Advances in Engineering and Science Informatics

"Volume 1, Issue 1, Year 2024"
website: https://www.c5k.com

Research Article

Cyber-Physical Systems: Integration of Computing and Physical Processes

Ishrat Jahan[1,*], Hasan Mahmud Sozib[2], Md Shawon Islam[3], Md. Shihab Hossain[4]

[1]*Department of Information Security, ITMO University, Kronverkskiy Prospekt, 49, St Petersburg, Russia, 197101.*
[2]*Department of Electrical and Electronic Engineering, Ahsanullah University of Science and Technology, 141 & 142, Love Road, Tejgaon, Dhaka, 1208, Bangladesh*
[3]*Department of Electrical & Electronic Engineering, Mymensingh Engineering College (University of Dhaka), Mymensingh-2208, Bangladesh*
[4]*Discipline of Physics, Khulna University, Sher-E-Bangla Rd, Khulna 9208.*
**Corresponding Author: isha_ijp@niuitmo.ru*

A R T I C L E I N F O

Article history:
05 Jul 2024 (Received)
18 Aug 2024 (Accepted)
26 Aug 2024 (Published Online)

Keywords:
Cyber-Physical System, IoT, Virtual World, Industry 4.0, Digital Logistics.

A B S T R A C T

The key forces behind the creation and advancement of Cyber-Physical Systems (CPS) are the improvement of planned goods along with the decrease in development time and cost. This survey paper's goal is to give a general overview of various system kinds and the related transition process from CPS and cloud-based (IoT) systems to mechatronics. The necessity that CPS-design techniques be a part of a multidisciplinary development process, where designers should concentrate not only on the individual physical and computational components but also on their integration and interaction, will also be taken into consideration. As a result, the study examines CPS-related challenges from the standpoints of physical processes, computing, and integration, in that order. A variety of system levels are used to pick illustrative case studies, with the first one describing the overlying idea of Cyber-Physical Production Systems (CPPSs). The examination and assessment of the particular. The details on a wind turbine's sub-system's attributes that are crucial for maintenance are provided via a condition monitoring system.

DOI: https://doi.org/10.103/xxx @ 2024 Advances in Engineering and Science Informatics (AESI), C5K Research Publication

1. Introduction

Cyber-Physical Systems (CPS) are revolutionizing the manufacturing industry by reducing development costs and time, improving designed products, and enhancing production and operation. The interaction between the designed product and production systems is crucial for Industry 4.0, which aims to transform traditional system paradigms into Cyber-Physical Systems or the global integration associated with the Internet of Things (IoT).

Automation, an evolved concept of mechanism, began to develop in the mid-1950s as computers became increasingly responsible for various processes. Since then, computers have been adopted throughout the entire industry for tasks such as design, development, manufacturing, financial control, marketing, and logistics. The role of industrial computing has expanded beyond manufacturing to fields like healthcare, where the ability to collect and manage large volumes of data has a potential value of billions of dollars (Baheti & Gill, 2011). Fig. 1 shows divisions of Cyber-physical systems. Next-generation systems need to consider factors such as a shift from product-based to information or knowledge-based economies integrated with system-level developments such as Cyber-Physical Systems and the Internet of Things.

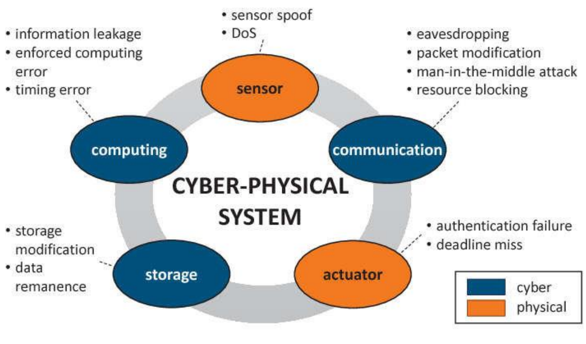

Fig. 1. Divisions of Cyber-physical systems (Onik et al., 2019).

This will require a redefinition of the role of users in various industry-based activities, considering the

*Corresponding author: isha_ijp@niuitmo.ru (Ishrat Jahan)

Cite: Ishrat Jahan, Hasan Mahmud Sozib, Md Shawon Islam, Shihab Hossain (2024). Cyber-Physical Systems: Integration of Computing a nd Physical Processes. *Advances in Engineering and Science Informatics*, 1(1), pp.1-4.

associative and collaborative nature of activities (Lee, 2015). Additionally, design processes must be reevaluated to account for increasing levels of system complexity and the inability of individuals to properly comprehend the nature of the system or its potential failure modes. The role of computers in industry is becoming increasingly permeating all aspects of industrial systems, it is necessary to reassess the relative roles and relationships between humans and computers (Lee, 2008). Fig. 2 shows the next-generation cyber-physical network plant.

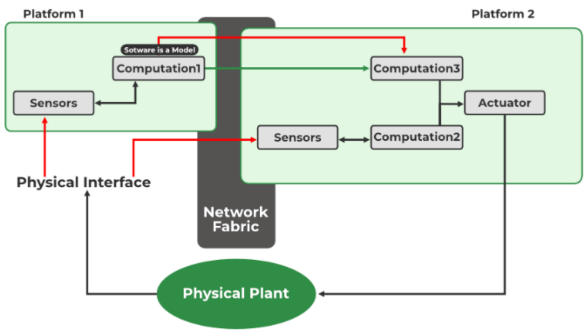

Fig. 2. Next-generation cyber-physical network plant.

This survey article focuses on methods and applications for designing, modeling, simulating, and integrating Cyber-Physical Systems, highlighting the importance of understanding the relationship between individuals and their information environment.

2. Literature review

Cyber-physical systems (CPSs) are a novel type of autonomous system that integrates computing, communication, and process control technologies, blurring the boundaries between the physical and virtual worlds. By equipping physical objects with interfaces to the virtual world and incorporating intelligent mechanisms, the boundaries between the physical and virtual realms become blurred. Interactions in the physical world can change processing behavior in the virtual world, allowing for constant improvement of processes in important application domains like transportation, energy, industrial, and medical systems. This special issue reports high-quality research on recent advances in Smart Cyber-Physical Systems, proposing solutions for data processing, architecture, platforms, technology enablers, energy and security management, and building smart and sustainable spaces (Delicato et al., 2020).

Research explores the integration of IoT, industrial IoT, and cyber-physical systems in the Industrial Revolution and Industry 4.0. It provides analytical data on their history, development trends, definitions, architectures, components, applications, and characteristics. The chapter compares IoT, IIoT, and cyber-physical systems in terms of origin, application, architecture, characteristics, and degree of integration. It also addresses control, network construction, computing, and security issues in integrated IoT, IIoT, and cyber-physical systems (Khujamatov et al., 2021). Another research discloses that Cyber-physical systems (CPS) have the potential to transform industrial value creation in Industry 4.0 by integrating technologies like big data analysis and artificial intelligence. However, there is a lack of comprehensive knowledge on CPS. This study reviews 2365 papers and creates a new categorization of industrial CPS, presenting 10 sections, 32 areas, and 246 fields. The categorization can be used as a web tool and offers a perspective on future research needs and potentials for enhancing Industry 4.0 (Oks et al., 2022).

Another paper focusing on Cyber-Physical Systems (CPSs), states a promising technology for future smart factories. Despite being in their conceptualization phase, there is a lack of knowledge on operations management characterization for CPSs. The paper reviews literature to distinguish between technological and operations management characteristics of CPSs, highlighting the need for research on these aspects. The paper identifies the characteristics of CPSs in manufacturing, distinguishes between technological and operations management aspects, synthesizes findings in a comprehensive schema, and identifies priorities for future research on CPS-based smart factories. The paper emphasizes the need for further research on operations management characteristics to guide the implementation of CPS-based factories in manufacturing (Napoleone et al., 2020).

3. Cyber-physical system evolution

Mechatronics is an interdisciplinary field that integrates mechanical, electrical, control, and computer science to design products. However, interaction between different fields is often hindered by insufficient understanding and shared platforms. CPSs integrate computation and physical processes, monitoring and controlling physical processes through feedback loops. Fig. 3 illustrates the transition process from Mechatronics to CPS to the Internet of Things.

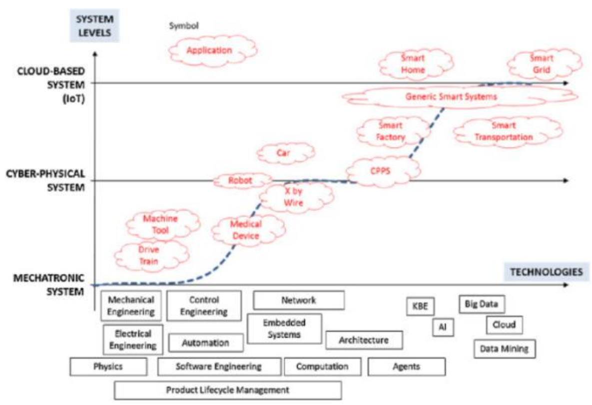

Fig. 3. Transition process from Mechatronics to CPS to Internet of Things (Jamaludin & Rohani, 2018).

3.1. CPS-paradigm:

Cyber-Physical Systems (CPS) are revolutionizing the way the physical world is monitored, controlled, and influenced. This paradigm is expected to have significant implications for engineering systems. However, the development of CPSs is intertwined with technological, economic, and social challenges, necessitating new transdisciplinary theories, models, methods, tools, and contexts. This convergence of the cyber world and the physical world is expected to become increasingly significant shortly. Cyber-physical systems are important from both academic and governmental perspectives. The European Union's ARTEMIS program invested seven billion euros in R&D between 2007 and 2013, while the US's PCAST positioned CPS research as the top priority for federal investment. Large and international companies also see CPS as a paradigm for their future systems and services.

3.2. The internet of things:

The Internet of Things (IoT) is a platform for the exchange of information between connected devices and systems, leading to the development of new system concepts like Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). This creates a context-based system where information is seen as a commodity with value determined by context. The IoT presents challenges for system designers, including the nature of information, uncertainty in design, and effective communication between team members. Designers must develop smart, adaptive interfaces, model abstractions, integrate information and physical models, prototype and test, and ensure data security.

3.3. Cyber-Physical Production Systems (CPPS):

Cyber-Physical Systems (CPPSs) are Cyber-Physical Systems applied in the manufacturing and production domain, with the term "Industrie 4.0" used in Germany. CPPSs are designed to offer services via the Internet, provide intelligent self-organizing capabilities, and enable communication between CPS, humans, and CPPS. They also provide information aggregation and representation for human involvement during engineering and maintenance. CPPSs can virtualize at different levels of detail, provide real-time capability for data analysis, and offer cross-disciplinary modularity. They can also provide real-time Big Data algorithms and technologies, optimize manufacturing processes, and enable secure communication. CPPSs need to provide intelligence, possibly implemented as agent knowledge, allowing agents to make decisions autonomously but after negotiation with their cooperating CPPS. One challenge for CPPS shortly is defining metrics for evaluating I4.0 compliance and the benefits of adaptivity, flexibility, and benchmarking different solutions. This will enable the implementation of new maintenance concepts for Cyber-Physical Systems, such as robotic maintenance and autonomous maintenance.

4. MDE of self-configuration agent-based CPPS

The SysML-based approach is proposed to develop self-configuration abilities of field-level functions using indirect redundant information or devices. This approach allows the system to reconfigure and continue operation in case of a fault, avoiding downtime using already available neighboured values or related values and devices. Single components of a CPPS are modelled as agents using the SysML element Block to encapsulate an agent's description model. This model covers information on the basic functionality a particular software component fulfils within the CPPS, such as handling or processing workpieces, using a State Chart, and the information on which devices can be replaced by redundant information in case of failures using a Parametric Diagram. Fig. 4 gives us an overview of the SysML-based approach to designing agent-based self-configurable CPPS.

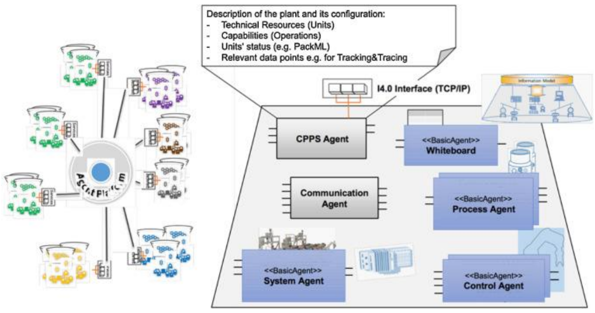

Fig. 4. Overview of the SysML-based approach to design agent-based self-configurable CPPS.

One of the main benefits of model-based approaches is the possibility to automatically generate the designed software components using model transformations. In this approach, the standard model transformation mechanisms of the OMG, such as the MOF Model-To-Text Transformation Language (MOFM2T) and the Query/View/Transformation-Language (QVT), are applied to generate model transformations that generate different parts of the software component automatically.

The required SysML model is discussed in the following paragraphs and illustrated by an application example from the process industry. The tank is equipped with two sensors to detect maximum and minimum filling levels, and the fill level is calculated based on the amount of fluid fed into the tank, the amount of fluid that flows out of the tank, the tank's dimensions, and the filling and emptying times.

The code generation of the SysML-based approach supports the transformation from the information modelled within the Parametric Diagram (PAR) into software components according to IEC 61131-3, the leading standard for PLC programming and the standard hardware platform for automated Production systems.

4.1. Maintenance concepts for CPS

CPSs can be designed, manufactured, maintained, and treated differently from conventional products and systems due to their labor-intensive nature. Robotic maintenance is considered promising, but its use is limited to inspection, monitoring, or servicing. Maintenance is difficult to automate due to its irregularity, non-uniformity, nondeterministic nature, and reliance on specialized tools. To address these challenges, a combination of robotic and autonomous maintenance could be promising. Autonomous maintenance involves a system equipped with sensors, controllers, and actuators responding to internal and environmental changes without human intervention. CPSs can achieve this by collecting data through embedded sensors and using robots for maintenance capabilities. When a fault is detected, the system diagnoses and repairs the fault, but the robot does not have specific maintenance knowledge.

5. Conclusion

The significance of Cyber-Physical System Design, Modelling, Simulation, and Integration has been covered in this study. Our attention is directed towards the crucial elements of techniques and applications. Future studies will concentrate on evolutionary tendencies, development plans, social integration strategies, and/or anticipated effects of CPSs. The suggestions made in this survey are crucial for researchers who operate within interdisciplinary systems. By using the chosen case studies, we hope to have illustrated the various granularity and consideration levels. Additionally, we hope that by sharing these insights, the many communities participating in the design of Cyber-Physical Systems would be encouraged to consider advancing in the direction of integration. Highlights include the systematic classification of systems that is presented and the comprehensive assessment of CPS-Design literature that focuses on design, modeling, simulation and CPS integration, as well as the creation of behavioural and architectural paradigms for CPS.

References

Baheti, R., & Gill, H. (2011). Cyber-physical systems. *The impact of control technology*, *12*(1), 161-166.

Delicato, F. C., Al-Anbuky, A., Kevin, I., & Wang, K. (2020). Smart cyber–physical systems: toward pervasive intelligence systems. In (Vol. 107, pp. 1134-1139): Elsevier.

Jamaludin, J., & Rohani, J. M. (2018). Cyber-physical system (cps): State of the art. 2018 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube),

Khujamatov, H., Reypnazarov, E., Khasanov, D., & Akhmedov, N. (2021). IoT, IIoT, and cyber-physical systems integration. In *Emergence of cyber physical system and IoT in smart automation and robotics: computer engineering in automation* (pp. 31-50). Springer.

Lee, E. A. (2008). Cyber physical systems: Design challenges. 2008 11th IEEE international symposium on object and component-oriented real-time distributed computing (ISORC),

Lee, E. A. (2015). The past, present and future of cyber-physical systems: A focus on models. *Sensors*, *15*(3), 4837-4869.

Napoleone, A., Macchi, M., & Pozzetti, A. (2020). A review on the characteristics of cyber-physical systems for the future smart factories. *Journal of manufacturing systems*, *54*, 305-335.

Oks, S. J., Jalowski, M., Lechner, M., Mirschberger, S., Merklein, M., Vogel-Heuser, B., & Möslein, K. M. (2022). Cyber-physical systems in the context of industry 4.0: A review, categorization and outlook. *Information Systems Frontiers*, 1-42.

Onik, M. M. H., Chul-Soo, K., & Jinhong, Y. (2019). Personal data privacy challenges of the fourth industrial revolution. 2019 21st International Conference on Advanced Communication Technology (ICACT),