ASROSAINTEK
Journal of Science, Informatics, and Technology
Vol. 1 No. 1, February 2026 | E-ISSN xxxx-xxxx
https://jurnal.desantapublisher.com/index.php/asrosaintek

THE ROLE OF ARTIFICIAL AUTONOMY IN THE INTERNET OF THINGS (IoT) ERA: A REVIEW OF PRIMITIVES, SENSING, THINKING, AND ACTION

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Received: March 2026 | Accepted: May 2026 | Published: June 2026

Abstract

The rapid development of the Internet of Things (IoT) has increased the need for intelligent systems capable of operating autonomously in complex and dynamic environments. In this context, artificial autonomy plays an important role in enabling IoT devices to sense environmental conditions, process information, make decisions, and execute actions with minimal human intervention. This article presents a conceptual review of artificial autonomy in the IoT era by focusing on four main pillars: primitives, sensing, thinking, and acting. The review explains how autonomous systems evolve from simple rule-based automation into adaptive intelligent systems capable of understanding context and responding to real-time data. Furthermore, this study discusses the main challenges in integrating autonomy into IoT ecosystems, including limited computational resources, data security and privacy, interoperability, reliability, and ethical considerations. The findings indicate that artificial autonomy can strengthen the development of smarter, more efficient, and more responsive IoT systems. This study provides a conceptual foundation for future research and development of autonomous IoT systems supported by artificial intelligence, edge computing, and data-driven decision-making.

Keywords: Artificial autonomy, Internet of Things, sensing, thinking, action, intelligent systems.

Introduction

The development of Internet of Things (IoT) technology has opened the way for the integration of Artificial Intelligence (AI) into various aspects of human life. IoT enables devices to connect with one another, exchange data, and operate automatically through internet networks. The integration of AI into IoT environments produces systems that are more adaptive, intelligent, and capable of making independent decisions based on data obtained from the surrounding environment (Panduman et al., 2024).

In this context, the concept of Artificial Autonomy emerges as the ability of AI-based systems to perform sensing, information processing, decision-making, and action without direct human intervention. This capability serves as an important foundation for the development of smart devices, autonomous vehicles, intelligent industrial systems, and modern virtual assistants (Siam et al., 2025).

One real implementation of Artificial Autonomy is the Intelligent Personal Assistant (IPA), such as Google Assistant, Siri, and Amazon Alexa. These systems use Natural Language Processing (NLP), Machine Learning (ML), and IoT sensors to understand user needs and provide appropriate responses automatically (Le et al., 2023).

Several previous studies have discussed the integration of AI and IoT from different perspectives. (Minardo et al., 2021) reviewed the application of Deep Learning in the Industrial Internet of Things (IIoT) and showed that AI can improve data analysis efficiency and automatic decision-making. (López Delgado & López Ramos, 2024) examined the use of Generative AI in IoT security to detect anomalies and strengthen cyber defense systems. Meanwhile, (Panduman et al., 2024) discussed the application of AI in real-time IoT-based environmental monitoring, while (Asro & Rukhviyanti, 2026) explored the use of Generative AI to support intelligent computing in IoT ecosystems.

Although many studies have discussed AI and IoT integration, studies that specifically explain the role of Artificial Autonomy based on the four main pillars of primitives, sensing, thinking, and acting remain relatively limited. Therefore, this article aims to conceptually examine how these four pillars contribute to the formation of IoT systems that are smarter, more adaptive, and more autonomous. The results of this review are expected to provide a more comprehensive understanding of the direction of Artificial Autonomy development in the era of the Internet of Things.

Literature Review

Artificial Intelligence of Things (AIoT) dan Artificial Autonomy

The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) has formed a new paradigm known as the Artificial Intelligence of Things (AIoT). (Siam et al., 2025) explain that AIoT is the result of integrating IoT and modern AI, consisting of three main components: sensing, computing, and networking and communication. Through this integration, IoT devices are not only able to collect and transmit data, but can also perform intelligent processing, pattern recognition, prediction, and automatic decision-making.

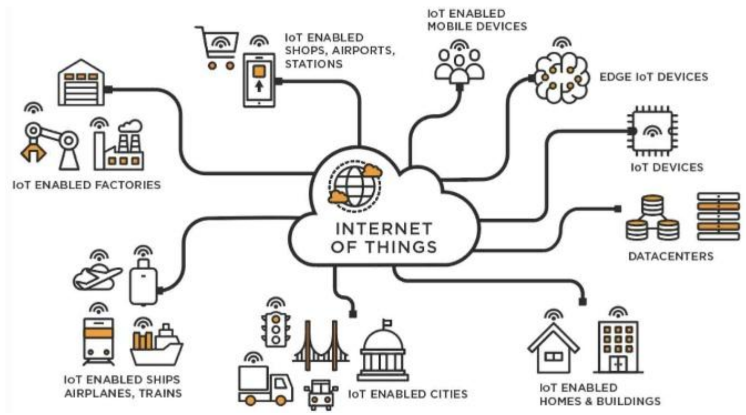

Figure 1. The Internet of Things (IoT) ecosystem in connecting various smart devices.

Source: https://smkglobin.sch.id/mengenal-apa-itu-internet-of-things-iot/

Figure 1 shows that IoT functions as an ecosystem that connects various smart devices, such as industrial equipment, transportation systems, smart homes, mobile devices, edge devices, and data centers. This connectivity enables devices to exchange data and support automation processes. In the context of Artificial Autonomy, the IoT ecosystem becomes the main basis for the sensing process or the collection of data from the environment. In line with this, Huang and (Huang & Khabusi, 2025) show that AIoT plays an important role in improving operational efficiency, real-time environmental monitoring, data-driven decision-making, and system automation. In this context, IoT sensors collect environmental data, while AI algorithms analyze the data so that systems can provide more adaptive and accurate responses.

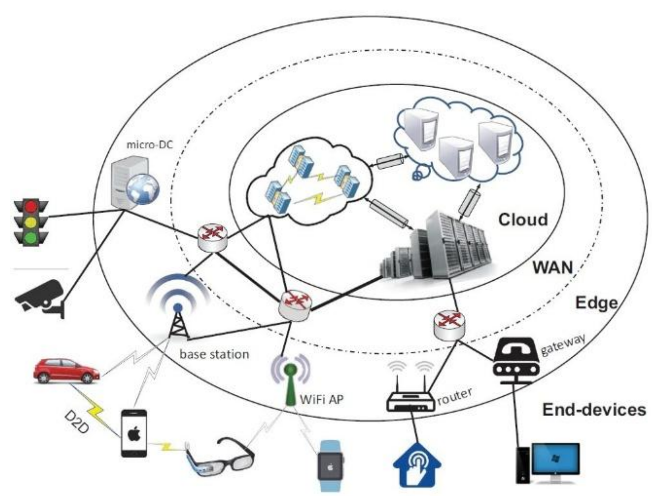

Figure 2. Edge intelligent computing and machine learning architecture in IoT systems.

Source: Processed by the authors, 2026.

Figure 2 illustrates that data collected from IoT devices can be processed through the edge layer or the cloud layer. Processing through edge computing allows systems to generate faster responses because data does not always have to be sent to the cloud. With the support of Machine Learning, IoT systems can recognize patterns, predict conditions, and make decisions more adaptively. Therefore, edge computing becomes an important component in supporting the thinking stage of Artificial Autonomy.

In the healthcare sector, (Chen et al., 2024) explains that IoT can be combined with Generative AI and Human Digital Twin technology to support smart healthcare services. These technologies enable real-time patient monitoring, health data analysis, and more personalized medical recommendations. This indicates that AIoT is not only relevant in industrial and environmental systems, but also plays an important role in data-driven healthcare services.

In addition to its benefits, AIoT implementation also faces challenges related to security and privacy. Zaman et al. (2026) emphasize that IoT devices generate large amounts of sensitive data, making privacy-preserving machine learning approaches necessary, such as federated learning, differential privacy, homomorphic encryption, and secure multi-party computation. These challenges are important because IoT systems are generally distributed, resource-constrained, and vulnerable to security attacks.

(Alakkari & Ali, 2025), (Robi Padri & Asro, 2026) also confirm that AIoT has great potential to support smart systems, edge computing, federated learning, and technological sustainability. However, AIoT development must consider ethical issues, data privacy, system security, and the social impact of automation. Meanwhile, Alabiech et al. (2025) state that AIoT can be applied in various fields, such as smart homes, healthcare, security, agriculture, and autonomous vehicles. Thus, AIoT becomes an important foundation for developing systems that are more intelligent, adaptive, and autonomous.

Figure 3. Example of Artificial Autonomy implementation in a GPS-based navigation system.

Source: Processed by the authors, 2026.

Figure 3 presents an example of Artificial Autonomy in everyday life, namely a GPS-based navigation system. This system can use location data, road conditions, and traffic information to automatically provide route recommendations to users. This example shows that artificial autonomy is not only applied to industrial systems or large-scale IoT devices, but also to location-based services widely used by society.

Based on these studies, it can be concluded that Artificial Autonomy in IoT is closely related to the AIoT concept. Artificial autonomy enables devices to perform sensing, information processing, decision-making, and action independently. Therefore, the discussion of primitives, sensing, thinking, and acting is important to understand how IoT systems evolve from simple automation into intelligent systems capable of operating autonomously.

Primitives: Basic Automation Capabilities

Primitives represent the foundational stage in artificial autonomy systems. At this stage, IoT devices execute automatic commands based on rules that have been predetermined. The system is still reactive, deterministic, and does not yet have the ability to learn from the environment. Examples of primitive implementation can be found in smart thermostats, motion-sensor-based automatic lights, time-based automatic plant watering systems, and sensor-based security alarm systems (Siam et al., 2025).

Although relatively simple, primitives play an important role as the foundation of autonomous systems. This component connects sensors, actuators, and basic control logic so that devices can respond automatically to specific conditions. Systems at this stage commonly use microcontrollers, basic sensors, and rule-based algorithms that have been programmed in advance (Huang & Khabusi, 2025).

The advantages of primitive systems include simplicity, energy efficiency, low implementation cost, and ease of testing and maintenance. However, these systems have limitations because they are not yet able to understand complex environmental contexts and cannot adapt dynamically to changing conditions. Therefore, the development toward smarter autonomous systems requires the integration of sensing, thinking, and acting capabilities (Alakkari & Ali, 2025).

Research Methodology

Research by (Aliyah1 et al., 2026) This study uses a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize various studies related to Artificial Autonomy in the Internet of Things (IoT) environment. The SLR method was selected because it provides a comprehensive understanding of the development of concepts, technologies, implementations, benefits, and challenges associated with the integration of Artificial Intelligence (AI) and IoT.

The data sources of this study consist of scientific articles, international conference proceedings, and academic publications obtained from reputable scientific databases, such as Scopus, IEEE Xplore, ScienceDirect, SpringerLink, ACM Digital Library, MDPI, and arXiv. The literature used in this study was limited to publications from 2021 to 2026 to ensure that the information remained relevant to recent technological developments.

The literature search process was conducted using several keywords, including Artificial Autonomy, Artificial Intelligence of Things (AIoT), Internet of Things (IoT), Machine Learning, Deep Learning, Edge Computing, Generative Artificial Intelligence, and Intelligent Personal Assistant. These keywords were used individually and in combination to obtain literature aligned with the research objectives.

The research procedure consisted of four main stages. The first stage was literature identification, namely collecting relevant articles based on predetermined keywords. The second stage was article selection and screening, namely selecting articles based on topic relevance, publication quality, and full-document availability. The third stage was data extraction, namely collecting important information from each article, including concepts, methods, technologies, benefits, and challenges of Artificial Autonomy in IoT. The fourth stage was literature analysis and synthesis, namely grouping research findings based on themes and their relationship with the concept of artificial autonomy.

Data analysis was carried out using a descriptive qualitative method by grouping the review findings into the four main components of Artificial Autonomy: primitives, sensing, thinking, and acting. This approach was used to explain how IoT devices evolve from simple rule-based automation systems into intelligent systems capable of sensing, information processing, decision-making, and autonomous action.

Results and Discussion

Sensing in Artificial Autonomy

Sensing is the process of collecting information from the environment through various sensors, such as temperature sensors, humidity sensors, pressure sensors, light sensors, cameras, GPS, and microphones. Data obtained from sensors becomes the basis for the system to understand environmental conditions in real time. In the Internet of Things (IoT) ecosystem, the quality and reliability of sensors strongly determine the effectiveness of the decision-making process performed by autonomous systems (Siam et al., 2025).

Thinking and Decision-Making

The thinking stage reflects the ability of a system to analyze data and generate decisions based on Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) algorithms. Systems can recognize patterns, detect anomalies, predict future conditions, and adjust responses based on the context being faced.

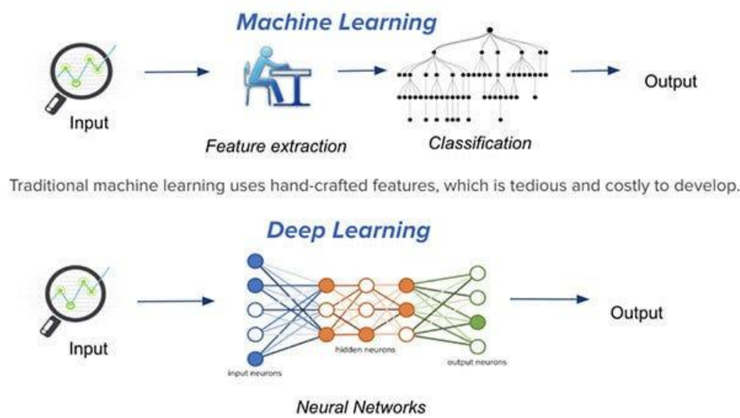

Figure 6. The process of Machine Learning and Deep Learning in Artificial Autonomy.

Figure 6 shows how data obtained from sensors are processed through several stages of analysis using Machine Learning and Deep Learning algorithms. The processing results are used as the basis for more accurate and adaptive automatic decision-making. This approach enables IoT systems to learn from historical data and continuously improve decision quality (Henderi et al., 2025).

Acting and Autonomous Response

The acting stage is the practical implementation of decisions generated by the system. After data has been analyzed and decisions have been made, the system executes specific actions through actuators or connected devices. Examples include autonomous vehicles that automatically avoid collisions, smart home systems that regulate room temperature, and smart agriculture systems that perform irrigation based on soil moisture conditions.

The ability to act makes a system not only capable of understanding environmental conditions, but also capable of responding proactively or reactively without requiring direct human intervention (Imron et al., 2024).

Challenges of Integrating Artificial Autonomy into IoT

Although it offers various benefits, the integration of Artificial Autonomy into IoT still faces several challenges. These challenges include limited computational resources in IoT devices, data security and privacy, the lack of interoperability standards among devices, the complexity of decision-making, and ethical and regulatory aspects that are still developing (Zaman et al., 2026).

Opportunities and Future Research Directions

Artificial Autonomy has great potential to be applied in various sectors, including smart manufacturing, autonomous vehicles, intelligent environments, smart agriculture, and healthcare services. The integration of technologies such as Edge AI, Federated Learning, Explainable AI (XAI), and Digital Twin is expected to become a major focus of future research.

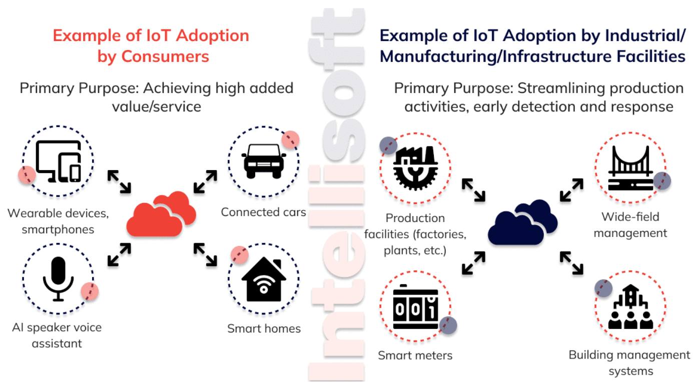

Figure 7. Future development directions of the Internet of Things (IoT).

Figure 7 illustrates the evolution of the Internet of Things toward systems that are smarter, more connected, and more autonomous. This development is supported by the integration of AI, edge computing, cloud computing, and new-generation communication technologies that enable devices to make decisions independently with higher levels of accuracy (Alakkari & Ali, 2025).

Conclusion

Artificial Autonomy is one of the main components in the development of the Internet of Things (IoT), enabling Artificial Intelligence (AI)-based systems to perform sensing, information processing, decision-making, and action independently. Based on the literature review, the concept of Artificial Intelligence of Things (AIoT) integrates primitives, sensing, thinking, and acting capabilities so that IoT devices are not only able to collect data, but also analyze environmental conditions and provide automatic responses. The application of this technology has developed in various sectors, including smart manufacturing, autonomous vehicles, smart healthcare, smart homes, and environmental monitoring.

Although Artificial Autonomy offers various benefits in terms of efficiency, adaptability, and automation, its implementation still faces a number of challenges, including device resource limitations, data security and privacy, system interoperability, and ethical responsibility in automatic decision-making. Therefore, future autonomous system development must balance technological innovation and user protection through the implementation of security principles, transparency, and responsible AI governance.

This study shows that Artificial Autonomy has great potential as a foundation for developing the next generation of IoT ecosystems. The integration of technologies such as Edge Computing, Federated Learning, Explainable Artificial Intelligence (XAI), and Generative AI is expected to further strengthen the ability of systems to operate intelligently and adaptively. Therefore, future research should focus on developing autonomy models that are safer, more efficient, and more trustworthy so that AIoT technology can provide optimal benefits for society, industry, and various sectors of life in the future.

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