CPS-based Model-Driven Approach to Smart Manufacturing Systems

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***Abstract*—With advent of new technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT) and BigData, the technologies have led to the new concept of "Smart Factory" in the field of manufacturing. Several challenges have been raised up on how to handle flexibility, optimization, and interoperability in production life-cycle. This paper proposes a model-driven approach by ETRI CPS Modeling Language (ECML) to solve the challenges and presents a case study of Smart Factory by implementing from the facility design to virtualization.**

Keywords-cpps; smart factory; industry 4.0; modeling and simulation

I. INTRODUCTION

Manufacturing industry is now transforming into the fourth industrial revolution, called Industry 4.0. This transformation has the meaning of embracing a number of contemporary automation, data exchange and manufacturing technologies such as CPS, IoT, Big Data [1]. Nowadays, the assembly of these new technologies has led to the new concept, "Smart Factory", in the field of manufacturing and the entire value chain from product design to delivery is digitalized and integrated.

Manufacturing competitors have used many technologies to solve the issues regarding the complexity of the manufacturing system, and Model-Driven Engineering (MDE) technique [7] becomes one of the solutions to handle the complexity. In this paper we propose a model-driven approach by ECML to solve the challenges in constructing a smart factory and present a "multiple-product production by process control system (MPPCS)" as an implementation for a smart factory. The rest of the paper is structured as follows: in Section 2, the background of smart factory regarding Industry 4.0 and related challenges are examined. Section 3 introduces a modeling and simulation technique described in ECML. Section 4 describes a case study and the paper concludes with a summarization in Section 5.

II. SMART FACTORY

This section describes how the fourth industrial revolution came up with in German and US, and it also explains about a CPPS architecture which plays an important role in a smart factory.

A. *Industrie 4.0, Industrial Internet and Challenges*

Manufacturing industry is currently changing to a new paradigm, targeting innovation, lower costs, better responses to customer needs, and alternatives towards on-demand production [2]. Along with the change, German government has been promoting "High-Tech Strategy 2020 Action Plan" since 2013 and mentioned "4th industrial revolution" or "Industrie 4.0" [3]. The "Industrial Internet" is first introduced by General Electric in US in its visionary paper [6]. Even though both nations use different terms, several key challenges are addressed in common:

- Flexibility: flexible adaptation of the production chain to changing requirements,
- Optimization: production optimization due to IoT, CPS, and BigData
- Interoperability: interoperable data exchange between cyber and physical entities

B. *CPPS Architecture*

CPS refers to the convergence of the physical and computing (cyber) systems over the network. When applied to production, CPS is specialized in Cyber-Physical Production Systems (CPPS) [6]. CPPS consists of autonomous and cooperative elements and sub-systems that connect with each other in situation dependent ways, on and across all levels of production [10]. Fig. 1 illustrates an architecture of CPPS.

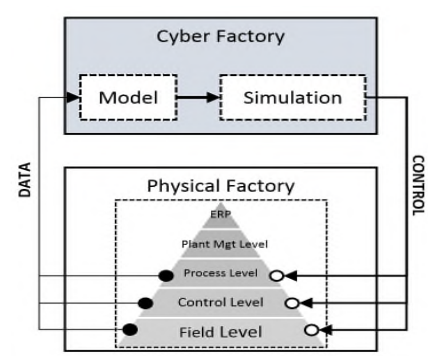

Figure 1. CPPS architecture

CPPS architecture refers to that the cyber and the physical factory are synchronized in time by exchanging data and control messages between them. The simulation in the cyber factory takes data in real-time from the physical factory so that the accurate model (the physical factory model) can be defined. Once the simulation is done, the simulator generates control messages and sends back to the actuators in the physical factory so that the flexible adaptation of the production chain and the production optimization are possible.

III. MODELING AND SIMULATION

For handling the flexible adaptation of manufacturing processes and the production optimization by a model-driven approach, it is very important to define the physical elements in a modeling language which enables modeling the factory as a whole in terms of processes, dependencies and interrelations, data and material flows [8]. ECML can be a possible candidate for it. Fig. 2 illustrates a representation of the physical factory in ECML.

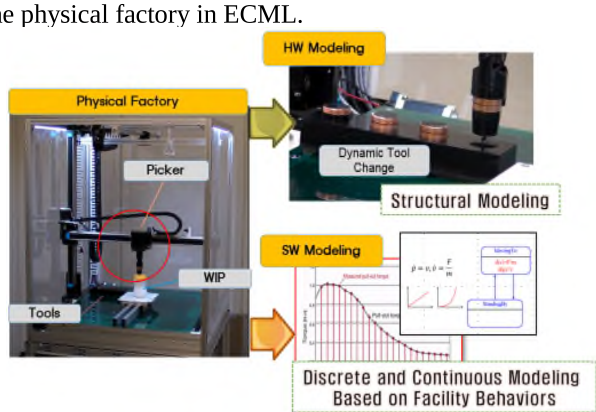

Figure 2. Physical factory modeling

ECML is a hybrid system modeling language as a basis of DEV&DESS formalism [5][10] and Meta Object Facility (MOF) [4]. It is a modular, hierarchical and graphical language for modeling and simulation of systems that can be a discrete event systems described by state transition rules and a continuous systems described by differential equations. It also supports an encapsulation of models, model reuse, and multi-resolution modeling. ECML enables to define, design, and verify the manufacturing resources such as 4M (Man, Material, Method and Machine) related to processes, products and physical resources in the plants.

Once the factory model is defined in ECML, the next step is to do simulation for constructing a virtual factory. Generally precise simulations depend on how closely and directly the models are associated with the target systems. CPS-based simulation takes models with real-time data from the physical factory. Once the simulation is done, the models can be represented as 3D models, as shown in Fig. 3, in a virtual environment on a third-party application.

IV. CASE STUDY

MPPCS, as a case study, is a conceptual facility to support the flexible adaptation of systematic processes according to CPS-based simulation. The goal of CPS-based simulation is to propose an optimized process regarding the resources, such as semi-finished products and parts, and to produce final products in the most effective way in terms of cost and time.

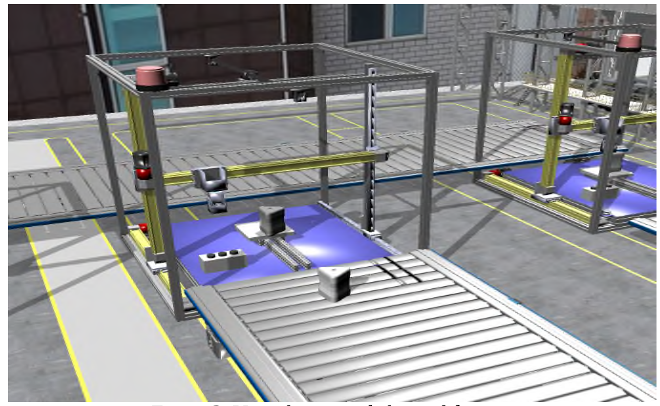

Figure 3. Virtualization of physical factory

First of all, MPPCS is defined in ECML according to the specification in terms of structures and behaviors. For example a picker and a lift of the facility are considered as structural parts, and dynamic movements of the picker are considered as behavioral parts. The facility receives a set of operating schedules from the CPS-based simulation. These schedules are generated by CPS-based simulation by receiving real-time data from sensors of the facility regarding whether the facility is in idle status or how much progress its facility has been done. If any congestions occur in a certain facility, the simulator will regenerate optimal operating schedules, and the resources will be redistributed to the other facilities according to the schedules.

V. CONCLUSION

This paper proposed a CPS based model-driven approach using ECML and presented a case study to test an optimal process generation which can be a solution to the challenges about smart manufacturing systems. Our future research will focus on covering other challenges such as a self-awareness of products and a human-machine interaction (HMI).

ACKNOWLEDGMENT

This work was supported by the ICT R&D program of MSIP/IITP. [R-20150505-000691, IoT-based CPS platform technology for the integration of virtual-real manufacturing facility]

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