Journal of Intelligent Systems and Internet of Things
Vol. 17, No. 01, PP. 271-278, 2025
DOI: https://doi.org/10.54216/JISIoT.170119

IoT Optimum Planning for Human Facilities Enhancement in Smart Cities

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Abstract

More environmentally friendly standards may be implemented as work environments, lifestyles, and our conception of a fulfilling life evolve. The COVID-19 pandemic highlighted the need for adaptable systems and revealed the flaws in our routines. Because smart cities are more flexible than traditional urban areas, they are becoming more and more important. While supporting citizens is the main goal of these networked smart city components, they also unintentionally enhance urban environments. This paper uses a methodical approach to investigate smart cities, breaking down and analyzing each component to clarify their beneficial interactions. This paper provides a direction for future research through its discussion of problems, challenges, and barriers related to the urban environment that affect the development of smart cities. Real-time monitoring is made possible by connecting these devices to the internet. The spacing between lighting poles significantly influences the overall uniformity and illuminance. This paper describes the architecture of Internet of Things (IoT)-based smart public smart utility system using forecasting techniques that interconnected with the sensors using IoT stack. Sensors are made to gather the timely data from different utility applications such as lighting, CCTV cameras, water usage, wastage volume, etc. The paper demonstrates the potential synergies between IoT and artificial intelligent for supporting smart cities. We deployed three convolutional neural networks namely: AquaNet, PredWasting and LightSage for forecasting the water requirements, wasting volume and light consumption in smart cities. Results shown that PredWasting is outperformed with 99.21% of accuracy over the other models.

Received: January 06, 2025 Revised: March 01, 2025 Accepted: April 18, 2025

Keywords: IoT; Smart Cities; Parking System; Lighting; Waste Management; Water Resources

1. Introduction

Cities will always be important, but as their population increases, so too will the environmental problems they face. It is anticipated that 75% of people will live in cities by 2050, which will have a major effect on the environment [1]. The worsening of the situation can be attributed to a number of factors, including population growth, climate change, natural disasters, and the migration of people from rural to urban areas in search of better employment and educational opportunities. Specifically, urban environmental infrastructures were not built to withstand the kind of surges that happen there because they were intended for denser populations. This highlights the pressing need for creative, affordable solutions [2][3].

In the 1990s, discussions about sustainability were dominated by worries about pollution and global warming. With the growing recognition of the Anthropocene's impact on ecosystems, new approaches to urban planning and management are needed. Since cities are responsible for 75% of greenhouse gas emissions and 60% of the world's energy consumption, technology particularly in the field of smart cities—has become a critical weapon in the fight against climate change [4][5].

The foundation for smart cities has been established by the development of information and communication technologies, particularly the Internet of Things (IoT). The global increase in internet accessibility has made the Internet of Things a reality, linking billions of devices and urban residents. Urban living has changed because of integration, and many jobs in the banking, government, and healthcare sectors have become easier. The Covid-19 pandemic has highlighted the importance of smart cities in maintaining operations during challenging times [6]. The likelihood that there will be up to 30 billion IoT devices in use by 2030 serves as an example of how pervasive IoT is in daily life. Sensationally simple, low-cost sensor nodes monitor the environment in real time. They possess the ability to identify and assess variations in elements such as temperature, pressure, and gases [7][8].

Three key components are required for the development of an Internet of Things (IoT)-based smart city: The fog layer is a transitional layer that processes and stores the environmental data collected by IoT-connected devices. One of the most important components is real-time environmental monitoring via sensor nodes, which enables behavioral changes to reduce pollution [9][10].

The battle against pollution of urban environmental infrastructure is seeing a rise in the use of Internet of Things-based monitoring techniques. Individual behavioral changes that support the reduction of pollution sources are encouraged by proactive monitoring. While a lot of research has been done on smart cities, researchers have focused especially on transportation, solid waste management, air and water pollution, and air pollution. By looking at studies that provide thoughtful answers to urban issues, this collection of studies defines the field of the smart city concept as a whole [11][12]. This paper attempt to address out the methods to develop the smart cities with help of IoT technology. The main contributions of the paper are listed as follows in bullet points.

- An IoT-Enabled Smart Utility Architecture: It proposes an IoT-based architecture that serves public utilities, incorporating sensors to enable real-time tracking of essential urban parameters, such as lighting, volume of water extracted, volume of waste produced, and CCTV surveillance.
- Deployment of AI Forecasting Models: The paper demonstrates three custom CNN's - AquaNet, PredWasting, and LightSage - which are used to predict the water demand, waste output, and lighting requirements of smart cities.
- PredWasting: A High-Accuracy Model for Waste Forecasting
- Integration of IoT and AI for Urban Efficiency: Urban centres increasingly rely on IoT for efficient management of resources, infrastructure and environmental impacts.

2. Smart City Concept

There is disagreement among academics regarding the definition of a "smart city," as definitions are often based on conflicting assumptions. Academics research the idea in relation to ICT (information and communications technology), sustainability, happiness, and quality of life (QoL) (Internet of Things). The meaning of the term has expanded since it was initially used in the 1990s to describe the combination of ICT and contemporary infrastructure [13][14]. The Internet of Things (IoT), citizen-centric apps, cloud computing, data collection, analysis, and machine learning, as well as several methods for sustainable urban living—such as efficient resource management, waste disposal, pollution control, and more—are all components of modern smart cities [15]. The COVID-19 pandemic highlighted the importance of sustainability in addressing environmental issues. Related urban environmental issues and their solutions interact intricately. It doesn't seem adequate to evaluate smart cities from just one angle. Through case studies, four different types of smart cities were identified: participatory, green, app-based, and socially conscious [16]. All of these different categories of smart cities used ICTs in a similar way. It is untrue to state that any of these categories gives environmental infrastructure top priority or explicitly addresses environmental pollution. The transition from traditional to smart cities is happening gradually, but problems with the environment and urban infrastructure appear to be unsolved. A number of critical issues need to be addressed, including urban transportation, air pollution, water and waste management, and other environmental factors [17]. To do this, it is necessary to look into Internet of Things (IoT)-based solutions.

3. Resources Management in Smart Cities

Urbanization, climate change, and careless use are making water a scarcer and more valuable resource. Water loss is a major concern when it comes to outdated water pipelines and poor maintenance. Urban water systems are further complicated by the requirement for multiple quality standards arising from a variety of water uses. The demand for water is rising due to the world's growing urban population, which makes the issue of water scarcity worse. Approximately 60% of people on the planet do not have access to clean water at this time. Reducing waste, pollution, and using water resources sustainably are the keys to finding a solution [18].

3.1. Waste management

Waste management is getting harder in rapidly developing urban areas due to factors like changing consumer behavior, rising living standards, urban population growth, and industrial development. Worldwide, people produce between 0.11 and 4.54 kg of solid waste per day; by 2050, it is anticipated that 2.01 billion tons of municipal solid waste will be produced annually. Interestingly, 600 million tons of recyclable waste are lost annually because of improper collection and segregation techniques [19]. Known as the "waste siege," this situation involves a number of spiraling issues that go beyond waste management, such as increased greenhouse gas emissions from stationary waste collection vehicles, excessive fuel consumption, noise, and increased pollution emissions. The average CO2 emissions from diesel trucks are 2.4 kg/km, whereas CNG vehicles emit 3.6 kg. By using subterranean trashcans, smart solid waste systems can reduce greenhouse gas emissions by 10% to 15% [20].

Although open landfills pose serious health and environmental risks, they are still the most popular way to manage solid waste globally. Chemicals that are harmful to human health and contaminate water sources, such as ammonia, toluene, and styrene, are leaked from these landfills. They also emit greenhouse gases. These landfills also produce leachate. Landfills, the world's third-largest source of methane emissions, play a major role in climate change and urban warming [21].

Urban solid waste, both residential and non-residential, is normally collected, moved, recycled, and disposed of in compliance with recognized waste management procedures. Nonetheless, intelligent waste management has become necessary due to the lack of landfill alternatives. Intelligent waste management systems are the result of IoT integration at every step of the waste management process. Research, especially in the fields of recycling, waste collection, and waste analysis, strongly supports IoT-based smart waste management as a practical response to the escalating waste management crisis. The United Nations Sustainable Development Goals, which seek to reduce waste, minimize chemical discharge, treat wastewater, and increase the use of safe water by 2030, place a high priority on sanitation and the use of clean water. Urban water management involves full infrastructure management, sewage systems, rainwater control, and pollution reduction, all of which call for Internet of Things (IoT)-based solutions. The necessity of modernizing and integrating the Internet of Things is highlighted by the three categories of urban water infrastructure: drainage, natural solutions, and water supply. Effective management of the water resources at hand is necessary to ensure water security, particularly in urban areas where water demands are rising. To reduce water loss, urban water supply systems, which include distribution networks, treatment facilities, water sources, and end users, need quick IoT-backed support. Smart meters and other Internet of things (IoT) devices have been shown to be useful in locating pipeline flaws and preventing water loss through the promotion of water conservation. Monitoring the water quality in the supply system becomes essential to safeguarding the public's right to clean water and health [8][21].

3.2. Smart Transportation

Urban water management is safer with IoT-based techniques that provide real-time water quality monitoring. However, in addition to environmental problems, cities are also struggling to accommodate the rapidly expanding urban population. Unmanageable traffic issues that arise from an exponential rise in the number of cars on the road and poor road infrastructure have an effect on emissions, fuel consumption, and public safety. Reducing emissions is challenging because the transportation sector emits comparatively less greenhouse gases than other industries [22].

Urban traffic also includes deliveries, parking, and commercial transportation in addition to vehicle traffic. Parking problems are the main source of traffic congestion. By utilizing IoT-based technologies, smart transportation management seeks to minimize needless waiting times, enhance traffic flow, and alleviate congestion. By drastically lowering traffic congestion, the installation of intelligent traffic solutions such as smart intersections, lights, and parking improves urban living [22].

Research utilizing Internet of Things-based solutions has reduced car wait times at busy intersections. By streamlining traffic, real-time traffic data analysis can greatly cut down on wait times. Two examples of integrated smart solutions that have shown promise for enhancing urban living and traffic control in cities are smart parking and traffic lights [17].

3.3. Smart Light Design

By combining different functionalities, the comprehensive design of the smart public lighting system seeks to create an intelligent lighting configuration for urban environments. This system uses Internet of Things (IoT) technologies to improve energy efficiency and lighting quality in addition to many other user-friendly features. These consist of a flood disaster warning system, an adjustable power supply, a CCTV-based security system, and the capacity to detect PM2.5 air pollution [23].

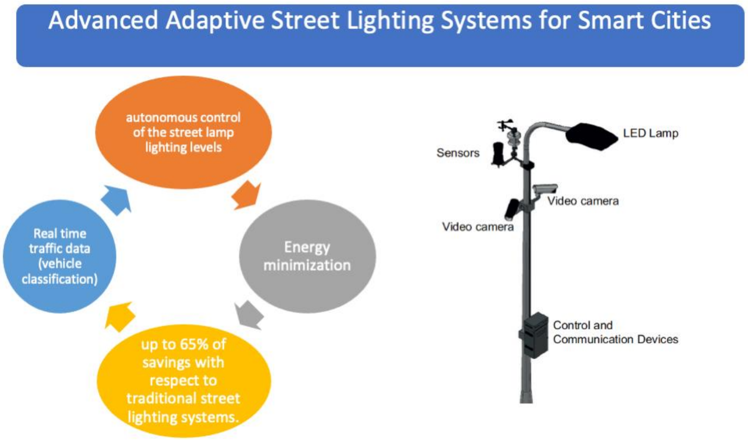

Figure 1. Smart light development and requirement for smart city.

As shown in Fig. 1, the smart public lighting system's component breakdown is as follows:

1. Motion Sensor: Because it is positioned to detect movement and has a larger detection radius, this sensor works best in front of the lamp.

2. Light Intensity Sensor: This sensor ensures accurate detection of ambient light. It's the one with the lamp shade behind it. It provides a result in lux units and measures light intensity rapidly.

3. Internet Protocol (IP) Camera: Located above ground, this 2.5-meter security camera allows for real-time remote viewing. It has an online image data analysis system installed.

4. Dust Sensor: This device detects dust particles in the atmosphere by using the principles of light diffusion.

5. Control Box: Situated one meter above the ground atop the light pole, this box is simple to measure and maintain.

6. Receptacle: This gadget serves as a stand-alone power outlet for tiny electric cars in parks in addition to charging phones.

7. LED Indicator: These LED lights are situated at the base of the light pole and function as navigational and flood warning lights.

8. Magnetic Float Switch: This switch, which is situated at the base of the light pole, senses when floodwaters are rising and activates the LED indicator there.

The 220V, 50Hz electrical grid powers the smart public lighting system, which includes an LED luminaire, driver, relay, switching power supply, percentage conversion module (%PWM), and indicators (Fig. 2). The Wemos D1 R2 microcontroller board, magnetic float switch, motion sensor, and light intensity sensor make up the control circuit [24].

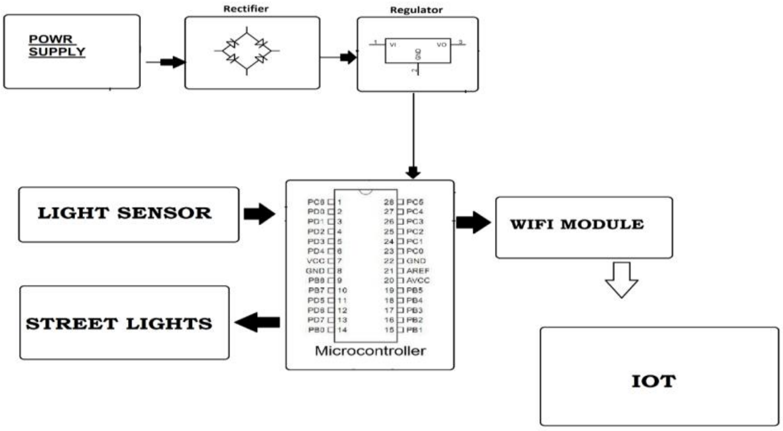

Figure 2. IoT circuit outline form smart city based sensing network.

4. Results and Discussion

It can be a difficult but worthwhile project to use three different neural networks to forecast the needs of smart cities, such as waste production, water consumption, light consumption, and more, based on data collected from sensors positioned throughout the cities using Internet of Things technology. The following terms can be used to refer to the three neural networks of type of convolutional neural network (CNN). Those three neural networks are trained using the IoT monitoring data and hence, the performance of each is recorded in terms of forecasting accuracy, mean absolute error and root mean square error.

1. AquaNet: The purpose of this neural network is to predict how much water smart cities will require. Using information from a range of sensors placed strategically around the city, AquaNet forecasts water demand, consumption trends, potential leaks, and overall usage trends. In order to optimise water distribution and management, AquaNet considers a number of variables, such as population density, weather patterns, and historical water usage.

Table 1: Performance metrics of AquaNet model based IoT.

Metric	Value
Accuracy	98.15
MAE	1.332
RMSE	1.15412304

2. PredWasting: This neural network's prediction of waste production in smart cities is its goal. PredWasting forecasts landfill requirements, recycling opportunities, waste generation rates, and segregation trends using data from sensors and Internet of Things-enabled waste management systems. For efficient waste disposal, it aims to maximise recycling programmes, landfill management, and waste collection schedules.

Tabel 2: Performance metrics of PredWasting model based IoT.

Metric	Value
Accuracy	99.21
MAE	1.11
RMSE	1.05356538

3. LightSage: LightSage is designed to forecast usage and consumption trends of light in smart city settings. LightSage forecasts energy consumption trends, lighting requirements, and illumination needs for different city zones using data from sensors and Internet of Things-connected lighting systems. LightSage uses information on user behaviour, traffic density, daylight hours, and other variables to optimise lighting systems for better lighting and energy efficiency throughout the city. These neural networks would require sophisticated machine learning techniques because Internet of Things sensors would produce massive volumes of data. With the use of this data, they hope to generate accurate forecasts and insights that will help cities with planning infrastructure, resource management, and sustainability coded all of which will increase the responsiveness and effectiveness of their smart cities.

Table 3: Performance metrics of LightSage model based IoT.

Metric	Value
Accuracy	99.19
MAE	1.219
RMSE	1.10408333

Results of proposed neural networks can be compared as following:

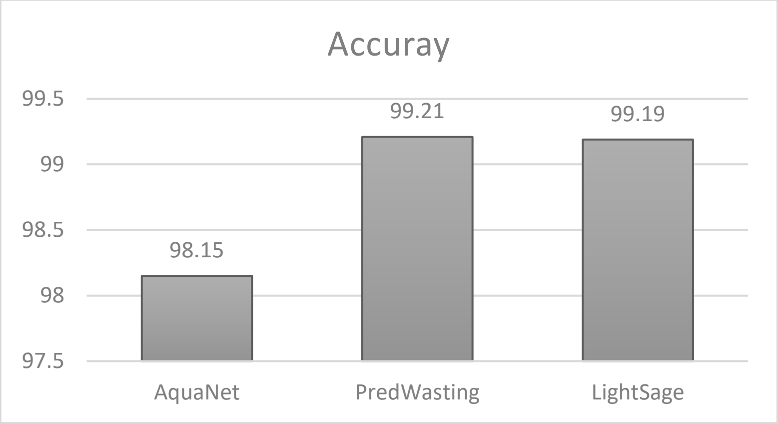

Figure 3. Accuracy of the forecasting in the smart city based IoT prediction models.

From prediction accuracy point of view, the all three neural networks have produced a reliable level of prediction accuracy and however, the PredWasting model is outperformed by producing the maximum prediction accuracy of 99.21 % (see Fig. 3).

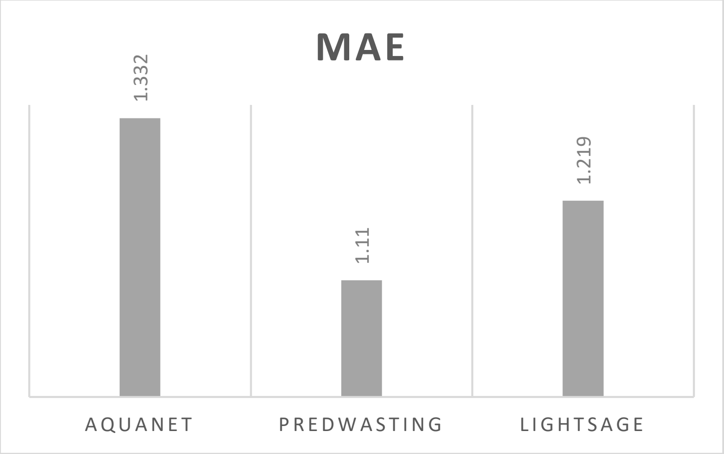

Figure 5. Mean absolute error (MAE) of the forecasting in the smart city based IoT prediction models.

The mean absolute error (MAE) and root mean square error (RMSE) is another metric, which was measured to estimate the amount of error in the results of the predictions. MAE and RMSE are found minimum at the PredWasting model (see Fig. 4 and Fig. 5).

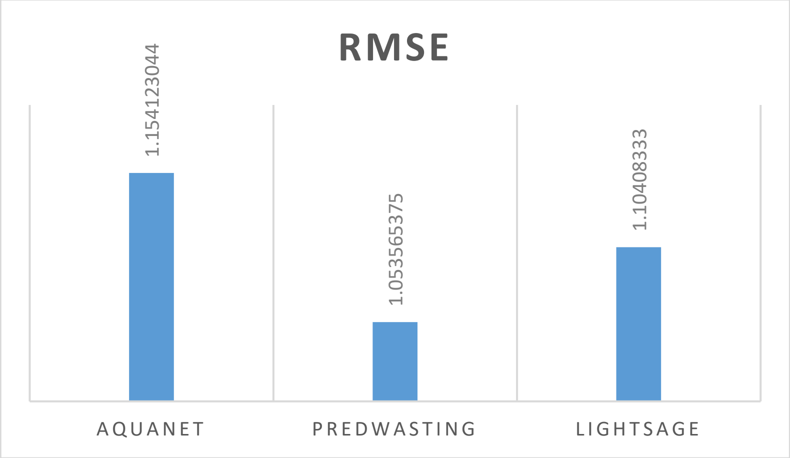

Figure 6. Root mean square error (RMSE) of the forecasting in the smart city based IoT prediction models.

5. Conclusion and Future Works

Future work environments, lifestyles, and ideas of what constitutes a good life may all change in order to comply with more environmentally friendly standards. We have seen firsthand how unforeseen circumstances can shortly and severely disturb our regular routines and habits during the COVID-19 pandemic. Smart cities are more significant because they are more adaptable than conventional urban areas with fixed structures. Positive results are produced by the interconnected and reciprocally advantageous advantages of smart city components. Although the primary goal of these applications is to improve citizen well-being, their intricacy and scope also unintentionally improve urban environments overall. This study examined smart cities from a broad perspective, breaking down and evaluating each component while highlighting how they interact. By highlighting important environmental issues in urban settings, outlining barriers to the development of smart cities, and offering a range of solutions, the study seeks to serve as a guide for future research. The paper demonstrates the potential synergies between IoT and artificial intelligent for supporting smart cities. We deployed three convolutional neural networks namely: AquaNet, PredWasting and LightSage for forecasting the water requirements, wasting volume and light consumption in smart cities. Results shown that PredWasting is outperformed with 99.21% of accuracy over the other models.

Funding: “This research received no external funding”

Conflicts of Interest: “The authors declare no conflict of interest.”

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