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The role of cloud computing in the evolution of the internet of things using artificial intelligence and machine learning

Saifullah Haidari [1,*] and Nasim Abdullah [2]

[1] *Lecturer of Computer Science Faculty, Information system Department, Jami University, Afghanistan.*
[2] *Lecturer of Computer Science Faculty, Network Engineering Department, Jami University, Afghanistan.*

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Abstract

With the advancement of new technologies, the four main pillars of digital transformation, including cloud computing, Internet of Things (IoT), artificial intelligence (AI), and machine learning (ML), are simultaneously shaping the future of information technologies. Cloud computing, as a scalable and accessible platform, provides the ability to store and process huge data generated by IoT devices. These changes, together with artificial intelligence and machine learning, which have the ability to analyze complex data and make intelligent decisions, will elevate IoT capabilities to a new level.This article examines the role of cloud computing in the development and evolution of the Internet of Things. Using cloud computing, data generated by devices connected to the Internet of Things is collected, stored, and processed centrally. This process leads to reduced hardware costs, improved scalability, and increased flexibility of systems. In this regard, machine learning allows systems to automatically learn from collected data and make accurate predictions, and artificial intelligence helps in deeper data analysis and enables IoT systems to make optimal decisions that are in line with environmental changes and user needs. Together, these two technologies enable systems to adapt more effectively to changing conditions and optimize their performance. Finally, the article examines the challenges and opportunities arising from the combination of cloud computing, the Internet of Things, artificial intelligence, and machine learning, and provides solutions for better use of these technologies in various industries. These industries include healthcare, transportation, renewable energy, and smart cities. Research results show that the use of these technologies can lead to improved productivity, reduced costs, and increased security in IoT-based systems. This article not only emphasizes the importance of the convergence of these technologies but also points out the need to develop strategies to better exploit them in order to create innovation in different industries.

Keywords: Cloud Computing; Internet of Things; Artificial Intelligence; Machine Learning

1. Introduction

In today's world, new technologies are evolving and progressing rapidly, and among them, four fundamental concepts are particularly shaping the future of various societies and industries. Cloud Computing, Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML) are recognized as the main pillars of these developments, and each of them alone offers enormous potential for improving and upgrading systems and services. But when these four technologies are combined together, their true power in creating fundamental and intelligent changes in all areas is revealed. (Maryam Loghmani Khozani1, Autumn & Winter 2022)

Cloud computing allows users to access processing resources and data storage over the Internet, without the need for complex physical infrastructure. This technology is especially effective in the modern world with its huge volume of data and the need for complex processing. On the other hand, the Internet of Things enables the connection and

* Corresponding author: Engineer Saifullah Haidari

interaction of millions of devices on a global scale, and these devices can collect data and communicate with each other through cloud networks. The combination of these two technologies brings a new world of connectivity, data mining and intelligent management. (Fogarty, 2009)

Artificial intelligence and machine learning are other technologies that are changing the face of the world. Artificial intelligence gives systems the ability to automatically learn from data, make decisions and even solve complex problems. Machine learning, a subset of artificial intelligence, provides algorithms that can identify patterns and predict outcomes based on historical data. As such, these technologies can be used to improve processes and system efficiency across all fields. (Michael Haenlein, 2024)

These four technologies have many capabilities individually, but when combined, they offer extraordinary capabilities that can lead to dramatic changes in many industries, including healthcare, transportation, manufacturing, smart homes, and financial services. In particular, the use of cloud computing to store and process data, along with the Internet of Things to connect devices, and the use of artificial intelligence and machine learning to analyze data and make intelligent decisions, can help develop intelligent, data-driven systems. (maryam mohaamdi, 2024)

This article examines the role of cloud computing in the transformation of the Internet of Things using artificial intelligence and machine learning. The aim of this article is to provide a comprehensive understanding of how these four technologies combine and their impacts on improving and transforming various industries.1.

1.1. Cloud Computing

Cloud computing allows users to access hardware and software resources (such as servers, data storage, and processing power) over the Internet. This technology mainly helps in reducing the need for physical infrastructure and reducing maintenance costs. Cloud computing provides the ability to store and process huge amounts of data, which is used to perform complex processing activities and run machine learning and artificial intelligence models. (Raji1, 2019)

1.2. Features

- Scalability: Cloud systems can easily increase or decrease their resources depending on the need.
- Remote access: Users can access data and services from anywhere and with any device.
- Cost savings: Cloud computing does not require the purchase and maintenance of expensive equipment, and costs are calculated based on consumption.
- Security: Claudication of systems allows for implementing more advanced security solutions.

1.3. Types of Cloud Computing

- Public Cloud: Resources are shared over the Internet.
- Private Cloud: Resources are exclusively available to an organization.
- Hybrid Cloud: A combination of public and private cloud resources.

2. Internet of Things (IoT)

The Internet of Things refers to a network of devices that are connected to each other via the Internet and are able to send and receive data. These devices can use various sensors and tools to collect data and send them to central or cloud systems. This data can include various information, such as temperature, humidity, speed, location and other physical parameters. This huge volume of data generated by IoT devices is easily stored and processed by cloud systems. (Farhang Padidaran Moghadam 1, 2019)

2.1. Features

- **Always-on**: Devices are always connected to the network and are able to send and receive data in real time.
- **Automation**: IoT devices can automatically collect data and make decisions based on it.
- **Data transfer:** IoT requires the transfer of data from devices to servers, processors, and other resources.
- **Decision-making**: The collected data can be used for predictions and decisions.

2.2. Applications

- **Smart homes**: Control of heating, lighting, and security systems.
- **Industrial:** Manage production and predictive maintenance of machinery.

- **Healthcare:** Connected medical devices that collect and send vital patient data.
- **Transportation**: Smart cars and traffic systems.

3. Artificial Intelligence (AI)

Artificial intelligence refers to systems that can perform a variety of tasks that typically require human intelligence. These tasks include simulating learning, reasoning, decision-making, pattern recognition, and natural language processing. AI is particularly important when vast amounts of data are collected from IoT devices and stored centrally. For example, AI systems can use it to analyze data and predict future behavior (Dehghanpoor, 1402)

3.1. Characteristics

- **Learning**: AI systems are able to learn from data and improve their performance (machine learning).
- **Automated decision-making**: AI can make complex decisions based on data and algorithms.
- **Cognitive simulation**: Some AI systems have the ability to simulate human thinking, reasoning, and problem solving.
- **Natural Interaction**: With the help of natural language processing (NLP), AI can communicate with humans in a natural way.

3.2. Branches

- **Machine Learning**: Using data to train algorithms for prediction or classification.
- **Computer Vision**: Analyzing and processing images and videos to identify and extract information.
- **Natural Language Processing (NLP):** The ability of computer systems to understand and produce natural languages.

3.3. Applications

- **Image and video processing:** Object recognition, face recognition, and scene recognition.
- **Customer support**: Chatbots and automated response systems.
- **Market forecasting**: Analyzing data to predict economic and financial trends.

4. Machine Learning (ML)

Machine learning, a subset of artificial intelligence, gives systems the ability to learn from data and make decisions without the need for detailed programming. In machine learning, mathematical models and algorithms are designed to identify patterns and relationships in data. This technology can be used to process data collected from IoT devices and predict future patterns or unexpected behaviors. (Institute, McKinsey Global Institute, 2022)

4.1. Features

- **Learning from data:** Machine learning models use input data to improve their performance.
- **Prediction**: This technology can be used to predict outcomes or classify data.
- **Interaction with data:** Machine learning allows systems to interact with real-world data and achieve more accurate results.
- **Spontaneous models:** Models are automatically optimized and do not require human intervention.

4.2. Types of Machine Learning

- **Supervised Learning**: Algorithms use labeled data to learn.
- **Unsupervised Learning:** Algorithms work without labeled data and look for hidden patterns in the data.
- **Reinforcement Learning:** Systems learn from experience and feedback to make better decisions. (G. M. Lee, 2022)

4.3. Applications

- **Pattern Recognition**: Such as handwriting recognition or spam detection.
- **Predictions**: Predicting trends in data for business, medicine, and other fields.
- **Natural Language Processing:** Analyzing and understanding human language, machine translation, and answering questions.

5. The Connection Between Cloud Computing, IoT, AI, and Machine Learning

In today's digital world, cloud computing, the Internet of Things (IoT), artificial intelligence (AI), and machine learning (ML) are the cornerstones of technological advancements. These four technologies have many advantages independently, but when combined, they have the potential to create fundamental and dramatic changes in various industries. Understanding the connection and interaction between these technologies can illuminate new perspectives on technological innovations and their practical applications. Here, we examine the connection between these four sectors. (Dastres, 2023)

5.1. Cloud Computing and the Internet of Things

Data Storage and Processing: IoT devices generate a lot of information that requires storage, processing, and analysis. Cloud computing allows data generated from IoT devices to be easily stored in the cloud and its processing resources to be used to perform complex analyses.

- **Accessibility and Scalability**: Due to the limitations of processing resources in many IoT devices, the need for cloud space is felt for scalability and faster data processing. Cloud computing allows IoT systems to access abundant processing resources without worrying about hardware limitations. (Yaqoob, 2016)

5.2. Cloud Computing and Artificial Intelligence / Machine Learning

Processing huge amounts of data: Artificial intelligence and machine learning require huge amounts of data to train complex models. Cloud computing helps these models use data as quickly and efficiently as possible by providing powerful processing resources.Higher processing power: AI and machine learning algorithms require processing resources to analyze and process complex and large data sets, which can be easily provided by cloud computing. Cloud services allow researchers and developers to easily take advantage of massive processing power and storage without worrying about hardware limitations. Scalability: One of the main advantages of cloud computing is that it can be easily scaled to perform heavy and complex calculations. This feature is very crucial in AI and machine learning processes, as these processes usually require processing and analyzing large volumes of data. (Akhloufi, 2023)

6. Internet of Things and AI / Machine Learning

6.1. Real-World Data Analysis

IoT devices continuously collect various data from the real world. This data can include sensor information, environmental conditions, or human behaviors. Artificial intelligence and machine learning can be used to analyze this data and predict future behaviors or identify hidden patterns in the data.Making smart decisions: Using artificial intelligence and machine learning algorithms, IoT devices can make decisions automatically. For example, in smart home systems, IoT devices can detect different environmental conditions and automatically select optimal settings using machine learning models. (creatScott!, 2022)

6.2. Connecting all sectors (Cloud computing + IoT + AI + ML)

Unified data management and smart decision-making: By combining these four technologies, an integrated ecosystem can be created in which IoT devices collect data and send it to the cloud system. Then, using artificial intelligence and machine learning, this data is analyzed and models are created for prediction or intelligent decision-making. This combination is particularly effective in applications such as healthcare, smart transportation, smart manufacturing, and smart homes. Real-time and advanced processing: These four technologies enable real-time data processing. IoT devices can collect data in real time, send it to the cloud, and then artificial intelligence and machine learning can analyze this data and make instant decisions.

Scalability and flexibility: Cloud computing, along with IoT and AI/ML, makes systems more scalable, allowing for massive amounts of data to be processed and analyzed.

6.2.1. Features and Functions of Each Technology

This table compares the features and functions of each technology (Cloud Computing, Internet of Things, Artificial Intelligence, and Machine Learning).

Table 1 Features and Functions of Emerging Technologies

Technology	Features and Functions
Cloud Computing	Data storage and processing, scalability, high flexibility, reduction in physical infrastructure costs
Internet of Things (IoT)	Data collection from devices and sensors, wireless communications, management of large volumes of data generated by devices
Artificial Intelligence (AI)	Simulating human-like data processing, automated decision-making, analysis of complex data, pattern recognition
Machine Learning (ML)	Advanced algorithms for data analysis, learning from data, prediction, and process optimization

6.3. The connection and synergy of these four technologies:

The combination and synergy of cloud computing, the Internet of Things, artificial intelligence, and machine learning in today's digital age has created significant changes in the performance of systems and processes. Together, these four technologies are able to help optimize and digital transformation in various industries. First, it is necessary to understand what role each of these technologies plays in creating this transformation and how their cooperation and synergy can simplify complex processes. (Institute, The State of AI in 2023, 25 October 2024)

As one of the main infrastructure technologies in today's world, cloud computing allows organizations to make processing resources, storage, and software services available via the Internet in a scalable manner. These resources are constantly increasing and updating, and organizations can access these resources without having to invest in costly physical infrastructure. This feature is especially useful as data volumes and computational complexity increase. In the context of the Internet of Things, these technologies are particularly useful because IoT involves a collection of devices and sensors that continuously generate large amounts of data. Since IoT devices are constantly sending data, there is a need for large and scalable computing platforms that can store, process, and analyze this data. Cloud computing provides the ability to efficiently store and process data generated by IoT devices, ultimately leading to useful analytics. (Dhote., 2016)

This is where artificial intelligence (AI) comes in. Artificial intelligence generally provides the ability for systems to perform tasks similar to humans, such as decision-making, prediction, simulation, and pattern recognition. In combination with the Internet of Things, AI is particularly used to analyze the huge amounts of data generated by sensors and IoT devices. For example, IoT devices can send data such as weather conditions, traffic conditions, a person’s physical health, or even the performance status of industrial machinery to AI systems. This data is then analyzed by AI algorithms, and intelligent and timely decisions are made to optimize processes and services. For example, in the automotive industry, AI can use sensor data to predict vehicle maintenance and repair needs, thereby reducing the cost of preventive maintenance. (Dehghanpoor, 1402)

Machine learning (ML), as an important subset of AI, plays a key role in this process. Machine learning specifically allows systems to learn from data and improve their performance without the need for explicit, pre-determined instructions. This capability is critical for analyzing the large and complex data generated by IoT devices. Machine learning algorithms can become aware of hidden patterns in the data and make predictions such as changes in equipment status, energy needs, consumer behavior, and disease prediction. These systems are constantly improving and can perform better even when new data is introduced. Thus, machine learning is particularly effective in situations where rapid and timely decision-making is required. (Akhloufi, 2023)

One key aspect of the synergy between these four technologies is the interaction between cloud computing and machine learning. Data generated by IoT devices typically grows rapidly and reaches huge volumes. Storing and processing this data requires high processing resources, which cloud computing can provide. In addition, machine learning systems can use this data to identify hidden patterns and extract useful information. These systems can effectively provide analytics that help make more accurate decisions. These decisions can include predicting different situations or optimizing processes.In many cases, cloud computing serves as the main platform for storing and processing IoT data, and machine learning is used as a tool for analyzing data and extracting knowledge from it. Thus, the combination of these two technologies allows for rapid processing of data on a large scale and can lead to the creation of systems with predictive capabilities and intelligent decision-making. (Fogarty, 2009)

Overall, the synergy of these four technologies together enables modern systems to process data efficiently and intelligently and provide timely and accurate results. For example, in an intelligent transportation system, IoT data related to traffic, road conditions, weather conditions, and even driver health can be collected in real time and transferred to cloud systems. In these systems, machine learning algorithms can use this data to predict traffic conditions, assess risks, and optimize routes. Ultimately, this information allows intelligent systems to make timely and accurate decisions that reduce traffic, improve safety, and reduce energy costs. (Zaei, 2017)

In addition, AI and machine learning can play an important role in creating advanced analytics in areas such as sentiment analysis in social networks, forecasting economic conditions, or investigating and diagnosing medical diseases. These capabilities are especially useful when combined with data

Table 2 Interconnection and Synergy of Technologies

Technology	**Connection with Cloud Computing**	**Connection with Internet of Things (IoT)**	**Connection with Artificial Intelligence (AI)**	**Connection with Machine Learning (ML)**
Cloud Computing	Provides storage space, processing, and analysis of data generated by IoT devices	Supports storage and processing of data generated by IoT devices	Provides processing infrastructure for AI models and data analysis	Provides computational resources for training and running ML models
Internet of Things (IoT)	Uses cloud computing for storing and processing device data	Collects sensor and device data for sending to the cloud for processing	IoT data can feed into AI models for analysis and automated decision-making	Data collected from IoT devices is used for training ML models
Artificial Intelligence (AI)	Uses cloud processing power for complex AI models	AI models process data from IoT devices and predict future behaviors	Direct interaction, such as AI systems for pattern recognition and decision-making	AI models require training and improvement, which can utilize data from ML
Machine Learning (ML)	Processes data and stores ML models in the cloud for high scalability	IoT data serves as input for ML algorithms for prediction and analysis	ML models can enhance AI model performance	ML algorithms are designed to analyze data, predict, and learn from input data

This table illustrates how technologies interact and synergize in a complex system that leverages the overlap between cloud computing, the Internet of Things, artificial intelligence, and machine learning.

6.4. Application examples

In smart homes, IoT devices (such as thermostats, cameras, sensors) generate data about the state of the home that is stored and processed by cloud systems. Artificial intelligence and machine learning analyze this data and predict optimal behaviors, such as automatically adjusting the temperature or lighting.In the automotive industry, Internet-connected cars send information about the state of the car, traffic, and road conditions to the cloud. Using machine learning, cloud systems make optimal decisions, such as steering the car or predicting possible breakdowns.In healthcare, IoT devices (such as health monitoring devices) collect information about the state of patients and send it to the cloud. This data is analyzed using artificial intelligence and machine learning algorithms and used to predict diseases, prescribe medication, or monitor treatment progress.

This table examines the challenges and obstacles in integrating these four technologies.

Table 3 Challenges and Obstacles in Technology Integration and Synergy

Challenge or Obstacle	Explanation
Security and Privacy	Protecting IoT-generated data and cloud-stored data from unauthorized access and cyberattacks
Standardization and Integration	Lack of common standards in data storage and communication protocols for the synergy of these technologies
Scalability	Cloud processing and storage may be pressured by the large volume of IoT data
Costs	Costs related to processing, storing, and transferring data at large scales
Development of Optimized Algorithms	Need for more advanced algorithms to analyze data quickly and make intelligent decisions at large scales

This table highlights practical examples of combining these four technologies in various industries.

Table 4 Practical Applications of Technology Synergy in Different Industries

Industry	Application of Technology Synergy
Smart Homes	Analyzing IoT data such as temperature, lighting, and security status of the home using cloud systems and AI algorithms to optimize energy consumption and security
Automotive Industry	Internet-connected vehicles sending data on vehicle status, traffic, and road conditions to the cloud system. Data analysis with ML to predict failures and optimize routes
Healthcare	IoT medical devices collect patient data and transfer it to cloud systems. AI/ML is used for predicting diseases and prescribing treatments
Smart Transportation	Analyzing traffic data, road conditions, and driver health status using IoT, with AI and ML for route optimization and traffic management

6.5. Research Background

Cloud computing, Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML) are four prominent technologies that are increasingly combining to drive the digital revolution in various industries. These four technologies are synergistically able to manage complex and big data processes and provide intelligent solutions. As a scalable and flexible platform for data storage and processing, cloud computing enables the Internet of Things to connect devices and sensors and transfer the generated data to cloud servers on a large scale. Artificial intelligence and machine learning are used to analyze this big data, identify hidden patterns, and predict future situations. The combination of these technologies creates intelligent and automated systems that can make optimal decisions and effectively improve processes. This synergy has significantly impacted areas such as smart city management, healthcare, transportation, and manufacturing industries, increasing productivity, reducing costs, and improving quality of life. At the same time, challenges such as scalability, security, and privacy remain that require further research and innovation in these areas.

6.6. Research Methodology

A review research method is used in this study to examine and analyze the interactions and synergies of four technologies: cloud computing, IoT, artificial intelligence, and machine learning. First, the research objective is precisely defined, which is to examine how these four technologies affect each other and identify their challenges and opportunities. Then, reputable scientific articles are collected from databases such as IEEE Xplore, Google Scholar, and Scopus and selected based on the criteria of relevance to the research topic, credibility, and appropriate time period. The collected articles are carefully analyzed and categorized to identify the main trends, findings, and challenges of each technology and how they interact in different contexts. After that, data is extracted from the articles and compared to identify differences and similarities in the findings. In this step, the strengths and weaknesses of each technology and the challenges in their integration are examined. The researcher also identifies research gaps and the need for further research in specific areas. Finally, the review is completed with conclusions from the existing findings and suggestions for future research. This review research method can serve as a basis for future research in these areas and provide solutions for the optimal utilization of these technologies.

6.7. Controversy

Controversy in the field of research on cloud computing, the Internet of Things, artificial intelligence, and machine learning is related to many complex and challenging issues. One of the main controversial issues in this field is the interaction and synergy of these four technologies. Although these technologies can jointly help create intelligent and scalable systems, there are significant technical and implementation challenges in their integration and cooperation.One of the important issues is the security complexities. Cloud computing, as a platform for storing and processing data, faces challenges such as information security, unauthorized access and cyber-attacks. These challenges become more complex with the need for rapid data processing by the Internet of Things and artificial intelligence. Especially in environments where large volumes of data are generated by various Internet of Things devices, ensuring the privacy and security of this data requires the development of more complex encryption methods and security protocols.Another controversy in this field is the need for standardization and integration between these technologies. While each of these technologies plays an important role in different industries and applications, the lack of common standards can lead to problems in their interaction and collaboration. For example, different standards for data storage in cloud computing, different communication protocols in the Internet of Things, and different machine learning algorithms can cause problems in the synergy of these technologies. In addition, scalability is another important issue. With the expansion of the use of the Internet of Things and the generation of big data, processing power and cloud storage may be put under pressure. In this context, the use of technologies such as cloud computing and machine learning to process data in real time can lead to challenges in scalability and efficiency, and costs are also one of the issues raised in these technologies. While cloud computing is a cost-effective solution for data storage and processing, at large scales, the costs associated with data processing and transmission can be significant. This can negatively impact the productivity and adoption of these technologies in some industries.

7. Conclusion

Finally, the existence of research gaps and the need for further research on the interaction of these technologies is another controversial aspect. Despite extensive research on each of these four technologies, their interactions are still not fully understood, especially in different industrial and application areas. This issue requires further research to find optimal solutions and mitigate the challenges.Therefore, while the combination of these four technologies can lead to the creation of intelligent, scalable and efficient systems, challenges such as security, standardization, scalability, costs and the need for further research still prevent the full use of this.

Compliance with ethical standards

Disclosure of conflict of interest

The authors Engineer Saifullah Haidari and Engineer Nasim Abdullah declares, no financial or non-financial conflicts of interest that might influence the research results or interpretation of the data. All activities and research conducted in this article were conducted independently and without any external influence.

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