

A Study of Design and Development of Cyber-physical Applications

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Abstract

After several industrial revolutions, reducing production costs, improving product quality and production line efficiency in the manufacturing industry has always been the primary goal. In recent years, Industry 4.0 has set off a wave of revolution in the global manufacturing industry. How to effectively integrate intelligent manufacturing knowledges to solve different technical problems to meet manufacturing standards, and dramatically shortening time for development, has become one of the mainstreams of research. The main purpose of this paper is to describe the development of a cyber-physical system to put together an interactive 3D industrial application in virtual world in which dynamic simulation in the control schematics in different technologies could be applied at the same time. This approach cannot be only used in simulating, verifying the accuracy of the design of the entire project but the final layout could also be fine-tuned by receiving different feedbacks under different circumstances. One industrial application was introduced in this article that a virtual system created with the Unity 3D virtual engine co-simulate with detailed control schematics of sub-systems in order to test and validate the feasibility of optimizing the simulation parameters, realizing the operation scenarios and assisting the designers to discover possible problems of the equipment in advance.

Keywords: *Cyber-Physical System, Virtual System, CAD, Digital Twins*



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INTRODUCTION

With the continuous improvement of computer technologies, complex manufacturing system simulation is no longer a difficult task to proceed. A full system simulation, especially in the product design stage, is undoubtedly a very important part for the industry to move towards Industry 4.0. The establishment of versatile departments related to artificial intelligence also symbolizes the next major change in the digitization of manufacturing technology and the practical application of intelligent technology. In response to the trend of product variety and the gradual popularization of high-speed internet, manufacturers have been experimenting to realize the concept of digital twins to simulate the physical responses of physical systems in a virtual environment which allows relevant personnel to quickly build multiple prototypes and validate different sets of parameters under different circumstances for the purpose of achieving the appeal of shortening the time to market and reducing the design cost. Through the infrastructure of the industrial Internet of Things (IoT) and Internet of Machines (IoM), most of the real-time information from sensor networks and control units such as industrial PC (IPC), programmable logic controller (PLC) could be collected for further processing. In this paper, a concept of a simulating system was proposed in which detailed schematics in its sub-systems such as mechanical and electrotechnical circuits, control logic diagrams etc. were created in the software platform *Automation Studio*® (Famic Technologies, 2022) for the engineers to test and justify their designs. Furthermore, a 3D virtual system with Unity 3D engine was also employed to interact with those circuits on the other side.

LITERATURE REVIEW

In the article (Hincapié *et al.*, 2014), the concept of cyber-physical systems was divided into two parts and then combined in different ways. The PLM software DELMIA Automation™ of Dassault in France was used to discuss its possibilities in different application. It took an electromechanical workstation as an example, concluded that virtual and hybrid platforms offer enormous opportunities for both education and industry. Those computer-aided software technologies that have emerged over the past few decades have provided powerful tools for increasing productivity, dramatically reducing the time required for product development and accelerating time-to-market (Chryssolouris *et al.*, 2009). Virtual reality applications in manufacturing could be used in the stages of design (product design and prototyping), operations management (planning simulation and training), and manufacturing processes (machining, assembly, and inspection) (Mujber *et al.*, 2004).

The construction of a virtual system is the first step of intelligent manufacturing and the integration of cyber and physical departments of a practical application, but how to fully recreate each technical detail in the physical departments and its interaction between different technologies has to be the most difficult tasks to fulfil. Taking a factory production line as an example, it can be clearly seen from Figure 1 (Sagarkolekar *et al.*, 2021) that it involves a very wide range of projects, including mechanical, electrical, control and other professional technologies, and all these projects need to be converted into cyber world in which their physical readings (such as pressure, flow, torque, voltage, current, etc.) are still capable of being simulated and imitating the physical responses in details. Moreover, the integrated interaction between different technologies must also be taken into account.

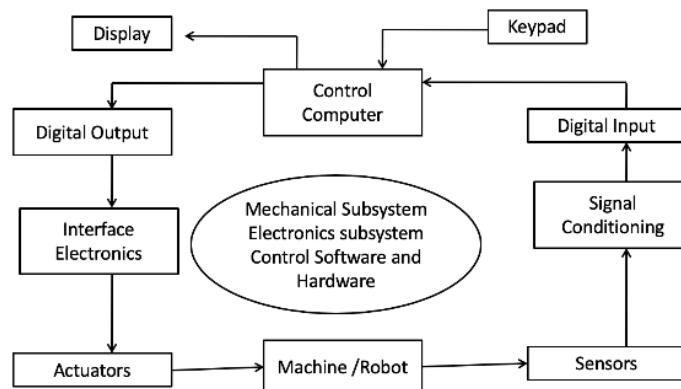


Figure 1. Technologies that need to be integrated in a virtual system

At present, most of the software platforms in the market focus on the manifestation of animation or the operation of integers, and cannot reflect the actual physical analogue data, and the coordination and integration of multiple technologies is even more difficult. Nowadays, the Automation Studio® simulation software platform developed by Famic Technologies Inc. in Canada has been widely used in education (Saikumar *et al.*, 2021), (Dosoftei *et al.*, 2019) and industry (Famic Technologies, 2022). From the perspective of system development, Automation Studio has the advantages of rapid modelling, multi-technology integration, and the function of using virtual systems for virtual commissioning compared to other similar software. The Unity3D virtual engine developed by Unity Software Inc. in San Francisco has powerful cross-platform features and realistic rendering effects. Combined with Automation Studio, it can present scenes that are close to the operation among actual applications, which is indispensable in the integration of multimedia technology.

Based on the above research background and motives, this research was targeted to create a type of virtual system that integrates Automation Studio and Unity3D software, analyses its value to intelligent manufacturing, and realizes the benefits of fault detection and correction of bottlenecks for future use.

RESEARCH METHODOLOGY

The research structure of design and development of cyber-physical applications is shown in Figure 2:

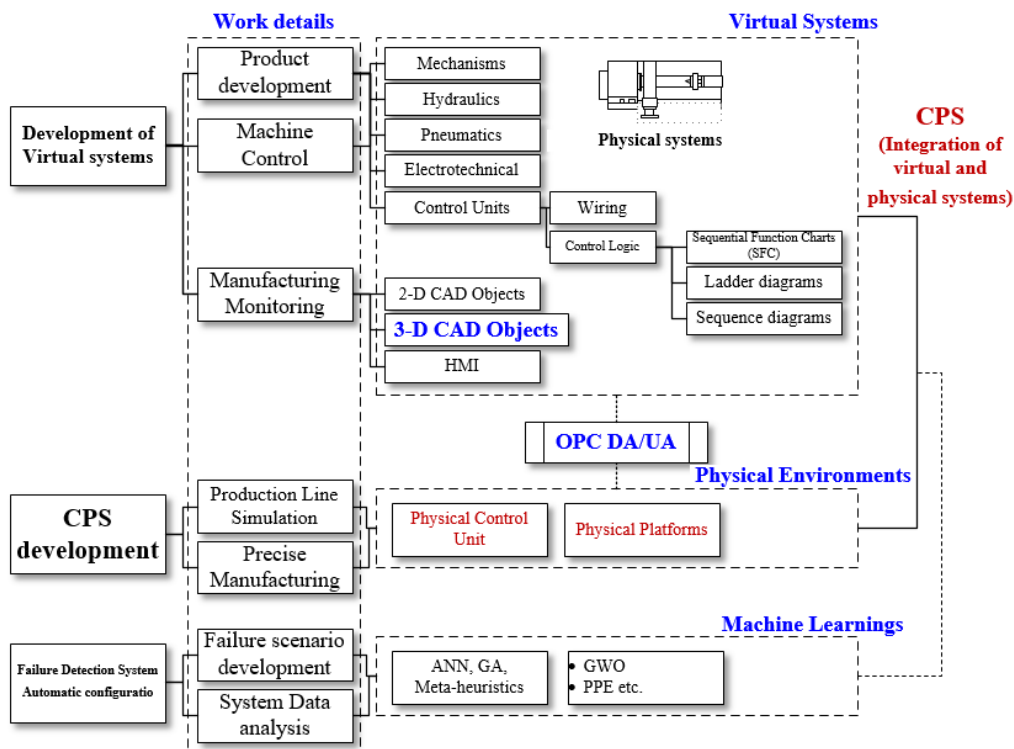


Figure 2. A structure of design and development of cyber-physical applications

In this paper, we will focus on the first phase, development of virtual systems in which three main portions are included. The first two portions, "product development and design" and "mechanical control" focus on establishing the schematics with virtual components in different technologies; for example, mechanism and actuation systems, pneumatic systems and their pipelines, electrical circuits, and control strategies using programmable controllers (PLCs), etc. In the portion of "production monitoring", the use of virtual human-machine interface (HMI) and three-dimensional virtual system is used to collect and interact the information of virtual equipment. The details are shown as follows:

- "Product development and design" and "Mechanical control":
 - Mechanical part: establishment and verification of hydraulic and pneumatic circuits.
 - Mechanism part: establishment and verification of mechanical parameters, such as dimensions, weight, positions of the centres of mass, etc. And the construction of the relative relationship between mechanism elements, such as sliding, pivoting etc. Also actuating points where forces and torques applied.
 - Electrotechnical part: including electrical circuit establishment and verification, circuit wiring diagram, cable configuration diagram, terminal block configuration diagram, etc.

- Control unit part: establishment and verification of control strategies with either Sequence Diagram, Sequential Function Chart (SFC), and Ladder Diagram (Ladder Diagram) according to different brands of PLC.
- Human-machine interface part: the configuration of buttons, switches, indicator lights, etc.
- 2D dynamic animation: constructed with built-in CAD objects.

For the integration of multiple technologies, Automation Studio software was used to build such a virtual system. Almost all subsystems stated in the previous paragraph can be created and simulated in the form of dynamic animation. For example, the pressure of the fluid in the pipeline is represented by different colours, the direction of flow is represented by arrows, the voltage, current of the wire and other set-ups can also be simulated. All technical data can be collected and recorded by dynamic measuring instruments or plotters. In this article, simulation for a production line was applied to test. It includes two long conveyers, two short conveyers, four line-sensors and one pusher etc. Different technologies were employed to construct the virtual system as shown in the following figures:

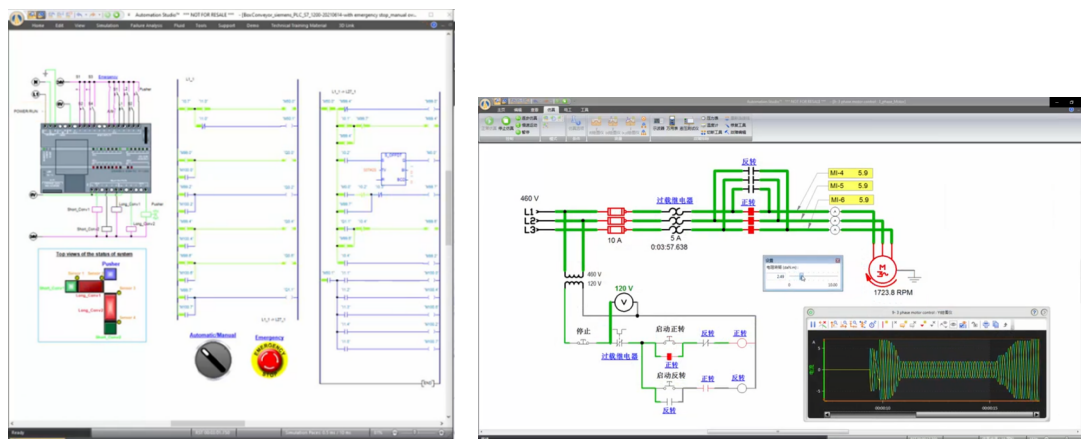


Figure 3. Virtual PLC, ladder diagrams, electrotechnical circuits and plotter

In the left side of the Figure 3, a virtual PLC for siemens S7-1200 was used to wire the relevant relays and sensors inputs. Also, the HMI components such as an emergency buttons and a dial were present. A small top view for the four conveyers and the pusher was created to indicate the status of their activation. In the right side of the Figure 3, electrotechnical circuits for powering motors of the conveyers were also constructed to simulate the behaviours in this department.

- "Manufacturing monitoring":
 - An Automation Studio- Unity 3D Link interface was used to bridge Automation Studio and the Unity 3D projects. With dynamic link libraries provided, the data exchange between these two environments are allowed.
 - It has an architecture as shown in Figure 4. (Famic technologies, 2021)

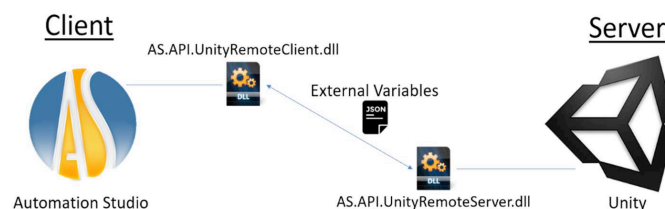


Figure 4. Overview of the architecture between Unity and Automation Studio

- Procedure to start a co-simulation with Automation Studio and Unity 3D project:
 - A Unity- 3D project will be called up once a proper sequence was executed. An independent window containing the 3-D production line was shown up as in Figure 5. in the case of this article.

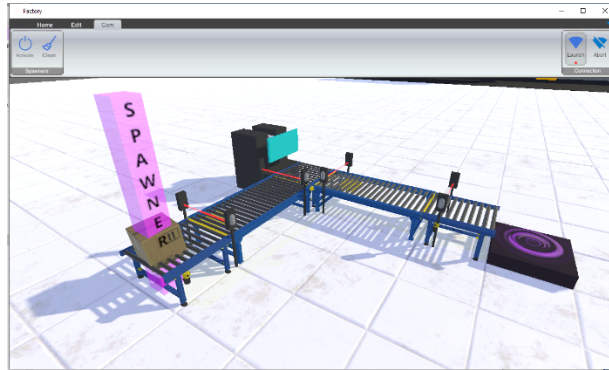


Figure 5. The production line in the Unity 3D environment

- The project in the Automation Studio can be initialized. Once the connection between both sides was established, an indicator in the ribbon bar of Unity 3D environment would turn green.
- Different scenarios could be activated from both sides. In the case of the production line, a box would be dropped after the power button was pressed. This box then moved along the conveyers and triggered those line sensors to start another process. The control of the process was executed in the side of Automation Studio and all the animations and different indicators would present the actual status of the current situations for different parts of the systems. To acquire more information during simulation, tools such as plotters could be inserted to visualize the operation.

FINDING AND DISCUSSION

The finding could be stated in several parts:

- The construction of a 3D virtual system with detailed sub-systems of multiple technologies: In the case of production line, pneumatics, electrotechnical circuits, control hardware, control strategies and HMI components were introduced into a detailed, interacted projects in which all the physical reading such as air pressure, temperature, electric currents and voltages were all simulated to imitate the practical responses from the real system.
- With the project on the Unity 3D environment, users could visualize the operation of the virtual system in great details. Furthermore, since the objects, for example, the boxes have physical properties such as weight and dimensions, they could sometimes produce unexpected situations to hinder the normal operation of the process. Therefore, engineers could learn from them and refine either the positions of virtual system in Unity 3D side or refine the initial conditions of sub-systems in Automation Studio side.
- Different failure scenarios could be implemented in the virtual system: with different failure set-ups of components in the sub-systems in Automation Studio, engineers from different departments could validate the robustness of their original designs and finetune the parameters of circuits or control strategies.

CONCLUSION AND FURTHER RESEARCH

In this paper, a virtual system, factory production line was created. It contains two main portions: (1) Product development and design in which the detailed schematics of different technologies created on the platform of Automation Studio. (2) A virtual environment in Unity 3D was integrated to simulate and obtain the physical responses from different virtual objects. It was shown that it is applicable to digitize complex factory systems into cyber world. Different initial conditions and failure scenarios could be implemented for different purposes. For the engineers, observing the outcomes to validate or finetune their original designs with ease have become possible. This will not reduce the time-to-the-market of the products but also cost effective. For the tutors either in industrial or academic sectors, such a virtual system will not only retain the attention of the trainees because of its visuality but it could give the possibility of fast developing skills in multiple technologies. Trainers could prepare different failure settings to test the abilities of the students without worrying the those risks in the real systems.

Further research could be developed in couple of directions: (1) Modelling an existing manufacturing system. (2) Realize the integration of virtual and real systems (CPS): the virtual control unit could be replaced by a physical control unit, and the operation is performed locally or remotely through the agreement of OPC DA/UA. (3) Use this virtual system as a base to acquire different responses from different locations in the systems. This information could form a database for developing a failure detection system with the implementation of certain AI algorithms.

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