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CPPS 101 - A Tutorial Introduction on Cyber-Physical Production Systems

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Abstract

Today we stand at the threshold of a new revolution towards Smart Manufacturing, which is leading us to the 4th Industrial Revolution. In a moment like this, companies need to adapt and go beyond existing industrial systems, into Cyber-Physical Production Systems (CPPS), to achieve added value. With this new revolution comes a new mindset and the need to train people to become aware of the major transformations, processes and concepts surrounding this new paradigm. The primary outcome of the *CPPS 101* European project is the *CPPS 101* e-learning course, which was designed to provide a clear and integrated view of CPPS. It covers the main essential topics and emergent technologies within Industry 4.0 in 8 different learning modules. Trainees have access to video tutorials, quizzes, and practical hands-on exercises that will help them learn and test their knowledge. Moreover, remote testbeds are available for the deployment and testing of developed applications within the hands-on tutorials. This work describes the *CPPS 101* project main goals and results, while discussing the pedagogical approach and main benefits regarding the learning experience of Smart Manufacturing related topics.

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Keywords: Learning CPPS; E-learning course; Guided Learning Platform; CPPS basics; Deployable remote testbeds

1. Introduction

Cyber-Physical Production Systems (CPPS) are the key enabling paradigm in manufacturing, and paving the way for Industry 4.0 (I4.0) [3], since they integrate important technologies, such as Internet of Things (IoT), Machine

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Learning (ML), Robotics, etc., creating a huge potential for new business opportunities and economic growth. Within the Smart Manufacturing concept, CPPS are changing the job requirements for several positions in manufacturing companies. According to Alqahtani *et al.* [1], the transition to I4.0 always resulted in the implementation of new technologies and in a substantial change in manufacturing and human resource management. Also, Mogos *et al.* [4] defend that these changes require the definition of tangible engineering skills and people mindset, which can apply to these emerging technologies. This means that workforce and managers are facing challenges regarding new skills development, which are translated into highly demanded scientific research topics, creating a need among students and professionals to develop skills and know-how in these topics. Also, the workforce needs to acquire a wide range of technical skills to enable effective operation in a highly complex manufacturing environment.

Given this, a CPPS training program was developed within the activity *The Smart Manufacturing Paradigm – A Tutorial Introduction on Cyber-Physical Production Systems* (*CPPS 101*). It integrates an online e-learning course with the Learning Factories (LF) concept, allowing workforce and students to upskill competencies within I4.0, according to the greater demands on employee knowledge and skills regarding digital production. The main activity's result is an end-to-end course, composed of several modules (or learning paths) covering a wide range and trendy topics related to CPPS and the I4.0 domain. All learning paths are based on video tutorials for the theoretical presentation of topics, quizzes for assessing acquired knowledge and practical hands-on exercises for applying the theoretical concepts. Finally, users have the opportunity to deploy and test the applications developed in the hands-on exercises in two different LF (remote testbeds).

The document is organized into two more sections: Section 2 details the methodology and main characteristics of the *CPPS 101* course, and the available remote testbedsn and Section 3 presents some final remarks and future work.

2. Proposed Approach

The *CPPS 101* e-learning course consists of 8 learning modules, each targeting a specific CPPS topic (Figure 1), being equivalent to 4 European Credit Transfer and Accumulation System (ECTS) (which represents 100 h of user engagement). Each learning module is a specific learning path by encompassing several learning nuggets regarding a different CPPS topic. A learning nugget is the actual learning content in a digital (online) format, which is expressed in 3 ways: *i*) Info nugget - video tutorial, assuming a format where the presenter is on camera and presents the content that is shown in the background; *ii*) Question nugget - a quiz to assess gained knowledge regarding the tutorials, typically in a single and multiple choice type of question; *iii*) Task nugget - hands-on exercise, which can assume different types of assignments, such as code development, diagram creation, software tool handling, among others.

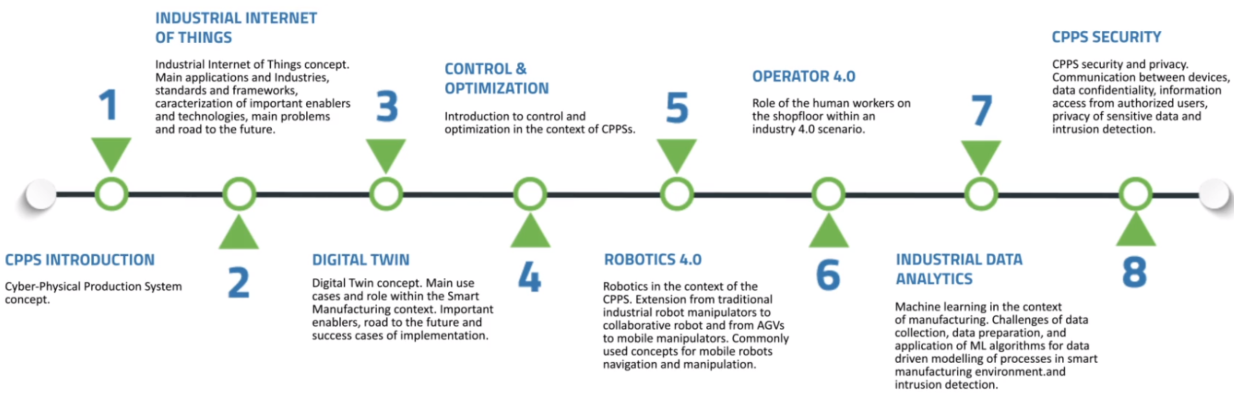

Fig. 1. *CPPS 101* Main Learning Path and Video Tutorials Examples.

Two remote testbeds were created and set up, on the form of two different LF, for deployment, testing and validation of developed source code during hands-on exercises. These LF are available online and enable to replicate testing of developed applications regarding hands-on exercises. The two developed LF are *SAMXL* and *Pizza Factory Testbed*.

- *SAMXL* [6] is a research centre based on the TU Delft campus, where companies and research institutes collaborate in the fields of automation, robotics and digitalization. It provides an environment for experimenting with advanced manufacturing on actual size robots. Technology suppliers can host their innovative hardware and software, and trainees can use the materials and workplaces. The main learning scenarios are virtual reality representation, learn from code snippets and use case analysis regarding Unity visualization and ROS/Gazebo for simulation robot's behaviour.
- *Pizza Factory Testbed* [2] is a 3D printable production line available at FEUP campus, used to demonstrate various technologies related to CPPS. It is prepared to mimic an autonomous production process of a pizza, based on a lab toy problem. It was developed as a generic (but complete) production line, mainly build with 3D printable components, such as 3D printable robotic arms and mobile robots, such as Automated Guided Vehicles (AGV), controlled with Raspberry Pis. It includes an information system, which mimics the main functionalities of a Manufacturing Execution System (MES) for production order and production line layout management. The primary learning scenario focuses on the DINASORE [5] usage, which is a framework used to design and implement CPPS by reconfiguring data workflows and distributed deployment of configuration pipelines in Edge devices.

3. Conclusion

This paper briefly presents the *CPPS 101* e-learning course, addressing a need among students and professionals to develop skills and know-how regarding Smart Manufacturing and I4.0 related topics. This course covers a wide range of topics in the domain of I4.0, since future manufacturing engineers need to acquire a large variety of technical skills to enable effective operation in a highly complex manufacturing environment. Our approach consists of an end-to-end course with 8 different (but related) learning modules, each one containing several video tutorials, quizzes, and hands-on exercises. There are also available remote testbeds within these exercises, where users can access and deploy the hands-on developed applications. Lectures, practice quizzes, exercises and remote LFs are offered, tackling the CPPS training demands, by integrating theoretical aspects with practical skills. Finally, we offer flexible learning paths, which tackles the demands for personalised and versatile learning content.

To assess the quality and suitability of the e-learning course content and format, a control group composed of 30 Master/PhD students and young researchers (aged between 25 and 35) consumed the learning modules of their interest and provided feedback through a satisfaction survey. 81.1 % of the participants indicated that they find the course format intuitive compared with other learning courses they have experienced before. All participants indicated that the course content and learning paths are suitable and cover all relevant topics to introduce CPPS. However, most replies expressed the preference of having small quizzes and exercises integrated into lectures, or right after each tutorial, instead of concentrating all exercises at the end of each module. The e-learning course is currently on a validation stage and will be available to the public later this year.

Regarding future work, we intend to extend the existing materials into training programs for the industrial workforce and managers, according to specific needs. The current course is an excellent approach to learn about I4.0 related topics in a comprehensive manner. However, up until now, it was only validated among students without considering manufacturing enterprises workforce specific training needs.

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