the technologies used and the different real-virtual aspects analyzed in each paper.

## 3 Working with HoloLens

HoloLens is the tool we adopt to access the AR environment. Actually, our research focuses on analyzing and testing HoloLens capabilities and potentiality by developing basic applications. The aim is to evaluate if HoloLens is a suitable AR tool for inspecting and comparing assemblies.

HoloLens is an optical see-through headset, released in 2016 by Microsoft. It is a holographic computer, equipped with Windows 10, which doesn't need to be connected to a PC by any cable. Being wireless and a robust spatial tracking allow user to move freely in the real space, furnish rooms with holograms and interact with them. In general, the interaction with holograms through the HoloLens consists of two phases: gaze to target, and then voice command or gestures to act. Currently, the device provides only two core component gestures, namely the air tap and the bloom. The combination of these two gestures allows user to execute a large variety of actions (select, translate, open a menu etc.). However, some issues in interactions with HoloLens have been pointed out. Hands, indeed, are just detected, but not precisely located in space. Contact with holograms and their direct manipulation are not provided. Moreover, the recommendation, by Microsoft HoloLens, to use one-handed gestures and the limitation to the only tap and bloom gestures lead to the need of methods for switching between actions as well as to lack of naturalness. Finally, a not solvable problem, deriving from HoloLens hardware, is the limited field of view, which is of 35°. Holograms are thus visible only in a restricted area of the entire user's field of view (Figure 4).



Figure 4: HoloLens field of view.

In the next subsections we will sum up, step by step, the analysis carried out on the HoloLens usage and performance. For each point, the motivations and the different aspects analyzed are described, together with the attempts made by us. The results achieved and the limitations encountered are commented.

#### 3.1 HoloLens and Unity

The easiest way to develop an AR application for HoloLens is using Unity 3D. To right configure a new Unity project, the HoloToolkit package has to be downloaded from GitHub<sup>1</sup> and imported in Unity. It contains all the prefabs and the scripts necessary for interacting with HoloLens my means of Unity.

Once ready, it is possible to test the application on the HoloLens in two different ways: directly from Unity remote to device or deploying on the device.

• To play remote to HoloLens, both the PC and the device need to be connected to the same Wi-Fi. To make Unity and the HoloLens communicate, it is enough to open the Holographic

<sup>&</sup>lt;sup>1</sup>The HoloToolkit version available at the following link has been used for our works:

https://github.com/Microsoft/MixedRealityToolkit-Unity/releases/tag/2017.4.3.0-Refresh

Remoting Player app on the device and select the Remote to Device option in Unity. Once the connection succeeds, just play the project in Unity and it will be visible on the HoloLens.

• To deploy the application on the HoloLens, the Build Settings window of Unity has to be opened. Here the scene to build has to be selected and after clicking Build the solution will be opened by Visual Studio and, with the HoloLens connected by USB, the deploy is possible. Once the deploy is completed, the application can be played on the HoloLens with no connection to Unity or the PC.

Trying both options, we find out that remote to device is very unstable and jittering. Sometimes the holograms aren't visible through the HoloLens even if the application is indeed running and the correct scene in the Game window of Unity is visualized. These issues probably happen because the running is based on Wi-Fi and it doesn't ensure a good connection, especially when the application to play is heavy. The deployment, instead, is reliable and permits a correct visualization of the application. However, it is more tedious because every modification requires a new build and deploy.

#### 3.2 Visualize CAD models

Since our intent is to create an AR environment to enhance user experience in the inspection of mechanical assemblies, it is important to examine how a CAD model is visualized as a hologram through the HoloLens.



Figure 5: Example of bringing the virtual assembly closer to user. The assembly appears cut and user sees a section of it.

We have imported in the current Unity scene a tessellated CAD assembly model. When playing the application on the HoloLens, the assembly is correctly visualized as a virtual object which stands in the physical room. However, there are some restrictions to point out. Due to HoloLens limited field of view, indeed, holograms appear only in a small rectangular area. If an assembly is too big, some of its portions will be cut out from the rectangle. Microsoft recommends to place holograms at a distance of about more than 1m; bringing them closer could be uncomfortable and cause loss of stability. Consequently, if the assembly is too close to the user, by default, it will be cut and user sees a section of it, feeling to be inside the assembly itself (Figure 5). Although, in Unity it is possible to render holograms closer to user by adjusting some Camera options. The Clipping Planes component defines the distances from the camera to start and stop rendering. For example, by setting the Near option almost to 0, holograms can be in front of the user without fading out. However, the size of the HoloLens field of view doesn't change: holograms are visible only in the limited rectangle of space.

#### 3.3 Gestures

HoloLens provides only few gestures (tap and bloom) and it isn't immediate to create and recognize new gestures. With the aim of improving the interactions with virtual objects, HoloLens integration with Leap Motion is attempted.



Figure 6: Integration of HoloLens with Leap Motion.

It is easy to configure the AR project for using also the Leap Motion: it's enough to import the Leap Motion packages (Core and Modules), then add in the scene the Leap hands (the Camera deriving from Leap Motion must be deactivate). When playing on the HoloLens, user see both his real and virtual hands, but only the virtual one could interact with objects. To make more realistic the visualization, we put in transparency the virtual hands and try to overlap them with the real one. In this way, if the two pairs of hands are well aligned, user seems to touch virtual object with his real hands. We use some scripts for gestures, implemented for VR applications [13], allowing to grasp, scale, rotate and translate an assembly using the HoloLens with the help of Leap Motion.

The first issue deriving from the integration of Leap Motion is that the application can't be directly deployed. In fact, Leap Motion can't be connected by USB to the HoloLens and it needs to be connected to a PC (where data are processed). Consequently, we could only test the application playing remote to device, and this causes a great instability, jittering, jumping and hologram disappearing. It is also difficult to precisely overlap the real and the virtual hands, so the performance is not optimal. Moreover, it is challenging to start or complete a dynamic gesture. This because Leap Motion field of view doesn't coincide with the HoloLens field of view: it could happen that hands are detected even if not visible through HoloLens or gestures are not recognized when, instead, hands are visible (because hand are not actually detected by Leap Motion). Finally, actions that involve approaching virtual objects (like grasp, translation or scale) are not convenient due to HoloLens limited field of view (especially when objects are brought too close to user). It is to say, HoloLens isn't primarily planned for touching holograms and directly manipulating them. In conclusion, the use of Leap Motion with HoloLens doesn't allow to achieve the expected improvement.

Taking inspiration from some online works (https://www.youtube.com/watch?v=XXhjZJoGo1Y, https://www.billmccrary.com/holotoolkit-simple-dragresizerotate/), we thus try to implement gestures without the help of Leap Motion, only using the tap gesture and some voice commands that specify the action to do. In this way it is possible to deploy the application and so have more stability.

#### 3.4 Object recognition and augmentation

We have decided to exploit AR in assembly operation in order to observe simultaneously both real and virtual components and make them interact. With this objective, it is important to analyze how to provide a good AR experience, where real and virtual objects realistically coexist. The idea is to recognize and augment a real part by attaching to it a virtual component. It is challenging to set the augmentation in a correct position, observing mechanical and geometrical constraints, and make it follow the real object when moved. To achieve better results in this field, there are several SDKs, equipped with computer vision techniques, that assist developers in the creation of AR applications: we primarily use Vuforia.

Vuforia is an augmented reality SDK that could be integrated in Unity. It allows to position virtual objects depending on real world objects. In particular, after relating a virtual model to a material target (an image or an object), the first is visible only if the target is detected by the camera.

The virtual model of the target objects must be stored in particular databases. The Vuforia package furnishes some examples of database containing target images or objects. It is then possible to create own database accessing to the section Develop of https://developer.vuforia.com/. User can create single image, cuboid, cylinder or 3D object targets, import the new database in Unity and utilize it.

Starting from scratch, our first achievement was to use an image as target and, when playing the application, see with the HoloLens an assembly model resting on the image. Then we used a target cube, with all six faces, and attached the assembly to it so that the assembly completely covers the cube. In this way, taking and moving the real cube with the hand provides the impression of grabbing and moving the virtual assembly (Figure 7): it could be an alternative to the manipulation gestures (rotation, translation and grasp).



Figure 7: Target cube recognition and augmentation with Vuforia: when augmenting the cube with a virtual assembly, moving the cube allow to move the assembly.

The most interesting challenge is to use a 3D complex object as target, anyway. It would be useful to have an assembly's part (or the entire assembly) as target and, once recognized, augment it with the assembly to which it belongs (or some its extra parts). Different methods to create a target object are found for the Vuforia environment and are here described.

- In the Developer Vuforia web site add a 3D Object target: as for images, cuboid and cylinder, user is required to upload a file containing the real object data, but in this case the only format allowed is the OD. To create OD files, the Vuforia Object Scanner tool is needed: with the help of a camera, it scans a real object and then creates the relatives OD file.
- Model Target Generator: it is a Vuforia tool which allows to create Model Target using the CAD model of the real object. With this application it is also possible to choose the detection position of the object and create one or multiple guide views (Figure 8). The guide view is an image that represents the profile edges of the target object in respect of a particular viewing angle, chosen by the user. If activated in Unity, the guide view will be visible with the HoloLens. To detect the target, user has to correctly overlap the real object to the guide view. Moreover, in the Databases tab of the Model Target Generator it is possible to create a trained database containing different model targets and/or different guide views. It is called "trained" because, to enable the recognition of the different targets and to allow the switching from one to the others, the latest Deep Learning technology is used to train a neural network from the selected models (https://library.vuforia.com/content/vuforia-library/en/articles/Solution/trained-model-target-datasets.html).



Figure 8: Creation of a Model Target an its guide views.

Our attempt to use the Vuforia Object Scanner failed. In fact, the application is only available<sup>2</sup> for Samsung Galaxy phones (from S7) and Google Pixel 2. Not having any of these devices, we find that it is possible to install the Scanner on the PC though an Android emulator. We download Genymotion and we manage to scan small real objects with a mobile web-cam. However, once the data are created, we didn't succeed in sending them from the emulator to the PC, because the emulator application crashes.

On the other hand, the Model Target Generator works successfully. The target model and the guide view appear in the scene through the HoloLens. The model target, once detected, is then correctly augmented with a virtual object. However, different disadvantages come out. The object is recognized by means of its shape, namely if the guide view is aligned with real object's edges, so it isn't a 3D recognition. Moreover, the guide view is fixed in a position and can't be moved. The real target object must be stationary. If you move or change position to the real object, the virtual augmentation doesn't follow it, and the tracking is lost. The only possibility for moving the real target object and, at the same time, maintaining the augmentation visible is to enable the Extended Tracking option by which, once the virtual object appeared, it is fixed in the scene, even if the real object is moved out.

Due to the several issues just pointed out, we seek a solution, for object recognition, different from the Vuforia SDK. VisionLib (https://visionlib.com/) seems to be a useful library. In particular, it is an augmented reality tracking library, which provides an SDK compatible with Unity and with HoloLens. It is possible to recognize a real object starting from its CAD model. Different from Model Target Generator, VisionLib provides a real 3D recognition. To better explain, the target object is automatically recognizable from every viewing angles, and not only through the shape associated with a specific guide view. Once recognized, the real object can be moved and the augmentation follows it (even if with a certain delay). Though, the virtual model and the real object must be perfectly superimposed and too much precision is required for our aim.

Table 1 summarizes the SDK for object recognition and tracking just illustrated.

#### 3.5 Spatial mapping

Spatial Mapping is one of most relevant features provided by HoloLens: it allows to track the surrounding (the room in which user is) and generate a spatial mapping mesh. When imported in Unity, the environment is so rendered as a generic 3D game object, equipped with its collider, so that game objects included in the scene can interact with it.

To use Spatial Mapping<sup>3</sup> is enough to enable the SpatialPerception capability in Unity and drag the Spatial Mapping prefab in the scene hierarchy. After the spatial mapping mesh has been created,

<sup>&</sup>lt;sup>2</sup>For supported versions details see https://library.vuforia.com/content/vuforia-library/en/articles/Solution/Vuforia-Supported-Versions.html.

<sup>&</sup>lt;sup>3</sup>See also Chapter 6 of [16].

		Vuloria
	ht	tps://www.vuforia.com
	https	://developer.vuforia.com
		- Image recognition by means of its features.
	Image Target	- The virtual augmentation follows the real target.
		- More than one image at time can be recognized.
		- Cylinder recognition by means of the images' features
	Cylinder Target	associated with the lateral surface.
		- The virtual augmentation follows the real target.
		- More than one cylinder at time can be recognized.
		- Cuboid recognition by means of the images' features associated
	Cuboid Target	with the lateral surfaces; every single face isn't considered as a
Vuforia Target		single image, but the cuboid is considered in its entirety as an
Manager		object.
		- The virtual augmentation follows the real target.
		- More than one cuboid at time can be recognized.
	3D Object Target	- 3D object recognition
		- Use Vuforia Object Scanner to create.OD file with the real
		object's model.
		- Android is required.
		- More than one object at time can be recognized.
		- Object recognition by means of its shape. Object is recognized
		when a 2D guide view is superimposed on it.
		- Real object's virtual model is created starting from its CAD
Vufaria Madal		model.
Vuioria Model	Single Model Target	- If the real target is moved from its initial position, the virtual
Target Generator		augmentation doesn't follow it, and tracking is lost.
		- If extended tracking is enabled, the augmentation is still visible
		in the scene, even when the target is out of the field of view.
	Trained Database	- A single model for scene can be recognized.
		By training a database more than one guide view of the same
		object or different objects can be recognized in a scene (one
		at time).
		VisionLib
	h	ttps://visionlib.com
		- Not free, a license is needed.
		- Object recognition as a 3D model (not only if its shape
		corresponds with a specific guide view)
<b>T</b> 71 • <b>T</b> •1		- Real object's virtual model is created starting from its CAD
VisionLib	3D Model Recognition	model.
VIUnitySDK		- The virtual model must be perfectly overlapped to the real one
		for recognition (too much precision is required).
		- The virtual augmentation follows the real target (if movements
		are very slow).
L		· · /

## Table 1: Summary table of the SDK used for objects recognition and tracking

it can be processed and modified. For example, by adding the SpatialProcessing prefab it is possible to automatically find and display all planes that meet certain conditions. Moreover, Spatial Mapping could be improved by Spatial Understanding prefab, which enriches the SpatialProcessing feature. Spatial Understanding, indeed, allows not only to find planes, but also to distinguish between floors, ceilings or walls and recognize sittable or placeable surfaces. For example, it is possible to identify chairs and couches where to sit virtual characters, ask for the largest/smallest empty wall or the largest/smallest empty floor, and to visualize all the possible plane where to place objects.

It is useful to exploit these HoloLens built-in features to realistically anchor virtual objects to real environment in order to provide user with a reliable mixed reality experience. For example, it becomes easy to place virtual objects on the furniture of the physical room (i.e. tables and shelves), on the floor, or hanging on the wall.

Moreover, since the Spatial Mapping generates a mesh of the room, we have considered the possibility to exploit it. For example, it would be interesting to segment the whole mesh and extract single objects' meshes. Then an object of interest, such as an assembly's component, could be detected, tracked and augmented. Unfortunately, the Spatial Mapping mesh is very coarse, consequently small objects are bad processed and they can't be recognized.

## 4 Conclusion

AR is considered one of the key enabling technologies for Industry 4.0 providing the possibility of merging real entities with digital ones. In this contexts we considered the possibility to exploit AR to improve user experience during the assemblies inspection and to exploit the results of retrieval systems for part substitution and assembly in industrial contexts.

In this report, a survey of the most interesting works using AR technologies in manufacturing engineering of the last decade is first provided. The aim is to give an overview of which results are achievable by exploiting AR device. The report describes several existing applications, the benefits they bring to the manufacturing process, as well as their limits. Then, our research in the AR field is shown. In particular, we have explored the HoloLens capabilities, mainly to evaluate if the device could be suitable for our intent. We can assess that HoloLens, definitely, is a very promising tool thanks, for examples, to its core gestures, the possibility to recognize and augment physical objects and to acquire the 3D mesh of the environment. However, HoloLens doesn't completely fit our aims. We have, in fact, found issues in the assembly visualization and manipulation, especially, because the field of view is limited and holograms can't be grasped with real hands. In its current state, the device is not designed to place virtual objects within reach distance of the user and interact directly with them, but to see holograms from a certain distance (at least 80 cm). Problems we dealt with are therefore related to the hardware itself. Future AR technologies improvements and HoloLens' new release (e.g. HoloLens 2) may resolve them.

Ref.	Tasks	AR	Technology for Gestures	r Tracking	Real-virtual interactions	Info for the virtual model
[2]	Assembly virtual instructions	HoloLens, Epson Moverio, smartphone	I	NS	Virtual part is superimposed on the corresponding real one.	I
[3]	Assembly simulation	PC	Virtual Hands (marker based)	Vuforia	Collision detection between virtual hands and virtual parts for grasping.	I
[5]	Two-handed gestures in AR	HoloLens	HoloLens	I	ı	I
[9]	Disassembly virtual instructions	NS	I	Open CV (ARUCO module)	Virtual part is superimposed on the corresponding real one.	Geometrical and mobility constraints.
[1]	Assembly virtual instructions for training	PC, HMD	I	Marker based tracking	Virtual part is superimposed on the corresponding real one. A sensor detects errors and virtual warnings are displayed.	I
8	Manipulation gestures	HoloLens	Leap Motion	I	Selection, translation, scale, rotation and deformation of virtual object with Leap hands.	I
[6]	Assembly virtual instructions	Vuzix WRAP 920AR		Microsoft Kinect	Virtual part is superimposed on the corresponding real one. Comparison of real and virual model in real time.	Estimation of the geometry based on a 3D voxel grid.
[12]	Training	NS	I	Computer Vision tracking techniques	I	Information from the CAD model

Table 2: Summary table of the references in subsection 2.2 (NS = not specified)

					Page 1	
Ref.	Tasks	$\mathbf{AR}$	Technology for Gestures	r Tracking	Real-virtual interactions	Info for the virtual model
[14]	Assembly virtual instructions, assembly sequence generation	NS		NS	Virtual part is superimposed on the corresponding real one.	Geometrical and semantic information from the CAD model.
[15]	Assembly virtual instructions	HoloLens	ı	NS	Position virtual parts using tap gesture.	Information from the CAD model.
[18]	Assembly virtual instructions	GT670 projector	ı	NS	Virtual part is superimposed on the corresponding real one.	I
[19]	Assembly virtual instructions	Smartphone and tablet	·	Tracking implemented by images or by CAD models	1	Geometrical information from the CAD model.
[21]	Assembly simulation, natural interactions	Z800 3D visor by Emaging	5DT Data Glove 5 Ultra	ı	Manipulate virtual parts with the grabbing pose of the hand.	Geometrical shape features and mating relations between parts.
[22]	Assembly simulation, natural interactions	Z800 3D visor by Emaging	Leap Motion		Manipulate virtual parts with the grabbing pose of the hand.	Information about mating constraints between virtual parts.
[23]	Assembly simulation	ЧМD	ViSP tracking platform	ViSP tracking platform	Manipulation of virtual parts with bare-hand by detecting collisions. Interaction between real and virtual assembly's parts.	Information about mating relationship between parts and their kinematics.
[24]	Assembly simulation	CIMH	ı	Computer Vision tracking techniques	Approach and grasp virtual parts with a marker cube tool. Interaction between real and virtual assembly's parts with contact detection and reliable alignment.	Geometric feature s information for creating geometric constraints.

Table 2 continued from previous page

	Info for the	virtual model	Geomteric features from the CAD model, constraints and collision detection between virtual parts.	Geometric features and surfaces contact constraints.	1	
; page	${f Real-virtual}$	interactions	Manipulation of virtual parts with bare-hand and the pinch gesture.	Manipulation of virtula parts with bare-hand by detecting collisions.	Virtual part is superimposed on the corresponding real one.	Virtual part is superimposed on the corresponding real one.
ntinued from previous		Tracking	Computer Vision tracking techniques	Computer Vision tracking techniques	NS	NS
Table 2 co	Technology for	Gestures	Computer Vision tracking techniques	Computer Vision tracking technique	I	·
		AR	NS	VUZIX WRAP 920 Video iWear	HoloLens	Vuzix WRAP 920AR
	$\Pi_{n,n} _{r,n}$	TASKS	Assembly simulation, natural interactions	Assembly simulation	Assembly virtual instructions	Assembly virtual instruction for training
	$\mathbf{D}_{\alpha}f$	.lau	[25]	[26]	[29]	[30]

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## References

- Andreea Blaga and Levente Tamas. Augmented reality for digital manufacturing. In 2018 26th Mediterranean Conference on Control and Automation (MED), pages 173–178. IEEE, 2018.
- [2] Jonas Blattgerste, Benjamin Strenge, Patrick Renner, Thies Pfeiffer, and Kai Essig. Comparing conventional and augmented reality instructions for manual assembly tasks. In Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments, pages 75–82. ACM, 2017.
- [3] Poonpong Boonbrahm and Charlee Kaewrat. Assembly of the virtual model with real hands using augmented reality technology. In Virtual, Augmented and Mixed Reality. Designing and Developing Virtual and Augmented Environments, pages 329–338. Springer International Publishing, 2014.
- [4] Julie Carmigniani, Borko Furht, Marco Anisetti, Paolo Ceravolo, Ernesto Damiani, and Misa Ivkovic. Augmented reality technologies, systems and applications. *Multimedia tools and applica*tions, 51(1):341–377, 2011.
- [5] Nikolas Chaconas and Tobias Höllerer. An evaluation of bimanual gestures on the microsoft hololens. In 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pages 1–8. IEEE, 2018.
- [6] MML Chang, SK Ong, and AYC Nee. Ar-guided product disassembly for maintenance and remanufacturing. *Procedia CIRP*, 61:299–304, 2017.
- [7] Michela Dalle Mura, Gino Dini, and Franco Failli. An integrated environment based on augmented reality and sensing device for manual assembly workstations. *Proceedia CIRP*, 41:340–345, 2016.
- [8] Poonsiri Jailungka and Siam Charoenseang. Intuitive 3d model prototyping with leap motion and microsoft hololens. In *International Conference on Human-Computer Interaction*, pages 269–284. Springer, 2018.
- [9] Bui Minh Khuong, Kiyoshi Kiyokawa, Andrew Miller, Joseph J La Viola, Tomohiro Mashita, and Haruo Takemura. The effectiveness of an ar-based context-aware assembly support system in object assembly. In 2014 IEEE Virtual Reality (VR), pages 57–62. IEEE, 2014.
- [10] Y.-D Kim and I.-Y Moon. e-training content delivery networking system for augmented reality car maintenance training application. 8:69–80, 01 2013.
- [11] Fabrizio Lamberti, Federico Manuri, Andrea Sanna, Gianluca Paravati, Pietro Pezzolla, and Paolo Montuschi. Challenges, opportunities, and future trends of emerging techniques for augmented reality-based maintenance. *IEEE Transactions on Emerging Topics in Computing*, 2(4):411–421, 2014.
- [12] Yi Liu, ShiQi Li, JunFeng Wang, Hongmei Zeng, and JiPing Lu. A computer vision-based assistant system for the assembly of narrow cabin products. *The International Journal of Advanced Manufacturing Technology*, 76(1):281–293, Jan 2015.
- [13] Katia Lupinetti, Brigida Bonino, Franca Giannini, and Marina Monti. Assembly retrieval results inspection in immersive environment. In *Eurographics 2019 Posters proceedings*, pages 7–8, 2019.
- [14] Sotiris Makris, George Pintzos, Loukas Rentzos, and George Chryssolouris. Assembly support using ar technology based on automatic sequence generation. CIRP Annals, 62(1):9–12, 2013.
- [15] Alexander Neb and Florian Strieg. Generation of ar-enhanced assembly instructions based on assembly features. *Proceedia CIRP*, 72:1118–1123, 2018.

- [16] Sean Ong. Beginning windows mixed reality programming. Berkeley, CA: Apress. doi, 10:978–1, 2017.
- [17] Roberto Pierdicca, Emanuele Frontoni, Rama Pollini, Matteo Trani, and Lorenzo Verdini. The use of augmented reality glasses for the application in industry 4.0. In *International Conference* on Augmented Reality, Virtual Reality and Computer Graphics, pages 389–401. Springer, 2017.
- [18] Oliver Sand, Sebastian Büttner, Volker Paelke, and Carsten Röcker. smart. assembly-projectionbased augmented reality for supporting assembly workers. In *International Conference on Virtual*, *Augmented and Mixed Reality*, pages 643–652. Springer, 2016.
- [19] Andrea Sanna, Federico Manuri, Fabrizio Lamberti, Gianluca Paravati, and Pietro Pezzolla. Using handheld devices to sup port augmented reality-based maintenance and assembly tasks. In 2015 IEEE international conference on consumer electronics (ICCE), pages 178–179. IEEE, 2015.
- [20] Anna Syberfeldt, Oscar Danielsson, and Patrik Gustavsson. Augmented reality smart glasses in the smart factory: Product evaluation guidelines and review of available products. *IEEE Access*, 5:9118–9130, 2017.
- [21] Pier Paolo Valentini. Interactive virtual assembling in augmented reality. International Journal on Interactive Design and Manufacturing (IJIDeM), 3(2):109–119, 2009.
- [22] Pier Paolo Valentini. Natural interface for interactive virtual assembly in augmented reality using leap motion controller. International Journal on Interactive Design and Manufacturing (IJIDeM), 12(4):1157–1165, 2018.
- [23] X Wang, SK Ong, and AYC Nee. Real-virtual components interaction for assembly simulation and planning. *Robotics and Computer-Integrated Manufacturing*, 41:102–114, 2016.
- [24] Xin Wang, Soh Khim Ong, and Andrew Y.C. Nee. Augmented reality interfaces for industrial assembly design and planning. In : Proceedings of the 8th international conference on interfaces and human computer interaction, Lisbon, pages 83–90, 2014.
- [25] ZB Wang, LX Ng, SK Ong, and AYC Nee. Assembly planning and evaluation in an augmented reality environment. *International Journal of Production Research*, 51(23-24):7388–7404, 2013.
- [26] ZB Wang, SK Ong, and AYC Nee. Augmented reality aided interactive manual assembly design. The International Journal of Advanced Manufacturing Technology, 69(5-8):1311–1321, 2013.
- [27] Sabine Webel, Uli Bockholt, Timo Engelke, Nirit Gavish, Manuel Olbrich, and Carsten Preusche. An augmented reality training platform for assembly and maintenance skills. *Robotics and Au*tonomous Systems, 61(4):398–403, 2013.
- [28] Stefan Werrlich, Elisabeth Eichstetter, Kai Nitsche, and Gunther Notni. An overview of evaluations using augmented reality for assembly training tasks. *International Journal of Computer* and Information Engineering, 11(10):1068–1074, 2017.
- [29] Stefan Werrlich, Phuc-Anh Nguyen, and Gunther Notni. Evaluating the training transfer of head-mounted display based training for assembly tasks. In *Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference*, pages 297–302. ACM, 2018.
- [30] Giles Westerfield, Antonija Mitrovic, and Mark Billinghurst. Intelligent augmented reality training for assembly tasks. In *International Conference on Artificial Intelligence in Education*, pages 542– 551. Springer, 2013.

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