XR Technology Brings about Innovative Changes in Manufacturing

As customer needs are diversifying, product specifications and manufacturing processes are becoming increasingly complicated, and at the same time, the passing on of skills by experienced workers has become an issue. Therefore, we are required to further promote the deepening of internal and external communication, as well as further improving interdivisional cooperation, quality assurance, cost reduction, and compliance with delivery dates. To solve this challenge, we are working to stimulate communication through the utilization of XR (Cross Reality) technology using 3D model data obtained through digitalization, with the aim of standardizing our work and eliminating the dependency on specific individuals.

Introduction

Recently, increasingly diverse customer needs have necessitated that we, as a manufacturer, offer products to meet such various needs.

1 Background

In response to increasingly diverse customer needs, we manufacturers must know our customers well, so communication with users is important. Our products encompass a wide range from mass-produced products to build-to-order products, and it is important to ensure quality (Q); to streamline work to reduce costs (C); and to ensure compliance with delivery dates (D) in each process. Therefore, we further must improve work processes (business process improvement) and standardize work. With regard to the passing on of skills by experienced workers, we need to ensure close communication between veteran and young workers as well as quantify, standardize, and digitalize veteran workers' tasks to eliminate dependency on specific individuals.

2 Policy and processes for solving challenges with XR technology

One way to solve such challenges is to utilize digital technology or to promote so-called DX (digital transformation). For example, if we can digitalize human movements and skills, which has been considered difficult, as well as product information, manufacturing information, and technical information, as data, it will become possible to represent them quantitatively. This will enable us to visualize our work processes and to improve them more deeply, thereby achieving standardization without depending on specific individuals. Also, using digital data in an integrated manner across diverse processes facilitates more active, deeper communication between departments as well as users. This will enable different processes to work in collaboration or to work concurrently.

3D model data is the type of digital data most commonly used in the field of manufacturing. 3D model data is created mainly by the design department with 3D CAD, and it is available throughout the value chain. Such data enables visualization of products, production equipment, and working environments, including jigs. Even at an early stage in which no actual product exists, 3D model data enables relevant personnel to share images of a product, making it quite useful for invigorating communication and improving work processes (business process improvement). XR (Extended Reality) technology is a means of utilizing information visualized with 3D model data with a high degree of realism.

XR technology is a generic term for VR (Virtual Reality), AR (Augmented Reality), MR (Mixed Reality), and other technologies. VR is a technology that enables users in a virtual space generated by computer graphics or other technology to feel as if they were in a physical space. AR and MR are similar technologies that present virtual objects and information in physical space. In particular, MR is characterized by the fact that a virtual object can be presented consistently at the same location in physical space by obtaining location information. XR is often used in the fields of entertainment, education, and virtual exhibitions, and it generally requires expensive hardware and software as well as large facilities. Recently, however, XR has become more readily available because of lower user interface prices and simplified operations.

XR enables us to verify work in advance and to issue accurate work instructions that can be understood intuitively. For example, when implementing a measure to reduce mistakes, improving a production process, or verifying in advance the actual work conditions, then effectiveness can be verified in advance through a virtual experience. Even when a product or service is in development, so long as 3D model data is available, an image of the product or service can be shared through visualization that involves not only the sales, design, manufacturing, inspection, and servicing departments but also the customer, thus facilitating communication. Previously, we developed an evaluation method that combines ergonomic assessment with VR and applied it to the design of train operator seats [1, 2]. At that time, both the hardware and software were expensive, so we could not apply the method to other divisions, but now their prices have fallen, making XR more readily available.

3 Example applications of XR

The following gives three examples of applying XR. The first example describes how VR was used in welding work to enable workers to verify their own work in advance, thereby reducing trouble during such work. The second example describes how MR was used to enable workers to carry out complex work without needing to hold the instruction sheet in their hands, thereby enhancing work efficiency and quality. The third example describes how XR was used in upstream processes, thereby enhancing design efficiency.

(1) Advance verification of welding work with VR

(i) Background

The Production Division of the Energy Solution & Marine Engineering Company develops production technologies to manufacture various products, including gas engines, steam turbines, aerodynamic machinery, and propulsion machinery. Among others, welding work is an important process for forming an enclosure that supports the product structure. In the past, we studied work details by imagining finished products based on 2D drawings issued by the design department. We were sometimes forced to start production while still unconfident about work feasibility. In fact, we experienced a problem in piping installation work in which a part could not be inserted due to insufficient space, and accurately simulating work in advance was a challenge. In addition, when we wanted to request a design change to the design department while studying the details of the work, we had difficulty communicating with the design department because we had no good way to share images.

(ii) Actions

We came up with a method to assess and improve work feasibility and to alleviate difficulties in advance by viewing the product's 3D model data in VR as shown in **Fig. 1** and verifying the workability of the work areas we were concerned about in a VR space that provides an environment similar to the actual one. We received positive feedback from field workers that they could work at ease because they could experience the work in advance.

By applying this method several times on a trial basis, we received helpful improvement proposals from workers and VR verification took off. This led to the establishment of a dedicated room for VR so that workers could easily verify their work at any time.

For example, we verified piping welding work in a narrow space in a steam turbine as shown in **Fig. 2**, and

Fig. 1 Advance verification of welding work with VR technology

Fig. 2 Steam turbine (for power generation)

we used VR to confirm that during such welding work, visibility was lower than expected. The manufacturing side then proposed to the design department a modification to the structure around the piping, and VR was used to explain this proposal. Use of VR enabled the engineers to understand the actual welding work and led them to judge that the design change was necessary. Also, the piping was originally planned to be divided into several parts before welding, but this proposal eliminated the need to divide the piping in advance. This department works on many made-to-order products, so workers are often forced to do work that they have never done before. Verifying such work in advance with VR enables high-level work planning and is highly effective in rectifying production processes and eliminating the need to plan work with actual products as was done previously, thus contributing to reducing costs and stabilizing quality.

Advance verification with VR has been well-received by design and manufacturing departments. We are working to establish it as a standard process in work planning, including recording of VR verification's purpose, timing, procedure, and judgment results as a work process.

(2) MR work instruction system

(i) Background

The Aerospace Business Division manufactures major commercial aircraft parts such as front fuselages. One of its many production processes is drilling holes necessary to mount parts. Most holes are drilled with automatic machines, but those that cannot be drilled by automatic machines are drilled manually by workers. Hole drilling work employs drill jigs to ensure the location accuracy and quality of each hole. Drill jigs are secured with index pins in the reference holes drilled in advance on the fuselage. Template sheets made of semitransparent polyester film are used to set multiple drill jigs on the fuselage's side. Template sheets have a height of 4 m and a length of 10 m, and their cutouts have the same shape as the jig. The worker aligns the jigs with the cutouts. Making a template sheet costs a lot, and the sheet must be modified if a design change is made or repaired if it gets damaged Also, setting a template sheet requires several people and 20 to 30 minutes. For these reasons, we wanted to improve this work, but we could not find an alternative to template sheets.

(ii) Actions

XR has become more readily available, so we studied a method to use MR to issue instructions on how to set the jigs without using template sheets.

We used Microsoft's HoloLens as a head-mounted display (HMD) for MR. HoloLens projects images onto a permeable screen and enables the user to see virtual objects in physical space. It has cameras and sensors to measure the areas around the HMD to obtain self-location information. This makes it possible to superimpose virtual objects on physical objects. We developed an MR work instruction system that tells workers where to set the jigs with HoloLens as shown in **Fig. 3**.

We conducted an element test in 2017, and we developed a prototype system in 2018. With the prototype system, we found that with respect to HoloLens's display location accuracy, error increases as the distance from the reference position increases, and the error is about 1% of the distance from the reference position. Many users commented that they felt uncomfortable when wearing HoloLens because of the poor weight balance of the first

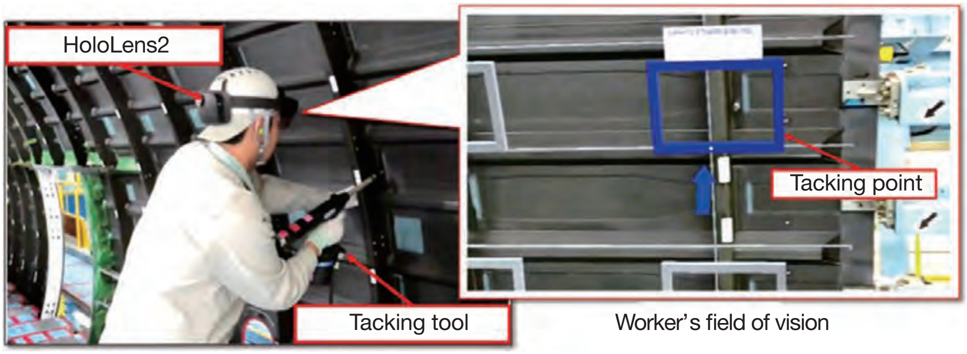

Fig. 3 Tacking work using MR work instruction system

version, which we used initially. In addition, the battery lasted only about two hours, which was a concern for practical use. However, the prototype system was well-received by the users, or field workers because instructions were displayed directly on the fuselage and could be understood easily and intuitively.

In 2019, we worked to solve the aforementioned problems. To improve accuracy, we set markers indicating the reference position, thereby achieving the display location accuracy required to set the jigs. Also, late 2019 saw the release of HoloLens 2, which featured a modified shape to improve wearing comfort. As for the battery life problem, we concluded that it could be addressed by improving usage and using multiple batteries. At the same time, we developed the MR work instruction editor shown in **Fig. 4**, which enables manufacturing engineers to create instructions. The MR work instruction editor does not require programming skills, and new work instructions can be created as usual.

The completed MR work instruction system supports HoloLens 2 and uses QR codes as markers. Field workers commented that with the wider viewing angle and improved wearing comfort, using the system in place of template sheets is no problem.

Though this system was developed for setting jigs, we studied its applicability to other types of work. In tacking work for temporarily joining frames, tacking is performed from inside the fuselage in the specified sequence. The MR work instruction system eliminates the need to view the instruction sheet during the work. This makes the work easier to perform because the worker only needs to hold the tool. In addition, HoloLens 2 displays each instruction directly on the outer surface of the fuselage, and the next tacking position is indicated by an arrow, preventing the worker from making a mistake in the work sequence. Also, this system has a check function that prevents the worker from proceeding to the next task until the specific task is completed, thus preventing omissions. We will apply this system to inspection and machining processes as well as other models. In addition, we are considering linking this system with the system for registering work records in the core system. We are also applying this MR work instruction system to other divisions throughout the company.

(3) Co-creative design with XR

To create products that meet diverse customer needs, we must verify various ideas, including original ones, not

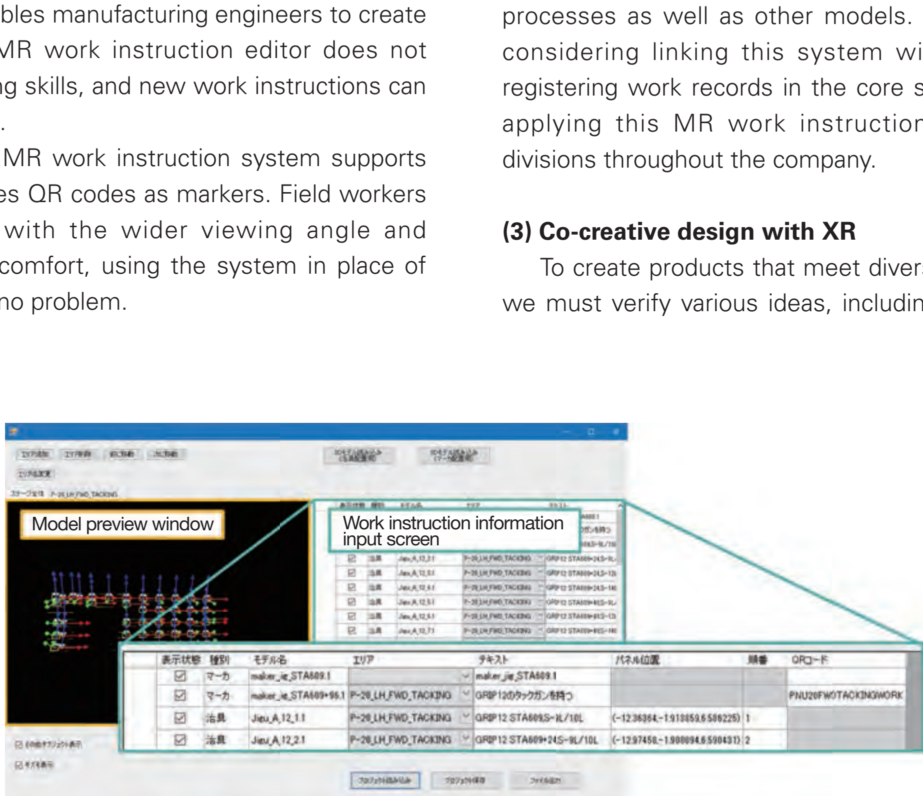

Fig. 4 MR work instruction editor

only in the design and development stages but even in the planning stage. Such activities should not be constrained by location, and we must proceed with verification even if there is no actual product yet. We are working to utilize XR to promote "co-creation," which refers to collaboration between customers and other external stakeholders and internal stakeholders in order to create new value. With XR, we will invigorate communication to strengthen our design capabilities.

In motorcycle development, for example, the rider's operations are input into a digital model of the vehicle from the riding simulator by the riders themselves, and the behavior of the running vehicle can be obtained through numeric simulation. Use of XR enables riders to experience motorcycles as if they were actually riding them as shown in **Fig. 5**. In addition, various data, including vehicle deformation and stress, can be obtained by executing multiple simulations simultaneously. With XR, the results of such simulations can be visualized and presented to the user in real time. This enables us to quickly obtain feedback during idea verification and decision making. Also, if it is possible to visualize information from the sensors incorporated into a product with XR even after the product is put on the market and to share actual product usage with development personnel, it will become possible to improve the product and to develop follow-up products based on customer usage.

To realize co-creation, we are also using XR to develop autonomous delivery robots. We are considering various operating scenarios to determine the specifications of these autonomous delivery robots. At this time, verifying all operating scenarios takes significant time and money. In addition, for market-oriented development, there is a need to share usage scenarios with users and to obtain comments directly from such users to quickly assess customer needs. We are using XR to do this.

Fig. 5 Co-creative design

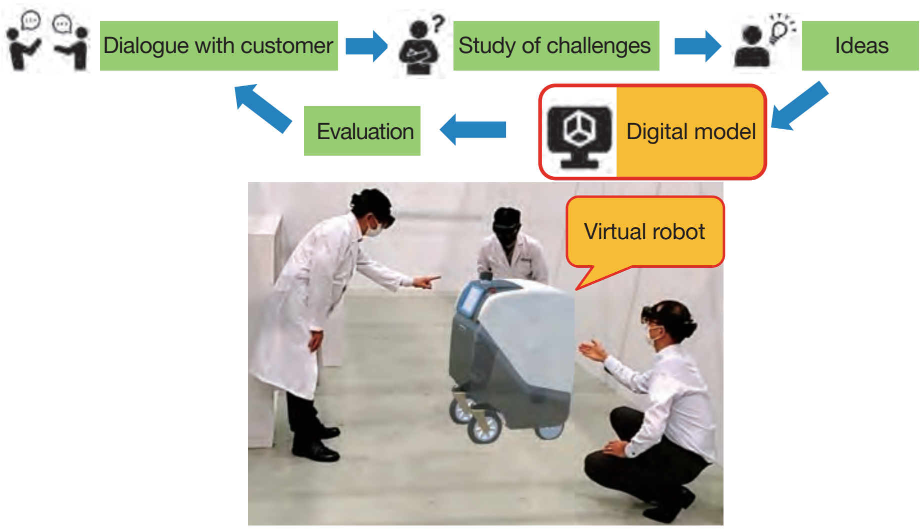

Fig. 6 Market-oriented development using XR

If a delivery robot is developed for use in hospitals, operational simulation must be carried out in a space in which the delivery robot and humans co-exist. Therefore, with MR, the delivery robot is superimposed onto the space as shown in **Fig. 6** to reproduce the co-existence of the delivery robot with humans. The delivery robot's behavior is then computed by simulation, and the behavior is reproduced with MR. This enables the evaluator to verify the behavior of the humans and the virtual robot in physical space with a high degree of realism. Since the robot is virtual, even if the hardware or software is modified, new behavior can easily be reproduced. This activity enables us to promptly confirm customer specificati on requirements, thereby knowing actual customer needs. Currently, we are verifying the utilization of delivery robots in hospitals.

Conclusion

We will further enhance QCD (Quality, Costs, and Delivery) by utilizing XR technology while promoting internal and external communication to meet diverse customer needs. Through such activities, we will offer products and services more speedily.

References

1) Takahashi, Tanaka, Nakamura, Takeda, Hamada, Tada: "Design Development to Improve Customer Satisfaction," Kawasaki Technical Review, No. 177, pp. 33-38 (2016)
2) Patent No. 6045338, "Posture sensation system and posture evaluation system"

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