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Human factor in intelligent manufacturing systems - knowledge acquisition and motivation

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Abstract

People play a central role in intelligent manufacturing systems because of two reasons: their knowledge is indispensable to create and improve intelligent manufacturing systems; and their motivation is very important to identify and solve causes of the problems which may occur in order to prevent them in the future. Therefore, adequate learning methods are required to accomplish these two goals: empower and motivate people. In this paper innovative methods such as learning by doing, simulations and virtual reality will be presented as the ways to transfer the knowledge about intelligent manufacturing systems and to increase motivation concerning their improvements.

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1. Introduction

Intelligent or Smart Manufacturing Systems (SMSs) have become popular after the emergence of the paradigm of Industry 4.0. Industry 4.0, the "fourth Industrial Revolution", is a wider concept that encompasses Intelligent Manufacturing Systems in a new way of interacting between humans and production machines. Its purpose is the creation of a whole smart factory characterized by strong digitalization of processes based on Cyber Physical Systems (CPS). Industry 4.0 makes use of the state of art ICT technologies and implements them in the manufacturing sector.

In this area, SMSs are a direct application of digital innovations that allow the switch from smart objects to smart interconnected systems.

The level of maturity of SMSs can be variable and depends on the enabling technologies implemented in a factory: Big Data and Cloud are ready to be applied in several industrial contexts, while additive manufacturing and collaborative robotics still require further research and development before their potential may be fully exploited.

While there is a strong emphasis on the technology adopted by SMSs, the proper training of human resources is neglected. This fact hinders the introduction of SMSs as they are strongly founded on the interactions between human workers and machines. If a human operator is not adequately trained to work in the new manufacturing environment, there is a serious risk of disappointing failures in disseminating innovation. The comparison with the introduction of a car as a replacement for horse carts is possible to draw here. A generation of people had to learn road rules and the skills necessary to drive this new transport system before replacing the old one. This event was made easy because in the past the introduction of a new technology was a slow process and it could extend to more than one generation. Currently, the time to introduce innovations has been shortened and it is necessary to train present workers to a new production paradigm. It is apparent that learning to work in an SMS is something that cannot be done using traditional education tools: manuals or classroom lessons. Potential students already work in a factory and they will need proper motivation and techniques of remote education.

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In this paper the authors present the practice of implementing different forms of knowledge, experience and motivation acquisition by students. In part 2 of the paper, motivations for application of different forms of learning activities are presented. In part 3, e-learning is introduced. Next, Simulation Methods in Learning are described. Part 5 discusses virtual reality (VR) in education and part 6 presents a Brief Review of Simulators in Technical Training. Then, an application of a human-robot collaboration in a learning process is presented. Finally, an example of a simulated assembly and transport system with manufacturing workstations is illustrated. The work is concluded in a summary.

2. Motivation

Industry 4.0 is a long-term objective. Presently, no industry implements thoroughly all the enabling technologies. As with everything related to digitalization, it is difficult to gain first-hand understanding of these technologies by simply using them. As a matter of fact, some technologies work seamlessly in an invisible way and the users could remain totally unaware of their existence even during their use. It is the case of CPS that are often integrated with an enterprise network through Wi-Fi connections. By means of an everyday life example, you realize that there is RFID embedded in large distribution products whenever the cashier forgets to remove it and a shoplifting alarm starts ringing then. As several instances show, it is more instructive to approach a digital domain through simulation or VR than experiencing it in the real world.

However, the real world can be reflected in games in which learning by doing methodology is implemented. In such games the reality is simplified but real problems are simulated and rules are adhered. Additionally, an element of competition can be incorporated. The advantage of games is that their participants learn while they play and have fun [1]. Gamification is widely applied in industrial and educational areas [2]. Games allow to perform experiments by implementing different solutions and assess the obtained results. By playing a role in a game, participants deal with predesigned tasks [3] which they are responsible for. This way they acquire not only technical but also social skills. In enterprises in which Industry 4.0 concepts are going to be implemented, responsibility is an important issue, although collaboration is also crucial. High levels CPSs have to be maintained by a team of experts from different areas who have to cooperate with one another. Therefore, the students have to learn effective collaboration. While playing, in a team different people have to collaborate.

Different learning modes can be identified as it is presented in Fig. 1. The classification is based on Lean [2] typology of simulations. One group of simulation games is based on IT solutions. Gaming simulations are implemented in order to understand how a certain reaction to a current situation can influence the future. Training simulations are implemented in order to develop a habit of proper behavior in a given situation. Modelling simulations are undertaken to collect data for decision-making process. VR is for playing a role in the virtual world to understand better the simulated situation without the necessity of being in it in the real world.

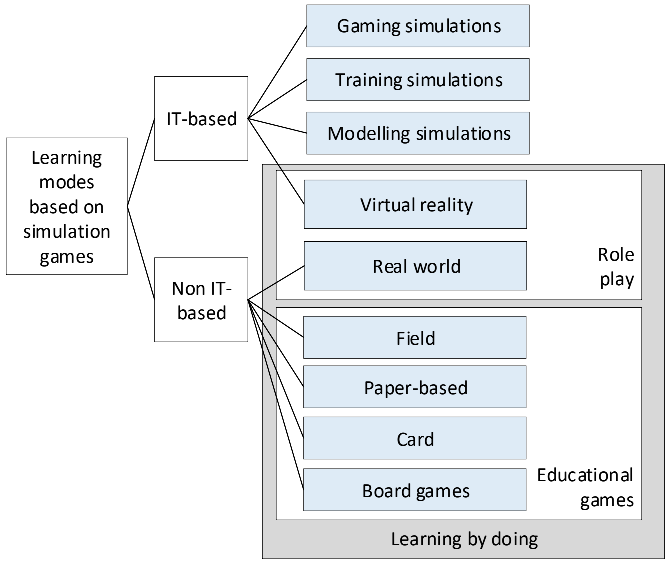

Fig. 1. Classification of learning modes based on simulation games

The other group of simulation games is not based on IT solutions. It can be a role playing in the real world. Itis simplified for the needs of the game. Game participants undertake real activities and they can see the physical results. This group also includes educational games.

The digitalization of education also means that learning becomes more collaborative [4]. The keyword “user generated content” describes the fact that content is rarely produced by just one single provider, but it is collectively generated by several users. This is the paradigm of Web 2.0. Transferred to the context of higher education, students’ roles change. Basically, students can get any information they want from the internet, but they can also contribute actively in forums, wikis or blogs. The trend is to shift the students’ role from passive users of information to co-creators of knowledge in a networked environment – with all accompanying advantages and disadvantages. With the goal in mind that is not only to boost the students’ knowledge and to support them to strengthen their personality over the years, but also to develop crucial competences for the working world they are about to step in, various types of collaboration must be adopted and tested in learning scenarios.

3. E-learning

E-learning means the use of multimedia and Internet technologies in order to improve the quality of learning by facilitating the access to resources and services, as well as enabling easier interactions with a teacher and the increased customization of the offered didactic.

E-learning is common in the offer of several Universities and High Schools. It is proposed as a complement to training in this presence, but often as an educational path aimed at remote users with difficulty in physical attendance. Furthermore, training on the job could be facilitated by e-learning, especially for global organizations.

A critical issue, if compared to traditional training, is the lack of a direct interaction with a teacher physically present in the room. The absence of this figure is superseded by tutoring actions that support the training of users regarding the study of the topics of study and motivation: a training tutor acts to reduce the students' leaving before the end of a training period (drop-out). Dropping-out in e-learning is significantly more frequent than in traditional training. The tutor interacts with the students using social tools (chat, forum, e-mail, etc.).

The basis of e-learning is the elementary unit of learning: the learning object (LO). Learning objects are special types of self-supporting learning resources, modular, reusable and interoperable, which can be used in different contexts.

LOs are self-consistent units, as they represent a minimum unit of learning and consist of one or more multimedia contents, i.e. a video or a presentation. The main issue is to find an appropriate size for the LO that would allow a dynamic assembly of several LOs in a self-consistent lecture.

With the aim of easy reusing, it is necessary to define a set of standards for the metadata. In such a way, the trainer can easily classify and select LOs to be used in a given lecture.

In order to ensure that LOs are aggregated and reused, it is necessary to standardize their description or define the so-called metadata set.

4. Simulation Methods in Learning

Recently, simulation methods have often been used in addition to the traditional theoretical and empirical approach. Simulation is commonly used in many areas of science and technology. The wide application of simulation methods results mainly from three factors:

- the development of computational techniques that give almost unimaginable performance of the simulation environment;
- lower costs of simulation experiments than in the case of traditional empirical experiments;
- the possibility of introducing differentiated assumptions allowing for a wide range of research.

According to Greenblat [4], the simulation is an operating model of the selected system. In turn, Crookall and Saunders [5] argue that simulation represents a real system that can present selected aspects of reality to users. The most important features of simulation are the representation of real systems; availability of rules and strategies allowing for the change of simulation scenarios; low error costs and protection against consequences of serious mistakes.

The presented characteristics of the simulation methods make them applicable to solving complex research problems. Such problems appear, among others, where the human factor (individual capabilities and talents, tiredness, emotions, stress) plays an important role. The role of Human Factor is particularly evident in the decision making process at the interface between a human and a technical system. At the end of the twentieth century, Simons [6] stated "If video games can be transformed so that their users learn, a great many people may come to understand and control dynamic systems". Today, after more than twenty years, we see how the vision has become a reality and simulation-based learning is an important teaching tool. Simulation-based learning means that trainees use a simulation environment instead of experimenting on a real-world system or machine. Such a simulation environment is usually technologically advanced and ranges from a desktop system simulator to a full flight simulator, i.e. full-size and functional replica of the cockpit of an airplane, with a computer system reflecting the behavior of an aircraft during ground and air operations. Simulation-based learning, like many other innovative solutions, was initially used in military organizations. After years of positive experience, this method of learning is increasingly used in many areas, including technical education. EmpowerTheUser (ETU) organization gives 5 reasons why simulation-based learning is a critical method of training [7]:

- Learning by doing – Simulations allow you to apply knowledge to solve complex problems;
- Time to competence – the exercise repeated in a simulator develops skills and leads to perfection in a cost-effective manner;
- Immersive and interactive – interactive simulation engages participants and triggers effective learning;
- Linking learning environment with work environment – simulation helps in increasing the knowledge transfer and promotes the change of skills and behaviors in a workplace;
- Personalized targeted coaching – simulation provides personalized and targeted learning in a safe and controlled environment.

5. Virtual Reality (VR) for Education

VR is everything that is not real. It allows you to experience a world that does not have a physical form.

Head Mounted Display (HMD) is the current form of a hardware delivering VR experiences to users, and one of the most common VR terms you'll hear about today. An HMD is typically a pair of goggles or a helmet of some type, with which you view the VR experience.

Augmented Reality (AR) is a technology that enhances the real world with virtual elements (computer-generated). It has three basic properties [8]: combination of real and virtual objects in the real environment; realignment of real and virtual objects; interaction working in real time.

[9] try to create a procedure for an assembly training system that is AR-based. They describe and analyze an assembly job, subdividing it into tasks and sub-tasks, and the generation of assembly instructions.

With a few exceptions, the research on AR is more oriented on the technology employed to insert visually credible artificial objects in a real environment. This is an answer to the question: 'how'? With the advancement in the AR supporting technology, both hardware and software, it has become possible to have recourse to commercial solutions in order to build AR applications. There are still two open questions: 'what' to display and 'why'? The questions should be answered in a reverse sequence: decide on the kind of assistance required by a student during the learning activity, select the information to display, chose the most appropriate AR device.

The discussion: the attention span is reduced in new generations. There are exceptions: the majority of them is able to engage for extended periods of time when gaming or using simulations. The research has shown that we remember 20% of what we hear, 30% of what we see, and up to 90% of what we do or simulate. VR yields the latter scenario impeccably.

Constructivist learning is fitted for VR as it allows students to actively practice what they are learning. Participative learning requires the simultaneous presence of a group of learners in the same place. If the place is virtual the students could be everywhere (but simultaneously the time constraint is still valid). VR has the assets of the real world classrooms and the assets of online (distance) learning.

Several defects are included:

- VR requires a lot of work to be implemented.
- It must be acknowledged that realistic VR is not cheap and headsets are not comfortable for a long time use.
- There is a cognitive effort in communicating through VR that is more than the effort required to talk face to face. [10].

6. Simulators in Technical Training – a Brief Review

The literature gives many examples of the use of simulation methods in training. There are selected examples below showing the spectrum of simulation applications in training.

As mentioned, the first applications of simulation appeared in military organizations. The example of a simulator used in military training can be a TR-23-2KG simulator [11]. The device is a training set for training an artillery set anti-aircraft operator. The simulator realism was ensured by the use of the ZUR-23-2KGI gun platform and accessories. The simulator is provided with an operator and a position of an instructor. The instructor can monitor the training of 1 to 4 operators. The operator's (trainee's) stand has equipment and operating principles as a real anti-aircraft artillery set, without combat equipment. The kinematics and dynamics of the simulator are the same as in the case of a real combat station, which makes the operator work in conditions close to reality. The monitor built into the simulator replaces the viewfinder of a real artillery station and presents the visualization of a battlefield. The instructor has a system that generates the battlefield simulation, providing realistic terrain mapping, various weather conditions and the profiles of combat targets. The use of the simulator allows you to learn how to use the combat kit equipment and how to combat air, ground and water targets moving at different speeds and in different directions. The training can be carried out in various weather conditions during the day or at night. The use of the simulator allows to reduce the costs of training operators of artillery sets and it substitutes difficult to imagine training during the real fight.

Simulators are also widely used in teaching of welding. Their high usefulness can be proved by the fact that such devices are offered by the world leaders in the welding industry (Fronius, GSI, HIK Consulting, Lincoln Electric). Such simulators allow you to learn how to weld in an environment imitating industrial conditions. The example is the welding simulator VRTEX 360 from Lincoln Electric [11]. The simulator set contains a device whose shape and dimensions reflect the look of a real welder. Simulator welding torches and electrodes imitate the equipment of an actual welding device. The kit also includes a welder mask that has a set of cameras with an electronic display and sound system. The simulator allows to practice different welding methods, as well as to work in different positions and with different materials. The lesson can be assessed on an ongoing basis or saved for the purpose of training documentation or subsequent analysis of results. The use of the welding simulator allows you to master the basics of welding in safe conditions (no harmful smoke, hot objects, risk of electric shock) and reduce the costs of energy and materials (electrodes, shielding gas, jointed parts).

The article [12] shows the application of a simulation environment in training miners working in an underground coal mine. The simulated activities were related to the detonation of an explosive charge in order to obtain coal in a mine corridor. The scope of the performed tasks included all activities covered by the workplace procedure, including: inspection of a workplace, measurement of gas concentration, drilling of holes, placing explosives, securing the corridor and detonation of the explosives. The participants of the training were equipped with HMD, VR glasses and gloves cooperating with the vision system registering the position of their hands and fingers. Such a configuration allows the student to get in touch with objects in a simulated reality. According to Grabowski [12], the use of highly immersive VR techniques will allow the recruiters to gain high competences even before starting work. Training with the use of VR will increase the awareness of miners about the risks and, as a result, the number of accidents in mining will decrease.

The site https://www.youtube.com/watch?v=1ofpuiSJUog contains a record of an example training session.

The flight simulator is one of the best-known simulators used for technical training. Devices for fly learning appeared along with the first aircraft, and 1929 is considered the beginning of the use of simulators in aviation. It is because then Edwin Link constructed the "Link Aeronautical Trainer" device [13]. Flight simulators are used to train pilots in the tasks carried out in the cabin, the implementation of subsequent flight stages and emergency procedures. According to Kozuba [13], some of the benefits of using flight simulators are:

- High training efficiency - the instructor can focus on a student, without the necessity to supervise the plane on the fly;
- Optimizing the use of financial outlays - the costs of mixed training (simulator - plane) are 50 percent lower than the training only on the plane;
- Safety of training - simulators are the only way to learn how to deal with unfavorable weather conditions;
- Possibility of training regardless of environmental conditions (weather, airport availability);
- The ability to practice the selected stages of a flight - there is no need to complete the full flight procedure if you want to practice the landing itself;
- Predictability - you can turn off the occurrence of dangerous situations;
- Learning from mistakes - the possibility of the repeated problem solving in safe conditions allows to determine an optimal solution;

- Fixing the desired habits - thanks to the systematically implemented exercises, the trained pilot is able to develop the right habits and spread the attention properly on all stages of the flight.

Showing the advantages of using flight simulators Kozuba [13] emphasizes at the same time that flight simulators are not able to replace completely the training in the real flight.

A conventional power plant simulator can be an example of using simulators to learn how to handle complex processes and systems . The first power plant simulator in Europe was built in 2008 at the Fawley power plant in the United Kingdom. According to Kosik [14], the use of the simulator allows to test new power plant settings before implementing them in the real system, to train emergency situations, including these critical for the operation of the power plant. It also significantly accelerates the training of power block operators. The high level of operator training translates into the reduction in costs associated with failures in meeting the declared production. The representatives of the power plant estimate that the investment in the construction of the simulator will be refunded within 6 months of its launch, and the number of failures caused by an operator's errors should decrease by 75 percent [14].

7. Learning by doing: a simple human-robot collaboration

The example of learning by doing experimented in the laboratory of Politecnico di Torino, Italy, is the collaborative human-robot assembly of flanges on a base, as represented in Fig. 2. The components are easy to find in every hardware store. The students are required to analyze the assembly task, subdivide it into several elementary operations, assign each operation respectively to a robot or to a human operator and, finally, program the robot to execute the collaborative assembly task (Fig. 3).

The first task is assigned to a human operator. It consists of placing a base and flanges on the reference position. The human starts collaborative task execution by sending direction command to perform the assembly in the prescribed horizontal or vertical direction. In the following task the robot grabs the flange, moves it to the assembly position and keeps maintaining the flange in the correct orientation and at the correct distance from the flange reference points. The task requires force and accuracy and it is best suited to the robot. The human can join the flange to the base by screwing.

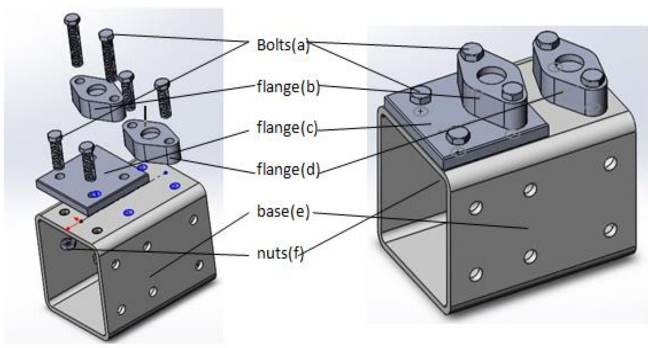

Fig. 2. CAD model of the simple assembly task


Fig. 3. Execution of a human-robot collaborative task

The task requires high dexterity and, this time, the human appears more proficient in it.

8. The example of a simulated manufacturing, assembly and transport system

As the example of a system which simulates real world, a mechatronic system, with its individual stations is presented in this paper. The system is dedicated for a didactic process in Rzeszow University of Technology, Poland [15]. The system is composed of the following elements:

- a storage and transport subsystem with a robot and a recognition system (Fig. 4), which transport elements to an assembly process,
- a modular assembly system (Bosch Rexroth) with a hydraulic press (Fig. 5),
- the finished product warehouse.

The system is realized in the following steps: (1) A component to be assembled is transported from the input warehouse to the transport line and to a recognition system, which assesses whether the correct element is on the transport belt. (2) A cylindrical robot grasps the element and transports it first to the preparation workstation and then to the assembly workstation. (3) The robot grasps the second element and puts it on the first one. (4) Both elements go to the hydraulic press to be assembled. (5) The ready product is transported to the second transport belt from which another cylindrical robot transports it to the place from which a Cartesian robot transports and places the product in the finish product warehouse.

Additionally, there is a possibility to connect to the presented mechatronic system the following elements:

- a technological subsystem in the form of a flexible machining socket (turning CNC machine ST-20 and milling CNC machine VF-2), grabber warehouse and feed material warehouse,
- a manipulation system connected with a vision system (iRVision) and robot (Fanuc M-10iA), for manipulating workpieces,
- a robotic assembly station (Mitsubishi RV-M2).

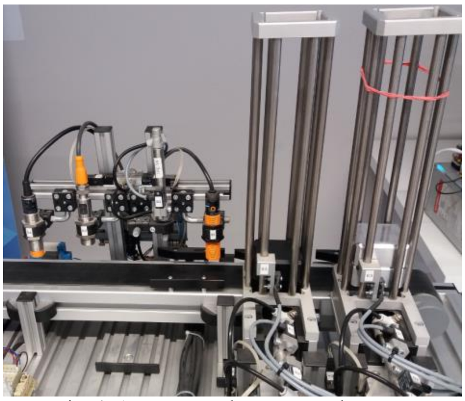

Fig. 4. A storage and transport subsystem

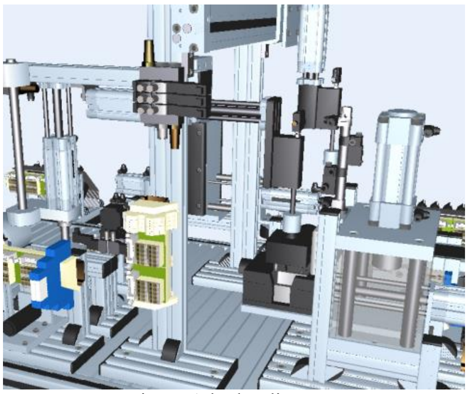

Fig. 5. A hydraulic press

The system is programmed so students can observe the work of an automatic line. Moreover, it is possible to reprogram the system to see how the implemented changes influence its work.

The learning process includes: (1) manufacturing process planning, scheduling and control, (2) programming of machine tools, (3) programming of robots and (4) programming of PLC controllers.

Among others, the following areas in automation technology can be incorporated in the teaching program [16]: logic control design, commissioning, automatic operations, assembly and alignment tasks, optimization of tasks sequences, set-up operations, emergency “off”, problem identification and elimination, mains voltage drop and power supply failure as well as safety functions.

A separate project can be realized by a team in each section of the system. All teams have to cooperate in order to achieve the established goals.

9. Summary

In order to develop intelligent systems within the Industry 4.0 implementation, it is indispensable to prepare employees for the changes. People should be able to understand the future situation and the consequences of undertaken actions. Additionally, they should be motivated to take on activities to achieve the required future state while avoiding different problems. Therefore, adequate learning methods have to be implemented to make employees awarded and motivated. The presented classification of learning modes based on simulation games gives a view of the possible learning modes which can be applied. The presented examples of simulations, VR and learning by doing illustrate how wide the application of simulations games may be.

Each company has to decide which learning modes are the most suitable for the organization context. It is also recommended to use simulations games in didactic programs. Each topic can be supported by a different type of the simulation game taking into account the possibility of application in the study program and financial as well as time-consumption aspects.

In the future work the authors would like to analyze the kind of simulation games that can support the learning process concerning different elements of Industry 4.0 concept.

Acknowledgements

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