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Improved System for Smart City Street-Lighting Controlling based on Web Technology Principles

Rezgar Hasan Saeed

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Abstract: The world's electricity consumption predominantly relies on non-renewable energy sources. Prior to implementing these comprehensive modifications, it is imperative to actively seek for chances to economize and optimize its utilization. Modern cities are progressively adopting the concept of smart cities, with smart energy being a key focus area. Smart energy is one of the components of smart cities that cities have incorporated. In this context, a sophisticated control system employing fuzzy logic is suggested for the purpose of regulating street lighting in a manner that ensures it operates solely when required. The purpose of this is to dynamically regulate the brightness of the lights based on the traffic conditions on the street and adaptively in real-time. This helps minimize potential harm to the eyes of the driver or pedestrians when the lights are switched on or off. The proposed lighting system allowed for a significant reduction in energy usage through efficient and intelligent means.

To assess how well the suggested controller performed, three test scenarios were run. Variations in roadway lengths, vehicle counts, and vehicle speeds were present in the first, second, and third scenarios. Comparing the suggested controller's performance to that of the controllers employed in the use case was the aim. MATLAB software has been utilized for the design and simulation of the system under examination.

The simulation results indicate that the suggested fuzzy controller is more advantageous for implementing smart city street lighting on lengthy roadways with a high concentration of traffic.

Keywords: *Smart cities, smart streets, fuzzy logic, energy saving.*

1. Introduction

The rise in electric energy demand, coupled with the constrained growth in generation capacity, and the pressing need for a sustainable and habitable environment, has prompted the introduction of the smart cities concept. This concept is deemed crucial for economic development, serving as a pivotal factor in generating prosperity, knowledge, and socio-economic diversity. The primary objective in attaining sustainability is to diminish energy use and levels of Greenhouse Gases (GHG).

Prior to achieving the ultimate objective of constructing a "smart city," it is imperative to consider all the subordinate domains of smart cities initially. Conducting comprehensive study is crucial to examine the architectural design and the management of lighting and heating systems in the buildings of this smart city. Similarly, this principle may be extended to the roadways within these urban areas, enabling them to be properly lit and traffic signals to be effectively managed, so maximizing operational effectiveness.

Commercial buildings account for 26% of energy consumption, with heating systems and cooling systems each consuming 13% and 14% respectively. Additionally, lighting consumes 19% of the world's electrical energy. Lighting accounts for 6% of total greenhouse gas emissions. The American city of Los Angeles spent a total of 15 million dollars on street lighting in 2009, resulting in the emission of 111,000 tons of carbon [1].

Information Technology Dept., Duhok Private Technical Institute, Duhok, Iraq, rezgarhasan1992@gmail.com

Using intelligent street lighting control improves the area's safety and security, as multiple studies have shown. The key to this idea is building an intelligent ecosystem, which requires using information and communication technology (ICT) to manage the environment and its limited natural resources in a sustainable and efficient manner. The implementation of effective street lighting can greatly reduce the frequency of crime and traffic accidents, as there are already over 90 million light sources illuminating the streets worldwide[2, 3]. Implementing clever methods to regulate street lighting can result in significant energy save.

Remote sensors and controllers for street lighting have significant promise for energy conservation, as they are widely regarded as dependable and efficient systems for controlling illumination. Street lighting operations are dynamically adjusted according to the surrounding data, including weather and traffic conditions, obtained from a network of local sensors. This There are other ways to exchange information, including SMS, a particular protocol, standard, algorithm, or a smartphone with both GPS and Internet access. Nonetheless, studies have shown that turning on a smartphone's GPS and internet connectivity causes a considerable rise in power consumption—by 650 megawatts.

Energy conservation has been the focus of many research programs in recent years, with a particular emphasis on developing technology that would allow for precise and flexible regulation of street lighting. Based on fuzzy logic, fuzzy control technology has grown significantly in popularity and interest across a wide range of devices and applications in many spheres of life. It provides more useful and affordable answers to actual issues than alternatives offered by other technologies.

2. Background Theory

2.1 Smart City Concepts

Smart city is a metropolitan area that leverages information and communication technologies (ICT) to optimize its functions and drive economic growth while improving the quality of life for its citizens. Essentially, it's a city that uses smart tech and data analysis to become more efficient, sustainable, and livable. The key elements of a smart city are:

Data-driven: Smart cities collect real-time data through sensors, networks, and connected devices (think: Internet of Things). This data is then analyzed to understand city operations and citizen needs. Tech-powered: Technologies like artificial intelligence (AI), machine learning, and automation are used to manage resources, optimize infrastructure, and deliver services more efficiently. People-centric: The ultimate goal of a smart city is to improve the lives of its citizens. This means prioritizing sustainability, inclusivity, safety, and well-being. Interconnected: Smart cities are networks of systems and people, working together to create a more synergistic and responsive urban environment [4].

Street-lighting control systems have transcended the simple on/off timers of the past. Today, they are evolving into sophisticated tools for urban management, energy efficiency, and citizen well-being. There are different types of Control Systems: Traditional: Timer-based, turning lights on at dusk and off at dawn. Sensor-based: Employ photocells and motion sensors to adjust light levels based on ambient light and pedestrian/vehicle activity. Smart systems: Utilize sophisticated hardware and software for granular control, including dimming, scheduling, and remote monitoring. The benefits of Advanced Control include: Energy savings: By adapting light levels to demand, smart systems can reduce energy consumption by up to 70% compared to traditional methods. Light pollution reduction: Lowering light levels when not needed minimizes upward light trespass, improving environmental health and astronomy observations. Enhanced safety and security: Strategic lighting adjustments can deter crime and improve visibility for pedestrians and drivers. Maintenance optimization: Real-time monitoring can identify faulty lights and schedule repairs proactively, reducing downtime and costs. Data-driven insights: Traffic patterns, pedestrian flows, and environmental data collected by smart systems can inform other city planning initiatives. The technologies Supporting Control are: LED lighting: Highly efficient and dimmable, LEDs are ideal for dynamic lighting control. Communication networks: Wireless mesh networks or cellular connections enable remote control and data collection. Central management software: Provides a platform for monitoring, configuring, and optimizing lighting systems. Sensor technologies: Photocells, motion sensors, and even cameras can provide real-time data on ambient light and activity. In other hand, the challenges and considerations are: Initial investment: Implementing smart systems can be costly, requiring upgrades to infrastructure and lighting equipment[5]. Data privacy concerns: Collecting and analyzing data raises concerns about citizen privacy and security. Cybersecurity vulnerabilities: Connected systems need robust cybersecurity measures to prevent hacks and disruptions. Public acceptance: Engaging citizens and addressing their concerns is crucial for successful implementation. The Future of Street-Lighting Control: Street-lighting control is a rapidly evolving field, with constant innovations in technology and applications. As cities strive for sustainability, safety, and citizen well-being, these systems are poised to play a central role in shaping the future of urban environments[6].

2.2 Web Technology

The web, woven from the threads of code and interconnected servers, forms a vast tapestry of information and interaction. But this intricate fabric isn't just held together by technological prowess; it's guided by a set of overarching principles that shape the user experience and define the very essence of how we navigate and engage with the digital world. Let's delve deeper into these core principles that underpin web technology:

- **a.** User-centricity: At the heart of every successful web experience lies the user. Developers and designers must prioritize user needs, crafting intuitive interfaces, clear communication, and engaging visuals. This means understanding user journeys, anticipating their goals, and removing any roadblocks that hinder their interaction with the website. From simple navigation menus to accessible layouts, every element should be thoughtfully considered to deliver a smooth and satisfying experience [6].
- **b.** Accessibility: The web thrives on inclusivity, and accessibility is the key that unlocks its doors for everyone. Websites must cater to diverse needs and

abilities, ensuring equal access and interaction for people with disabilities or using different devices. This involves adhering to W3C guidelines, employing assistive technologies like screen readers, and incorporating features like keyboard navigation and adjustable font sizes. Building an accessible web ensures that no one is left behind in the digital revolution [7].

c. Performance: In today's fast-paced world, patience is a precious commodity. Web users expect swift responses, quick loading times, and seamless interactions. Performance, therefore, becomes a crucial principle for web technology. This involves optimizing code, minimizing bandwidth usage, and strategically caching resources. Developers must strive for efficiency at every level, delivering experiences that are not only functional but also delightful in their responsiveness [8].

d. Open Standards: The web's strength lies in its openness. Standardized protocols like HTML, CSS, and JavaScript provide a common language for developers and browsers, ensuring consistency and interoperability. This allows information to flow freely across platforms, devices, and geographic boundaries. Adhering to open standards fosters innovation, encourages collaboration, and prevents the web from becoming fragmented.

e. Progressive Enhancement: Just as a well-built house caters to different weather conditions, websites should adapt to diverse user contexts. Progressive enhancement ensures that core functionalities are accessible on any device, while progressively enriching the experience for users with more advanced browsers or faster connections. This layered approach balances inclusivity with innovation, delivering a satisfying experience for everyone[9].

f. Mobile-First Approach: In a world dominated by smartphones and tablets, the web must prioritize mobile experiences. Websites should be designed and developed with mobile devices in mind, ensuring optimal readability, intuitive touch interactions, and efficient resource consumption. This mobile-first approach recognizes the changing landscape of internet access and ensures that no user is left out of the online conversation.

g. Security and Privacy: Trust is the cornerstone of any online interaction. Web developers must prioritize user security and privacy, employing robust encryption protocols, protecting user data with utmost diligence, and being transparent about data collection and usage practices. Building a secure and privacy-conscious web fosters trust and encourages users to engage with the online world freely[10].

h. Sustainability: The web has a significant environmental footprint. Developers must employ sustainable practices to minimize the energy consumption of websites and servers. This involves optimizing code, utilizing renewable energy sources, and employing eco-friendly hosting solutions. A sustainable web not only benefits the environment but also aligns with the growing demand for responsible digital practices.

i. Innovation and Experimentation: The web is a living, breathing entity, constantly evolving. Web technology principles act as guideposts, not restrictive frameworks. Developers should embrace innovation and experiment with new technologies to create better, more engaging experiences. This spirit of exploration pushes the boundaries of what's possible, propelling the web forward and enriching our digital lives[11].

j. Continuous Learning: The web is a vast ocean of knowledge, and there's always more to learn. Developers must commit to continuous learning, staying abreast of the latest trends, technologies, and best practices. This commitment to professional development ensures that the principles guiding web technology remain relevant and impactful, paving the way for a thriving and interconnected digital landscape.

These core principles not only shape the technical aspects of web development but also inform the ethical and social implications of the online world. By adhering to these principles, we can build a web that is user-centric, accessible, performant, and inclusive, enriching the lives of users across the globe and forging a brighter future for digital interaction[12].

2.3 Attacks Related to Webservers

Web servers, the unsung heroes of the internet, silently work behind the scenes to deliver the websites and applications we rely on daily. Unfortunately, these critical digital engines are also attractive targets for malicious actors, facing a constant barrage of attacks aimed at disrupting, compromising, or stealing data. Let's delve into the dark alleyways of the web and explore the diverse landscape of web server attacks:

a. Denial-of-Service (DoS) Attacks: Imagine a mob of digital ruffians flooding a restaurant, preventing legitimate customers from entering. DoS attacks operate similarly, overwhelming web servers with a deluge of requests, consuming resources and rendering them inaccessible to genuine users. These attacks come in various flavors: Flood Attacks: Bombarding the server with an overwhelming number of HTTP requests, emails, or pings, causing it to buckle under the pressure. Resource Depletion Attacks: Consuming server resources like memory, CPU, or storage space by running resource-intensive processes, effectively starving legitimate users.

Protocol Attacks: Exploiting vulnerabilities in communication protocols like TCP/IP to disrupt server operations and crash the system. DoS attacks can cripple businesses, causing financial losses, reputational damage, and frustrated customers[13].

b. Injection Attacks: Think of injection attacks as injecting malicious code into the veins of a website, manipulating its behavior and potentially gaining unauthorized access. Common variants include: SQL Injection: Injecting malicious SQL code into website forms or input fields to manipulate databases and steal sensitive information. Cross-Site Scripting (XSS): Injecting malicious scripts into website pages, which then execute on users' browsers, potentially stealing cookies, tracking activity, or spreading malware. Command Injection: Injecting malicious commands into server-side applications, allowing attackers to execute unauthorized commands and gain control over the system. Injection attacks can expose sensitive data, compromise user accounts, and even hijack entire websites [14].

c. Cross-Site Request Forgery (CSRF): Imagine tricking a friend into signing a check for you without their knowledge. CSRF attacks operate similarly, tricking a user's browser into sending unauthorized requests to a trusted website on the attacker's behalf. This can be used to steal sensitive data, hijack sessions, or perform unauthorized actions[15].

d. Brute-Force Attacks: Think of a burglar trying every key in the bunch until one opens the lock. Brute-force attacks bombard login pages with countless username and password combinations, hoping to guess the right one and gain access. These attacks can be automated and target specific accounts or vulnerabilities in authentication systems[16].

e. Zero-Day Attacks: These are the digital equivalent of surprise attacks, exploiting previously unknown vulnerabilities in web server software or operating systems. Since no patch exists, these attacks can be highly effective and cause significant damage before developers can issue fixes.

For Protecting Your Web Server: Defending against these diverse threats requires a layered approach: Regularly update software: Patching known vulnerabilities promptly is crucial for closing security gaps. Implement strong authentication and authorization: Use complex passwords, multi-factor authentication, and role-based access control to restrict unauthorized access. Secure your network: Utilize firewalls, intrusion detection systems, and network segmentation to monitor and filter traffic. Waf (Web Application Firewall): Deploy a web application firewall to filter malicious traffic and block common attack vectors. Backup regularly: Having regular backups allows you to quickly restore your website in case of an attack[17].

2.4 Cloud Systems

Imagine a vast, ethereal landscape, limitless and ever-evolving, where computing resources stretch like clouds across the horizon. This, my friend, is the world of cloud systems, a paradigm shift that has revolutionized the way we store, access, and process information. Gone are the days of bulky servers confined to dusty basements. Cloud systems offer a dynamic, on-demand playground for businesses and individuals alike, providing a smorgasbord of resources accessible from any corner of the globe, all you need is an internet connection and a sense of digital adventure[18].

a. Unveiling the Layers of the Cloud:

But what exactly lurks beneath the fluffy surface of these digital clouds? Let's peel back the layers and explore the intricate architecture that powers this remarkable phenomenon:

- Infrastructure as a Service (IaaS): Think of IaaS as the foundation upon which the cloud kingdom rests. It's the raw computing muscle, offering virtual servers, storage, and networking resources that you can rent and scale on demand. No more upfront investments in expensive hardware - simply pay for what you use and adjust your resources as your needs evolve[19].
- Platform as a Service (PaaS):Ascend a level higher to PaaS, a pre-built platform prepped for the development and deployment of applications. Imagine it as a fully equipped chef's kitchen, complete with tools and ingredients (development frameworks, databases, analytics) - all you need is your recipe (application code) to whip up a culinary masterpiece.
- Software as a Service (SaaS):Reach the pinnacle of the cloud with SaaS, where software applications are delivered directly over the internet, like renting a fancy car instead of buying and maintaining your own. Think email, office productivity suites, or even CRM systems - they're all readily available, accessible from any device, and always kept up-to-date by the provider[20].

b. Benefits Galore: A Bounty of Advantages

So, why should you consider migrating your digital treasures to the cloud? Well, the benefits are as vast as the cloud itself:

- Agility and Scalability: Adapt to changing demands in a snap. Need more storage for your booming business? Just spin up additional virtual servers in minutes. The cloud scales with you, not against you.
- Cost Efficiency: No upfront hardware investments, no maintenance headaches. Pay only for what you use,

optimizing your IT budget and freeing up resources for innovation.

- Accessibility and Mobility: Work from anywhere, anytime. Cloud resources are accessible from any device with an internet connection, empowering remote workforces and global collaboration.
- Resilience and Security: Cloud providers offer robust security measures and disaster recovery plans, safeguarding your data from unforeseen events and malicious attacks.
- Innovation at Your Fingertips: Tap into a plethora of cutting-edge technologies like AI, machine learning, and analytics, all readily available in the cloud, propelling your business forward[21, 22].

c. Challenges to Consider: Navigating the Cloudscapes

However, the cloud isn't always sunshine and rainbows. Here are some potential challenges to be mindful of:

- Vendor lock-in: Choosing the right cloud provider is crucial, as migrating to another can be complex and costly.
- Security concerns: While cloud providers offer robust security, data breaches still occur. Ensure you understand your provider's security measures and implement additional safeguards if necessary.
- Network dependency: Reliable internet connectivity is essential for accessing cloud resources. Prepare for potential downtimes and have backup plans in place.
- Hidden costs: While seemingly cost-effective initially, cloud usage can rack up unforeseen charges if not monitored closely.

Despite these challenges, the future of computing is undeniably intertwined with the cloud. As technology advances and cloud offerings become even more sophisticated, the benefits will continue to outweigh the drawbacks. So, embrace the cloud, my friend, and prepare to soar into a future of boundless possibilities, agility, and innovations[23, 24].

2.5 Smart City Controlling Systems

Imagine a city that breathes, adapts, and learns. One where traffic lights dance to the rhythm of the commute, energy flows like a well-rehearsed concerto, and resources are utilized with the precision of a seasoned conductor. This, my friend, is the vision of smart city control systems: a technological symphony orchestrating the complex movements of an urban environment.

At the heart of this symphony lies a diverse ensemble of interconnected systems:

- Traffic Management: Smart cameras and sensors monitor traffic flow, adjusting stoplights and rerouting vehicles in real-time to alleviate congestion and optimize travel times. Think synchronized conductors keeping the urban traffic orchestra in harmony.
- Energy Optimization: Intelligent grids adapt to demand, distributing power from renewable sources while minimizing waste. Imagine solar panels and wind turbines as energetic soloists, feeding the grid with their clean melody[25].
- Waste Management: Sensors and connected bins track waste levels, optimizing collection routes and promoting recycling initiatives. Think garbage trucks transformed into rhythmic bass players, collecting waste efficiently and minimizing their environmental impact[26].
- Public Safety: Surveillance systems and advanced analytics detect criminal activity and emergencies, enhancing security and response times. Picture security cameras as vigilant watchdogs, their sharp eyes keeping the city safe.
- Environmental Monitoring: Air quality sensors and weather stations track pollution levels and weather patterns, enabling proactive measures to protect public health and the environment. Imagine air quality sensors as sensitive clarinets, their melodies reflecting the city's environmental health[27].

These systems, like seasoned musicians, work together under the baton of a central platform:

- Data Gathering and Analysis: Sensors and connected devices feed real-time data into the platform, providing a comprehensive understanding of the city's pulse. Think of this as the conductor meticulously studying the score, gathering information from each instrument.
- Decision Making and Automation: Algorithms and AI interpret the data, generate insights, and trigger automated actions to optimize city operations. Picture the conductor analyzing the data and making informed decisions to guide the performance.
- Monitoring and Evaluation: Performance metrics help evaluate the effectiveness of the system and inform continuous improvement. Imagine the conductor listening to the orchestra, identifying areas for improvement and refining the performance[28].

The benefits of smart city control systems are as harmonious as a well-played symphony:

- Reduced traffic congestion and emissions
- Optimized energy consumption and increased reliance on renewables
- Improved public safety and emergency response times
- Enhanced public health and environmental protection
- Increased efficiency and cost savings in city operations

- Improved quality of life for residents
- However, like any complex performance, challenges exist:
- Privacy concerns: Balancing data collection with individual privacy is crucial.
- Cybersecurity threats: Robust security measures are essential to protect critical infrastructure.
- Equity and inclusion: Ensuring all communities benefit from smart city technologies is paramount.
- Cost and infrastructure requirements: Implementing these systems requires significant investment and upgrades[29].

Despite these challenges, the potential of smart city control systems is undeniable. As technology advances and cities face increasing pressure to become more sustainable and livable, these intelligent systems will become increasingly vital in orchestrating the symphony of urban life. So, raise your baton, city leaders, and prepare to conduct the future, one smart note at a time[30].

3. Related Works

A comprehensive analysis of numerous research examining the notion of smart cities and remote sensing has been initiated, as smart streets play a crucial role in the development of smart cities.

(Vito Albino et al.) provided a clear definition of the term "smart" as it pertains to cities. They also defined the key dimensions and features that define a smart city. The user's text is [31]. The notion of smart cities increasingly encompasses not only information and communication technology, but also the attributes of individuals and local communities.

This study examines the criteria for classifying cities as "smart" by analyzing their definitions, components, and performance measurements. It also explores the pivotal role that cities play in global social and economic aspects, as well as their substantial impact on the environment. Cities have distinct ideas and priorities in order to accomplish their objectives, but they must foster the comprehensive development of both tangible and intangible elements [32].

(Amy Glasmeiera et al.) and (Levenda et al.) have conducted research on the topic of 'smart cities'. They have written multiple articles that analyze the ongoing discussions surrounding the objectives, potential, and constraints of the smart cities concept, which has come to symbolize urban modernization [33, 34].

(Miguel Castro et al.) provided a theoretical analysis on how to add sensors, control, and communication functionalities to the street lighting management systems' architecture. Four interconnected layers comprise the suggested architecture for smart lighting, which includes smart functions and interfaces [35]:

- Embedded layer: the source of illumination.
- System layer: the control system, for instance.
- Network layer: is responsible for overseeing and regulating energy sources and generation facilities.
- Layer dedicated to communication and sensing.

This study showcases the methodology for obtaining an intelligent and compatible lighting system using upcoming machine-to-machine (M2M) protocols including CoAP architecture and REST architecture. This complies with the IPS Alliance's guidelines for establishing a semantically compatible degree of street illumination. At this level, the current street lighting infrastructure must be integrated with logic and communications. It also highlights how important smart lighting control is to making smart cities sustainable [36].

The researchers (De Paz et al.) introduced a new approach based on the smart cities concept, designed to offer remote control of smart lighting [37].

To assess the efficacy of an adaptive structure that centralizes control for smart management and general lighting, comparative research was conducted. The idea was to provide maximum visual comfort in illuminated spaces at a lower cost of lighting. ANOVA-based techniques, EM Algorithm, Artificial Neural Networks (ANN), Multi-agent Systems (MAS), and the Service Oriented (SOA) method are among the Artificial Intelligence (AI) technologies that are combined in this framework [38].

Furthermore, MLP networks are employed to forecast luminosity by leveraging power data. The most efficient solution, taking into account both energy usage and cost, is to utilize a fully customized Modular architecture for contemporary lighting systems. The efficacy of this architecture has been empirically validated, and its further advancement can be pursued [37].

The efficacy of LED technology was proved by (Abrol et al.) through the proposition of a system that regulates street lighting according to traffic density [39]. By substituting conventional LEDs with LED LEDs and employing the energy-conserving mechanism of the microcontroller through wireless connection based on the Zigbee wireless communication standard.

Motion sensors are coupled to a microcontroller, which serves as the system's primary control unit. The motion sensors are placed in between each pair of lightbulbs, at the beginning and end of the street. When one of these sensors is triggered, the controller quickly modifies the surrounding lights' status while accounting for their previous state. The system also makes use of sensors. The proposed project's main goals are to use infrared technology to provide dynamic control signals based on traffic movement and to govern the automatic adjustment of street lights based on brightness level.

The system offers an efficient energy-conservation solution by preventing the superfluous consumption of electricity resulting from human adjustments of lighting or unnecessary activation of street lights. This implements a dynamic technique for controlling traffic flow.

Previous studies have relied on human involvement to control non-adaptive lighting. However, recent studies have attempted to eliminate the need for human labor by developing an intelligent lighting system. This system utilizes a network of independent sensors and operates on the TALISMaN (Traffic Aware Lighting System Management Network) algorithm. The system tracks the movement of cars, bicycles, and pedestrians to optimize lighting conditions [40].

The sensors communicate wirelessly to share data regarding the presence of an individual in a vehicle. Each node, consisting of a sensor, LED, and controller, adjusts its light intensity by utilizing information from all sensors. This adjustment aims to minimize energy wastage by avoiding continuous street lighting. Figure (1) illustrates the movement of illuminated sections of the road as described in reference [40]. The system was not physically deployed, but instead simulated. Based on the simulation results, it was observed that the savings rate ranged from 45% to 82% (depending on traffic) compared to the newly assessed schemes. Additionally, the total energy consumption for each lighting scheme was found to be 112 LEDs on the street throughout the entire week.

A fuzzy control system using fuzzy logic was presented as an algorithm for data processing in the intelligent urban street lighting control system after research on fuzzy logic traffic light control was done. Three main components are included in the proposed system: the management of lighting based on occupancy, the implementation of adaptive lighting for enhanced visual comfort, and achieving energy savings as a percentage, as indicated by prior studies [41].

Hence, the proposed study introduces an enhanced formulation to minimize the wastage of electrical energy in illuminating the streets of intelligent urban areas, by regulating it to achieve optimal efficiency. An intelligent adaptive system is proposed to control road lighting using fuzzy logic in the MATLAB environment. The device smartly and efficiently lowers greenhouse gas emissions and energy consumption by dynamically adjusting the light's brightness in real time to the ideal level. Next, in order to visually monitor the simulation and assess the efficacy of the suggested controller, the system was simulated both programmatically and visually. Comparing its performance to that of other controllers.

4. The Operational Mechanism of the Smart City Street Lighting Control System.

The illumination conditions for the street segment are depicted at various times[40] in Figure (1), as the proposed system operates based on the following principles. The mechanism remains inactive unless there is darkness, which can occur at sunset, during rainfall, or when the sky gets cloudy. Upon detecting the presence of vehicles or pedestrians, the lights are incrementally illuminated in the following manner:

The lights in close proximity to the object are initially subdued.

- As the body gets closer to these lights, the brightness of their lighting progressively increases until it achieves its maximum intensity.
- Simultaneously, the lights beneath it are dimmed and emit a faint glow.
- As the body transitions onto the street, the taillights are gradually lowered and subsequently switched off.

5. Sensors Incorporated into the Suggested Control System.

The implementation of the suggested control system necessitates the inclusion of optical sensors and field sensors. The optical sensors are tasked with determining the operational timing of the system (during periods of darkness caused by precipitation or clouds, or from sunset to sunrise). The function of the field sensors is to ascertain the vehicle's distance from the illumination poles.

6. Structure of Case Diagrams for the Suggested System.

The operation of the system may be examined by means of state diagrams. The operational state of the street lighting control system is depicted in Figure 2. It is worth noting that the system begins in the inert state, with the power supply in the Off state. If the power supply is turned On, the system will transition to the active state.

The state diagram of the field sensor is represented by Figure (3). It is important to observe that the field sensor starts in an idle state. It transitions to an active state when it detects an object on the street and the power supply is functioning. Once in the active state, As long as there is an object on the roadway, it will remain in this mode. When there are no objects on the roadway, it goes into the waiting mode and stays there as long as there is electricity and nothing to do. If the power supply is switched off, it will either go to the active state or return to the idle state. after spotting something on the road.

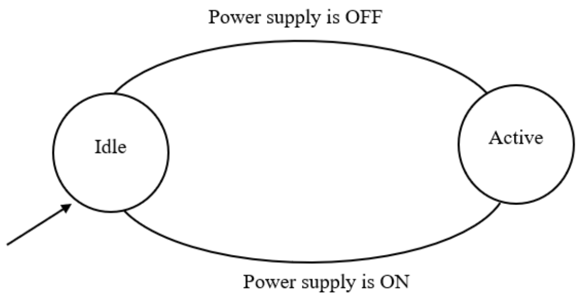

Fig 1: displays the case diagram of the suggested controller.

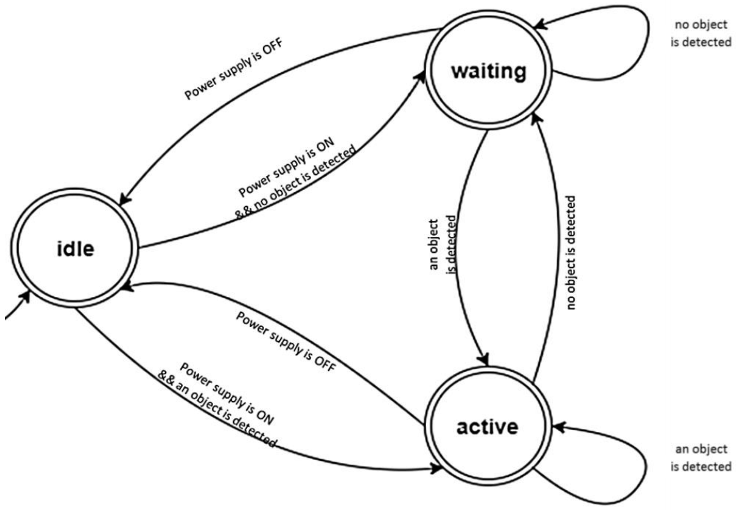

Fig 2: Displays a Case Schematic of the Field sensor.

The suggested street lighting system's spatial diffusion diagram is shown in Figure (3). It shows where two different kinds of sensors are located: field sensors at a low altitude, about at vehicle height, and optical sensors at the top of the pole. It also shows where the suggested fuzzy controller should be mounted on the light pole.

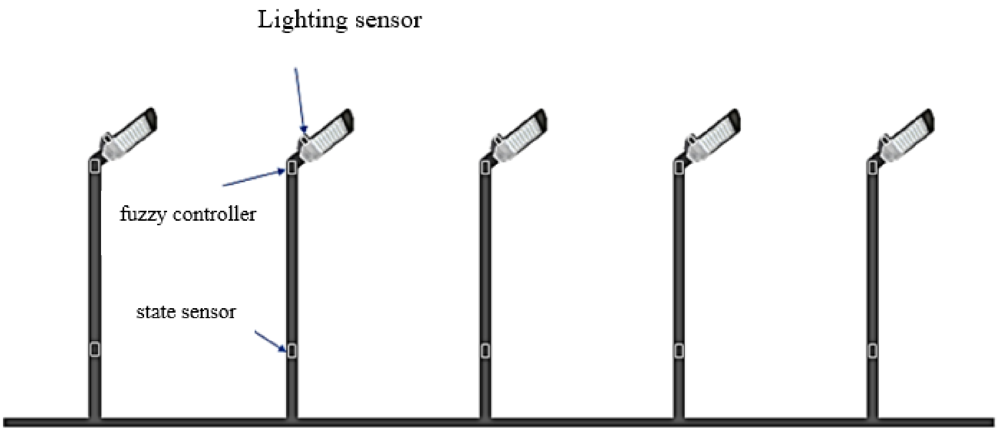

Fig 3: Display a Spatial Diffusion Diagram of Proposed Lighting System.

7. Fuzzy Controller System for the Smart City Street Lighting Design.

The suggested lighting system's box diagram, as seen in Figure (4), has one output and three inputs. The first input, which gauges illumination intensity, is coupled to the optical sensors. The second input, which locates the closest object within the laser sensor's detection range, is connected to the field sensors. The neighborhood lights' condition is displayed in the third input. The fuzzy controller receives readings from these sensors. Then determines whether to activate or deactivate the lights based on the prevailing traffic conditions.

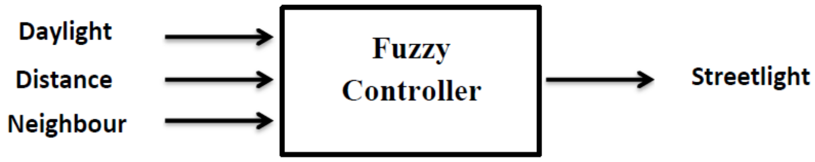

Fig 4: The Street Lighting System Box Diagram for a Smart City.

7.1 Daylight

The first input, referred to as "daylight," indicates the level of brightness emitted by the sun. Figure (5) depicts fuzzy clusters of sunshine, with a value of 100 indicating the highest level of brightness, and a value of 0 indicating complete absence of brightness when the intensity of sunlight is below 40%. The lights will only be activated when deemed essential. Photosensor values below 15 indicate a dark or nighttime state. Values ranging from 15 to 45 indicate the occurrence of sunset or hazy weather conditions. Values exceeding 45 indicate ample natural lighting, obviating the need for artificial illumination. This scenario corresponds to daytime.

When this entrance is in a bright state, natural lighting is adequate and lights won't be turned On, even when there are cars or pedestrians on the street. However, when the input is in a DARK state, the lights will illuminate with a brightness that is determined by the object's proximity to it, and to a greater extent than in the scenario of DUSK.

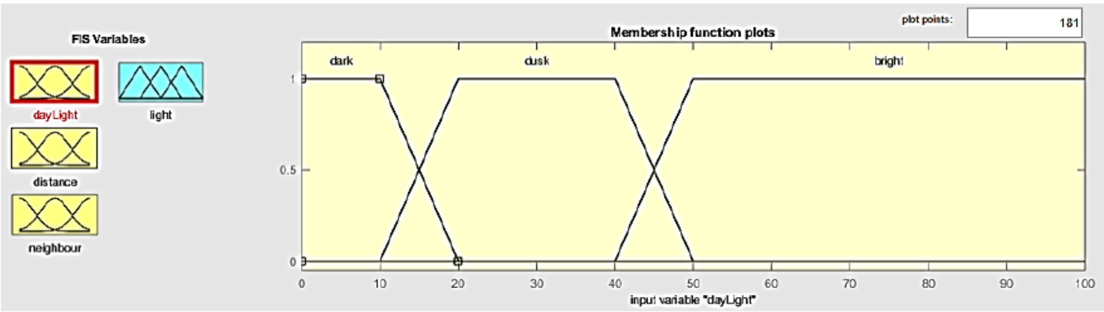

Fig 5: Displays the Daylight (First-Input).

7.2 Distance

This is referring to the second input, which is the closest object within the laser sensor's detection range. The fuzzy distance groupings are displayed in Figure 6. The position of the object as it moves through the sensor's detecting region will determine how intense the LED illumination is. As a result, the lights will only come on when anything is in the roadway, near the LED, and at an appropriate distance from it. The measurement of the body's distance in meters from the LED falls between the range of numbers 10 to 10. The item is positioned to the left of the LED when the numbers are negative. Positive readings, on the other hand, suggest that the object is situated to the right of the LED. The object is in close proximity to the LED when the reading trends towards 0. The values acquired from the sensors that are directly connected to the fuzzy controller are represented by the first and subsequent inputs.

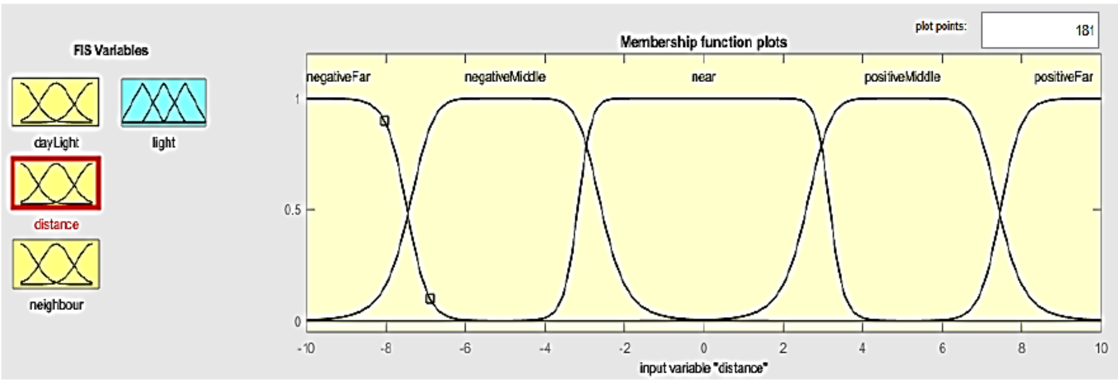

Fig 6: Displays the Distance (Second-Input).

7.3 Neighbor

The third input is depicted in figure (7) as the neighbor fuzzy controller. This controller receives input from the central control unit and is responsible for two duties. The initial objective is to elevate the illumination level beyond the standard level in order to offset the insufficient lighting resulting from the defective LEDs. The entity that transmits the signal to this input serves as the central control unit responsible for monitoring the state of all LEDs. If any of the LEDs have a problem, the controller will notify the two closest LEDs, one located to the right and the other to the left of the faulty LED. Practically, this input is expected to only accept two values: 0 or 1. This device's second goal is to detect how close the closest object is to the broken LED and send that information to the new LED's fuzzy controller.

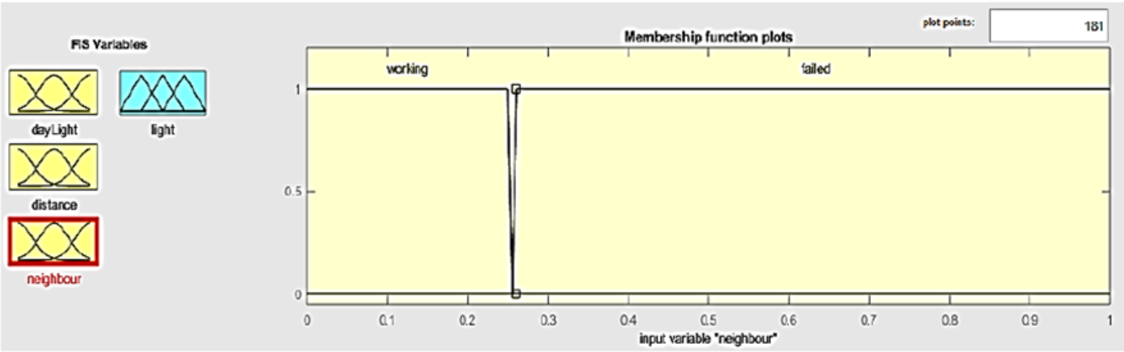

Fig 7: Displays the Neighbor Corresponding (Third-input).

7.4 Light

There are five states represented by the output, each of which is an LED that is either totally on, partially on, or completely off. The output indicates how each LED's brightness level is determined at any given time by the state of the three inputs. The light output's fuzzy clusters are seen in Figure (8).

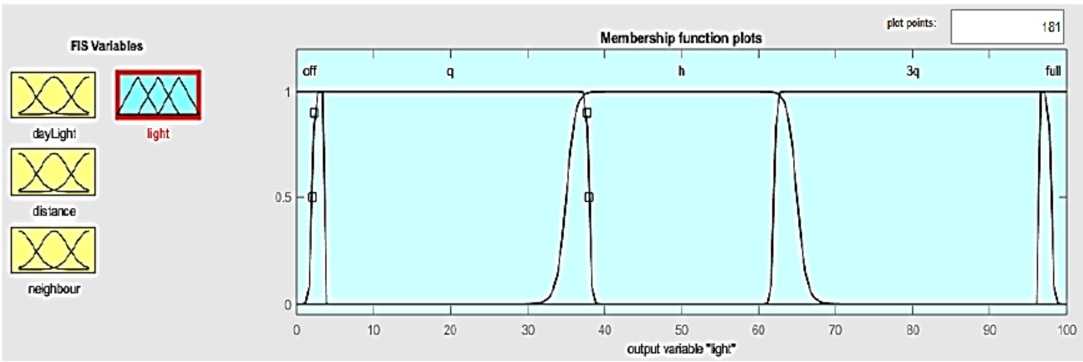

Fig 8: Illustrates the Phenomenon of the Light.

8. Evaluation of the Fuzzy Controller in Relation to Other Systems

- The illumination operates continually in times of requirement and is not required when the sun's brightness is below 40%. Given that the overall lighting of the LED in the proposed system is 100%, the LEDs will always have 100% illumination once the intensity of the sun's brightness falls below 40%. The constant state of being turned on will serve as a baseline condition for comparing the brightness of each LED on the other controllers.
- When employing the ON/OFF control method, the LEDs are activated when an object traverses the street, and deactivated when it exits the street, as long as there are no other objects present within the street. Provided that there is an object passing on the street, all the LEDs will be illuminated.
- When employing the TALiSMaN algorithm, the field sensor detects the presence of an object as it traverses the street and triggers an LED to illuminate at full intensity. Additionally, the LEDs located within a 60-meter range behind the initial LED also light up. Once the object exits the sensor's detection range, the LEDs are deactivated, unless another object is detected in the vicinity [41].
- The Fuzzy controller will activate the LEDs only when necessary, and their brightness will change based on the position of the object inside the sensor's detection range. Consequently, the LED will only be activated progressively when an object is present on the

roadway and approaches it at a suitable distance, while considering the existing natural illumination conditions.

9. Using the Talisman Algorithm to Manage Street Lights

Figure (9) depicts the operational process of the TALISMaN algorithm as a vehicle traverses a unidirectional street.

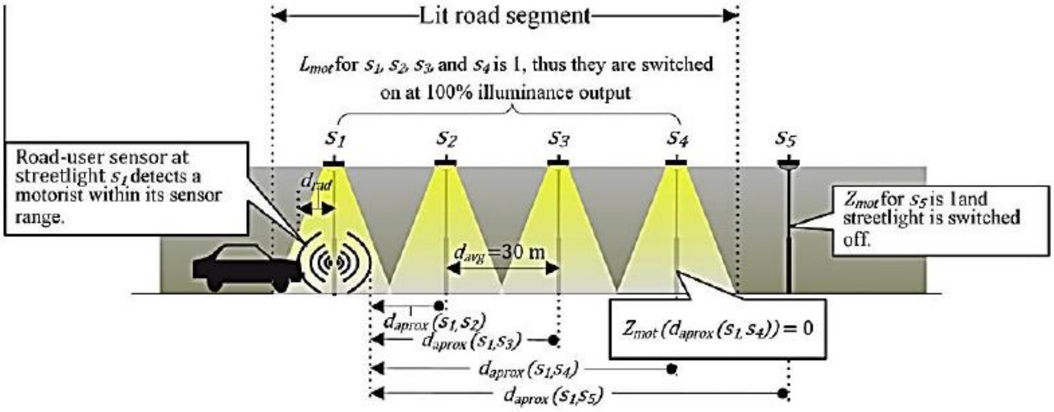

Fig 9: TALiSMaN algorithm-powered LED lighting [40].

Regarding the TALiSMaN algorithm, take note that there are three scenarios in which the lamp may illuminate. There are three possible reasons for the sensor to detect an object: As shown in Figure (10), there is either an object close to the lamp next to it, or an object nearby, or there is a deliberate time delay of a few seconds after the object has vanished.

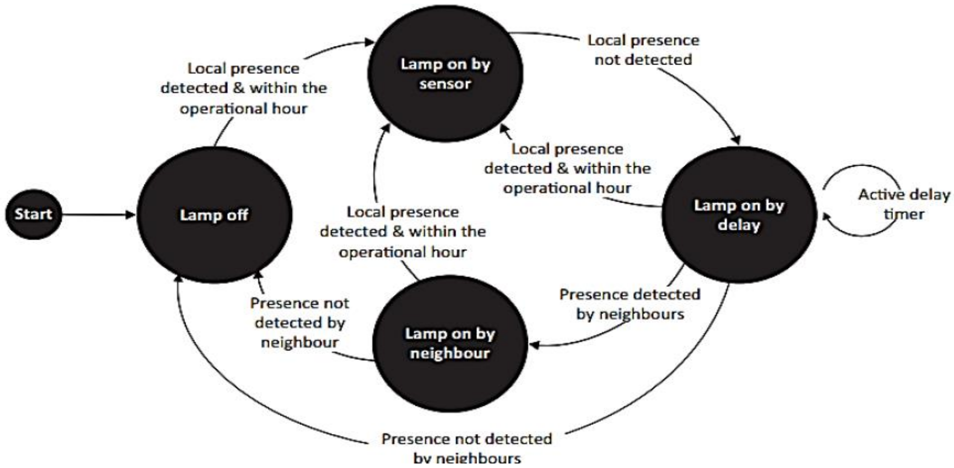

Fig 10: Case diagram of a luminaire governed by the TALiSMaN algorithm [40].

10. Discussion and Results

By modifying particular parameters in the environment of the proposed system, it is possible to produce an assortment of simulation scenarios. Varying vehicle speeds were implemented in the third and final test scenarios, while various street lengths and vehicle counts were utilized in the first and second scenarios, respectively.

Scenario 1: Variations in Street Lengths

The simulation function processes a designated test scenario, which serves as an input for the defined parameters. The function outputs the energy savings percentage achieved by the fuzzy controller, the on-off controller, and the TALiSMaN algorithm.

Figure (11) illustrates the energy conservation achieved by employing the fuzzy controller in comparison to the on-off controller. It also demonstrates the energy savings achieved by utilizing the fuzzy controller in comparison to the TALiSMaN algorithm.

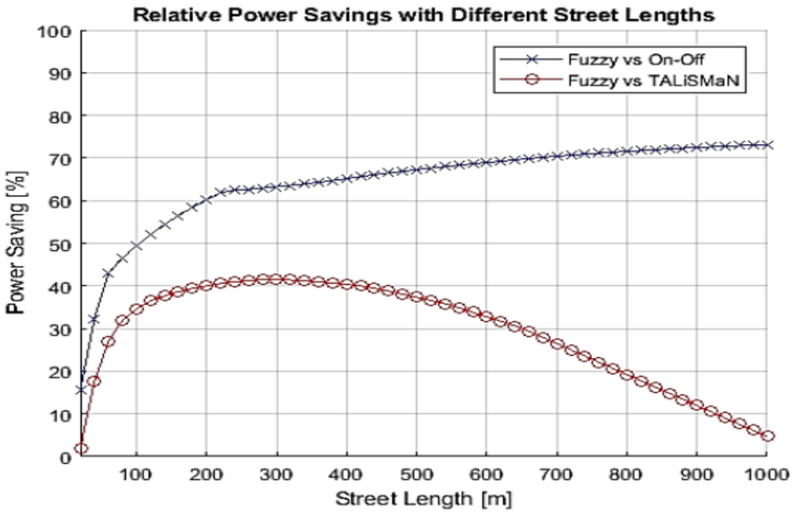

Fig (11): Fuzzy controller energy savings vs. other approaches.

Scenario 2: The Situation Involving Varying Vehicle Numbers

If there are only a few passing vehiclesthe savings percentage will be negative, suggesting that the recommended fuzzy controller performs worse than the other two controllers. This is because the fuzzy controller consistently activates the lights, even at nighttime, albeit at a low intensity. However, when the number of passing vehicles on the street increases, the preference shifts towards the fuzzy controller, as depicted in Figure (12).

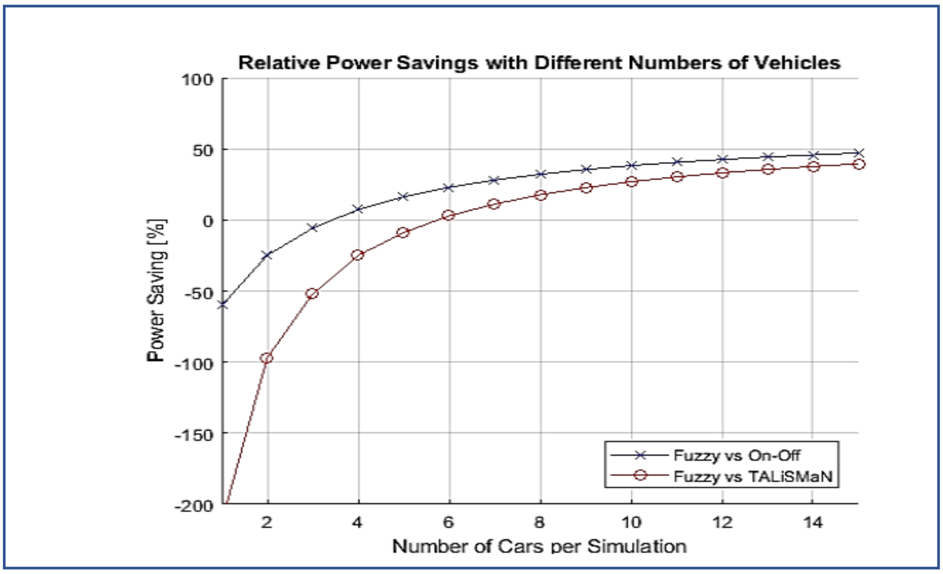

Fig (12): Fuzzy controller energy savings against other control approaches with varied vehicle counts.

Scenario 3: The Situation with Various Vehicle Numbers

This scenario demonstrates a direct correlation between the increase in speed and the corresponding increase in savings percentage for all controllers. Upon comparing the fuzzy controller with other controllers, as depicted in Figure (13), it is evident that the values remain in close proximity as the speed of the vehicles increases.

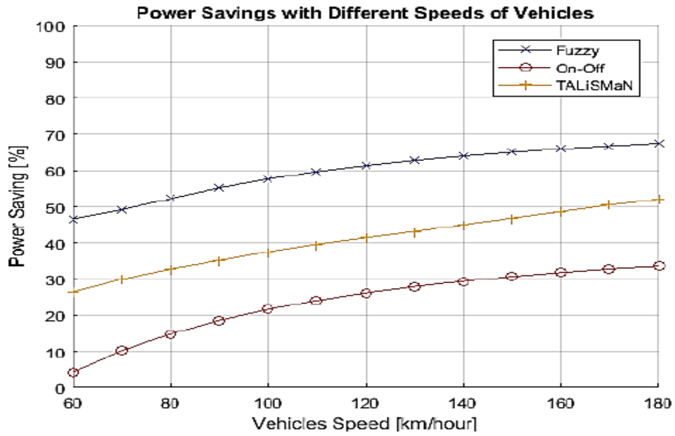

Fig 12: Displays the Proportion of Energy Saved while Employing Various Control Strategies at Different Vehicle Speeds.

11. Conclusion

The design of the street lighting control system for the smart city utilized fuzzy logic, which relied on a range of deduction methods. Upon comparing the simulation results, it was determined that the fuzzy controller outperforms other alternative controllers in terms of energy savings. This is attributed to the utilization of inference mechanisms for efficient decision-making.

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