CONVERGENCE OF ARTIFICIAL INTELLIGENCE AND IOT IN SMART CITY SCENARIOS

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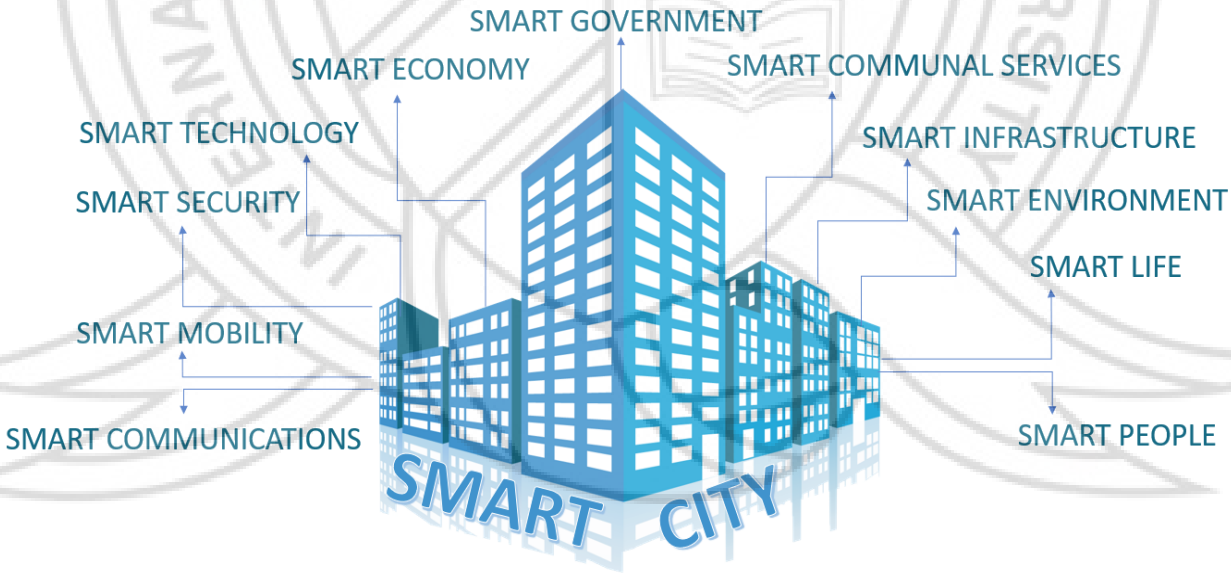
Abstract
The progress of modern society is directly linked to advancements and innovations in information and communication technologies. The new economic and social opportunities that are part of this progress have transformed the urban landscape and led to the emergence of smart cities. Residential buildings, vehicles, and social systems strive to achieve complete connectivity known as the "Internet of Things" (IoT). The use of the IoT in smart cities generates a massive amount of data that must be collected and analyzed. To do this effectively, artificial intelligence (AI) applications are used, as they are the only ones capable of processing such large volumes of data from various sources. Through AI algorithms, it is possible to continuously monitor data, analyze it, optimize resource usage, simplify decision-making, and facilitate the resolution of key urban life challenges in smart cities. This paper explores the ways in which the integration of AI and IoT can contribute to the improvement of various urban aspects. The primary focus of the paper is to highlight the transformative potential of such integration in the scenarios of smart cities.
Keywords*: artificial intelligence, IoT, smart city*
JEL classification: L86; L96; O32; O33

INTRODUCTION

Migration of the population to urban centers poses challenges in terms of modernizing urban infrastructures and ensuring sustainable environments that provide a high quality of life for residents of large cities. New technologies and smart devices used by residents are transforming the ecosystems of modern cities. The growing population and increasing use of technology generate vast amounts of data transmitted via wireless technology and cloud systems. "Smart" communication networks facilitate data exchange between interconnected IoT devices, analytical systems, and other urban infrastructure. Smart cities consist of various interconnected components that continuously exchange data and enhance the quality of life for a nation's population (Baig et al., 2017). To ensure sufficient speed and bandwidth, real-time communication, and prevent data loss during data exchange, cutting-edge network technologies such as 4G, 5G, and LPWAN networks are utilized. All these advancements have contributed to the emergence of smart cities built on the latest technological achievements. The concept of a smart city includes several key guidelines:

- efficient infrastructure with an information network,
- the use of technology to create efficient systems and improve services for citizens,
- ecological mobility, creativity, and sustainability,
- high productivity.

Scheme 1 illustrates the basic dimensions of a smart city, which include: smart mobility, smart governance, smart environment, smart living, smart economy, smart infrastructure, smart technology, smart communication, smart utility services, and smart people.

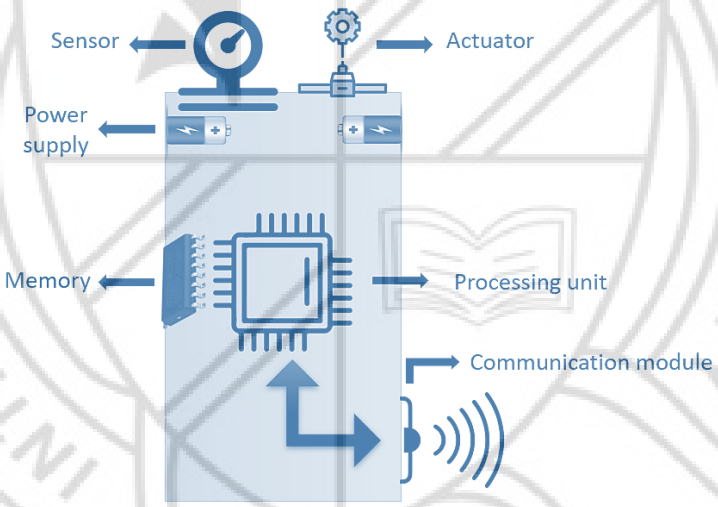


Scheme 1; Dimensions of a smart city
Source: Authors' work

Some studies predict that by 2050, 70% of the global population will live in cities, which will need to incorporate the complex infrastructure of smart cities. The journey of transforming an "ordinary" city into a "smart" city is long and demanding. The first step on this path is understanding how a particular city plans to use smart technology and data to achieve its ambitions and its aspiration to attain smart city status. Being a smart city means utilizing all available technologies and resources in an intelligent and coordinated manner to develop urban centers that are simultaneously integrated, livable, and sustainable (Kourtit & Nijkamp, 2012). Today, the concept of a smart city is unimaginable without the convergence of IoT devices and the most innovative computing technology - AI.

1. INTERNET OF THINGS (IoT)

IoT has become one of the most important technologies of the 21st century, offering opportunities to integrate the physical world into computer systems, thus enabling improved efficiency, economic benefits, and reduced human effort (Yang et al., 2017). The fundamental concept of IoT is an environment where objects can interactively communicate and produce data that can be processed, analyzed, and used to perform various tasks through machine learning. IoT can also be described as a system enabling interconnection between devices, computers, machines, objects, and other entities equipped with unique identifiers, where all elements of this system can transmit data over a network. The basic components of IoT devices are shown in Scheme 2.

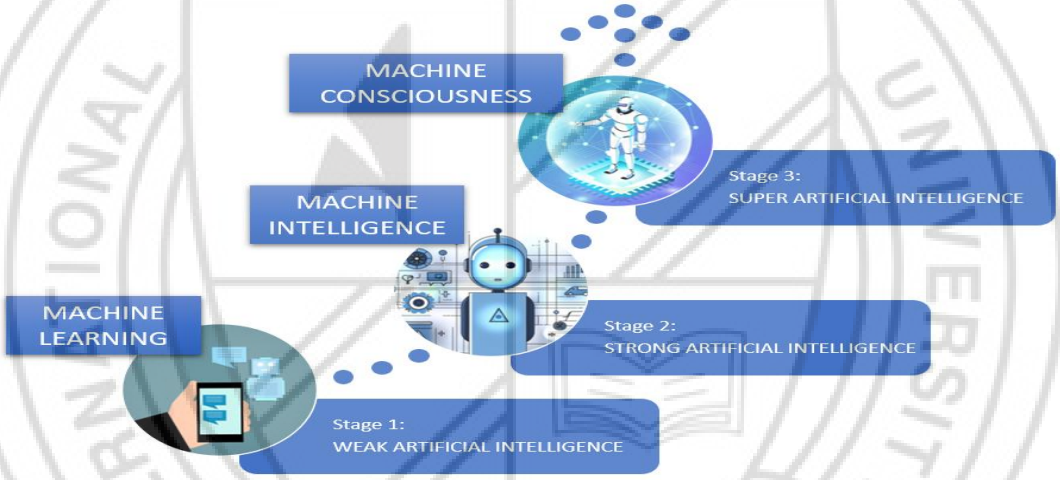


Scheme 2; IoT device components
Source: authors' work

The intelligent objects within such a system can automatically organize themselves and act according to changes in the environment. It is possible to define three categories to which IoT relates: (1) A network that interconnects heterogeneous and smart devices, representing an expansion of the traditional internet, (2) The necessary technologies to support and enable this interconnection (such as RFID, sensors/actuators, etc.), and (3) Services and applications that utilize this vision across various fields (Miorandi et al., 2012). IoT technology can be confidently described as the foundation of the future internet, and with the incorporation of AI, it will enable intelligent operations and communications among intelligent objects. Thus, for IoT to become truly intelligent, it must be based on AI.

2. ARTIFICIAL INTELLIGENCE (AI)

The most innovative and fastest-growing computing technology - AI - is difficult to define unambiguously. Artificial intelligence represents any form of simulation/imitation of human cognitive processes (association, recognition, problem solving...) by non-human factors (computers, information systems, machines, etc.) (Ćosić, et.al., 2023). One of the "better" definitions was provided by the High-Level Expert Group on AI, which defines AI as systems that exhibit intelligent behavior by analyzing their environment and taking actions—with a certain degree of autonomy—to achieve specific goals (AI HLEG-EC, 2019). In particular, AI is a transformative technology that mimics human intelligence, harnessing data to understand, learn, and adapt in order to autonomously execute tasks and attain defined objectives (Ahmić, 2023). The concept of AI is based on combining computing systems and large datasets, as well as modeling human thinking and cognitive processes. Hypothetically, the progression of AI from lower to higher levels of intelligence will, at some point, result in the emergence of a form of AI possessing human-like characteristics, such as emotions and thought processes. This form is referred to in the literature as "super AI" (see Scheme 3).



Scheme 3; Basic types of AI

Source: authors' work

- Narrow AI: This is a form of AI designed to perform a limited set of tasks and is the type of AI we interact with today. All the most popular applications currently in use are based on this type of AI.
- General AI: Often referred to as strong AI, this represents the next stage in AI development. The focus of this type is to create intelligent machines that are indistinguishable from human intelligence.
- Super AI: Although still a theoretical concept, this stage of AI development envisions the creation of self-aware machines capable of performing tasks, solving problems, and making decisions in ways superior to human capabilities.

All contemporary manifestations of AI, such as natural language processing, data mining, and image recognition, are built on three main pillars: machine learning, deep learning, and neural networks.

3. EXAMPLES OF AI AND IoT APPLICATIONS IN SMART CITIES

AI, one of the most versatile and promising technologies offered by computing, is increasingly being applied in the context of smart cities. The combination of AI and IoT technologies is revolutionizing how smart cities operate and how people live within them. The positive transformation brought about by the convergence of these technologies is evident in cities like Dubai, Barcelona, and Singapore, among many others, where IoT sensor devices are embedded across various parts of urban infrastructure. These sensors generate massive amounts of data, such as temperature, traffic congestion, water levels in rivers, and more. AI plays a significant role in analyzing this data and producing actionable insights that can be used to make timely and intelligent decisions. Below, some representative examples of AI and IoT applications in smart cities are presented.

- **E-Government**

The OECD defines e-government as the use of information and communication technologies (ICT), particularly the internet, to achieve better governance (OECD, 2003). E-government represents an upgrade of the traditional government model, enhanced by the use of various ICT tools such as cloud computing, AI, machine learning, and, of course, IoT technologies. Many countries aim to improve access to and delivery of public services to citizens, businesses, and other stakeholders interacting with the government through e-government initiatives. Although e-governments have been around for some time, the integration of AI into government services adds a completely new dimension to the quality of those services. AI enables predictive analytics, which can be utilized in various ways. For example, it can help identify citizens at risk of becoming homeless and allow governments to take timely actions to assist these individuals. AI also enables e-governments to adapt to the specific needs of citizens, businesses, or NGOs by analyzing their past interactions with e-government platforms. There are many successful programs based on IoT and AI technologies. For instance: "Ask Jamie" (Singapore): A virtual assistant powered by natural language processing, implemented on e-government websites. It facilitates intelligent communication with citizens and can answer questions across various domains. FedRAMP (USA): A program that ensures a standardized approach to security and risk assessment for cloud technologies. Examples of IoT and AI applications in e-governments include:

- Smart policymaking
- Disaster management
- Intelligent administrative processes
- Document analysis based on natural language processing
- Smart urban planning services
- Intelligent chatbots, and more

The convergence of IoT and AI in the context of e-government is expected to contribute to realizing the vision of Society 5.0 and Industry 5.0 in the future.

- **Efficient energy management**

Electric power is one of the primary needs of modern humanity, and due to the increasing population in urban centers, ensuring the required amount of energy has become highly challenging. To address this issue, smart cities aim to leverage IoT and AI technologies to build sustainable systems for the distribution, monitoring, and consumption of electricity.

Based on data gathered from IoT sensors and processed using AI algorithms, these systems can promptly identify energy-intensive operations, pinpoint risk areas and inefficiency factors, and enable automated energy usage adjustments. Before the advent of these technologies, transformer failures due to poor power supply were frequent. However, IoT devices now allow real-time monitoring of transformers, enabling suppliers to take timely actions to prevent potential failures. Through the implementation of predictive maintenance based on IoT and AI technologies, smart cities can proactively address problems and make intelligent decisions regarding the production, distribution, and consumption of electricity. A large number of IoT devices, which can be installed on the producer's side (e.g., sensors on power lines) and the consumer's side (e.g., smart meters), generate vast amounts of data. To analyze this data, AI technologies such as machine learning, deep learning, and neural networks are essential. One of the key advantages of integrating AI and IoT is the creation of intelligent systems capable of learning and adapting to changing circumstances, as well as automating repetitive tasks. For example, AI algorithms can analyze user preferences to optimize lighting and increase energy efficiency. Key Advantages of IoT and AI Integration in Smart City Power Systems include:

- Increased system reliability
- Reduced downtime through predictive maintenance
- Real-time energy consumption monitoring
- Lower environmental pollution
- Faster response to potential hazards
- Reduced human error
- Higher levels of automation
- Improved performance of electrical equipment
- Examples of Successful Projects

Numerous projects of successfully utilizing AI and IoT to optimize energy consumption involve: smart buildings in Marina Bay Sands resort, Singapore; the Empire State Building, New York; Siemens' energy efficiency solutions for smart factories built on the Totally Integrated Automation (TIA) platform; and many other initiatives worldwide.

- **Intelligent security cameras**

Surveillance systems are considered the eyes of a smart city (Eldrandaly et al., 2019). While smart cities are characterized by a high degree of automation and intelligence, they also prioritize public safety. Public security and infrastructure protection in smart cities heavily rely on intelligent IP cameras integrated with AI. By analyzing footage from these cameras, the nature of a specific event can be assessed, allowing for alerts to be issued and enabling smart real-time responses. Timely reactions and appropriate smart decisions can protect assets and human lives, enhance worker safety in factories, and even improve productivity. Although the primary role of cameras in smart cities is to ensure security, AI algorithms are increasingly being used for advanced analytics in scenarios such as evaluating retailers' operational efficiency or monitoring parking payment compliance. Additionally, because AI can process large datasets—such as video footage—quickly, it is increasingly employed for statistical analyses of specific events. As AI and IoT technologies continue to evolve, the scope of applications for intelligent security cameras in smart cities will expand. In the future, for example, smart cameras may be used to "capture" biometric characteristics, enabling precise identification of individuals. While this will enhance security, it will also raise concerns related to privacy. When combined with robust deep learning

models and computer vision, smart cameras can be applied across a wide range of use cases, such as:

- Detecting violent behavior
- Preventing suicides in public spaces
- Managing disasters
- Monitoring adherence to hygiene regulations
- Detecting traffic violations, and more

Cities like Genk already utilize advanced video analytics systems such as Nokia Scene Analytics, while Melbourne employs similar systems to combat illegal waste disposal. On a national level, countries like China and the United States stand out for their extensive implementation of AI-based video analytics systems.

- **Smart environmental protection systems**

The high population density in smart cities implies significant economic activity and intensive energy usage. When combined with the heavy consumption of other resources, it becomes evident that such activities have a considerable impact on the environment. This creates a major challenge for smart cities to ensure their ecological sustainability. To address this challenge, smart cities aim to leverage innovative solutions, cutting-edge technologies, and the latest scientific advancements to ultimately transform into sustainable smart cities. Advanced information and communication technologies, including AI, IoT, and big data technologies, are considered a promising response to ecological sustainability challenges due to their vast, yet untapped, potential for solving issues related to energy consumption, air pollution, and noise (Bibri and Krogstie, 2020). Smart cities strive to harness the synergistic potential of these technologies in their efforts to progress toward environmental sustainability. Examples of successful incorporation of IoT and AI technologies in the context of sustainable smart cities include:

- Smart transportation systems: Utilizing IoT and AI to reduce congestion and increase the efficiency of public transportation, leading to lower fossil fuel consumption and reduced air pollution.
- Smart grids: Using IoT and AI to optimize energy consumption and distribution, while facilitating the integration of renewable energy sources.
- Smart water and sewage management systems: Employing IoT and AI to detect faults and water losses, ensure efficient water use, and enable predictive maintenance of sewage systems.
- Smart waste management systems: Implementing IoT and AI to optimize waste collection, sorting, transportation, and recycling, thereby reducing the environmental impact of waste.

London stands out as a leading smart city with one of the highest numbers of air quality sensors. By integrating IoT and AI with advanced green technologies, London has set an ambitious goal to achieve net-zero emissions by 2030. Other modern smart cities, such as Barcelona, Stockholm, and Amsterdam, are also working toward sustainability by incorporating IoT and AI technologies into their green development strategies.

CONCLUSION

IoT and AI technologies, when combined, create a powerful synergy that is revolutionizing how smart cities operate and how people live within them. The convergence of these technologies generates opportunities that are critical for achieving peak efficiency and sustainability in smart cities. IoT technology facilitates communication and data exchange between interconnected devices, while AI processes and analyzes vast datasets. The synergistic effect of their integration enables intelligent actions and decision-making. This paper presented several representative examples of the application of AI and IoT in smart cities, including e-governance, efficient energy management, intelligent security cameras, and smart environmental protection systems. Urban policymakers, in their pursuit of technocentric solutions to the critical challenges of urbanization, are increasingly focusing on incorporating IoT and AI technologies into their development strategies. As these technologies continue to evolve rapidly, it is expected that new opportunities will emerge in the near future, enabling further optimization of resource utilization, simplifying essential decision-making processes, and addressing key challenges of urban life in smart cities.

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