The Role of Microservices in the Internet of Things: Applications, Challenges, and Research Opportunities

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***Abstract*—The Internet of Things (IoT) is a rapidly growing field, encompassing various devices and sensors that produce enormous quantities of data. On the other hand, microservices architecture has emerged as a popular solution for developing complex software applications on a large scale. Combining these two technologies has the potential to revolutionize the creation of powerful and scalable IoT applications. By leveraging the benefits of microservices, such as modularity and decoupling, developers can design more flexible, scalable, and resilient IoT systems. In this paper, we present a thorough analysis of the state-of-the-art research regarding the use of microservices in the development of IoT systems. We summarize thirty selected studies and discuss their contributions to the field. Additionally, this paper offers valuable insights into the use of microservices in IoT applications, which can inform the design and development of future IoT systems. Finally, we outline and explain the future research opportunities that the microservices paradigm can offer in the context of the IoT.**

***Keywords*—Microservices, Internet of Things (IoT), Monolithic architecture, Edge cloud.**

I. Introduction

The Internet of Things (IoT) is a rapidly growing paradigm that has the potential to revolutionize various domains, including healthcare, transportation, manufacturing, and agriculture. Although the concept of IoT has existed for several decades, recent technological advancements and the availability of affordable devices and sensors have led to a significant increase in the quantity of connected devices and the data they produce. According to Gartner, by 2025, there will be approximately 75 billion connected devices worldwide, generating massive amounts of data that can be leveraged for various purposes. IoT offers several advantages, including improved efficiency, productivity, safety, and cost savings in various industries. For example, in the healthcare industry, IoT can monitor patient vital signs and transmit data to healthcare providers, provide real-time tracking of medical equipment, automate medication management, enabling remote monitoring, and improving patient outcomes [1]. In manufacturing, IoT devices can provide real-time data on machine performance, allowing for predictive maintenance, optimizing production processes, enhancing worker safety, and reducing downtime [2].

Despite its potential benefits, IoT faces several challenges. One of the biggest challenges is security and privacy. IoT devices often collect sensitive data, such as personal health information and financial data, which can be vulnerable to cyber attacks and data breaches [3]. Additionally, the lack of standardized protocols and interfaces for IoT devices can lead to interoperability issues, limiting the scalability and flexibility of IoT applications [4]. Another limitation of IoT is the complexity and cost of deploying and managing large-scale IoT systems. The diversity of IoT devices, networks, and applications requires specialized skills and expertise, which can be challenging for organizations with limited resources. As the number of devices continues to grow, traditional monolithic architectures may not be able to handle the scale and complexity of IoT applications and face various challenges related to scalability, security, interoperability, and data management. Most current applications have been developed using a monolithic approach to software design and deployment, where a single server is responsible for executing the entire application or process. This makes it difficult to redeploy and maintain, and finding a solution to the problem of physical heterogeneity is more challenging. To address these challenges, researchers have proposed various architectures, protocols, and frameworks for IoT systems.

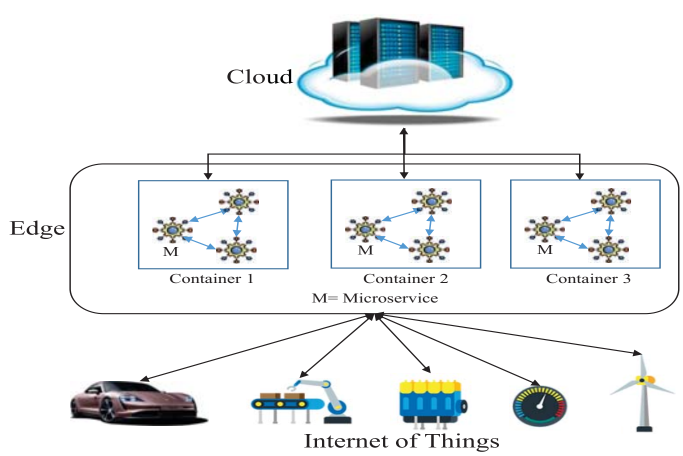

Fig. 1. Microservice-based architecture for IoT applications.

On the other hand, the microservices architecture has become a promising way to build large, complex software systems, with benefits like better scalability, flexibility, and

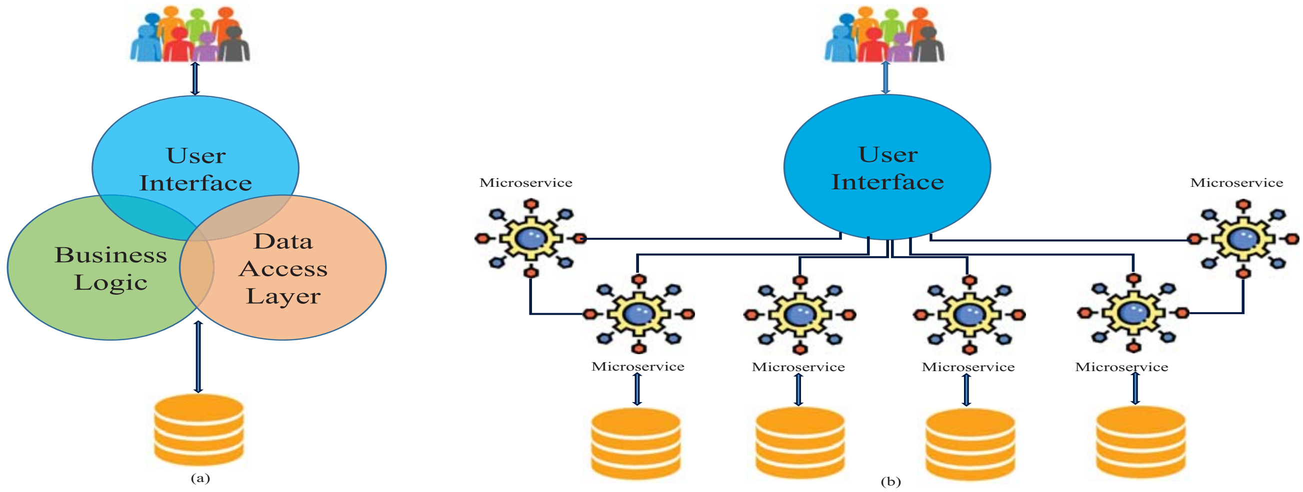

Fig. 2. (a) The monolithic architecture versus (b) the microservice architecture.

reliability. Microservices are independent, modular, and highly decoupled services that can be developed and deployed independently. These services can communicate with each other using lightweight protocols and interfaces, making them highly scalable and flexible [5]. By breaking down an application into smaller, independent services, the microservices architecture can improve the resilience of the system as a whole, making it easier to manage and update. The use of microservices offers several advantages in the computing platform, including the ability to deploy and launch them quickly and migrate them easily. This makes microservice-based IoT platforms emerge as a promising solution for delivering low-latency services using IoT devices (Fig. 1). Integrating these two technologies has the potential to revolutionize the design and deployment of distributed systems by enhancing performance, minimizing latency, and enabling real-time decision-making. Fig. 2 illustrates a comparison between the monolithic architecture and the microservices architecture.

However, it is difficult to provide flexible and robust services to IoT applications in a constantly changing environment. On the other hand, deploying microservices on IoT platforms has become a challenging task, despite the advantages that the architecture offers in designing IoT applications. Previous research has mostly focused on microservices or IoT independently, with little consideration of their integration. However, most surveys have been limited in scope and have not fully explored the potential of microservices in the IoT. Consequently, a comprehensive understanding of the opportunities and future directions of the microservices approach in IoT is lacking. This paper aims to address this gap by providing an extensive analysis of microservices in the IoT, emphasizing different applications, challenges, and future research opportunities. The following are the main contributions of this study.

- We present an overview of IoT and microservices, including their introduction, benefits, and challenges. Moreover, this paper also explores the potential applications of microservices in the IoT across various domains.
- We provide a thorough review and summary of the current research on the use of microservices in IoT environments. Our review covers the state-of-the-art research on microservice frameworks for IoT applications, the IoT platforms, and security issues associated with microservice-enabled architectures in the IoT.
- Finally, we identify and discuss the potential future research opportunities in this field. These research directions include integration of blockchain technology, container orchestration, dynamic resource allocation, edge intelligence, integration of digital twins, DevOps for IoT, domain-specific applications, and so on.

This paper is organized as follows in the remaining sections. Section II provides a summary of the state-of-the-art research on the use of microservices in IoT environments. In Section III, we explore the potential applications of microservices in IoT across different domains. Section IV outlines the future research opportunities, while Section V concludes the paper.

II. Literature Survey

Microservices have emerged as a key architecture for developing and deploying IoT applications. The microservice architecture has gained popularity among service providers, including Facebook, YouTube, Netflix, Amazon, and Apple, due to its capability of breaking down an application into lightweight services and facilitating the reuse of functionalities. The integration of microservices and IoT has been a focus of research and industry interest in recent years. Researchers have proposed several microservice roles for the IoT with different design objectives. In this section, we will provide a state-of-the-art survey of thirty papers that focus on the use of microservices in IoT applications, the IoT platform, and security issues. The first category of papers provides the design and implementation of microservices-based IoT applications (Table I). The second category of papers focuses on the development of microservices-based IoT platforms, which provide a framework for building and deploying IoT applications using

TABLE I
A SUMMARY OF DIFFERENT MICROSERVICE ROLES FOR IOT APPLICATIONS

Reference	Aspects	Contributions	Year
[5]	Microservices approach for IoT applications	This paper explores the similarities between microservices and IoT and how microservices architecture can be used to overcome scalability and maintainability issues in IoT applications.	2016
[6]	Microservices as agents in IoT systems	The authors present a collaborative approach for managing services in machine-to-machine (M2M) devices in IoT environments that is based on microservices.	2017
[7]	Microservices-based IoT for smart buildings	The authors offer a prototype of a platform that makes use of a distributed microservices architecture and an advanced sensor network to handle several concurrent applications for smart buildings.	2017
[8]	Fault tolerance in IoT systems based on the microservices framework	The authors propose a microservices architecture to process real-time fault tolerance detection. They also use an online machine learning (ML) approach to detect and mitigate flaws.	2018
[9]	Microservices for connected vehicles	The authors propose a novel testbed architecture that incorporates a microservices, an edge server, virtualization, open APIs to extend the services delivered, and experimentation capabilities.	2018
[10]	Microservices to provide predictive analytics for IoT applications	The authors develop a design methodology for IoT applications built on microservices, and they integrate both data-driven and knowledge-based techniques to facilitate predictive analytics.	2018
[11]	Microservices scheduling for IoT Applications	The authors develop a model for efficiently scheduling microservices in IoT scenarios to reduce energy consumption over cloud-edge environments with heterogeneity.	2018
[12]	Microservices-based architecture for industrial IoT (IIoT)	This paper proposes a flexible and lightweight microservices-based architecture that incorporates ideas from modern information technology, industrial automation systems, the Internet of Things, and cloud architectures to enable the seamless and automated integration of various devices and protocols at the device level.	2018
[13]	Orchestration of microservices for IoT	This paper suggests a scalable and modular IoT architecture using Docker orchestration and lightweight virtualization to distribute the application logic across different layers for fault tolerance and system availability with minimal performance impact.	2018
[14]	Microservices-based IoT application placement	The authors propose a strategy for placing IoT applications by deploying microservices in proximity to the data source to minimize network utilization and latency.	2019
[15]	Edge-based microservices for IoT applications	This paper presents a case study on the implementation of distributed edge services for IoT applications using the microservices paradigm, with an emphasis on user mobility analysis.	2019
[16]	Microservice-enabled smart wireless sensor networks for IoT applications	The authors propose a microservices-based middleware design to integrate wireless sensor networks with the IoT. The proposed design enables services to interact dynamically and can handle unlimited services while taking into account the capabilities of different devices.	2019
[17]	Load balancing for IoT microservices	This paper shows a new approach to balancing the load across IoT microservices by using a graph-based model that takes into account how microservices depend on each other.	2019
[18]	Microservices-based framework for IoT and people (IoP) applications	This paper suggests a framework for serverless, context-aware, and cloud-centric IoT and people (IoP) applications based on microservices and demonstrates its application in the healthcare domain.	2019
[19]	Dynamic microservice scheduling in IoT environments	The authors propose a scheme for scheduling microservices in mobile edge computing that ensures maximum energy efficiency, optimal execution of user tasks, and guarantees quality of service.	2020
[20]	Microservices-based edge computing for workload modeling	This paper introduces a technique for modeling workloads in microservice-based edge computing to improve the configuration and scheduling of computing resources for the best performance in IoT environments.	2021
[21]	Deploying IoT microservices in a hybrid edge-cloud environment	This paper introduces a problem called the microservice-based deployment problem (MSDP) and proposes a solution using a multiple buffer, deep deterministic policy gradient algorithm to minimize the waiting time of IoT devices in a hybrid edge-cloud environment.	2021
[22]	Dristributed microservices caching strategy for IoT	The authors propose a microservice caching scheme called DIMA for IoT devices that leverages mobile edge computing to alleviate the load on the core network and enhance the quality of service.	2022
[23]	Microservices-based service sharing in IoT applications	This paper evaluates how a microservice-based architecture impacts the performance of building edge-based IoT applications. The authors created a prototype implementation and did performance evaluations to show how well this architecture works.	2022

TABLE II
A SUMMARY OF DIFFERENT MICROSERVICE ROLES FOR IOT PLATFORM

Reference	Aspects	Contributions	Year
[24]	Microservices-based smart city IoT platform	This paper explores how microservice architecture can be utilized in designing an IoT platform for smart cities and highlights the advantages of this approach over conventional service-oriented architecture methods.	2015
[25]	Microservices-based interoperable IoT platform	This paper proposes a microservice-based middleware architecture to connect heterogeneous devices, achieving functionality irrespective of network size and complexity while supporting large numbers of users and data processing.	2016
[26]	A microservice-enabled open IoT framework	The authors propose a new IoT framework based on microservices architecture that supports interoperability, accommodates various types of objects, and enables the integration of Geo service, Big Data applications, intelligence, and automation.	2017
[27]	Orchestration of IoT slices through microservice platforms	This paper introduces an architectural design that enables automated orchestration of end-to-end IoT services for various users by integrating network slicing, edge computing, and cloud computing. The authors demonstrate the feasibility of their proposed solution through a functional prototype implementation.	2019
[28]	Lightweight container and microservices-based IoT platform	The authors present the design and implementation of an IoT platform using microservices architecture, the Spring Framework, and Docker container technology. The platform is designed to integrate and analyze data from various devices to improve economic benefits for enterprises.	2020
[29]	Microservices-based IoT platform for energy power management	This paper introduces a new platform for the IoT that utilizes microservices architecture to deal with the challenges of heterogeneity of devices, scalability, and security. The proposed platform optimizes energy usage based on resource usage and outperforms another method in terms of memory usage, CPU usage, and throughput.	2021

TABLE III
A SUMMARY OF DIFFERENT SECURITY ASPECTS OF MICROSRVICE-ENABLED IOT SYSTEMS

Reference	Aspects	Contributions	Year
[30]	Microservices and blockchain technology-based smart surveillance systems	The authors propose a smart surveillance system that is designed to be secure using microservices and blockchain technology. The proposed system uses independent microservices for video analysis algorithms, blockchain for synchronizing video analysis databases, and smart contracts for access control to prevent unauthorized user access.	2018
[31]	Graph-based securing microservices in IoT systems	This paper presents a graph-based access control solution for securing microservices in IoT systems. The proposed solution is designed to firewall intercept, firewall inter-service communication, and create a model of legitimate communication relationships.	2018
[32]	Microservices-based secure edge computing solution in IoT networks	This paper suggests a secure edge computing solution for managing services, IoT devices, users, and data by utilizing a microservices architecture and a security gateway. The security gateway makes sure services are safe by placing security services on the internet, while a client support gateway is implemented to facilitate user authentication and authorization.	2020
[33]	Person re-identification using a microservices-based architecture over an IoT edge computing gateway	The authors propose an architecture for person re-identification applications where microservice is deployed on an IoT edge computing gateway that can be connected to multiple cameras in a surveillance system and balances efficiency with privacy protection.	2021
[34]	Microservices-based privacy for industrial IoT	This paper suggests a machine learning framework based on microservices to protect the privacy of data in the context of the Industrial IoT and emphasizes the need for a trade-off between privacy and model performance in edge networks.	2023

microservices architecture (Table II). Finally, the last category of papers provides security threats to microservice-based IoT applications (Table III).

III. APPLICATION

Microservices offer a powerful approach for developing scalable and efficient IoT applications in a variety of domains. Microservices make it easier to process and analyze data by breaking up complex systems into smaller, independent parts. This leads to more accurate predictions, improved efficiency, and better overall performance. This section provides key applications of microservices in the IoT.

- **Smart Home Automation:** Smart homes are becoming increasingly popular, with a growing number of households adopting IoT-enabled devices to make their homes easier to use, safer, and more energy efficient. Microservices can be used to make smart home automation systems that let people control things like lights, heating, and security systems from afar [7]. By breaking the system up into smaller parts, microservices make it easy to connect it to other devices and systems. This makes the smart home easier to manage and control.

- **Healthcare:** In the healthcare domain, microservices play a crucial role in the development of telemedicine systems, medical diagnosis systems, and treatment planning systems. Microservices help to integrate different medical devices and applications to provide a seamless healthcare experience to patients. This system can improve patient outcomes by providing real-time data analysis, personalized treatment recommendations, and reducing healthcare costs.
- **Transportation:** One of the key applications of microservices in transportation is the development of intelligent transportation systems (ITS). These systems leverage data from sensors and other sources to provide real-time location tracking and traffic monitoring, route optimization, and other services that can help reduce congestion and improve safety.
- **Industrial Automation:** Industrial IoT (IIoT) is one of the key applications of microservices in industrial automation. Microservices can be applied to develop real-time monitoring and control systems for industrial equipment [12]. These systems can help improve efficiency, reduce downtime, and enable predictive maintenance by processing large amounts of data from sensors and other devices.
- **Smart Cities:** Microservices can be used to build smart city systems that bring together services like transportation, energy, and public safety [24]. These systems can help make life better for people in a city by enabling more efficient and sustainable city management.
- **Agriculture:** Microservices can be used to make smart irrigation systems, crop monitoring systems, livestock monitoring and management systems, and real-time monitoring systems. By processing data from sensors and other devices, microservices can help farmers to optimize crop yields, reduce waste, and improve overall efficiency.

IV. Future Research Directions

Microservices are a software architecture pattern for building scalable and flexible IoT systems. However, research on the utilization of microservices in IoT applications is still in its infancy, and there are several avenues for further exploration. As the IoT continues to grow and evolve, there are several areas for future research that can enhance the application of microservices in the IoT. In this section, we present some possible future research opportunities that can extend the current state-of-the-art and address the existing research gaps.

- **Integration of Blockchain Technology:** IoT systems can use blockchain technology to handle transactions and data in a safe and decentralized way. Future research should focus on making microservices architectures that can use blockchain technology to make IoT systems more secure and reliable, such as blockchain-based security mechanisms.
- **Container Orchestration:** Container orchestration is a critical aspect of microservice deployment and management. Therefore, the development of efficient and scalable container orchestration mechanisms for microservices in the IoT to enhance their performance and resilience remains an open research challenge.
- **Dynamic Resource Allocation and Management:** The efficient resource allocation and management of resources such as computing, storage, and network bandwidth are crucial for the efficient operation of microservices in the IoT. Future research should focus on developing microservices architectures that can enable dynamic resource allocation, including techniques such as containerization and serverless computing, to improve system efficiency and reduce costs.
- **Edge Intelligence:** Edge intelligence is when machine learning algorithms are used at the edge of the network to let IoT systems analyze data and make decisions in real time. Future research should focus on making microservices architectures that can use edge intelligence to make IoT systems work better and be smarter.
- **Distributed and Federated Learning:** Federated learning involves the use of machine learning algorithms across multiple devices that can enable more intelligent and autonomous IoT systems. Future research should look into how to combine federated learning with microservices architectures so that data can be analyzed and decisions can be made in real time.
- **Integration of Digital Twins:** Digital twins are virtual copies of real devices or systems that can be used to test and improve the real thing. Future research should focus on making microservice architectures that can work with digital twins to allow IoT systems to be tested and improved in real time.
- **DevOps for IoT:** DevOps can provide a framework for continuous integration and delivery of IoT systems. This might open the door for developing microservices architectures that can enable seamless DevOps processes for IoT systems, including automated testing, deployment, and monitoring.
- **Domain-specific Applications:** Most studies on microservices and the IoT have focused on general-purpose applications, such as smart homes and smart cities. Future research can focus on investigating microservices-based architectures for domain-specific applications, such as healthcare and agriculture.

V. Conclusion

Microservices have emerged as a promising architectural approach for developing IoT applications. They offer a number of benefits, such as scalability, flexibility, and fault tolerance, which are crucial in the context of the IoT, where devices and data are distributed and heterogeneous. In this study, we have reviewed thirty papers that discuss the use of microservices technology for IoT systems. Through our analysis, we have identified several key categories of research, including industrial automation, smart cities, security, smart home automation, and blockchain. Within each category, we have found that microservices have been proposed as a viable solution for addressing various challenges and improving the performance of IoT systems. Furthermore, in this article, we highlighted future research opportunities regarding the adoption of microservices-based architecture for the development of IoT systems.

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