

# Cyber-Physical Systems and Edge Computing

Subir Balo<sup>1</sup>

## Contents

|          |   |          |
|----------|---|----------|
| <b>1</b> | <b>Motivation</b>   | <b>2</b> |
| <b>2</b> | <b>The Evolution of Cyber-Physical Systems and Edge Computing</b> | <b>3</b> |
| <b>3</b> | <b>How Edge computing is changing Cyber-physical systems</b>      | <b>4</b> |
| <b>4</b> | <b>Challenges for CPS and Edge Computing</b>                      | <b>5</b> |
| <b>5</b> | <b>Ask ChatGPT</b>  | <b>7</b> |
| 5.1      | ChatGPT . . . . .   | 7        |
| 5.1.1    | Scientific discussion Whit ChatGPT . . . . .                      | 7        |
| <b>6</b> | <b>Conclusion</b>   | <b>8</b> |
| <b>7</b> | <b>Declaration of Originality</b>                                 | <b>8</b> |

## Abstract:

Cyber-physical systems (CPS) and Edge computing are changing modern technology. Edge computing, which involves fewer computational tasks near to data sources, provides enhanced security, real-time data processing and reduced latency for CPS applications. This paper explains the intertwined links between CPS and Edge computing by exploring some advantages that edge computing offers to CPS developments. We will try to understand the technical aspects of Edge computing and its influence on CPS design. We will also clarify its Impact on innovative applications in areas such as Self-Driving car smart cities, healthcare, industrial Automation. [S2]

---

<sup>1</sup> subir.balo@stud.hshl.de

## 1 Motivation

CPS and edge computing are revolutionizing industries through increased production, safety, and resource utilization. For instance, self-driving cars employ edge computing for real-time decision making to avoid an accident and precision farming for analyzing the sensor data and efficient watering. Real-time applications such as industrial automation benefit from edge technology since a quick response can substantially affect productivity and risk outcomes. In healthcare, edge computing can include live patient observation and data analytics that would allow for quick diagnosis of patients' conditions and tailored treatment plans formulations. Also, edge computing appears to be the perfect subject to the CPS nature because it is decentralized which is also true for many CPS applications such as smart grids with consumption and production sites dispersed all over the place. Because of such data processing, edge computing can manage energy distribution in the most efficient and optimize the sensing of anomalies and prediction of the failure of key infrastructure for the grid, thereby improving the fault tolerance and efficiency of the grid. Nevertheless, to optimize CPS, it is crucial to solve such issues as huge amounts of data that are produced, which is an issue for classical cloud computing because of latencies, bandwidth, and security constraints. Therefore, edge computing provides a solution by carrying out processing closer to the data source, which is characterized by increased security, real-time data processing, efficiency in the use of energy, and low latency levels. However, the complexity of these systems also increases important issues on reliability, safety, and the time-inspired consideration of edge-based CPS on the edge. [JR18]

Cyber-Physical Systems (CPS)



Fig. 1: Cyber-Physical Systems (CPS) Rezahosseini, Rezahosseini (2024, January 8). Cyber-Physical Systems (CPS) and Supply Chain Management. HTN. <https://htn-expert>

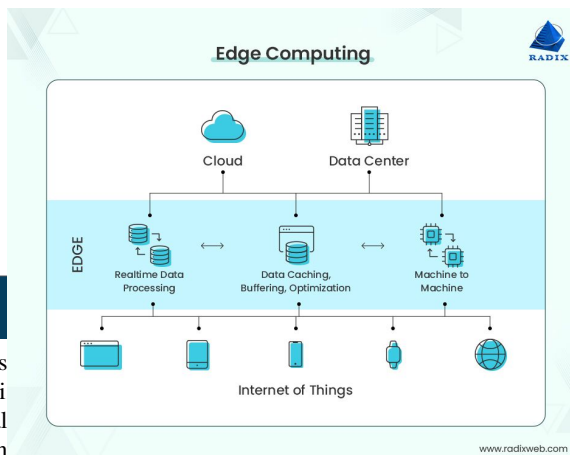


Fig. 2: Darshil-Kansara. (2023, August 21). Edge Computing vs Cloud Computing: Choosing the Right Computing Model. Radixweb. <https://radixweb.com/blog/edge-computing-vs-cloud-computing>

As we can see from the figure 1 and the figure 2 that how they work, it is safe to say

that it is possible to change many area of life, starting from transport logistics and ending with manufacturing, medical care, and smart city construction for making society more connected and effective.[JR18]

## **2 The Evolution of Cyber-Physical Systems and Edge Computing**

A cyber physical system can be defined as a computerized system where embedded computing devices are controlled through the internet to communicate with users. These systems are made up of many decentralized connected computing components that control and coordinate the physical Hardware. Currently CPS is widely applied in different sectors because of its functions which improve automation, productivity and interconnectivity. For example, smart homes apply CPS to lighting, heating and security using smartphones. Given that over 2 billion people are already using smartphones. The flow of data enabled by CPS is extremely large. Advances in technology, Make it possible to manage this information resulting in new mods of interactions between the system, components and users. CPS can indeed be associated with embedded systems as well as wireless networks and sensors, but due to its incorporation of physical and computational facts together, it is quite different and important for future technologies.[Ab21]

Edge computing on the other hand is a new form of distributed computing where computing is done towards the edges of networks. The figure 3 shows that cloud computing is trying to overcome such issues as the processing time of large volumes of data as it is done by connecting the machines close to each other. This led to the emergence of edge computing due to the rising traffic through IoT devices that causes congestion in clouds. It has been identified that edge computing, due to its ability to perform data analysis at local edge devices, can support real-time analysis of the data, decrease required throughput, and enhance the overall system interactivity. Likewise, edge computing holds some of the advantages as it implies that the data can be processed locally, thereby ensuring that sensitive data does not have to be relayed to the cloud for analysis.[Ab21]

To manage such challenges, the new millennium has come with an approach known as edge computing, a strategy that starts computation at the source of data. Based on the above explanation, Edge computing involves processing the data at the periphery nodes of the network as this can be more responsive to the core network, offloads the central system with some data that may not be very crucial, and in general improve the performance of the system through reduction of latencies on the core system. The above proposed input is helpful in enhancing the CPS because it incorporates a robust set of tools in the enhancement of complex CPS.[Ta20]

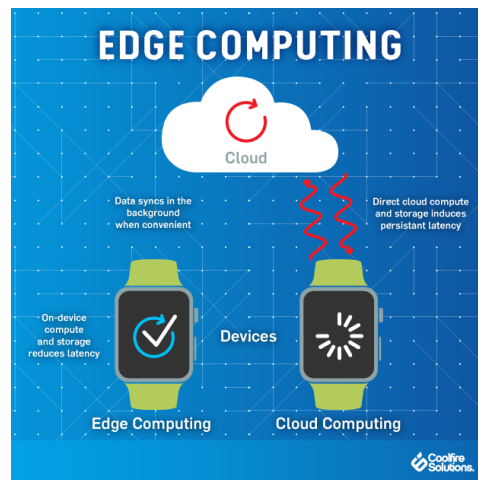


Fig. 3: Ramesh, N. (2020b, November 23). Edge computing. <https://nikku1234.github.io/2020-11-23-Edge-Computing/>

### 3 How Edge computing is changing Cyber-physical systems

Cyber-Physical Systems (CPS) include relationships between cybernetic and the physical environment. This happens when sensors record information from the physical structures to pass the information to the cyber-space. They then forward commands from cyberspace and these are implemented by the actuators on the infrastructure. In CPS, data processing through edge computing at source enhances the near-real-time functioning of the system. The main benefit of edge computing is better computational ability at the local level, thus, the cost of CPS is narrowed down. Edge computing combined with CPS provides technical advantages and indicates how CPS may result in a revolution.[Me22]

**Real-Time Responsiveness:** Since technology can process large volumes of data in short time frames, CPS must make decisions as well as control the actions made in a short amount of time. An edge can process the data close or on the computing devices to minimize the latency response time which makes it support real or near-real response. This is especially crucial for certain segments such as autonomous vehicles, manufacturing floor automation, and smart electricity grids, where the AI agent must respond instantaneously as soon as it receives some data from the sensors.[Yi19]

**The bandwidth optimization and cost reduction:** CPS may lower bandwidth consumption and related expenses by processing information locally at the edge instead of sending massive amounts of raw data to the cloud. Systems that generate a lot of data, like video surveillance systems or environmental monitoring networks, will especially benefit from this.[Yi19]

**Enhanced reliability and Resilience:** By allowing localized processing and decision-making even in the event of a disruption in the cloud connection, edge computing can increase the dependability and resilience of CPS. For important infrastructure systems that cannot withstand downtime, such as production automation or healthcare monitoring, this is crucial.[Yi19]

**Data Security and Privacy:** By reducing the need to send sensitive data to the cloud, edge computing can improve data security and privacy by enabling data processing closer to the source. apps that handle sensitive data, such as financial systems or healthcare apps, require this.[S2]

**Innovative Applications and Services:** Regarding CPS, edge computing enables the smart weighing at the edge through permitting sophisticated data processing and analytics. This results to the chances of new applications like social collaborative robotic systems in production, active recognition of errors in production lines and augmented reality in servicing and repairs.[Yi19]

**Scalability and Flexibility:** The architecture provided by edge computing is both scalable and adaptable, enabling it to adjust to the evolving requirements of CPS. It is easily adaptable to new hardware and software, enabling the system's smooth expansion and development.[Yi19]

**In conclusion,** edge computing is strengthening data privacy and security, enabling new applications, boosting real-time responsiveness, decreasing bandwidth usage, increasing dependability, and offering a scalable and adaptable architecture that are all revolutionizing cyber-physical systems. These developments are opening the door for more sophisticated, effective, and reliable CPS in the future.[S2]

The figure 4 gives us a clear view of how edge computing is revolutionizing our daily life through IoT devices. it starts from Energy efficient smart homes to integrated electricity grids and from data-driven healthcare to smart farming. They are expected to boost productivity, provide comfort and sustainability.[S2]

## 4 Challenges for CPS and Edge Computing

Cyber-Physical Systems (CPS) and Edge computing have promising potential in enhancing automation and interface. Nevertheless, they are still exposed to a number of great challenges which should be solved if the mentioned organizations are to achieve their full potential.[Ca21]

**Service Latency:** Delay is a major issue that needs to be addressed most especially in simulation of CPS applications. It does help, but it requires a completely new look at the system, using the task-management capabilities of systems like Intel's SDC, and setting up VMs to be able to handle many connected devices.[Ca21]

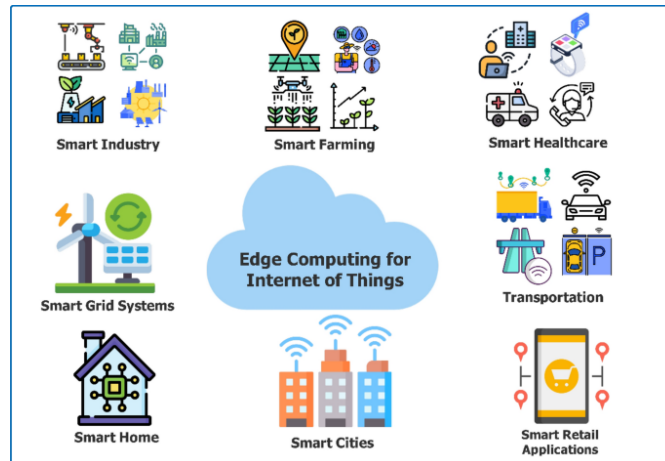


Fig. 4: Quy, N. M., Ngoc, L. A., Ban, N. T., Van Hau, N., Quy, V. K. (2023c). Edge Computing for Real-Time Internet of Things Applications: Future Internet Revolution. *Wireless Personal Communications*, 132(2), 1423–1452. <https://doi.org/10.1007/s11277-023-10669-w>

**Energy Consumption:** Most of the CPS devices are battery operated, therefore their working time is restricted. Optimizing energy consumption is mandatory, especially for battery-operated elements in the case of edge computing. Large energy consumption also, raises production costs and can results in high regulations.[Ca21]

**Security and Privacy:** Security and privacy of data should not be compromised in any way. There is a requirement for unique authentication and safe interaction to cease unlawful infiltration and safeguard against different invasions. The wireless technologies applied to the contexts of edge computing are comparatively more open and exposed, and therefore this one is a larger issue.[Ca21]

**System Reliability:** That is why, making sure that the system will run smoothly in the future, even with inevitable failures, is crucial. This require operational and deliberate processes to address the issues associated with CPS and edge computing integration.[Ca21]

These problems have to be dealt in order to harness the synergy between CPS and edge computing. Solving these problems is paramount to the realisation of CPS and edge computing integration and their effectiveness.[Ca21]

## 5 Ask ChatGPT

### 5.1 ChatGPT

In this part, I explain the role of edge computing and cyber-physical systems for IoT and computing in the future in a scientifically analytical dialogue with ChatGPT, a chat-bot.

#### 5.1.1 Scientific discussion Whit ChatGPT

**Prompt:** ChatGPT, what are your thoughts on the significance of cyber-physical systems and edge computing for the future of IoT and computing? How do you see these technologies shaping the landscape and transforming the way we interact with the digital world?

**ChatGPT:** Cyber-Physical Systems (CPS) integrate computational algorithms with physical components, enhancing interactions between the physical and digital worlds. These systems are essential in healthcare, transportation, manufacturing, and smart grids, where real-time data processing and responsive actions are critical. Traditionally, CPS relied on cloud computing for data processing and storage, but this approach faces challenges like latency, bandwidth constraints, and security vulnerabilities.

Edge Computing offers a solution by decentralizing data processing to the edge of the network, closer to data sources. This shift brings several advantages to CPS. It significantly reduces latency, enabling real-time processing and decision-making vital for applications like autonomous vehicles and industrial automation. It optimizes bandwidth usage by filtering and processing data locally, reducing the amount transmitted to central servers, which alleviates network congestion and enhances system responsiveness.

Furthermore, Edge Computing boosts the security and privacy of CPS by processing sensitive data locally, minimizing exposure to potential cyber threats during transmission. This approach ensures continuous operation and reliability of CPS, as edge devices can function autonomously without constant cloud connectivity.

In conclusion, integrating Edge Computing into CPS addresses traditional cloud-centric model limitations, paving the way for innovative applications requiring real-time processing, enhanced security, and improved reliability.

**My Scientific Statement:** "There is no doubt that the edge computing can be seen as a new paradigm for CPS improvement, which provides advantages beyond the cloud-based solutions. Thus, by distributing signal data processing through edge computing, CPS decreases latency, optimizes bandwidth, becomes more secure and increases reliability. This makes it possible to allow real-time decision making as well as timely actions in tactical areas such as self-driving vehicles, manufacturing processes, and health care among others, thus creating the genesis of the next generation of far intelligent, effective and robust CPSs"[Ta20].

## 6 Conclusion

Therefore, it can be said that the application of the edge computing together with the cyber-physical systems is transforming the modern technology. Compared to centralized cloud computing, edge computing addresses the problems that occur due to processing data universally; better timed reaction, security, less time in processing, cost-efficiency[Me22]. Thus, it is creating new opportunities for further development of innovative CPS with a focus on various domains such as transportation, buildings, health care, and industries. Though there are still some questions about the security and dependability of CPSs operating in the peripheral, coupling produces a structural shift that is difficult to argue against[JR18].

## 7 Declaration of Originality

I, Subir Balo, herewith declare that I have composed the present paper and work by myself and without the use of any other than the cited sources and aids. Sentences or parts of sentences quoted literally are marked as such; other references with regard to the statement and scope are indicated by full details of the publications concerned. The paper and work in the same or similar form have not been submitted to any examination body and have not been published. This paper was not yet, even in part, used in another examination or as a course performance. I agree that my work may be checked by a plagiarism checker.

---

07/07/2024&Lippstadt - Subir Balo

## Bibliography

- [Ab21] Abikoye, Oluwakemi Christiana; Bajeh, Amos Orenyi; Awotunde, Joseph Bamidele; Ameen, Ahmed Oloduowo; Mojeed, Hamed Adeleye; Abdulraheem, Muyideen; Oladipo, Idowu Dauda; Salihu, Shakirat Aderonke: Application of internet of thing and cyber physical system in Industry 4.0 smart manufacturing. In: Emergence of Cyber Physical System and IoT in Smart Automation and Robotics: Computer Engineering in Automation, pp. 203–217. Springer, 2021.
- [Ca21] Cao, Kun; Hu, Shiyang; Shi, Yang; Colombo, Armando Walter; Karnouskos, Stamatis; Li, Xin: A Survey on Edge and Edge-Cloud Computing Assisted Cyber-Physical Systems. IEEE Transactions on Industrial Informatics, 17(11):7806–7819, 2021.
- [JR18] Jamaludin, Juliza; Rohani, Jemmy Mohd: Cyber-Physical System (CPS): State of the Art. In: 2018 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube). pp. 1–5, 2018.
- [Me22] Mei, Qian; Xiong, Hu; Chen, Yeh-Cheng; Chen, Chien-Ming: Blockchain-enabled privacy-preserving authentication mechanism for transportation CPS with cloud-edge computing. IEEE Transactions on Engineering Management, 2022.



- [S2] Sánchez, José Manuel Gaspar; Jörgensen, Nils; Törngren, Martin; Inam, Rafia; Berezovskyi, Andrii; Feng, Lei; Fersman, Elena; Ramli, Muhammad Rusyadi; Tan, Kaige: Edge Computing for Cyber-physical Systems: A Systematic Mapping Study Emphasizing Trustworthiness. *ACM Trans. Cyber-Phys. Syst.*, 6(3), sep 2022.
- [Ta20] Talebkhah, Marieh; Sali, Aduwati; Marjani, Mohen; Gordan, Meisam; Hashim, Shaiful Jahari; Rokhani, Fakhrul Zaman: Edge computing: architecture, applications and future perspectives. In: 2020 IEEE 2nd International Conference on Artificial Intelligence in Engineering and Technology (IICAJET). IEEE, pp. 1–6, 2020.
- [Yi19] Yin, Shiyong; Bao, Jinsong; Li, Jie; Zhang, Jie: Real-time task processing method based on edge computing for spinning CPS. *Frontiers of Mechanical Engineering*, 14:320–331, 2019.