Construction of a digital twin educational environment for training digital engineers

*Akira Komatsu, Jun Suzuki, Koji Kawasaki, Taku Sato, Fuga Sato, Shohei Sakurai, Kazuhiro Wako and Kuniaki Yajima

National Institute of Technology (KOSEN), Sendai College, Japan
* akomatsu@sendai-nct.ac.jp

Abstract

Digital technology has developed remarkably in recent years, and the development of DX and the promotion of its use in industry have progressed rapidly over the past few years. Because of this, society expects the development of digital human resources. Digital twin is being used to reproduce work in real space on a virtual space, and to apply it to real work and provide feedback, such as at the Nippon Institute of Technology and the Tokyo University of Science. KOSEN, Sendai college has been promoting the construction of a digital twin educational environment and the development of learning contents Digital Manufacturing: we called DM). This paper describes on the construction of the digital twin educational environment being promoted at KOSEN, Sendai college: the introduction of digital twin and the efforts made up to the previous year. This paper describes the following perspectives on the development of educational programs in collaboration with companies, participation in educational programs by people from companies and educational reforms in collaboration with companies. 1. introduction of Internet of Things (IoT) scalar robot with Operational Technology (OT) field in mind, 2. introduction of factory simulator in virtual space, 3. study and development of digital twin education program, 4. integration of virtual and real space, 5. introduction of education from active business people, 6. study of digital twin education through inter-campus collaboration, 7. study of inter-college of technology development model (introduction to two colleges of technology) , 8. sharing and development of educational materials among technical college, 9. expansion to KOSEN. This project aims to develop human resources who can handle the concept of digital twin and its environment, which seamlessly and effectively reproduces the improvement of factory production efficiency in real space in a virtual space. KOSEN, Sendai college consists of two campuses: the Hirose Campus, mainly for electronics and information science, and the Natori Campus, mainly for mechanical, material and electrical architecture. Taking advantage of this location, we have developed a digital twin educational environment and its content materials, in which the collaborative work of each scalar robot is shared in a virtual space in collaboration with the other campuses, and which assumes a single improvement. The digital twin education system we have developed has been set up at KOSEN, Nara college and Kurume college as a development model, and the three technical colleges are collaborating to organize a curriculum map, brush up the contents of teaching materials and verify them, with a view to future nationwide development.

Keywords: *Digital twin, sideline teacher, corporate partnership education, rollout model*

Introduction

In 2019, the Digital Manufacturing Human Resource Development Project was promoted by the National Institute of Technology (KOSEN) to realize a shift to education for manufacturing human resources that will lead to innovation, with KOSEN, Kitakyushu college, Anan college, Nara college, and Sendai college as practicing schools. KOSEN, Sendai college will participate in the project from FY2023, the final year of the practical promotion. The project started as a project to strengthen education for the development of digital human resources, which is different from other KOSENs. With the keyword “digital twin”, we have strengthened the educational program for the development of digital manufacturing (DM) personnel who can respond to effective and efficient cycles of engineering chains that have been promoted mainly in physical space, utilizing the advantages of both directions without being conscious of real and virtual space.

In building and implementing the digital twin environment and educational environment, we have been developing both software and hardware teaching materials targeting the robot control field, which is the mainstay of development work and processing sites, while incorporating the necessary elements for DM manufacturing into the teaching materials. Including the case of factory development that requires joint operation by multiple robots, a robot control system and an application that enables robot control in a virtual reality (VR) space were introduced as a digital twin environment construction in a processing work space where real and virtual spaces are linked. In addition, educational content includes the development of teaching materials based on actual onsite experience and the introduction of digital twin cases in actual onsite development work by hiring "sideline teachers" who have experience in the private sector to implement the education. With a view to expanding the system to other KOSENs, a low-cost version of the robot system, which is a robot control system and communication-capable equipment, was introduced at the KOSEN, Natori campus of Sendai college. This system was also installed to the Kosen, Hirose campus of Sendai college, Nara college, and Kurume college, and preparations were made for the construction of a development environment for teaching materials utilizing a digital twin environment to realize collaborative development, etc. in a virtual space, which was difficult to realize in a real space due to the constraint of distance.

This paper describes the construction of the digital twin environment at two campuses of KOSEN, Sendai college, an overview of the teaching materials developed, and the effects of implementing classes through the use of sideline teachers.

Methods
-Human Resource Development for DM at KOSEN, Sendai college-

A. Introduction of Internet of Things (IoT) SCARA robot with awareness of IoT field

KOSEN, Sendai college has been promoting the construction of an integrated real and virtual environment for DM (introduction of a development environment using a digital twin) as its goal. In this context, we have introduced industrial robots to connect real production and virtual space, as shown in Figure 1, and have aimed to develop engineers with practical skills in DM.

In doing so, we have aimed for high-precision and high-efficiency DM brought about by "real" × "data" × "virtual.

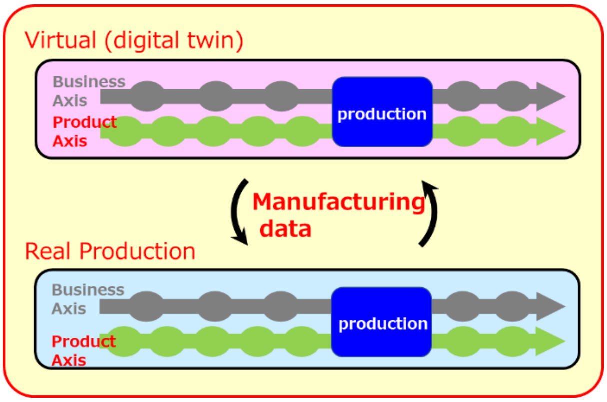

Figure 1. Schematic diagram of DM based on a digital twin environment.

B. Installation of factory simulator in virtual space

A factory simulator was introduced to optimize the entire production site along with the introduction of industrial robots at the actual site. A digital twin environment can be constructed by transferring the items in real space directly to cyber space, enabling the construction of a process to eliminate waste in production in the simulator, and the introduction of a system that enables the understanding of production costs, etc. prior to the introduction of production equipment. Figure 2 shows the factory simulator focusing on robots.

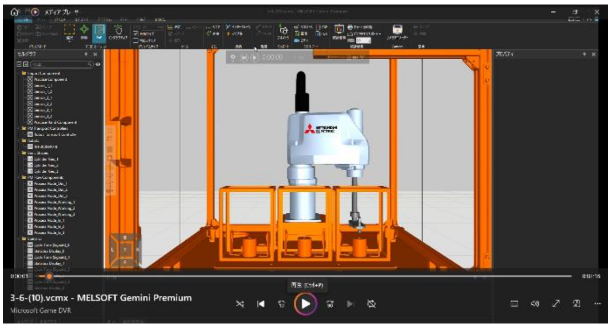

Figure 2. Factory simulator focusing on robots.

C. Development of teaching materials

As for the development of educational materials at KOSEN, Sendai college, we have been developing common educational materials for the introduction of DM, which is the foundation of DM shared by all campuses. At the Hirose campus, where courses in information electronics are mainly offered, we have been developing educational materials focusing on software such as factory simulators, robot simulators, circuit simulators, etc. At the Natori campus, where courses in robotics and mechanics are mainly offered, we have been developing educational materials focusing on software such as robot simulators, robot simulators, circuit simulators, etc. On the Natori campus, where the courses are mainly hardware-based such as robotics and mechanical engineering, we have been developing educational materials focusing on the control of actual industrial robots.

In the introductory education for first-year students of the main course, which is common to all the specific contents, the transition of manufacturing, what manufacturing means, DXing of manufacturing and its case studies were introduced, and the digital twin leading to applications was explained and its implementation examples were shown (Figure 3). After that, we explained to the students examples of how digitization improves efficiency, as well as the point where digitization lacks information (Figure 4), how to determine the resolution of time, and practical training on extracting the parameters necessary for digitization. In addition, the final educational material was designed to show that the future vision of the digital twin will lead to a cyber-physical system (CPS) incorporating AI and IoT,

Figure 3. Classroom scene of the Digital Twin concept.

Figure 4. Analog and digital quantities.

and that the CPS cycle can be used to rapidly optimize the production system. Other initiatives included inviting a sideline teacher who was involved in digitization in the private sector to give a lecture during introductory education (Figure 5).

Figure 5. Lecture by a sideline teacher.

At the Hirose Campus, educational materials were developed for second-year students to experience the digital twin experience using actual microcomputers and simulations (Figure 6). At the Natori Campus, we developed educational materials for students to practice control of an actual robot and to study its operation in consideration of efficiency (Figure 7).

In addition, MATLAB/Simulink, which can configure a digital twin, was introduced for all students in all grades and used in classes and in graduation research activities to make the construction and analysis of digital twin simulations more accessible (Figure 8).

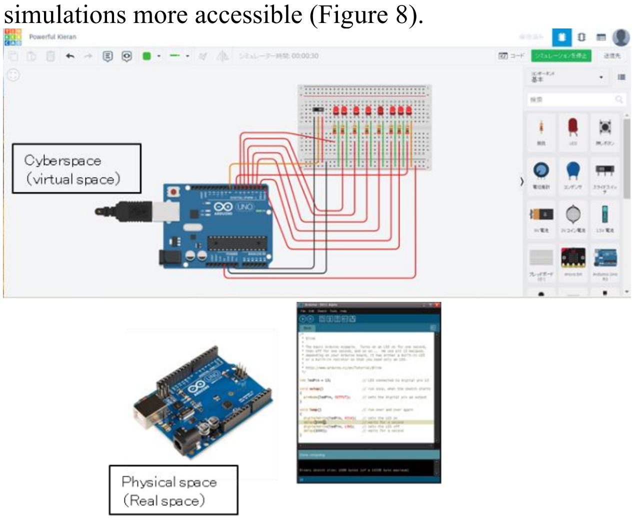

Figure 6. Teaching materials for digital twin experience using actual microcomputer equipment and simulations.

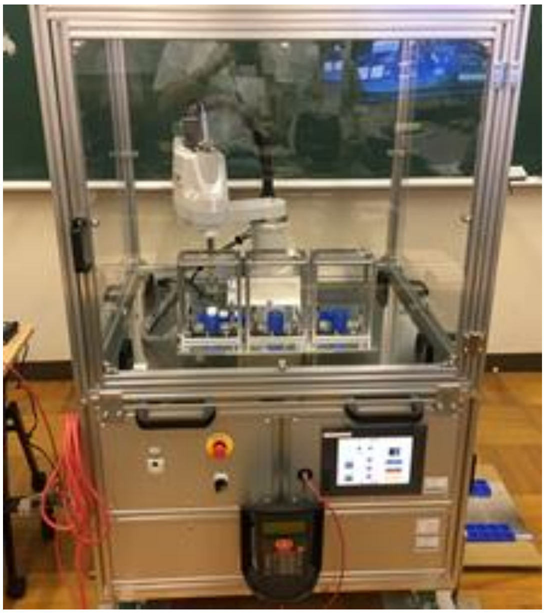

Figure 7. Appearance of digital twin educational robot system for sequence control experiment combined with scalar manipulator robot.

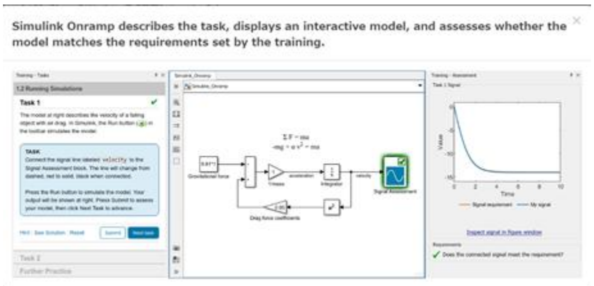

Figure 8. Numerical analysis and control simulation experiments using MATLAB/Simulink.

C. Enhancing the realization of a digital twin environment

In the aforementioned B, we have been developing educational materials with the idea of eventually synchronizing industrial robots and simulators through both campuses using actual industrial robots on the Natori Campus and robot simulators of the factory simulator on the Hirose Campus to build a system that enables a digital twin experience. The project has been developing educational materials with the idea of eventually synchronizing industrial robots and simulators through both campuses to create a digital twin experience.

In particular, in order to operate industrial robots remotely, it is necessary to construct many safety systems in areas where the robots operate alone without human intervention. For this reason, a web camera monitoring system is currently being constructed. In addition, we are in the process of coordinating with each department to handle the same communication system on both campuses and to deal with cyber security issues.

Through the development of this system, we would like to connect KOSEN, Nara college, Kurume college, and Sendai college, where simple robots have been introduced, to build a system that allows robots to perform coordinated actions remotely, and have students experience these actions. An example is shown in Figure 10.

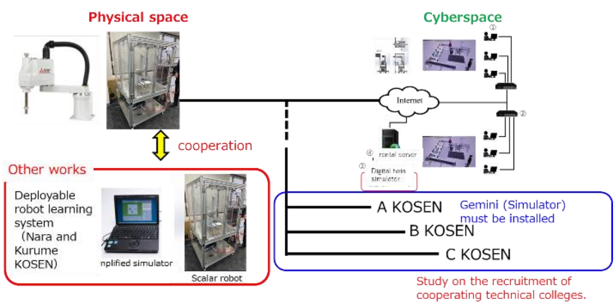

Figure 9. Image of building a remote system for collaborative work with industrial robots with other KOSEN.

D. Installation and Practice

KOSEN, Sendai college has been introducing the development of teaching materials while at the same time providing students with up-to-date information through educational practices. In parallel, we have also created video content for development in terms of creating a medium for recording (Figure 11).

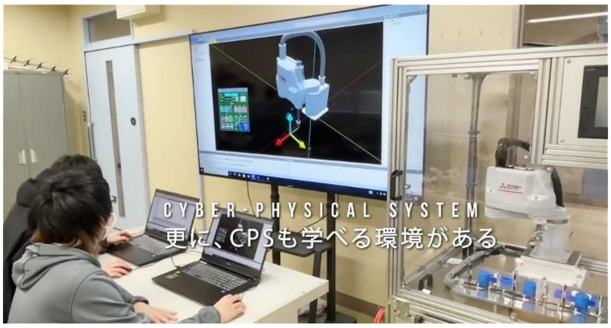

Figure 10. Video content for developing teaching materials

Results
- Conduct questionnaire on improvement of class content regarding digital twin-

The development of the teaching materials in the previous chapter, particularly regarding the introductory class for first-year students on the concept of the digital twin, we conducted a class improvement questionnaire was conducted before and after the class on the attainment objectives and level of understanding (Figure 11). Details of the results are omitted, but a check of the changes before and after the class showed that the level of understanding of front-loading and rapid prototyping was lower than the other items. Therefore, we plan to improve the method of explaining the lessons in the future.

Class : Attendance number : Name :

Technical item	Attainment target	Level 3	Level 2	Level 1	Self-assessment (before class)	Self-assessment (after class)
Understanding manufacturing transitions	Can explain themselves about the transition of manufacturing	Be able to explain the transition of manufacturing to digitalisation on their own	With some advice from teachers and others, explain the transition of manufacturing to digitalisation	With detailed advice from teachers and others, explain the transition of manufacturing to digitalisation		
Understanding the manufacturing process	Can explain themselves about the manufacturing process	Understand and be able to explain themselves about the manufacturing process	With some advice from teachers and others, be able to explain the manufacturing process	Be able to explain the manufacturing process with detailed advice from teachers		

Figure 11. Classroom improvement questionnaire (extract).

Discussions
-Future developments-

The following are some issues that need to be addressed for future development.

First is the establishment of a method for developing educational materials. We have described mainly the construction and implementation of the digital twin education system in KOSEN, Sendai college, however we will develop the educational materials horizontally and vertically, i.e., within the college and outside the college based on the system. Based on the results of the digital twin class in the course using this system, we are going to develop the system in KOSEN, Sendai college in the future. In addition, we would like to maintain cooperative relationships with KOSEN, Nara college, and Kurume college in order to package teaching materials for other national technical colleges.

The second is to establish a communication method between the robot and the simulator and to ensure safety. To solve this problem, we will study the configuration of the KOSEN network environment for communication and address the issue of communication security.

Thirdly, we will consider collaboration with internal and external projects, especially with IoT, AI, etc., which KOSEN, Sendai college is mainly promoting, as DM has a very high affinity with them. By incorporating AI, image recognition using machine learning and deep learning, and big data processing, the degree of freedom as an educational tool that can be realized with DM can be increased, and a more flexible environment can be constructed as DX teaching materials that can study multifaceted production line processes and solve problems entirely in a digital twin environment. We will cooperate with each of the projects being conducted within the university and consider joint development that includes the sharing of teaching materials, security, etc. in the future.

The last is the implementation of delivery classes. We will study and develop the implementation of the hands-on delivery class with the digital twin in mind, not only inside and outside of the college, but also to elementary and junior high school students who may enter the college in the future, to let them know on the college.

Conclusions

This paper describes the introduction of the digital twin promoted at KOSEN, Sendai College of Technology, and the efforts made to build a digital twin educational environment up to the last academic year. Specifically, the following items were promoted.

1. introduction of IoT (Internet of Things) SCARA robots with an awareness of the OT (Operational Technology) field, 2. introduction of a factory simulator in a virtual space, 3. examination and development of digital twin education programmes, 4. fusion of virtual space and real space, 5. introduction of education by active business people, 6. Examination of digital twin education through inter-campus collaboration; 7. Examination of inter-college of technology collaboration development models (introduction to two technical colleges); 8. Sharing and development of teaching materials between technical colleges; 9. Development into KOSEN.

Improvements in classes, etc. were obtained from class improvement questionnaires, etc. and used as guidelines for improvement. FD and other activities are planned for deployment to other technical colleges in the future.

Acknowledgements

We would like to express our profound gratitude to Associate Professor Chiyako Araya and Professor Hiroaki Ichii of KOSEN, Nara college, Associate Professor Hiroaki Koga and Associate Professor Ryo Tanaka of KOSEN, Kurume college, Mitsubishi Electric, Kameya Electric, and MathWorks for their great cooperation in implementing this project.

We also express our profound gratitude to Ms. Kanako Toshida, Mr. Tsunetaka Yamaguchi, and Mr. Tatsuya Koriyama of KOSEN, Sendai college for their administrative work and assistance in the implementation of this project.

This project was funded by KOSEN headquarters: Digital Manufacturing Human Resource Development Project.

Author Contributions

Conceptualization, A.K., J.S., K.K., T.S. and K.Y.; data curation, F.S. and S.S.; formal analysis, A.K. and J.S.; funding acquisition, J.S, K.K. and K.Y.; investigation, J.S., T.S., F.S., and S.S.; methodology, J.S., T.S., F.S., and S.S.; project administration, K.K. and T.S.; resource, J.S., T.S., F.S., and S.S.; software, F.S., and S.S.; supervision, K.W. and K.Y.; validation, A.K., J.S., F.S. and S.S.; visualization, J.S.; writing – original draft, A.K. and J.S.; writing – review and editing, K. K., T.S. and K. Y.

References

Cimino, C., Negri, E., & Fumagalli, L. (2019). Review of digital twin applications in manufacturing. *Computers in industry*, *113*, 103130.

Kritzinger, W., Karner, M., Traar, G., Henjes, J., & Sihn, W. (2018). Digital Twin in manufacturing: A categorical literature review and classification. *Ifac-PapersOnline*, *51*(11), 1016-1022.