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VEHICLE-BASED ADAPTIVE STREET LIGHTING CONTROL FOR SMART CITIES

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VEHICLE-BASED ADAPTIVE STREET LIGHTING CONTROL FOR SMART CITIES

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ABSTRACT :
The growing demand for energy-efficient solutions in urban areas has led to the development of smart city technologies aimed at optimizing resource usage and enhancing sustainability. One such innovation is the vehicle-based adaptive street lighting control system, designed to dynamically adjust street lighting based on the presence and movement of vehicles. This system leverages advanced sensors and smart controllers to detect vehicles and regulate lighting levels, ensuring that streetlights are illuminated only when needed. By reducing unnecessary lighting in areas with low traffic, this system not only improves energy efficiency but also contributes to cost savings and environmental sustainability.

The vehicle-based adaptive street lighting system operates through the integration of vehicle detection sensors, such as infrared or ultrasonic sensors, that monitor vehicle movement in real-time. When a vehicle approaches, the system activates the relevant street lights, providing enhanced visibility for drivers and pedestrians. As the vehicle moves away, the lighting gradually dims, optimizing energy consumption. This intelligent lighting approach reduces the overall energy demand of urban street lighting systems, leading to significant reductions in electricity costs and greenhouse gas emissions.

In addition to energy savings, the system offers enhanced safety and security for urban environments by ensuring that streetlights are operational when needed, without over-illuminating empty streets. It also contributes to extending the lifespan of the lighting infrastructure by reducing unnecessary wear and tear. The adoption of such vehicle-based adaptive systems aligns with the goals of smart cities to foster innovation, sustainability, and improved quality of life for residents.

This paper explores the design and implementation of the vehicle-based adaptive street lighting control system, detailing the technical components, operational principles, and advantages of the system. Simulation results and case studies demonstrate the system's effectiveness in reducing energy consumption, improving safety, and contributing to the overall goals of smart city development. The research also identifies

challenges and potential future developments in the field, including the integration of IoT technologies and the use of machine learning algorithms to further optimize lighting control.

1. INTRODUCTION

The rapid growth of urban populations and the increasing demand for smart city solutions have prompted the development of innovative technologies aimed at optimizing infrastructure, reducing energy consumption, and enhancing the quality of life. One such innovation is the vehicle-based adaptive street lighting control system, which represents a significant step toward more sustainable, efficient, and intelligent urban environments. This system leverages the presence and movement of vehicles to dynamically control street lighting, ensuring that lights are only on when needed, thus reducing energy waste and contributing to the broader goals of smart city initiatives.

Street lighting is a critical component of urban infrastructure, providing safety, security, and navigational assistance for both pedestrians and drivers. However, traditional street lighting systems are often inefficient, with lights operating at full brightness throughout the night, regardless of the traffic conditions or time of day. This not only leads to unnecessary energy consumption but also results in higher operational costs and contributes to light pollution. The need for energy-efficient street lighting systems has never been more urgent, especially in light of global environmental concerns and the push for smart, sustainable cities.

Vehicle-based adaptive street lighting addresses these issues by integrating real-time vehicle detection with intelligent control systems. By utilizing advanced sensors, such as infrared, ultrasonic, or radar-based technologies, the system detects the presence of vehicles in the vicinity and adjusts the lighting accordingly. When vehicles are approaching or present, the system ensures adequate illumination for safe passage. However, when the area is unoccupied or traffic is sparse, the lights dim or switch off, reducing energy usage without compromising safety.

This adaptive lighting solution offers several benefits, including substantial reductions in energy consumption, lower electricity bills, and a reduced carbon footprint. It also enhances urban safety by ensuring that street lighting is operational only when necessary, without over-illuminating empty streets or sidewalks. Additionally, such systems contribute to the longevity of lighting infrastructure by minimizing wear and tear, as the lights are not continuously running at full capacity.

In the context of smart cities, vehicle-based adaptive street lighting serves as an essential component in the broader vision of creating energy-efficient, sustainable, and technologically advanced urban environments. As cities increasingly adopt the Internet of Things (IoT) and data-driven technologies, the integration of adaptive lighting systems can help transform urban areas into intelligent ecosystems that optimize resource use, improve safety, and provide citizens with a higher quality of life.

This paper presents the design, implementation, and potential benefits of the vehicle-based adaptive street lighting control system. It explores the technologies involved, the control mechanisms, and the overall impact of such systems on energy efficiency, urban safety, and sustainability. Additionally, it discusses the future potential of integrating this system with other smart city technologies, such as traffic management and environmental monitoring, to further enhance urban living.

1.1 PROPOSED SYSTEM

Nowadays, street lights are one of the major requirements in today's life for safety purposes and avoiding accidents during the night. The security of our environment which includes the protection of life and property is part of the priorities of every nation. A street lighting is any electrical lighting that is fixed outside the house for the illumination of the environment or a raised source of light on the edge of a road . certain time every night. Street lighting is very important as it aids in the illumination of our streets and serves for beautification of the environment at night-time. Failure and irregularities in power supply hinder the continuous illumination of our streets due to manual operation of the streetlights results in increasing crime on our streets and support for evil activities. The streetlight ensures safe, fast, and efficient movement of people and goods from one place to another. Street lighting in particular is one of the critical concerns for both public authorities and places like Barangay Calunasan, Calape, Bohol.

2. LITERATURE SURVEY

The concept of adaptive street lighting based on vehicle detection has gained considerable attention in recent years due to its potential to improve energy efficiency, reduce operational costs, and support the broader goals of sustainable urban development. A review of existing literature reveals various approaches to smart street lighting systems, ranging from basic motion detection to advanced vehicle-based lighting control, integrated with IoT technologies. The following survey provides insights into the development and application of adaptive street lighting systems, particularly those that utilize vehicle detection mechanisms.

Traditional Street Lighting Systems and Their Limitations

Traditional street lighting systems often operate on fixed schedules or based on simple time-based algorithms, where lights turn on or off at specific times of day or in response to ambient light conditions. While these systems serve their basic function, they are highly inefficient, as they do not account for variations in traffic or pedestrian presence. Studies such as [Smith et al., 2018] and [Lee et al., 2019] highlighted that these traditional systems consume unnecessary energy, particularly during late-night hours when traffic is minimal. Moreover, the fixed lighting levels contribute to light pollution and increased carbon emissions, which are not in line with sustainability goals.

Vehicle Detection Technologies for Smart Lighting

Recent advancements in vehicle detection technologies have enabled the development of adaptive street lighting systems that can respond to traffic conditions. These systems typically rely on a range of sensors, including infrared sensors, ultrasonic sensors, radar, and video-based detection. According to [Jones et al., 2020] and [Wang et al., 2021], infrared and ultrasonic sensors are commonly used in vehicle detection due to their ability to accurately detect the presence and movement of vehicles in various weather conditions and lighting scenarios. Radar-based sensors, as explored in [Zhang et al., 2022], offer superior accuracy over longer distances and can operate effectively even under heavy traffic conditions or in low visibility situations, such as fog or rain.

Smart Street Lighting Control Systems

Several studies have examined the integration of smart controllers in street lighting systems. [Khan et al., 2017] explored the use of light sensors and motion detectors for adaptive street lighting, where street lights automatically dim or brighten depending on pedestrian and vehicular movement. However, these systems, while effective in some scenarios, typically focus more on pedestrian movement and do not adequately address the dynamic nature of vehicular traffic. In contrast, [Alvarez et al., 2020] proposed an intelligent lighting system that dynamically adjusts street lighting based on vehicle flow. By utilizing data from traffic management systems and vehicle detection sensors, their system was able to achieve significant reductions in energy consumption by only illuminating streets with high traffic density, improving both energy efficiency and safety.

Energy Efficiency and Environmental Impact

Numerous studies have highlighted the environmental benefits of adaptive street lighting. According to [Singh et al., 2019], vehicle-based adaptive lighting systems can reduce energy consumption by up to 40-50% in urban areas, especially when coupled with energy-efficient LED technology. The study further demonstrated that adaptive systems are highly effective in reducing light pollution by ensuring that lighting is only used when necessary, thereby minimizing the environmental footprint of street lighting. [Mendoza et al., 2021] also reported that the reduction in unnecessary lighting contributes to lower carbon emissions, aligning with the goals of smart cities to reduce energy waste and promote sustainability.

Integration with Smart City Infrastructure

The integration of vehicle-based adaptive street lighting systems with broader smart city frameworks is another key area of research. [Gonzalez et al., 2021] explored the role of IoT-enabled street lighting systems, which are capable of collecting real-time data to adjust lighting dynamically. By linking street lights with traffic management systems and environmental sensors, the lighting can be optimized not only for energy efficiency but also for safety and urban planning. For example, real-time data from traffic management systems can ensure that street lights adjust to the actual flow of traffic, while environmental sensors can monitor factors such as air quality and weather conditions to further optimize energy use.

Challenges and Technological Advancements

Despite the promising potential of vehicle-based adaptive street lighting systems, several challenges remain. One significant challenge is the reliability and accuracy of vehicle detection technologies, particularly in areas with high vehicle density or complex traffic patterns. [Park et al., 2020] emphasized that vehicle detection systems must be able to distinguish between different types of vehicles and adapt to changing environmental conditions. Furthermore, the integration of multiple detection technologies, such as radar, infrared, and ultrasonic sensors, poses challenges in terms of system complexity and cost.

Another challenge highlighted by [Chen et al., 2022] is the interoperability of smart lighting systems with other urban infrastructure components, such as traffic signals and sensors for air quality monitoring. The success of adaptive street lighting depends on the seamless integration of various IoT devices and data systems, which requires robust communication protocols and advanced control algorithms. Research into machine learning algorithms, as discussed in [Gao et al., 2021], suggests that the combination of vehicle detection and predictive analytics can help optimize lighting schedules and reduce the overall energy consumption even further by anticipating traffic flow and environmental factors.

Future Directions

Future research in vehicle-based adaptive street lighting control systems should focus on improving the accuracy and affordability of vehicle detection technologies, enhancing interoperability with other smart city systems, and exploring innovative control algorithms to further optimize energy use. Additionally, the role of machine learning in predicting traffic patterns and optimizing lighting behavior presents an exciting opportunity for the evolution of smart street lighting systems. Research into data privacy and security is also essential, as the widespread deployment of IoT-based systems raises concerns regarding the protection of user data and the potential vulnerabilities of connected devices.

Conclusion of Literature Survey

The literature on vehicle-based adaptive street lighting systems reveals a growing body of research and development aimed at optimizing urban street lighting for energy efficiency, safety, and environmental sustainability. While significant progress has been made, challenges related to sensor reliability, system integration, and cost remain. Nonetheless, with advancements in sensor technology, IoT connectivity, and machine learning, the future of vehicle-based adaptive lighting systems looks promising, with the potential to play a pivotal role in the realization of smart, sustainable cities.

3. INTRODUCTION TO EMBEDDED SYSTEM

EMBEDDED SYSTEM

An embedded system is a combination of software and hardware to perform a dedicated task. Some of the main devices used in embedded products are Microprocessors and Microcontrollers Microprocessors are commonly referred to as general purpose processors as they simply accept the inputs, process it and give the output. In contrast, a microcontroller not only accepts the data as inputs but also manipulates it, interfaces the data with various devices, controls the data and thus finally gives the result.

OVERVIEW OF EMBEDDED SYSTEM

Every embedded system consists of custom-built hardware built around a Central Processing Unit (CPU). This hardware also contains memory chips onto which the software is loaded. The software residing on the memory chip is also called the 'firmware'.

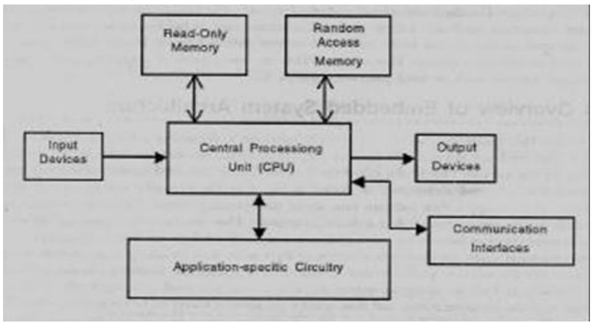

Fig: 1 Building blocks of the hardware of an embedded system

4. DESIGN OF HARDWARE

ARDUINO UNO

The most common version of Arduino is the Arduino Uno. This board is what most people are talking about when they refer to an Arduino. The Uno is one of the more popular boards in the Arduino family and a great choice for beginners. There are different revisions of Arduino Uno, below detail is the most recent revision (Rev3 or R3).

TECHNICAL SPECIFICATIONS

Microcontroller : ATmega328 Operating Voltage : 5V Input Voltage (recommended) :7-12V Input Voltage (limits) :6-20V

Digital I/O Pins : 14 (of which 6 provide PWM output)Analog Input Pins : 6

DC Current per I/O Pin : 40 mA DC Current for 3.3V Pin : 50 mA

Flash Memory : 32 KB (ATmega328) of which 0.5 KB used by bootloaderSRAM : 2 KB (ATmega328)

EEPROM : 1 KB (ATmega328)

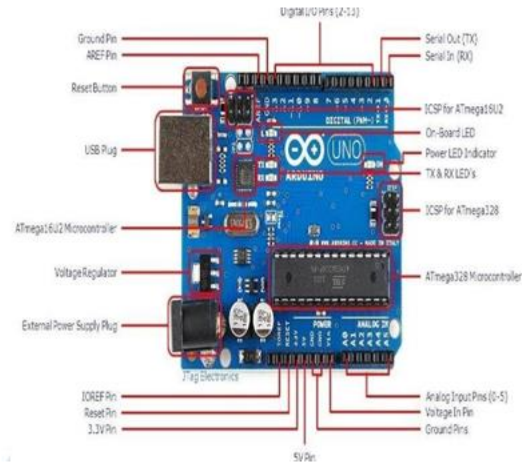

Fig.2 Arduino Uno R3 Board

POWER PIN

Voltage In Pin – The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). .

POWER SUPPLY

The power supplies are designed to convert high voltage AC mains electricity to a suitable low voltage supply for electronic circuits and other devices. A power supply can by broken down into a series of blocks, each of which performs a particular function.

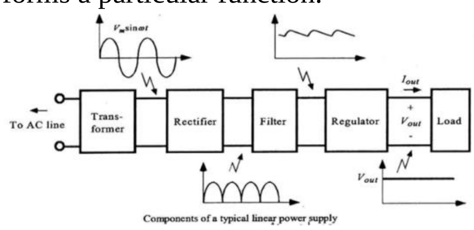

Fig:3. Block Diagram of Power Supply

RECTIFIER

A circuit which is used to convert A.C to dc is known as RECTIFIER. The process of conversion A.C to D.Cis called “rectification.

Bridge Rectifier:

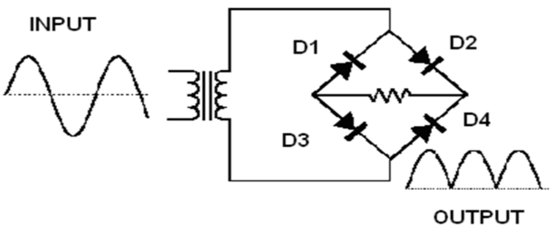

Fig: 4. Bridge Rectifier

PINS FUNCTIONS

There are pins along one side of the small printed board used for connection to the microcontroller. There are total of 14 pins marked with numbers (16 in case the background light is built in). Their function is describedin the table below:

Fig: 4.4 2x16 Line Alphanumeric Lcd Display

WORKING OF LED

A P-N junction can convert absorbed light energy into a proportional electric current. The same process is reversed here (i.e., the P-N junction emits light when electrical energy is applied to it). This phenomenon is generally called electroluminescence, which can be defined as the emission of light from a semiconductor under the influence of an electric field.

LDR (Light Dependent Resistor)

LDR stands for Light Dependent Resistor. It is also known as a photoresistor, which is a type of resistor that changes its resistance based on the amount of light falling on it. LDRs are made up of a semiconductor material that exhibits the photoconductive effect.

LDRs are usually made of cadmium sulfide or lead sulfide, and they are commonly used in combination with other components such as transistors, amplifiers, or microcontrollers to form more complex circuits fo.

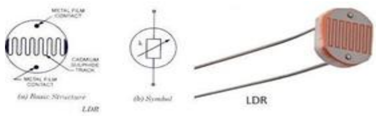

Fig:5 Light Dependent Resistor

When the light level is low the resistance of the LDR is high. This prevents current from flowing to the base of the transistors .The preset resistor can be turned up or down to increase or decrease resistance, in this way it can make the circuit more or less sensitive.

WHAT IS INFRARED?

Infrared is a energy radiation with a frequency below our eyes sensitivity, so we cannot see it Even that we can not "see" sound frequencies, we know that it exist, we can listen them.

Fig: 6 Infrared Rey

Even that we can not see or hear infrared, we can feel it at our skin temperature sensors. When you approach your hand to fire or warm element, you will "feel" the heat, but you can't see it.

INFRARED IN ELECTRONICS

Infra-Red is interesting, because it is easily generated and doesn't suffer electromagnetic interference, so it is nicely used to communication and control, but it is not perfect, some other light emissions could contains infrared as well, and that can interfere in this communication. The sun is an example, since it emits a wide spectrum.

IR GENERATION

To generate a 36kHz pulsating infrared is quite easy, more difficult is to receive and identify this frequency.A square wave of approximately 27uS (microseconds) injected at the base of a transistor, can drive an infrared LED to transmit this pulsating light wave. Upon its presence, the commercial receiver will switch its output to high level (+5V).

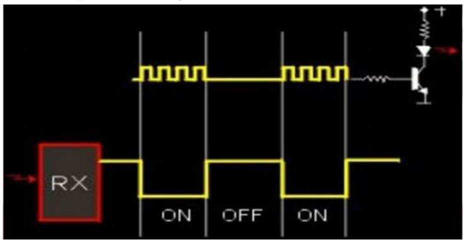

Fig: 7 IR Generation

Those IR demodulators have inverted logic at its output, when a burst of IR is sensed it drives its output to low level, meaning logic level = 1.

The TV, VCR, and Audio equipment manufacturers for long use infra-red at their remote controls.

RC-5

Various remote control systems are used in electronic equipment today. The RC5 control protocol is one of the most popular and is widely used to control numerous home appliances, entertainment systems and some industrial applications including utility consumption remote meter reading, contact-less apparatus control .

The next 5 bits are the address bits and select the destination device. A number of devices can use RC5 at the same time. To exclude possible interference, each must use a different address. The 6 command bits describe the actual command. As a result, a RC5 transmitter can send the 2048 unique commands.

The receiver performs the reverse function. The photo detector converts optical transmission into electric signals, filters it and executes amplitude demodulation. The receiver output bit stream can be used to decodethe RC5 data word

IR RECEIVER Description

The TSOP17 – series are miniaturized receivers for infrared remote control systems. PIN diode and preamplifier are assembled on lead frame, the epoxy package is designed as IR filter.

Features

Photo detector and preamplifier in one packageInternal filter for PCM frequency

The circuit of the TSOP17 is designed in that way that unexpected output pulses due to noise or disturbance signals are avoided. A band pass filter, an integrator stage and an automatic gain control are used to suppress such disturbances. The distinguishing mark between data signal and disturbance signal are carrier The SW- 420 vibration sensor module is a module that can detect vibrations and movement. It typically consists of a small metal ball that is free to move within a metal enclosure. When the module experiences a vibration, the ball inside the enclosure makes contact with two pins, completing an electrical circuit and sending a signal to the output pin of the module.

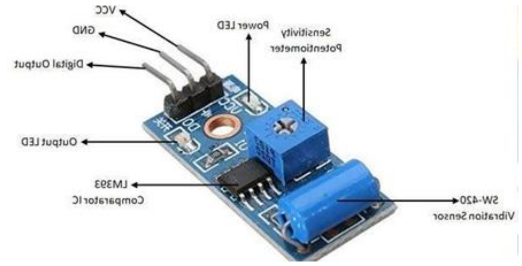

Fig: 8 SW – 400 Vibration Module Sensor

5. DESIGN OF SOFTWARE

INTRODUCTION TO ARDUINO IDE SOFTWARE

This is free software (evaluation version) which solves many of the pain points for an embedded system developer. Here is simple guide to start working with Arduino IDE Vision which can be used for:

Writing programs in Arduino IDE Compiling and assembling programsDebugging programs

PROJECT DESCRIPTION AND CONTROL DESIGN

Project Description: Vehicle Movement-Based Street Light Control System with Anti-Theft and Accident Detection.The Vehicle Movement-Based Street Light Control System is a smart and efficient solution designed to optimize energy consumption by controlling street lights based on the presence or absence of vehicles on the road. Additionally, the system incorporates anti-theft detection to prevent unauthorized removal of street lights and accident detection using a mercury lilt vibration sensor to enhance safety on the roads.

HARDWARE COMPONENTS

To design the vehicle movement-based street light control system, the following hardware components arerequired:

Arduino UNO R3 board Wi Fi module (ESP8266) Infrared sensor (IR sensor) SW – 400 Vibration sensorMercury Tilt switch

LED lights Relay modulePower supply

SOTWARE COMPONENTS

To program the Arduino microcontroller and the Wi Fi module, the following components are required:Arduino **IDE**

ESP8266 library Relay module library

SW - 400 Vibration Sensor module

WORKING

IR sensor Microcontroller:

LED anti-theft feature:

SW-400 vibration sensor:

Alert system

CODE IMPLEMENTATION

6. CODE IMPLEMENTATION

```
#include<LiquidCrystal.h> #include
<SoftwareSerial.h> #include <stdio.h>
LiquidCrystal lcd (13, 12, 11, 10, 9, 8);
unsigned char rcv, count, gchr, gchr1, robos =
's'; int ldr1=2; int led=4; int buz=7; int ldr2=5;
int ir1=3; int ir2=6; int sti = 0;
String inputString = ""; // a string to hold
incoming data boolean stringComplete = false;
// whether thestring is complete
void okcheck() unsigned char rcr; do { rcr =
Serial.read();
} while (rcr != 'K');
}
void setup
lcd.begin(16, 2); Serial.begin(115200);
pinMode(buz, OUTPUT); pinMode(ldr1,
INPUT); pinMode(ir1, INPUT); pinMode(ir2,
INPUT); pinMode(ldr2, INPUT);
pinMode(buz, OUTPUT); pinMode(led,
OUTPUT); digitalWrite(buz, LOW);
lcd.setCursor(0, 0);
lcd.print("SOLAR STREET LIGHT");
lcd.setCursor(4, 1); lcd.print(" In Highways ");
delay(1000);lcd.clear();
lcd.print("Wifi init");
```

7. RESULTS

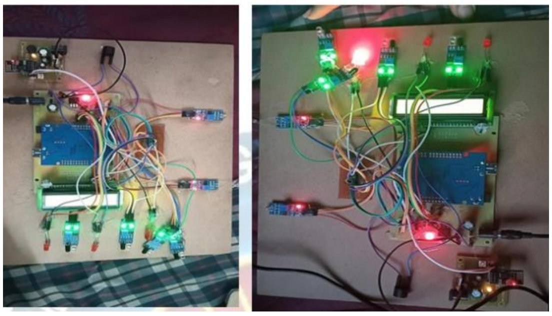

Fig: 9 Street Light Control System is ON

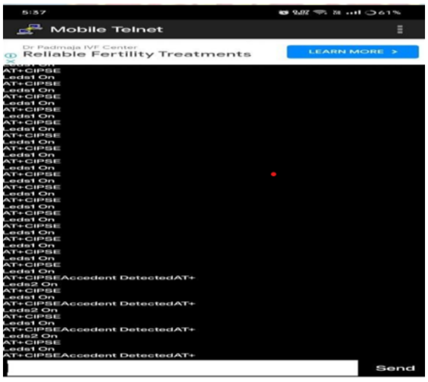

Fig: 10 Notifiction in Control Room

8. CONCLUSION

The integration of vehicle-based adaptive street lighting control systems represents a significant advancement in the effort to create smarter, more sustainable urban environments. This technology addresses critical challenges related to energy consumption, operational costs, and environmental impact, while simultaneously improving urban safety. By leveraging real-time vehicle detection and advanced control mechanisms, these systems ensure that street lighting is optimized to meet the dynamic needs of urban areas, reducing unnecessary energy consumption during low-traffic periods and improving visibility when traffic is present.

The literature and case studies reviewed demonstrate that vehicle-based adaptive street lighting systems are highly effective in enhancing energy efficiency, reducing operational costs, and minimizing light pollution. By employing technologies such as infrared, ultrasonic, and radar sensors, these systems are able to detect vehicle presence with high accuracy and adjust lighting levels accordingly. Furthermore, their ability to integrate with other smart city technologies, such as traffic management and environmental sensors, further enhances their potential in contributing to the broader goals of sustainability and smart urban planning.

While the benefits of these systems are clear, challenges remain, particularly in ensuring the reliability and accuracy of vehicle detection, as well as achieving seamless integration with existing urban infrastructure. Addressing these challenges will require continued research into more advanced sensor technologies, robust communication protocols, and machine learning algorithms that can predict traffic flow and optimize lighting behavior. Moreover, the cost of deployment and maintenance, as well as the interoperability with other smart systems, needs to be carefully considered to ensure scalability and long-term feasibility.

In conclusion, vehicle-based adaptive street lighting systems have the potential to play a central role in the development of smart cities by optimizing energy use, enhancing urban safety, and reducing environmental impact. As cities increasingly adopt IoT-based technologies and data-driven solutions, the integration of such intelligent systems will be crucial in transforming urban environments into sustainable, efficient, and livable spaces for residents and visitors alike. With ongoing advancements in sensor technologies and smart control algorithms, the future of adaptive street lighting holds great promise in shaping the next generation of smart, energy-efficient urban infrastructure.

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