



SIEMENS

Ingenuity for life

Siemens Digital Industries Software

The future of manufacturing

Designing a robust industrial augmented reality solution

Executive summary

As Pokemon GO and Ikea Place applications drive awareness of augmented reality (AR), technology companies continue to develop solutions to solve key productivity, quality and efficiency challenges. Manufacturers are looking for innovative ways to solve today's problems, and AR may be the key. Gartner predicts that in 2020, 20 percent of large enterprises will evaluate and adopt augmented reality, virtual reality and mixed reality solutions as part of their digital transformation strategy¹.

Jay Gorajia, Nir Sagi, Eran Nadel, Shai Newman
Siemens Digital Industries Software

Abstract

One of the key challenges to achieving a scalable, robust AR solution is an accurate and reliable visual experience that requires accurate positioning/tracking and visual processing. Tracking is how the augmented reality algorithm can recognize real-world objects in the camera feed, so it can accurately overlay virtual objects onto it. Most of the common commercial solutions that perform tracking today, such as ARCore by Google and ARKit by Apple, use vision algorithms that inspect visual features in the camera feed to determine the exact position of the camera in space, enabling the algorithm to place the correlated 3D model. These solutions allow flexibility and simplicity but are sensitive to environmental factors, such as light and line of sight, and require visual features that are clear enough to achieve accuracy.

This white paper describes the design and implementation of a robust industrial augmented reality assembly instruction and validation solution in which various tracking methodologies are reviewed to address challenges of environmental factors such as light, and the prerequisite of having fixed visual features in an environment. The resulting solution is being tested in a production line at the Siemens Gas and Power factory, gas-insulated switchgear manufacturing line in Berlin, Germany.

Exploring AR applications

The future of manufacturing will include elements of AR. According to an article in Cognizent, innovative companies such as Ikea, Mitsubishi, Toyota, Lego and 10 percent of the Fortune 500 companies have already begun exploring augmented reality applications².

Augmented reality has been around for some time. However, the crossroad of visual processing power, data processing capabilities and compute power has suddenly made mixed reality solutions viable.

programming and commissioning validation, and real-time quality processing and visualization.

Most use cases in manufacturing seem to focus on integrating AR with the production line where it's most feasible to link the physical machinery, robots and parts with 3D graphic models. Some of these use cases include helping a shop floor worker identify the next part in the assembly sequence (figure 2), validating a robotic program using an AR-generated part instead of a physical

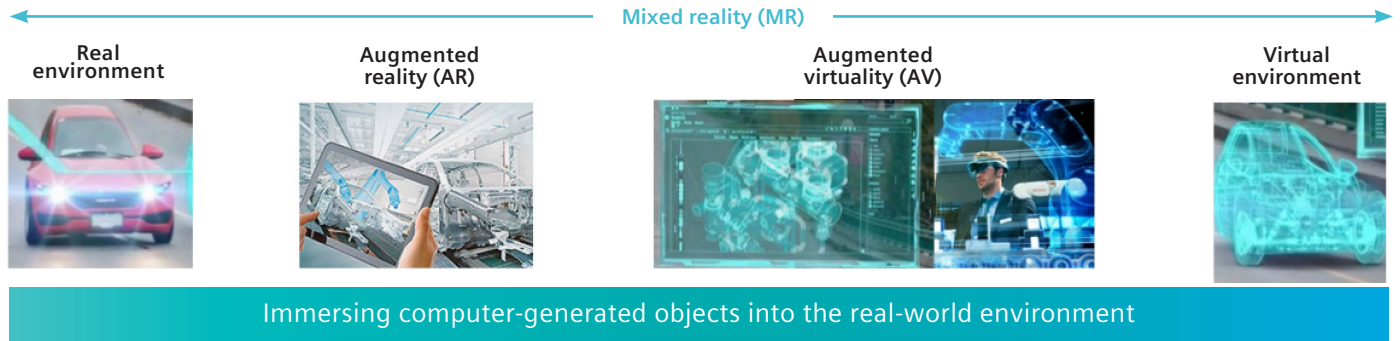


Figure 1. Reality-virtuality continuum.

The reality-virtuality continuum

The notion of a reality-virtuality continuum was first introduced by Paul Milgram, professor of engineering at the University of Toronto, more than two decades ago.

In a paper published in 1994 Milgram describes the concepts of mixed reality in the context of the reality-virtuality continuum³, whereby the space between the real and virtual environment is the mixed reality environment, as described in figure 1.

In the manufacturing context, the far-right side describes what is often referred to as the digital twin of a factory, product and production, whereas the far-left side describes the physical factory floor with workers operating machines based on information on screens or other instruments.

Use cases for augmented reality in manufacturing

There are several use cases in which augmented reality has had a significant impact on manufacturing. These use cases for manufacturing include: assembly instructions and validation of complex assembly, asset maintenance instructions, expert remote instructions and support,

part and overlaying the 3D model on top of the physical part for quality inspection purposes (as-planned versus as-built scenarios). When reviewing use cases throughout the product lifecycle (figure 3), use cases relevant to AR technology are the ones further down the cycle where the digital twin, the virtual model of the product, can interact with the real production line and related products.



Figure 2. Demo on an airplane nose (One Aviation) from the 2018 Hannover Messe trade show, Hannover, Germany.

Model-based work instructions, such as leveraging the design and assembly process data within managed data structures, could easily clarify an assembly process for the shop floor worker by overlaying the design data 3D model on top of the current physical, assembly structure, thus shortening the process cycle time and reducing human error. Another significant benefit for such an AR, a model-based work instruction solution, resides within the automation that comes with model-based work instructions, leveraging the computer-aided design (CAD) model and the process sequence that are byproducts of work done in earlier stages of the product lifecycle. Such a solution should obviate the need to manually create and update documents as part of the work instruction authoring process. It also speeds up onboarding processes as it makes the work instruction product more intuitive.

Another relevant use case that addresses production assembly planning validation includes an AR part precisely mounted on a fixture on the real production line to validate a welding operation program written directly to the robot controller. Such a solution saves time and money on manufacturing a physical prototype, which in addition to its costs and manufacturing time, also might not comply with common standards.

Training new employees on the shop floor on assembly procedures is an AR use case that could accelerate the new employee learning curve and save valuable time for experienced employees who mentor new ones. For quality issues and validation, AR can also be used to validate part manufacturing and assembly structures in an

as-planned versus as-built scenario, in which an employee compares the physical product and the digital twin, which is overlaid for quality purposes.

To address the use cases described above, a scalable, robust solution must be designed that includes accurate and reliable tracking. Tracking is how the augmented reality algorithm recognizes real-world objects, so it can accurately place virtual objects onto it. Most of the common commercial solutions that perform tracking today, such as ARCore by Google, ARKit by Apple and Vuforia, use vision algorithms that inspect visual features in the incoming image stream of the physical object to determine the exact position to place the 3D model. These solutions allow flexibility and simplicity when setting up but are sensitive to environmental factors such as light variances and line of sight and require clear, highly detailed features for the scanned object to gain a high level of accuracy.

This white paper describes the design and implementation of a robust industrial augmented reality assembly instruction and validation solution in which various choices of AR and tracking methodology are reviewed to address challenges of environmental factors, and the need to have visual features in the environment. In addition, the solution validates that a manual operation was performed, which is key to ensuring a robust solution. Simply providing instructions is not enough for critical manufacturing needs. This solution is being tested on a production line at the Siemens Gas and Power factory, gas-insulated switchgear manufacturing line in Berlin, Germany.

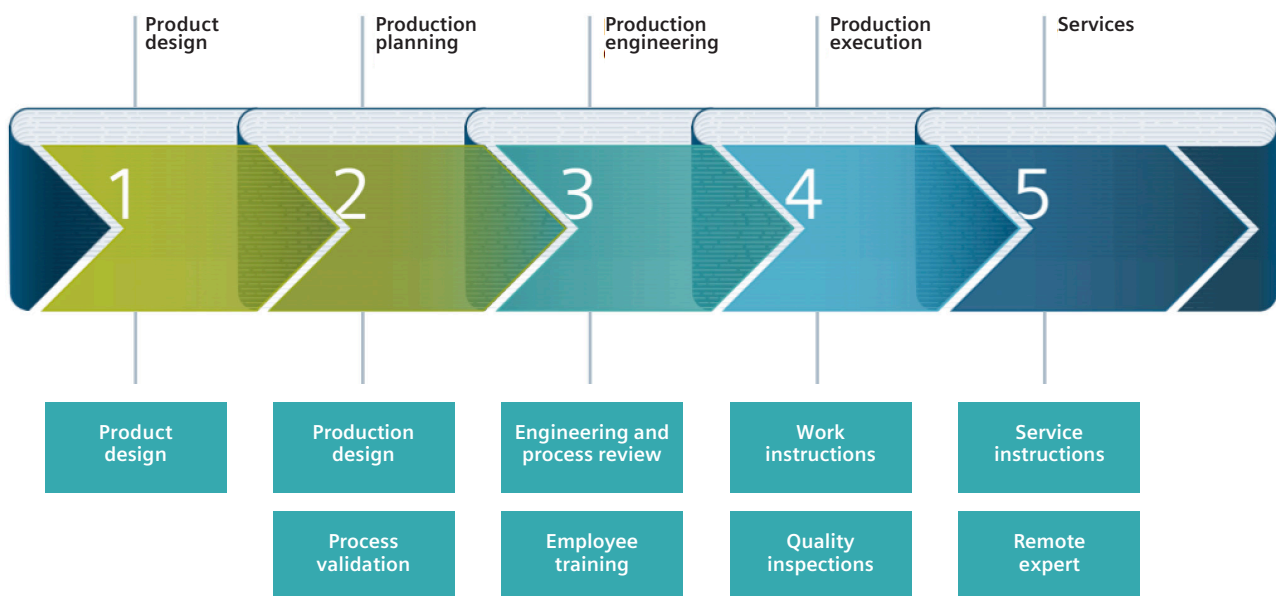


Figure 3. Siemens' holistic product design through the manufacturing value chain.

Technology overview

Current AR solutions are based on two main factors, 1) the type of camera being used and 2) the analysis of visual features within the camera feed. The main demand of such AR solutions is that they require an environment that has sufficient differentiating visual features, which can be defined as trackers. These visual features are identified by computer-vision-based algorithms that allow the user to calculate the camera's location relative to the physical environment and enables augmenting virtual objects over the camera feed of the target physical object to generate the AR effect.

As clear visual features are not always available in the physical environment, the use of visual stickers, also known as markers, help enrich the environment to inspire reaching optimal detection by placing them accurately onsite next to the target object being tracked.

Other popular solutions in use today by the AR market include embedded 3D cameras, which add an indication of depth between the camera and the target object (for instance, integrated in Microsoft's HoloLens head mounted wearable) and improving the tracking mechanism by adding a 3D mapping layer. Another possible solution for accurate AR is to place many cameras that can track physical objects with visual trackers attached to them (usually infrared reflective spheres) and then locating the position of these objects via computer-vision algorithms that process the images generated by the array of accurately calibrated cameras in real-time.

There is an important differentiation regarding AR implementations from a user interface perspective, as current AR developments divide into two major categories, 1) wearable, head-mounted devices and 2) mobile devices. Some major companies in the industry (Microsoft, Magic Leap) are developing and customizing hardware devices that are meant to achieve transparency on the user's mixed reality experience. Other major companies (Google, Apple) focus on their software development kits, intended for developers creating the AR applications and experience on mobile devices.

Challenges

One of the key challenges to developing an augmented reality solution for industrial application is that in most industrial environments (for example, a fuselage of an airplane) there are not always clear visual features on all surfaces, limiting the use of AR. Furthermore, such solutions create a prerequisite for good lighting conditions in industrial environments and are often sensitive to variation between the physical part(s) and the 3D representation in scale, color, etc.

Using visual stickers as markers to enhance the visual features in an industrial environment requires excessive preparation work, is prone to user error and inaccuracy and acts only as a partial solution as it is not always possible to get full coverage using this technique. One of the key benefits to an integrated solution is to overcome data revision issues. Using visual stickers would not solve that problem.

The use of 3D cameras to attempt to map an area and provide a better feed to an augmented reality solution is also a partial solution as there are use cases in which the target environment is covered with uniform surfaces where it's impossible to differentiate between those surfaces based on depth information. Using an array of cameras is also limited, as it is expensive, requires complicated calibration between the devices, adds substantial infrastructure and hardware to the setup, and can create security and layout issues.

The reasons provided above are currently preventing commercial AR solutions based on visual features, markers and high-end cameras from instantly becoming widely used by manufacturers around the world.

When referring to industrial, shop floor use cases, it's also important to address the most suitable hardware devices to use. Wearable devices that give the user an intuitive, hands-free experience also have their limitations. The most significant limitation is the reluctance of workers in the shop floor to put these devices on their heads for long periods of time, as required in production line use cases. They tend to also limit field of view and the related orientation issues that have been identified by many tests and add health concerns.

There are many challenges to existing AR solutions and a new approach is needed.

Solution design

Analysis and technology decisions

After performing an in-depth feasibility study focusing on specific production, shop floor use cases and AR implementations in manufacturing environments, it was concluded the limitations of existing AR solutions has dictated the need for new technology.

All those efforts eventually led to a paradigm shift and development of a new technology we call PointAR. Siemens has recognized that a new generation of low-cost and low-energy laser lighthouses and related sensors have been developed in the virtual reality (VR) industry. However, after testing it was found there is no complementary off-the-shelf software solution for these devices. The reason is VR headset tracking does not require absolute accuracy, but rather consistency and continuity (namely, it is not important if the absolute position is not accurate if the change in movement is consistent). On the contrary, a robust AR solution for manufacturing requires absolute accuracy as it relates to objects in the physical environment. Further calculations and experiments demonstrated that fusing computer-vision algorithms to achieve accurate algorithms can be accomplished by using the same VR lighthouse hardware while generating good results seven meters from the lighthouse and four meters from the target object. This new technology enables us to supply an AR solution that is based on computer-vision algorithms fused with laser lighthouses and inertia sensors that are reliable and inexpensive. The outstanding results and

great feedback from proof-of-concept environments and customers made us understand that PointAR can become a game changer that can eventually move AR technology to the operational stage, introducing a new and powerful tool for advanced manufacturing.

Solution architecture

As a prerequisite for a robust AR solution for manufacturing, the data source must consist of precise 3D CAD data along with metadata that describes additional information on the given process. We recommend an enterprise data management solution to manage electronic CAD, mechanical CAD, process information and metadata related to process dependencies. Normally, this is done at many manufacturing and technology companies by implementing a strong connection with the product lifecycle management (PLM) system. The PLM system may act as a tool to create, store, author and configure the data that is later loaded in the AR solution.

The 3D models materialize via CAD software and dedicated CAD libraries stored in the PLM database in the early product design and production planning phases. Additional metadata related to the production process is added in the production planning and engineering phases before dedicated plugins output the data from the PLM system to the AR solution. The PLM system acts as a configuration management system that ensures transparency between the latest datasets and the AR visualization software.

	Marker/3D model based	Tracker-less	2D+3D cameras	Point AR (patented)
Main vendors	Vuforia	ARCore, ARKit	Hololens	Compedia
Positioning method	Computer vision	Computer vision	Computer vision and 3D data	Computer vision and laser sensors
Accuracy	Low to high (depends on visuals)	Low	Medium	High
Robustness	Low to medium	Low	Medium	High

Table 1: AR software technology comparison.

When designing a new AR solution for manufacturing, one must consider the following components:

- A hardware component that reports the exact location of the camera (mandatory) and optionally other components in the environment
- An interface mechanism that translates and transmits the hardware output to the software layer
- A software layer that uses the location information to apply the AR layer on top of the camera feed, reads and parses the data package exported from the PLM system, and loads the application layer with the required interface for the user

The AR system described should be agnostic to the hardware component that is used to retrieve the location of the camera and other components in the environment. This provides flexibility for the manufacturer to acquire hardware that may be more relevant and cost efficient, delivering the best performance for their manufacturing environment. The tracking is done by connecting a tracker to the camera via a dedicated mounting device so the camera's movement is aligned with the tracker as one complete unit (figure 4).



Figure 4. A PointAR unit equipped with IR-based sensors for tracking and a standard Logitech 4k web camera. PointAR is available in several versions to support different use cases, ranges and accuracy demands.

Additional trackers can be connected to other physical objects in the environment to track their movement. For instance, a tracker can be placed on a fixture in the assembly station to track its movement and maintain the AR experience.

A unique calibration process is done per each PointAR unit to precisely output the offset between the tracker, camera and the connecting unit's tip. This calibration process is essential to accurately overlay the 3D model on top of the physical part, as part of an initial positioning method. On initial launch of the AR application, a simple positioning process needs to be performed in which predefined points selected on the 3D model are matched with points on the physical object and are recorded using the PointAR unit's end tip. This process aligns the coordinate system of the real world with the coordinate system of the 3D model and allows free movement of the camera along with other tracked objects in the environment without damaging the AR tracking experience.

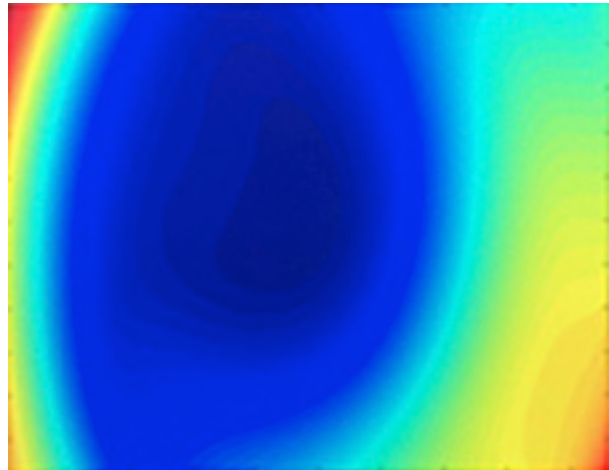


Figure 5. The image represents the system accuracy in different positions of the camera feed. Blue colors indicate the accuracy is better than one mm (from two meters to the tracked object). Green and bright yellow colors indicate accuracies of one to two mm (from the same two-meter distance).

Test methodology

The challenge while developing and fortifying the AR solution was defining how to implement accurate AR in real-time and with low latency. For this, we developed special proprietary graphics processing unit (GPU) based algorithms to ensure we can achieve the required accuracy and performance.

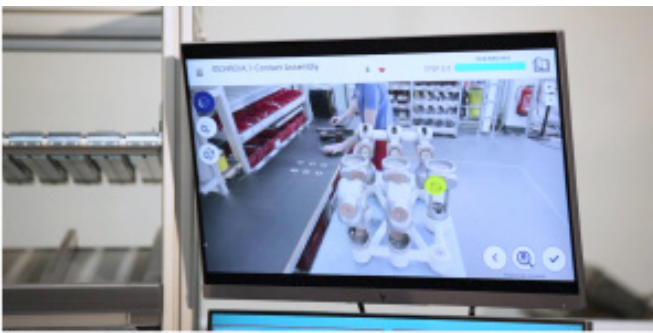


Figure 6. Precise AR image placement (CAD model emphasized in yellow) on complex assembly procedures.

Accuracy testing was done by supporting the zoom and enabling the user to move the 3D overlay image on the projection plan to reach full accuracy. The physical length in the real world for this correction movement can be calculated and then used to define the AR accuracy. In many use cases we have achieved even one to two millimeters (mm) of AR accuracy in real-time while using low-priced sensors and a standard personal computer.



Figure 7. An AR-enhanced work instruction solution for an assembly station at the Siemens Gas and Power factory, gas-insulated switchgear manufacturing line in Berlin, Germany.

Results

A proof-of-concept pilot of the Siemens PointAR solution has been launched at the Siemens Gas and Power, high voltage products series, gas-insulated switchgear

manufacturing line in Berlin, Germany. The project consisted of equipping three manual assembly stations with a full hardware and software solution for work instructions on the shop floor (figure 7). The main motivation for such a solution came from the need for this newly built manufacturing line to quickly ramp up production and accelerate the learning curve of the precise assembly process for new employees without having experienced employees use their time on supervision and guidance.

Next steps

As the AR solution is agnostic to the specific sensors, Siemens is evaluating a variety of sensors for different use cases and requirements. Siemens is also looking for new use cases.

Future planned software updates will include a more-fitted user experience, enabling alignment with suitable wearable devices as they evolve, connectivity with the Internet of Things (IoT) devices on the shop floor, such as Atlas Copco's smart tools, and improved algorithms for supporting the tracking accuracy.

From a business perspective, as the AR-enhanced work instructions solution is now officially part of the Siemens portfolio (figure 8), it is most important to validate other AR use cases and leverage the available infrastructure to provide accurate AR technology throughout various scenarios with good return-on-investment (ROI) on the shop floor.

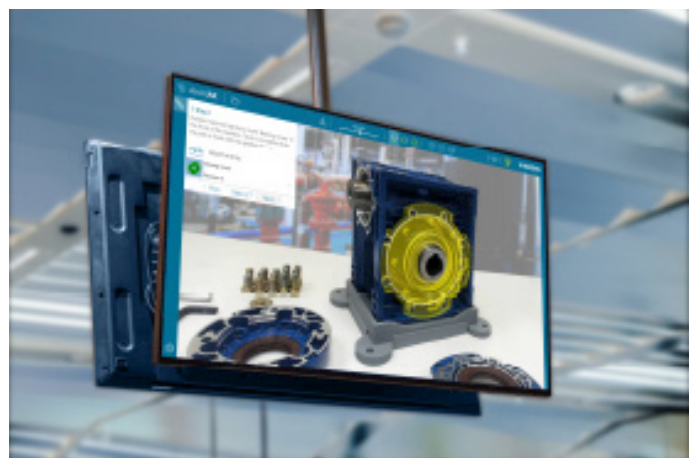


Figure 8. AssistAR is an AR-enhanced work instructions solution.

Conclusion

This white paper describes AR for manufacturing use cases, the challenges with current popular technologies and how Siemens has developed a new approach to implement a robust industrial augmented reality assembly instruction and validation solution. Siemens reviewed various tracking methodologies and developed a unique hybrid, computer-vision and sensors-based solution to achieve an accurate image overlay. This new AR for manufacturing solution, PointAR, yielded a robust solution with one-half to two mm absolute position accuracy and a 0.05 to 0.2 degree of angular accuracy (depending on sensors selected, setting and range). The solution also overcame challenges of environmental factors and the need to have scanned objects in the environment that are not affected by lighting or background. In addition, the solution is accurate enough to validate that a manual operation was performed, which is key to ensuring a robust solution. Simply providing instructions is not enough for critical manufacturing needs. Siemens completed successful initial tests and the AR solution continues to be tested on a production line, the Siemens Gas and Power factory, gas-insulated switchgear manufacturing line in Berlin, Germany.

References

1. Griffen, Bryan. "Augmented Reality and the Smart Factory." [www.manufacturing.net](http://www.manufacturing.net/article/2019/04/augmented-reality-and-smart-factory), April 12, 2019, www.manufacturing.net/article/2019/04/augmented-reality-and-smart-factory.
2. "Building the Business Case for Augmented Reality." Building the Business Case for Augmented Reality, Cognizant, June 19, 2018, www.cognizant.com/perspectivesbuilding-the-business-case-for-augmented-reality.
3. Milgram, P., Takemura, H., Atsumi, A, and Kishino, F. , "Augmented Reality: A class of displays on the reality-virtuality continuum," in *Telem manipulator and Telepresence Technologies in SPIE 2351* (1995): 282–292.

Siemens Digital Industries Software

Headquarters

Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 972 987 3000

Americas

Granite Park One
5800 Granite Parkway
Suite 600
Plano, TX 75024
USA
+1 314 264 8499

Europe

Stephenson House
Sir William Siemens Square
Frimley, Camberley
Surrey, GU16 8QD
+44 (0) 1276 413200

Asia-Pacific

Unit 901-902, 9/F
Tower B, Manulife Financial Centre
223-231 Wai Yip Street, Kwun Tong
Kowloon, Hong Kong
+852 2230 3333

About Siemens Digital Industries Software

Siemens Digital Industries Software is driving transformation to enable a digital enterprise where engineering, manufacturing and electronics design meet tomorrow. Our solutions help companies of all sizes create and leverage digital twins that provide organizations with new insights, opportunities and levels of automation to drive innovation. For more information on Siemens Digital Industries Software products and services, visit [siemens.com/software](https://www.siemens.com/software) or follow us on [LinkedIn](#), [Twitter](#), [Facebook](#) and [Instagram](#). Siemens Digital Industries Software – Where today meets tomorrow.

[siemens.com/software](https://www.siemens.com/software)

© Siemens 2019. A list of relevant Siemens trademarks can be found [here](#). Other trademarks belong to their respective owners.

81106-C4 12/19 A