On the development of educational resources for smart industrial manufacturing teaching and learning

Carmen STAN, Mihaela OPREA

Petroleum-Gas University of Ploiesti, Department of Automatics, Computers and Electronics, Bdul Bucuresti No 39, RO-100680, Romania

carmen.nica1991@yahoo.ro, mihaela@upg-ploiesti.ro

Abstract: *Smart industrial manufacturing systems development is based on an efficient education of manufacturing engineers that integrates advanced technologies (e.g. related to Industry 4.0). From the academic education point of view, an important issue that need to be addressed when developing e-learning platforms or different types of tutoring systems for computer aided learning (such as distance learning or online learning) refers to educational resources identification, design, and implementation. A literature review in this area reveals different types of educational resources as for example: theoretical resources (e.g. course modules), practical resources (e.g. laboratory or seminar modules), ontologies, software tools, educational applications, demonstrators, and simulations. The paper presents methodological issues associated with the development of educational resources for smart manufacturing teaching and learning. Also, some educational resources, a prototype ontology and some simulations for industrial manufacturing are discussed.*

Keywords: Educational resource, Smart manufacturing, Learning process, Ontology, E-learning.

1. Introduction

The new software and hardware technologies that are or will be integrated in modern industrial manufacturing systems (more efficient and customer-centered) based on Industry 4.0 require the development of specific educational resources for an efficient education of future manufacturing engineers. Different types of educational resources need to be included in computer-based education systems. Examples of such types of resources are: course modules, laboratory modules, ontologies, software tools, applications, demonstrators, and simulations. Engineering education is based on laboratory work, thus, either real-world laboratories (directly or remotely accessed), or simulated/virtual laboratories are essential educational resources. Moreover, theoretical notions as well as practical aspects (given, for example, by simulations, demonstrations) should be basically given by a domain ontology that explains manufacturing fundamental concepts and the relations between them. A methodology for the identification, design and implementation of the educational resources for smart manufacturing teaching and learning is proposed in this paper. A case study of applying the methodology for a smart manufacturing system development is presented.

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It is important to highlight that laboratory work (simulated, virtual or real-world) in the industrial manufacturing domain is fundamental for the success of future manufacturing engineers. Thus, simulations and demonstrators are essential for their education. An example is given by the simulation of a flexible production line (see e.g. (Stan & Oprea, 2022)) which is a basic educational resource for a manufacturing engineer working in an enterprise.

An important remark related to smart manufacturing education is that the fourth industrial revolution based on Industry 4.0 that incorporates smart technology, artificial intelligence and robotics, has a correspondent type of learning approach given by Education 4.0 that has four core components as described in (Miranda et al., 2021): competencies, learning methods, information and communication technologies, and infrastructure. The learning outcome in Education 4.0 is training of key soft and hard competencies using online sources and a student-centered approach, where the student has an active role.

The paper is organized as follows. Section 2 presents briefly a literature review on selected educational resources/systems in the manufacturing domain and proposes a general methodology for the development of some educational resources for smart manufacturing. A case study is described in Section 3 focusing on some educational resources that were developed for industrial smart manufacturing such as a prototype ontology and simulations. The final section concludes the paper and highlights future works.

2. Manufacturing education

2.1 Literature review

Modern manufacturing systems are currently named as intelligent or smart, both terms being similar but not identical. In general, smart manufacturing refers to the use of smart/intelligent technology (e.g. smart sensors, cloud computing, digital twin) while intelligent manufacturing is based on artificial intelligence and machine learning. A comparative review is detailed in (Wang et al., 2021).

A set of recently reported educational systems or educational resources (e.g. demonstrators, simulators, methodologies, reviews) developed for the manufacturing domain were selected and we present a synthesis of them.

A demonstrator for engineering education in the area of digital manufacturing is presented in (Keaveney et al., 2021). The authors provide details related to the design and implementation of such a demonstrator that is a valuable educational resource for students that will be future manufacturing engineers.

A systematic literature review on training simulators for manufacturing processes such as welding, assembling and soldering is presented in (Knoke ad Thoben, 2021). The authors analyzed also the applicability of the simulators.

A material flow design methodology for flexible manufacturing systems is proposed in (Florescu & Barabas, 2020). The main purpose of the methodology is to generate the optimal architecture of the manufacturing system. The authors used Tecnomatix Plant Simulation 15 software developed by Siemens.

The use of ontologies in smart manufacturing is discussed in (Shilov et al., 2020). The authors present a framework for ongoing study of planning and control based on ontology for smart manufacturing systems.

A core ontology that conceptualizes theoretical knowledge associated to production equipment monitoring, diagnosis and forecasting according to Industry 4.0 is introduced in (Vlasenko et al., 2022). A set of terms and relationships were identified, defined and characterized for the description of equipment state during the manufacturing process.

An example of ontology for manufacturing systems developed according to Industry 4.0 is described in (Ramírez-Durán et al., 2020). The authors designed with NeOn methodology and implemented in Protégé, ExtruOnt, an OWL ontology for the description of an extruder machine.

A recent article (Jing et al., 2022) that tackles education sustainability for intelligent manufacturing in the context of current developments in the domain of artificial intelligence (focusing on machine learning, deep learning) provides a detailed analysis of the published literature. The analysis performed by the authors is an educational resource related to the evolution of the manufacturing domain focusing on the use of artificial intelligence in manufacturing during the period 1979-2021.

The development of educational laboratories under Education 4.0 approach is tackled in (Cordero-Guridi, 2022). Virtual and digital technologies were applied for the design and implementation of an automotive manufacturing laboratory according to the guidelines of ISO/IECTR 23842-1 standard.

Remote and virtual laboratories developed for mechanical engineering education are discussed in (Grodotzki et al., 2018).

A remote laboratory for online smart manufacturing education developed at a German university is presented in (Terkowsky et al., 2019). The authors analyse the suitability of a remote experiment for smart manufacturing competencies teaching by using a modern engineering Education 4.0 laboratory.

The use of suitable software packages for the simulation of production lines in engineering education is analysed in (Rostkowska, 2014). The author evaluated three programs: Arena, FlexSim and Tecnomatrix Plant Simulator. Depending on the specific industry as well as on course goals it is selected the suitable program.

An important paradigm that was introduced in manufacturing education is connected to the Teaching Factory concept (Mavrikios et al., 2013) that integrates support for the “knowledge” workers in the future factories. Actually, it integrates learning and working environments, academic and industrial organizations, providing novel long-life learning schemes for the last achievements in technology, tools and techniques for an efficient industrial production. The teaching factory network viewed as a new collaborative form of education in manufacturing is presented in (Mavrikios et al., 2019). In such a network, academia and industry are connected providing specialized educational resources.

From the brief literature review that was presented, we can conclude that the main educational resources that are proper for a practical manufacturing education are: demonstrators, simulations, educational laboratories, manufacturing software, ontologies, case studies, reviews etc. Also, more of the latest educational resources that were reported in the literature were developed according to Industry 4.0 for smart/intelligent manufacturing systems.

2.2 General methodology for manufacturing educational resources development

The main steps of the general methodology for developing educational resources for smart manufacturing education are given as follows:

General Methodology for course educational resources development (Course_EduRes)

Input: course type, course level, course goals - smart manufactory, type of industry

Output: educational resources for teaching and learning (EduRes_Teach and EduRes_Learn)

1. Identify the *educational resources* that are necessary for the course teaching/learning

2. Design the educational resources that were identified for teaching and learning

2.1 Design the *course domain ontology/ontologies* with basic and advanced terms and relations

2.2 Design educational resources for a laboratory work (simulators, demonstrators)

2.3 Design some educational applications (case studies)

3. Implementation of the educational resources that were designed at step 2

3.1 Ontology/ontologies implementation

3.2 Simulators and demonstrator’s implementation

3.3 Implement the educational applications (case studies)

4. Testing the educational resources that were implemented at step 3

4.1 Testing the prototype ontology

4.2 Testing the simulators, demonstrators and educational applications

4.3 Evaluation of the tested educational resources from teacher/learner viewpoint

5. Return EduRes_Teach, EduRes_Learn

The main types of educational resources that can be used for smart manufacturing teaching and learning are shown in Fig. 1.

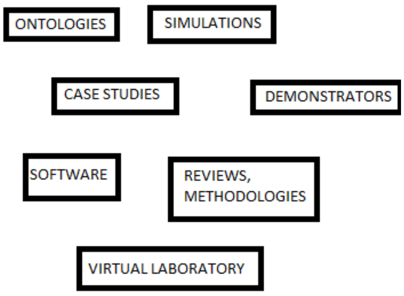

Figure 1. Main types of educational resources for smart manufacturing

During the first step of the methodology the educational resources that are necessary for smart manufacturing course teaching and learning are identified, for a specific type of industry, according with the course goals and level. For example, a general ontology for manufacturing and more ontologies (for equipment/machine, production lines, type of industry, smart/intelligent manufacturing etc), demonstrators (industry specific manufacturing process demonstrator), simulators (flexible production line simulator), and industry specific case studies.

In the next two steps, the educational resources identified in step 1 are designed and implemented with specific methodologies and software. Finally, the educational resources that were developed are tested and evaluated by teacher and students.

3. Case study: educational resources for smart manufacturing systems

3.1 A prototype ontology

The main educational resource that we propose for smart manufacturing education is a prototype ontology that we have developed in Protégé 4.3, Onto-EduSmartManufact 1.0. The ontology includes basic terms (such as process, task, machine, robot, assembly robot, welding machine, production line, flexible production line) and advanced terms related to smart and intelligent manufacturing (e.g. predictive maintenance, data analytics, digital twin, cloud computing, artificial intelligence, machine learning, deep learning). Also, we have added terms related to manufacturing software (including software for modelling and simulation) that is used for the implementation of demonstrators, simulators and various real-world case studies.

We have included in the ontology a set of terms for learning methods. Figure 2 shows the taxonomy for learning methods proper in smart manufacturing education.

Figure 2. The learning methods taxonomy

Figure 3 presents some terms specific to control in case of smart manufacturing that were included in the prototype ontology. For example, the quality control of a product can be made either by visual inspection (with a camera and image processing and recognition module) or by vibration analysis.

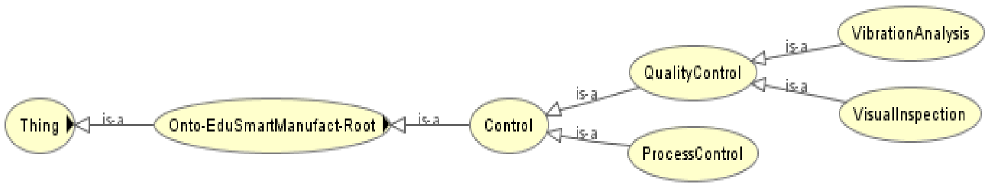

Figure 3. The control taxonomy

As in smart manufacturing, robots are important components, we have included in the prototype ontology some types of robots, as e.g. assembly robot, welding robot and painting robot. In figure 4 it is depicted the robot taxonomy.

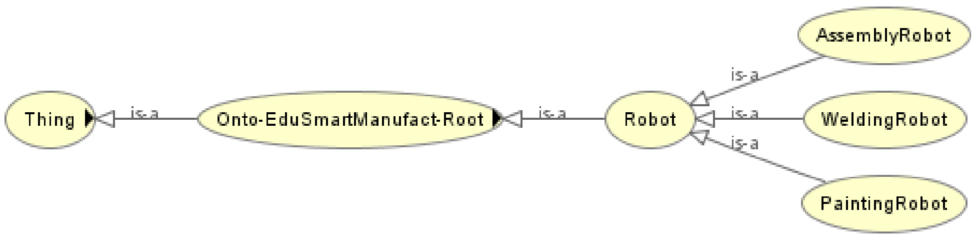

Figure 4. The robot taxonomy

An important issue that is tackled by smart manufacturing is that of equipment maintenance approach. In Figure 5 is shown the taxonomy of the maintenance concept.

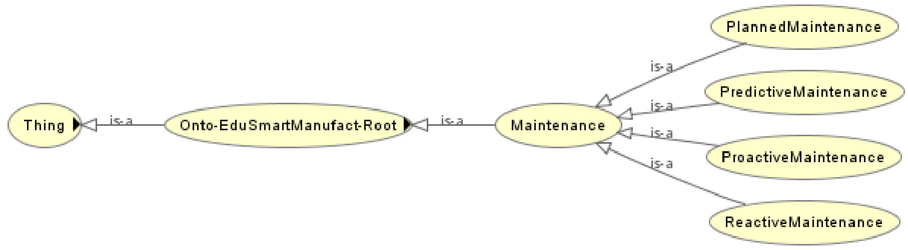

Figure 5. The maintenance taxonomy

Figure 6 shows the main types of processes that were considered in the prototype ontology. Examples of concepts from this taxonomy are packaging process, sorting process, assembling and welding.

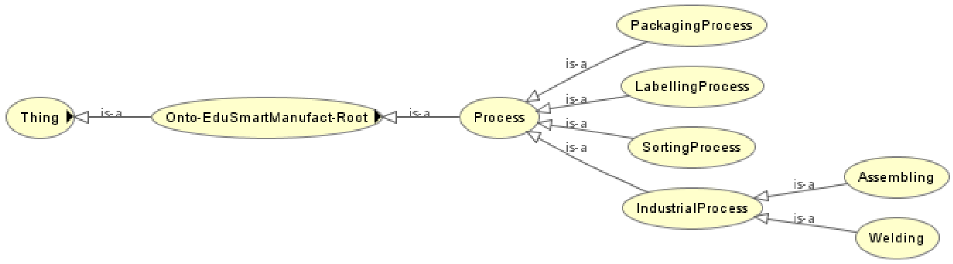

Figure 6. The process taxonomy

Finally, figure 7 depicts the taxonomy for manufacturing software that can be used for modelling, simulation and development of smart manufacturing systems.

Figure 7. The manufacturing software taxonomy

Machine learning and artificial intelligence can provide efficient techniques and methods for smart manufacturing. We have included in the prototype ontology some terms for artificial intelligence methods as is shown in figure 8.

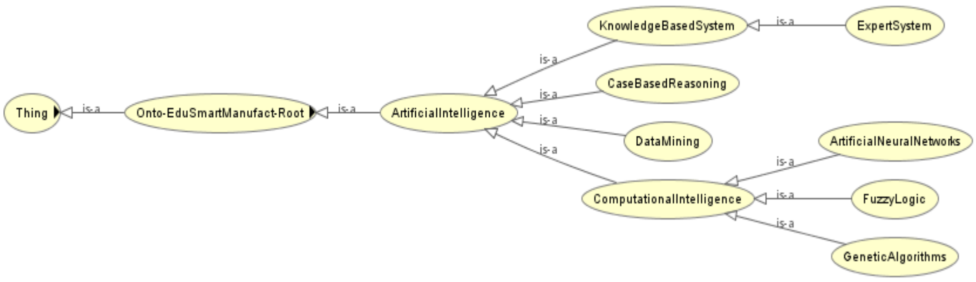

Figure 8. Artificial intelligence taxonomy

Summarizing, each basic or advanced concept from the prototype ontology is defined and characterized by attributes with specific constraints, and relations with other concepts. Apart from the taxonomic relations (*is_a*, *a_kind_of*), other relations such as *has*, *part_of*, *component_of*, and various domain specific relationshis are included.

The Onto-EduSmartManufact 1.0 ontology can be used by students to learn the main concepts from smart manufacturing as well as some practical issues, and also, by teachers when preparing the course material.

3.2 Simulators

Examples of simulations that can be developed by teachers for course preparation and by students for practical applications development are flexible production line modelling with PetriNets and simulation with Matlab-Simulink, and demonstrators for different types of machines or robots that execute some manufacturing tasks. For example, a virtual learning simulator for product manufacturing implemented with PetriNets was presented in detail in (Stan and Oprea, 2022). In this case, the educational resource that was developed, a simulator of a flexible bottling production line composed of a number of five main workstations, will help students to better understand the manufacturing process. A recent example of flexible manufacturing system simulation with FlexSim software (Gelenbe and Guennouni, 1991) is provided in (Azarian et a., 2021). This example can be used as an educational resource to show the cases of machine failure when reconfigurable machines are used in order to compensate the production loss of a specific production line. Students can learn how to improve the performance of a manufacturing process to have a better reaction to unexpected events occurring in the production line.

4. Conclusions

This paper presented a general methodology for developing educational resources for smart manufacturing systems and a prototype OWL ontology, Onto-EduSmartManufact 1.0, implemented in Protégé that can be used as an educational resource for teaching and learning smart manufacturing.

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