# Applications of Virtual Reality in Industrial Repair and Maintenance

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## Abstract

Virtual reality technique is generally considered as a natural extension to 3D computer graphics. This technique has matured enough until today to guarantee effective industrial applications. The virtual reality (VR) technique with up-to-date software systems supports various industrial applications such as design, engineering, manufacturing, operations and maintenance. The integration between virtual reality and industrial operations provides necessary support to develop cost efficient production system with sophisticated maintenance management. This paper highlighted the generic concept of the application of virtual reality technique in industrial maintenance. An application case on virtual reality technique in power plant operations and maintenance is demonstrated within the scope of this research. Overall research implications on virtual reality concept in various industrial applications are concluded with future research directions.

## Keywords
Virtual reality, industrial maintenance, robotics, case study

## 1. Introduction

There is a growing interest on business process reengineering with the objective to overcome problems and deficits in manufacturing industries. In order to face in today's business problems such as integration in international markets, product complexity, increasing number of product variants, reduction in product development time and cost, etc. To compete with global business market companies need to develop product or services, which can be easily repairable. Such need can be augmented through proper and efficient maintainability. Maintenance is an important part in the product life cycle. In a narrow sense, maintenance comprises of removal of faulty system components and replacement or repair of these components. In maintenance work, the reliability and confidence of an engineer is fundamental to effective maintenance system. Therefore, proper training of maintenance engineers has been identified as the fundamental technique to improve the quality and reliability of the maintenance work (Buriol et al., 2009).

Over the years, researchers have proposed various approaches to maintenance activities. One of them is considered 'virtual reality' as the way to provide industrial maintenance (Frampton, 1995; Canetta et al., 2011; Choi et al., 2015). This VR approach employs a computer-generated environment to simulate interaction with real system. With VR system different technologies can be integrated with the objective to allow users to interact with the virtual scenario in a multi-sensory manner. The VR system provides a range of benefits compare to traditional learning and training (Gomes de Sa and Zachmann, 1999). It provides training under learning-by-doing approach (Golambos et al., 2015).

VR has been applied widely in real world, non-trivial problems. There are several commercial 3D engineering tools for digital mock-up but all of them lack one thing: intuitive direct manipulation of the digital mock-up by human (Canetta et al., 2011). Therefore, available commercial 3D engineering tools are inherently inferior to VR for specific applications. VR technique as a tool has already begun to routinely use in different business domains. It is widely used in styling and design reviews in the conceptual phase of product development, but not been elaborately and efficiently used in products operations and maintenances.

## 2. Theoretical framework

Product development processes have to be more systematic in order to be efficient and economically competitive. The advancement of computer technology contributes to movement from mass production to the production of a variety of goods in small quantities. Today's customers' needs are mostly on one-of-a-kind products, which can easily accommodate an individual customer's needs. To fulfill such need, VR technique can be employed successfully (Choi et al., 2015; Golambos et al., 2015). The application of virtual reality technique can be helpful to simulate and improve product development processes before they are actually carried out in real-life manufacturing environment. This technique ensures the product development activities such as design, planning, machining, etc., is performed well advance without the need for subsequent modifications and rework (Gutierrez et al., 2012; Golambos et al., 2015).

Research on the application of VR is a strong and fast growing area. It is well known technology and is currently being investigated for practical use in various industrial applications. The application of VR in manufacturing processes as well as product and process development can lead to shorter developmental time with reduced cost and improved quality (Nomura and Raton, 1999; Golambos et al., 2015). The objective of VR is to create a system that is as perfect as the real world, if not better and more efficient. The concept of virtual manufacturing is evolved from VR, which has greatly changed traditional manufacturing industries (Gomes de Sa and Zachmann, 1999). VR technique enables customers to examine a design and make changes at the initial phase of the product development process. In addition to design, prototyping, and layout planning, VR technique applies in teleoperations, operator training and entertainment (Frampton, 1995; Golambos et al., 2015). This technology is offers a cost-effective means of supporting the development of human skills and training in various fields from automotive engineering to defense, surgery to education, retail, petrochemical exploration, and heritage to micro-robotics.

Applications of VR in industrial environment can be found in literature from past several decades. For instance, VR is successfully applied in such as automotive industries (Gomes de Sa and Zachmann, 1999), video game (Gawade et al., 2018), health science (Christian et al., 2017), education and training (Lim et al., 2019), etc. Although, in literature vast amount of researches have been found on the applications of VR in multi-directional fields, however, very limited amount of works are found in the operational maintenance and training. This research gap is mainly focused within the scope of this study. The development of VR-based maintenance and training can be used cheaply and efficiently in industrial applications.

## 3. Virtual reality to enhance operations and maintenance

Virtual operations and maintenance requires the integration of multiple domains and it is important to synchronize related technologies to enable industrial applications of virtual maintenance. It is envisioned that the VR system will converge as new maintenance system in virtual manufacturing environment. This virtual environment will allow the maintenance engineer to virtually maintain the product to make it operable. The virtual maintenance system offers relevant training and learning to the maintenance engineer with an easy and flexible way. This paper describes work related to VR for industrial maintenance, the design of a virtual maintenance environment and preliminary results from the use of this environment. For this research work, VR is defined as the use of computer-generated virtual environments and associated hardware and software systems to provide the user with the illusion of physical presence within that environment.

VR technologies that allows for virtual operations and maintenance are not yet fully utilized by industry. Although VR is growing rapidly but it is not completely understood in regards to its applications within manufacturing industries. It is considered as a key component of virtual manufacturing, where the use of computer tools assist with maintenance-related engineering solutions by analysis, visualization and presentation of activities without physical realization of the supporting processes [2]. Virtual maintenance (VM) is assisted by several technologies such as advanced visualization, simulation, decision theory, maintenance procedures and maintenance equipment development.

As mentioned above, virtual maintenance technologies cross multiple domains and technical structure. These technologies are needed to be synchronized to efficiently support the virtual maintenance. The functionality and acceptance of VM is mainly dependent on the following issues:

- How the virtual maintenance activities enable corresponding maintenance engineer to achieve a cohesive view of maintenance issues?
- How the VM activities supports corresponding maintenance engineer to decision-making process?
- How the relevant supporting technologies can be successfully implemented to real mechanical maintenance needs?
- How efficiently and comfortably the maintenance engineers to perform the relevant tasks can use the developed system?

It is important that designers thoroughly analyzed the manufacturability and maintainability of the new products during early design phase in order to avoid high developmental cost. This design realization supports the user to have high confidence during virtual maintenance system. As the virtual maintenance is developed, the exploitation of the knowledge and information is required to mapping VR and CAD descriptions to maintenance plans. This abstract maintenance model contains sufficient maintenance information such as component sequence, feature datum's, maintenance trajectories, component orientation and tolerance data to support decisions in maintenance process selection and enabling more detailed process definition.

## 4. Framework for virtual maintenance environment

The framework necessary to create virtual maintenance environment can be outlined as in Figure 1. From Figure 1, it is noticed that the framework is consisted of five layers namely, database layer, product data model and management layer, resource and maintenance layer, virtual reality system layer and monitoring and evaluation layer. Each layer contains its own significance and characteristics.

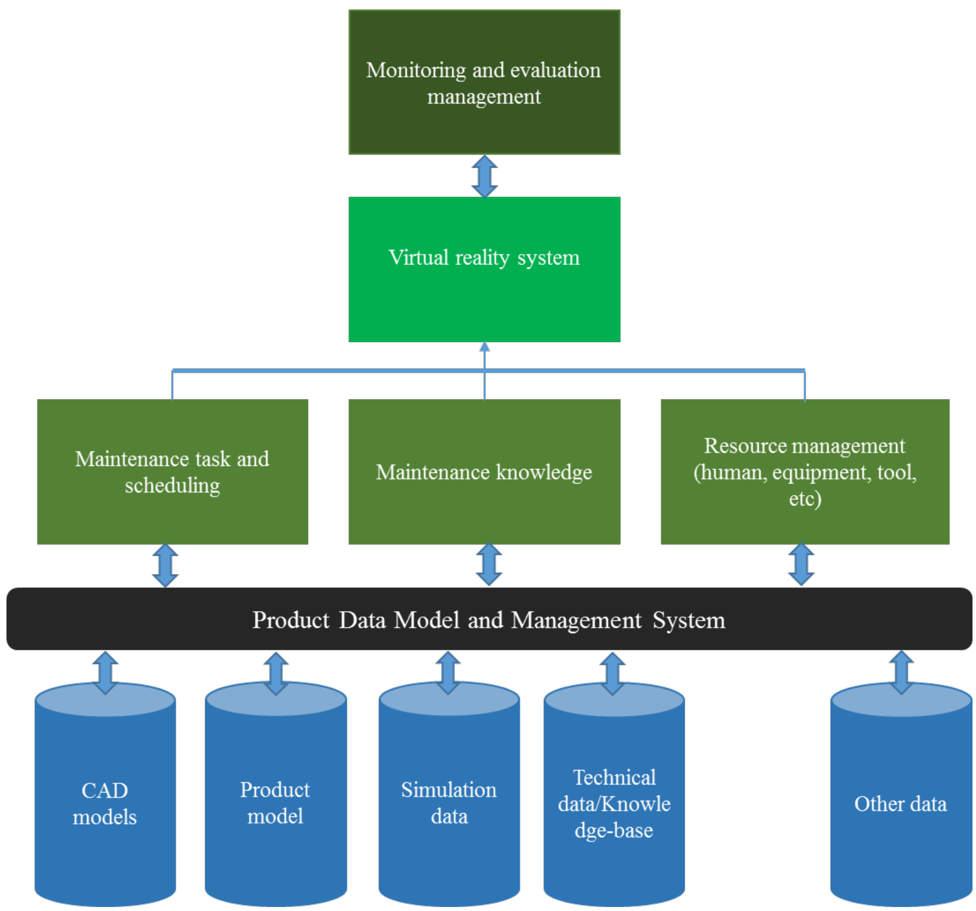



Figure 1. Framework for virtual maintenance environment (adapted from Gomes and Zachmann, 1999)

Database layer consists of various database as necessary to execute virtual maintenance environment. This layer may contains critical databases like CAD model, product model, simulation data, technical data/knowledge-base and other relevant data. Each of the data model has its own contents and significance. For instance, CAD model contains detailed information related to a design of a product including dimensions, 2D or 3D features, etc.

In the product data model and management layer, all the databases are stored and retrieved according to necessary. All such data can be converted, reduced and prepared for use in VR maintenance system. This data as stored at this layer also maintains administrative data together with other relevant data.

In the third layer, where relevant information on maintenance activities are stored. At this layer three different modules namely maintenance task and scheduling, maintenance knowledge and resource management are presented. This layer maintains the repair and maintenance activities of the virtual maintenance environment. It maintains the relevant schedule for maintenance tasks, store maintenance knowledge and arrange necessary resources (human, tools, equipment, etc.) to perform repair and maintenance tasks efficiently.

The fourth layer known as virtual reality system executes the basic virtual reality system, which is considered as the backbone of virtual maintenance tasks. At this layer, necessary engineering model of the intended product including geometry, physics and quantitative or qualitative data from the real product. Through this layer, the user would be able to virtually walk through the operating system and be able to response any changes in the design, operation or any other necessary modification of the product.

The final layer responsible to overall monitoring and evaluation of the virtual maintenance environment. From this layer the progress of maintenance work along with its bottlenecks or difficulties are monitored. In case of any abnormalities, this layer interact with virtual reality system to overcome the associated problems.

The framework as highlighted here can be useful to form and operate any format of maintenance activities executed virtually. This framework supports manufacturing companies through bridging the communication gap among operational activities. It integrates the complete data pipeline from the CAD systems to the VR system for necessary maintenance activities. Furthermore, this framework carry over necessary data from the product data model and management system.

## 5. Virtual prototyping to enhance VR maintenance environment

In order to promote VR maintenance environment it is essential to develop prototype. Through creating the prototype of the product or process, it is possible to reduce the virtual maintenance work well ahead. However, building the prototype is often very time consuming and expensive as well. Moreover, this prototype does not always offer enough material and dynamic functionality for testing and validation process. The fundamental objective of virtual prototyping is to replace a product or process by using the CAD data of the product or process in combination with available virtual reality tools. This virtual prototype at least to some extend represents the physical prototype.

The virtual prototype offers added benefits to companies. It provides a simulated product or process that can be quickly reproduced and easily modified according to the need. In general, by using simulation systems the designs of products or processes are evaluated. Nevertheless, physical prototyping or mock-ups are still applied in most of the cases. In case of virtual prototyping, virtual reality technique is used to present the digital data realistically and manipulate it intuitively. The main functional requirements of virtual prototyping are to provide a 3D virtual maintenance environment. The overall schematic of a VR-based maintenance environment is displayed in Figure 2.

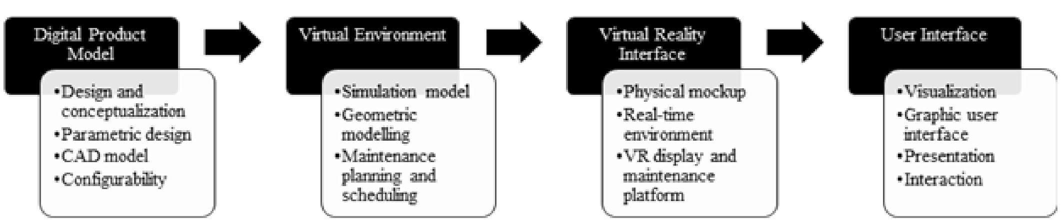



Figure 2. Schematic diagram of a VR-based environment

From Figure 2, it is noticed that VR-based maintenance environment consisted of four phases namely, digital product model, virtual environment, virtual reality interface and user interface. Each of the phases contains its tasks. For instance, digital product model contains tasks as design and conceptualization, parametric design, CAD model and configurability, whereas, virtual environment phase contains simulation model, geometric modelling, maintenance planning and scheduling tasks. Similarly, virtual reality interface consisted of tasks as physical mockup, real-time environment, VR display and maintenance platform, while user interface phase contains of visualization, graphic user interface, presentation and interaction tasks.

## 6. Virtual reality design environment

The VR maintenance system can be defined as a system that is implemented to address a specific maintenance scenario representative of actual issues facing an industry maintenance facility. It is consisted of virtual reality hardware and software, which allow the designer to be immersed in the environment. This system provides the maintenance engineer with high quality, stereoscopic graphics by using a head-mounted display. The movement of the head is monitored and controlled by electromagnetic positioning devices that automatically allow the user to look around. The head movements are tracked by the hands of the user with the help from additional positing devices. These movements are used to create and manipulate a model by the hands in the virtual environment. To monitor the movement of the fingers and wrist, an instrumented glove is used by the user. The maintenance personnel would be able to use such virtual maintenance environment to select optimal maintenance sequencing, evaluate required tolerances, create maintenance plans and visualize the results.

### 6.1 Creation of virtual environment

The challenges until the recent years for VR glasses have been the medical issues related to the effects on human eyes and head. In addition, moving towards the virtual reality world have been missing proper methods. There are several commercially reasonable options are available in the market today. For instance, HTC VIVE and Oculus Rift came to the market during summer 2016. At the same time, the major game engines become compatible with the VR glasses. Of course, the main software solution for the glasses are from game industry.

The manufacturing design tools that have been developing to support to the VR same time. The support for VR in ABB Robot Studio (http://new.abb.com/products/robotics/robotstudio) was released in summer 2017 and Visual Components software (http://www.visualcomponents.com/) usable for VR environment also have been released by ABB company (www.abb.com) at its early release for VR as well (confidential).

The more convenient way to build initial models for factory VR demos is to use the game engines like Real engine of Unity. The 3D models can be imported from the 3D design tools and the factory layout can be built using the game engines.

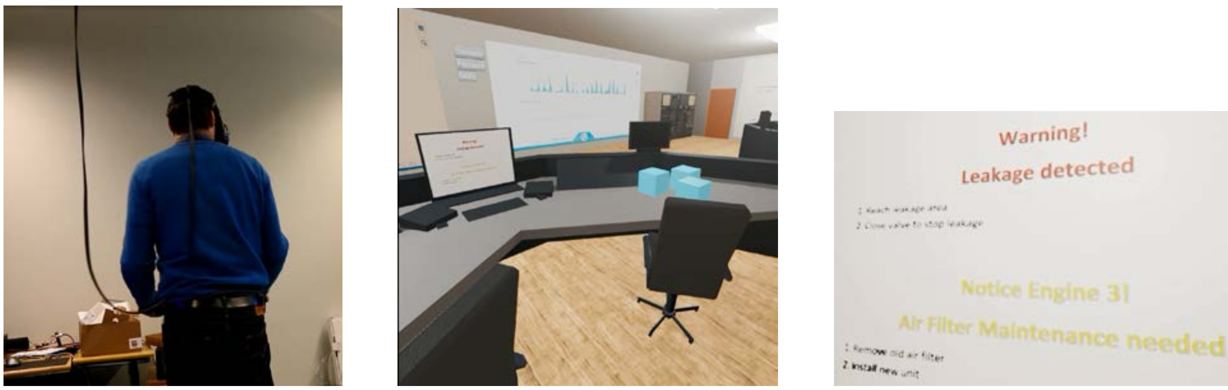
### 6.2 Calibration of virtual space

Once the user uses VR glasses there needs to allocate free space for short movements. User is using teleporting for longer movements to reach the devices for service needs in the virtual world. Once the user is close enough to the specific area within the free space, fine-tuning of the user's movements is done by walking. HTC VIVE uses two lighthouses (https://en.wikipedia.org/wiki/HTC_Vive) using laser technology to place the user and the remote controllers in the virtual world. The glasses are covering all the view of vision but the user can use front-facing camera that enables the user to monitor their surroundings without removing their headset (https://en.wikipedia.org/wiki/HTC_Vive).

## 7. Virtual reality for industrial maintenance: a case study

With the objective to demonstrate the application of virtual reality in industrial operations and maintenance, a case example is presented in this section. This demonstration offers an exclusive guideline to operation and maintenance of a case company's product. The case company is engaged in global energy business and its product is power generation engine, which can be operated by either diesel or gas as fuel.

This demonstration is especially orchestrated to present the systematic methodology to perform virtual operational maintenance within the case company's product. Figure 3 (a, b, c) highlights the maintenance engineer with VR control, virtual control room (where necessary maintenance works are scheduled on a dashboard), and display of faults respectively. Any operational abnormalities are displayed over the dashboard as seen in Figure 3(c). From Figure 3(c), it is seen that displays a warning notice on leakage detection and air filter maintenance needed. The dashboard works as the base of monitoring all the status update of each workable process in the case company. Both the maintenance works are controlled and managed virtually.




(a) Virtual maintenance by an engineer (b) Virtual maintenance dashboard (c) Display of faults summary

Figure 3. Demonstration of virtual reality in industrial maintenance work

The necessary maintenance work at the engine room associated with the detection of leakage is displayed in Figure 4 (a, b, c). From Figure 4 (b) it is seen that the detected leakage was controlled virtually by closing the valve. Figure 4 (c) also notified that the necessary maintenance task to close the valve is completed. Both the status updates are displayed over the virtual dashboard accordingly.


(a) Display of engine room (b) Display to close the valve (c) Display of task completion

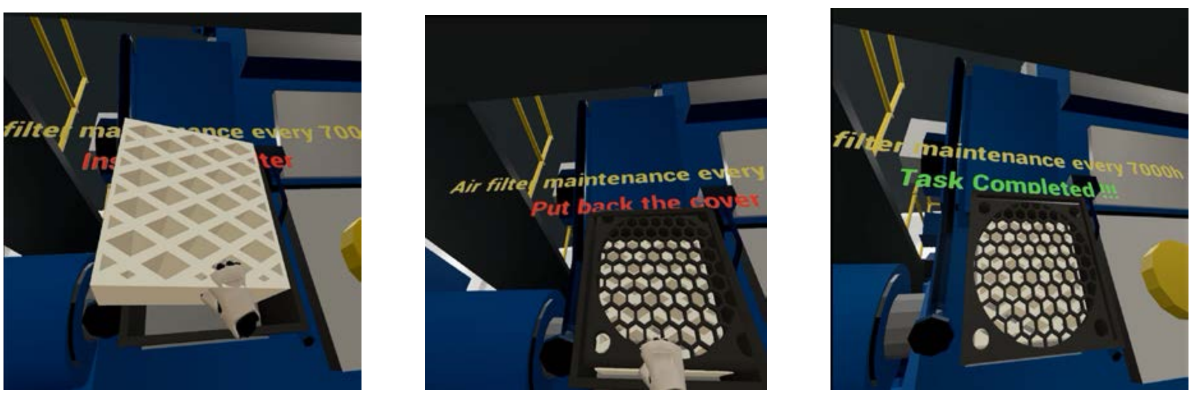
Figure 4. Display of virtual maintenance task related to leakage control

Second maintenance task related to maintaining the air filter is displayed in Figure 5 (a, b, c). This maintenance task is accompanied by displaying the required command or guideline. For instance, Figure 5 (a) displays the command to 'remove the cover', which is necessary before removing the dirty filter. Figure 5 (b) displays the command 'remove dirty filter', while Figure 5(c) shows the command on 'install new filter.


(a) Display of cover removal (b) Display of filter removal (c) Display of filter installation

Figure 5. Display of virtual maintenance task related to change dirty air filter

When the dirty filter is removed as shown in Figure 5(c), a new filter is replaced as displayed in Figure 6(a). After properly installed the new filter, it is necessary to put back the filter cover as shown in Figure 6(b). After completing the installation process the task is considered as completed as dispalyed in Figure 6(c).




(a) Display of new filter (b) Display of put back the cover (c) Display of task completion

Figure 6. Display of virtual maintenance task related to install new air filter

This complete case demonstration shows the importance of virtual maintenance to the manufacturing and maintenance engineers. It provides the systematic guidelines to required maintenance work virtually. This virtual maintenance work is especially important to the maintenance engineers with respect to training and learning perspectives.

## 8. Conclusions and future research direction

The virtual reality platform for industrial maintenance tasks is complex activities that require specific knowledge and procedure. As in industrial environments there are variety of machines are in use, industrial firms find themselves difficulties in operations and maintenance. Such maintenance works are also complicated, risky and expensive as well. Therefore, it would be a good idea for the industrial firms to find ways to train engineers efficiently in order to perform maintenance tasks.

In such circumstances, application of virtual reality platform can offer promise of making industrial maintenance and training better and more efficient. The virtual maintenance system works within a computer-generated environment, where the necessary simulation to interact with the real system is performed. To enable such environment efficiently there needs to integrate different technologies with virtual reality system to allow the users to interact with the virtual scenario in a multi-sensory manner.

The use of virtual maintenance system using virtual reality technologies has been found to provide a range of advantages over the traditional training and maintenance systems. It offers necessary maintenance training under the learning-by-doing approach, which is not possible in real-life environment due to limitations such as cost, time, safety, etc. In addition, virtual maintenance system facilitates the training process through visual, auditory or haptic cues and allows simulating the task in a flexible way to adapt the users' requirements and training objectives.

The research works that are provided in this paper supports the virtual maintenance nicely. A case example is demonstrated to visualize the systematic maintenance work by virtual reality. The case demonstration enables to illustrate the relevant maintenance works, which can be helpful for the engineer\technician to acquire sufficient knowledge and expertise before conducting the real life maintenance works.

This research work was mostly concentrated to apply the virtual reality technique in industrial maintenance without considering the accompanied cost analysis. The future work will be concentrated to analyze the financial contents between the virtual maintenance with real-life maintenance task. In addition, the effectiveness between the virtual maintenance works with real-life one will also be compared with respect to duration, performance and quality as well.

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## References

Buriol, T.M., Rozendo, M., de Geus, K., Scheer, S. and Felsky, C., A virtual reality training system for live line maintenance of power distribution networks, *Proceedings of International Conference on Business Logistics (ICBL2009)*, Florianopolis, Brazil, 2009.

Canetta, L., Redaelli, C. and Flores, M., Digital Factory for Human-oriented Production Systems, *The Integration of International Research Projects*, 1st ed. London: Springer, 2011.

Choi, S., Jung, K. and Noh, S.D., Virtual reality applications in manufacturing industries: past research, present findings, and future directions, *Concurrent Engineering Research and Application*, vol. 23, no. 1, pp. 40-63, 2015.

Christian, M., Zane, S. and Allan, S., Virtualisation devices for student learning: Comparison between desktop-based (Oculus Rift) and mobile-based (Gear VR) virtual reality in medical and health science education, *Australasian Journal of Educational Technology*, vol. 33, no. 6, pp. 1-10, 2017.

Frampton, R., VR: Multimedia and more – the role of virtual reality in the commercial and industrial society, *Proceedings of International Conference on Virtual Systems and Multimedia'95 (VSMM'95)*, Gifu, Japan, pp. 225–229, 1995.

Galambos, P., Csapó, A., Zentay, P., Fülöp, I.M., Haidegger, T., Baranyi, P. and Rudas, I.J., Design, programming and orchestration of heterogeneous manufacturing systems through VR-powered remote collaboration, *Robotics and Computer-Integrated Manufacturing*, vol. 33, pp. 68-77, 2015.

Gawade, A.,Vaishnavi, G., Aditya, M. and Akshay, L., Research of game development based on virtual reality, *International Journal of Advanced Research in Computer Science*, vol. 9, no. 1, pp. 381-383, 2017.

Gomes de Sa, A. and Zachmann, G., Virtual reality as a tool for verification of assembly and maintenance processes, *Computers & Graphics*, vol. 23, no. 3, pp. 389-403, 1999.

Gutierrez, T., Gavish, N., Webel, S., Rodriguez, J. and Tecchia, F., Training platforms for industrial maintenance and assembly, In: M. Bergamasco, B.G. Bardy, and D. Gopher, (Eds.), *Skills Training in Multimodal Virtual Environments*, Boca Raton: CRC Press Taylor & Francis Group, pp. 227–239, 2012.

Lim, D.H., Han, S.J., Oh, J. and Jang, C.S., Application of Virtual and Augmented Reality for Training and Mentoring of Higher Education Instructors, in *Handbook of Research on Virtual Training and Mentoring of Online Instructors*, IGI-Global Publisher, pp. 325-44, 2019.

Nomura, J. and Sawada, K., Virtual reality technology and its industrial applications, *Control Engineering Practice*, vol. 7, no. 11, pp. 1381-1394, 1999.

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