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5G and AI Technology Application in the AMTC Learning Factory

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Abstract

5G and AI (Artificial Intelligence) are changing industrial production and offer great potential for manufacturing enterprises. One of the effects resulting from the increasing quantity of production data is the increasing demands of transmission of large amounts of data, fast transmission speed, and rapid data analysis. However, merely relying on traditional communication technology and manual data processing does not lead to high transmission performance and low analysis time. It is essential to integrate 5G and AI technology to flexibly transmit large amounts of data and real-time data. To demonstrate the feasibility and potential of these two technologies, a concept was developed at the Advanced Manufacturing Technology Center (AMTC) at the Tongji University (Shanghai, China) and further implemented in the AMTC learning factory in cooperation with wbk of Karlsruhe Institute of Technology (Karlsruhe, Germany) and Ruhr-University Bochum (Bochum, Germany). This paper presents the learning factory design in detail, describing the concept design, training environment and training phases in the AMTC learning factory. It is followed by a case study consisting of specific examples of 5G and AI, implemented in the AMTC learning factory. The importance of integrated 5G and AI applications is pointed out and discussed.

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Keywords: 5G; AI; Learning factory

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1. Introduction

Nowadays, advanced industry 4.0 technologies, such as the Internet of Things (IoT) and Artificial Intelligence (AI) technologies, are developing rapidly, bringing new possibilities and potentials to manufacturing industry [1, 2]. 5G technology is expected to massive expand today's IoT field and is becoming more readily available as a major driver of the growth of IoT applications [3]. AI technology is also displaying its incomparable advantages as an analytical method to analyze vast masses of data accurately and rapidly in the industry [4]. Industrial application empowered by the 5G and AI adoption allows businesses to use data-driven strategies to optimize their performance by gathering and analyzing data through the whole product lifecycle [5, 6]. Consequently, it is even more crucial for manufacturing enterprises to apply 5G and AI technologies to support production planning, enhance their competitiveness and add their commercial value [7].

Manufacturing, as a subject, cannot be treated efficiently in the classroom alone [8]. Therefore, it is necessary to integrate real industry practice with manufacturing education and training for the transition from simulated teaching patterns to real and productive ones [8, 9]. However, manufacturing teaching and training now have neither kept pace with the advances in manufacturing technologies nor with the demands from the labor market [10]. In addition, a lack of multidisciplinary teaching methods makes it difficult for students to solve challenging and comprehensive problems efficiently and effectively [11]. To meet these needs, a modern learning environment is prepared to make the teaching and training of the manufacturing industry much better in the AMTC learning factory. Advanced 5G and AI technologies education can be realized here to cultivate high-quality manufacturing talents. By this means, the students can experience the actual production state and practically deal with a given task of industry application, which helps them to accumulate manufacturing technology experience and master key competence and skills [12].

This paper presents a learning factory program implemented in the AMTC learning factory that allows students to practically experience 5G and AI application scenes and discuss what 5G and AI mean for manufacturing enterprises. By involving these new technology applications, it offers possibilities for students to get interdisciplinary knowledge and skills as well as a multidisciplinary view for being able to solve engineering problems effectively [13].

2. Learning factory design

The AMTC learning factory design is introduced from three aspects: concept design, training environment, and training phases. How to train students is illustrated in concept design (see 2.1) to make all the participants have a basic understanding of what they could experience in the training process. The infrastructure at the AMTC is included in training environment (see 2.2) to help participants know more about equipment that they could use. Also, training courses, the main part of the learning factory design, are presented in training phases (see 2.3).

2.1. Concept design

There are three main application scenes defined in the 5G era and they are enhanced mobile broadband (eMBB), ultra-reliable low latency communications (uRLLC), and massive machine type communication (mMTC) respectively. AI can be applied to machine vision, for example, product quality monitoring and intelligent positioning on the shop floor. However, it is difficult for a student to master a lot of knowledge of these two technologies. Therefore, a minimum set is proposed to present students with a specific case about these two technologies. Besides, the ABCD principle is defined to illustrate what we have in the minimum set and role-play learning explains how to implement the learning factory program in a more interesting way.

<u>Minimum set including 5G and AI applications</u>

Based on the essential elements of a learning factory, a minimum set is designed to simulate a manufacturing enterprise in all kinds of respects entirely. The cloud server can be replaced with a local server if the company itself wants to keep the data locally for data security or saving cloud server expense. This minimum set, as the cornerstone of learning factory, includes the following three basic features (see Fig. 1. (a)): (i) a tangible product is being manufactured or an intangible service is being provided in manufacturing industry [14]; (ii) 5G technology is used to connect machines with network and transmit big amounts of data rapidly; (iii) AI technology is used to analyze acquired data and derive useful measures.

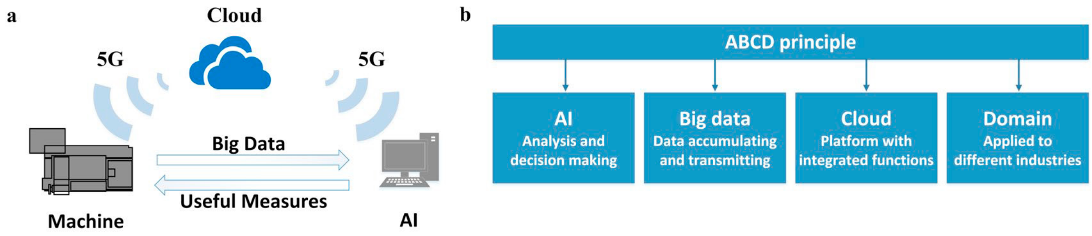

Fig. 1. (a) Minimum set design; (b) ABCD principle.

ABCD principle

The minimum set is implemented in the AMTC learning factory according to the original and creative ABCD principle. The ABCD principle (see Fig. 1. (b)) consists of: A means AI; B means big data; C means cloud; D means domain. The ABCD principle is created to identify and improve the weaknesses of an enterprise. AI technology can be applied to data analysis and decision making. Big data technology can be used to accumulate data from various sources to form a shared knowledge library and solve two main challenges: data standard-setting and data analysis. Cloud is defined to be a platform to store and analyze data from the terminal device and give guiding principles and technical proposals. Domain principle means that the scheme derived from the ABC principle could also be applied to different industries as long as the design idea is individually reasonable and suitable.

Role-play learning

Role-play learning is an interesting and explorative way to teach emerging technologies to mechanical engineering students in universities [15, 16]. It involves students in doing things and thinking about things from a given role, such as acting like a 5G engineer or an AI algorithm analyst in the AMTC learning factory. The main purpose of role-play learning is to improve the classroom experience and to motivate students to become more active and participative in classes [17]. Moreover, Students will experience theoretical input, practical application scene visits, and a rich context for case solutions before they can identify, analyze and solve real challenges.

2.2. Training environment

The learning factory program is implemented at the AMTC at Tongji University. The AMTC was set up in 2013, aimed to cultivate high-quality international students together with Karlsruhe Institute of Technology. Nine state-of-the-art machines (milling, turning, grinding), two industrial robots, one conveyer line, one coordinate measuring machine, two assembly stations, and various peripheral sensors allows students to have a full understanding of all kinds of industry devices (see Fig. 2). All these devices are now connected with the Internet to promote the IIoT infrastructure in the AMTC learning factory, making it easier for students to collect the data that they need to analyze. Visualization can be done on a large touch screen, facilitating a complete and intuitional data analytical result show for students. To give students a visual scene presentation about 5G and AI applications, these two technologies have already been applied in the AMTC learning factory.

5G application

Until now 5G is more than just fast. Because this network technology's reliability is so high and its latency so low, equipment can communicate wirelessly with control systems for time-critical operations in ways that were not possible before. Two 5G base stations have already been installed in the AMTC learning factory so the user can transmit and save data locally for data security. 5G technology is applied to the demo production line at the AMTC to transmit real-time data to the controller. Once the part reaches the stop position, the sensor detects the movement signal, which will be transmitted to the conveyer programmable logic controller (PLC) by 5G.

AI application

Navigation in a production environment is challenging because of the changing environment, disturbance of compass signals, and reflections of radio waves or ultrasound waves. Therefore, ultra-wideband (UWB) radio frequency localization and camera-based localization are combined for an aerial drone used for the transportation of small parts in the AMTC learning factory, such as identifying the landing spot, flight trajectory, pickup location and orientation of objects. The camera and the UWB tag are mounted on the same drone and are connected to the same CPU. Here, an AI algorithm is used to extract position information from images shot by the camera based on machine vision and predict the error of the UWB signal based on intelligent positioning.

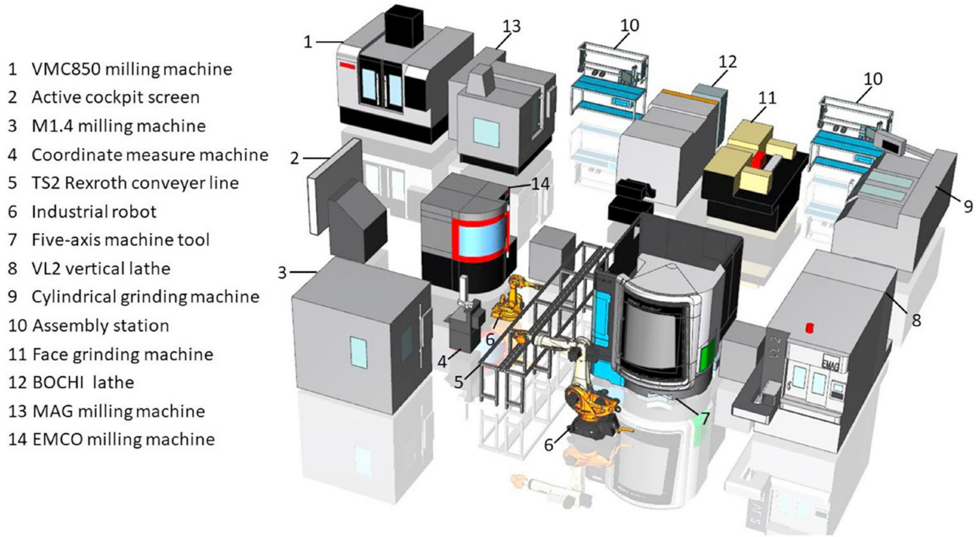

Fig. 2. Training environment at the AMTC

2.3. Training phases

The previously described physical scene form the basis of the following course of training, which consists of 3 phases that are built upon another (see Fig. 3. (a)). Phase 1: The training starts with an introduction to the current AMTC learning factory state to ensure that all participants get to know the learning factory itself, the production demo line, and the product. After the introduction part, the participants could have a common understanding of the pain points and requirements of the factory. A theoretical input on 5G and AI is also included, as it is necessary for all participants to gain basic knowledge about 5G and AI as well as their challenges and potentials. When all participants have become familiar with the production demo line transformed by 5G and AI technologies, active operation in the demo production line takes place. Here, the participants firstly observe the behavior of teaching assistants who are doing operations in the demo line and then actively experience simple operation on their own. The phase 1 ends in a discussion session to help the participants have a full understanding of 5G and AI technologies.

Phase 2: Before phase 2, the participants are divided into groups of four members, and the reason for subdividing the group is that different participant plays different task role and works with their partners to finish a task that they select in the following phase. And the focus on learning for each group member is different, which depends on whether 5G or AI is their preference, but the number in both technologies must be the same. In phase 2, 5G and AI scene visits will be carried out to help participants become familiar with the specific implementation process and the main application fields of 5G and AI technologies, which are the core part of the training program. Based on the information and knowledge each group acquired, the groups need to act like a 5G and AI engineer team to analyze the production demo line, identify 5G and AI potentials, and select a design task. They do not need to put the task into practice. They need to come up with a design scheme and create a roadmap instead. Reflection and wrap up will be used to summarize phase 2 and lead to phase 3, during which the participants join in a workshop to extend and develop 5G and AI solutions.

Phase 3: The trainer will give a lecture on what potential 5G and AI could have in the manufacturing industry to make these two technologies more clear for students, and the groups will work together, share and discuss their different design schemes, and perfect their solutions together. After a short break, the solutions are presented by the students publicly in a meeting room, and then the training is finished with a brief conclusion.

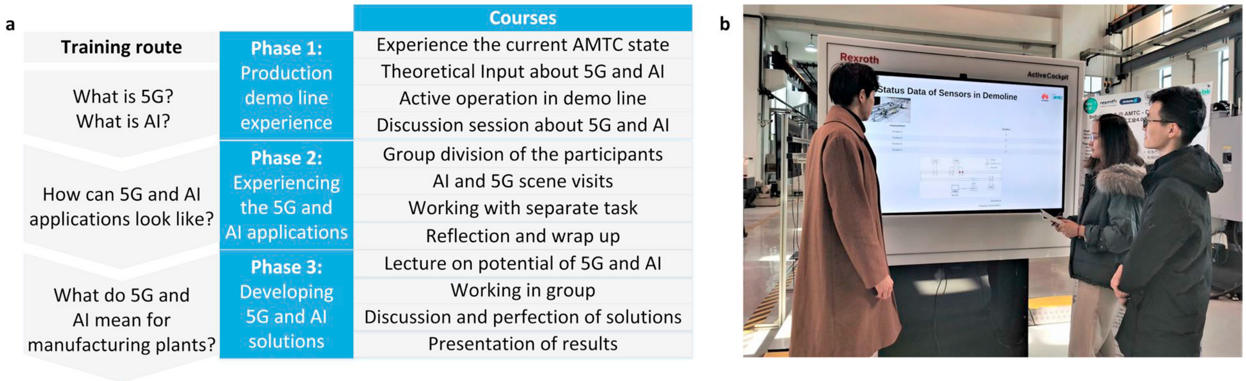

Fig. 3. (a) Phases of the 5G and AI training [18, 19]; (b) Actual 5G and AI application scene

3. Case study

A use case has been implemented in the AMTC learning factory according to the previous learning factory design. Students, in this case, will be confronted with a real production situation and experience the actual 5G and AI application state [20]. To exemplify the learning factory training program, the core training process is presented in more detail based on the 5G and AI applications mentioned before (see 2.2), which help students know the functions realized by applying 5G and AI technologies.

Students will get input about 5G and AI through practical application scene visits and active operation in the production environment based on the prepared applications (see Fig. 3. (b)). We present hardware used to the participants and share the challenges and difficulties we met when we design and realize these two technologies applications. For example, the 5G adapter consists of a Raspberry Pi, a sensor and a battery and is connected with an Ethernet interface to transmit sensor data to the conveyer line PLC and send the status of conveyer line to a monitor. Students can also use the drone and know the position on the shop floor extracted by a UWB tag and camera mounted on the drone. In the development process, one chanllenge is stability testing, because the written program can work for a while, but over time it can go wrong, and finding causes is not easy. In this section of the case study, valuable details about 5G and AI applications are given, and students are encouraged to explore original ideas and claims about new technologies.

4. Conclusion and outlook

In this paper, a flexible and universal concept design of a learning factory was proposed. The ABCD principle can be adjusted to fit various domains as long as the learning factory design originates from a reasonable and matched start. In addition, the applications of utilizing state-of-the-art technologies such as 5G and AI are included in the courses to help students keep abreast of the latest technologies application trends in industry. The students will have an overall understanding of 5G and AI applications in manufacturing including technical, economic, and social aspects when they finish the training program. From a practical point of view, they know why 5G and AI technology should be adopted, what hardware and software they can use, and what challenges they can meet. Theoretically, they acquire knowledge about 5G and AI, as well as know the framework of how to implement these two technologies. According to the questionnaire filled by the trainers, the participants and all those observing the training sessions, the ABCD principle serves as an interesting and indispensable complement for a learning factory program mainly for two reasons. Firstly, it clearly and simply states what we have in the learning factory, e.g. a cloud platform to use AI technology to analyze a large amount of data transmitted by 5G technology. Secondly, all participants have a common understanding of organizing training courses to fit different subjects according to domain principle.

For future work, the courses comparing the advantages and disadvantages among similar technologies, especially specific examples comparison, will be added in the training phases. The sessions will be aimed at engineers and teachers, etc. instead of being limited to only students. Finally, the industrial scenes will continue to be extended and enriched. For instance, the application of 5G and AI can be exemplarily and conveniently extended to the Robot-based flexible forming process (Roboforming), where incremental and flexible forming processes are collaboratively executed by two heavy-load and high-precision KUKA600 robots equipped with a series of sensors. The establishment of the Roboforming equipment refers to that at the Ruhr-University Bochum, and it is adjacent to the AMTC at Tongji University.

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