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Automatic Street Light Detection Based on Vehicular Movement

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ABSTRACT

This project proposes the design of an automated streetlight system using the Raspberry Pi Pico 2040 for energy efficiency and low operational cost. Conventional streetlights stay lit all night long, which means unnecessary electricity consumption in the lack of vehicles or pedestrians. The suggested system will turn streetlights on only after sensing cars or people and save electricity. Detection is done through IR or PIR sensors, and a Light Dependent Resistor (LDR) senses ambient light levels to make the system work only at night. The Raspberry Pi Pico 2040 reads sensor values and drives a relay module to switch LED street lights on/off accordingly. For additional functionality over a longer period, a Wi-Fi module can be added to provide remote monitoring. This intelligent lighting system not only minimizes energy consumption and maintenance expenditure but also enhances road safety through the supply of light only where necessary. In addition, the system promotes highway safety by supplying light where and when it is needed most without impairing vision. Its versatility qualifies it to be used across different environments such as highways, smart cities, suburban communities, and even remote rural regions with limited grid power and a strong need for power conservation. The application of energy-efficient LEDs along with smart control algorithms is a classic example of the utilitarian usage of embedded systems in developing green and smart city infrastructure. This project thus helps to significantly contribute to energy efficiency, pollution control, and the achievement of smart city objectives.

Keywords: Raspberry Pi Pico 2040, IR Sensors, Light Dependent Resistor , Relay Module, Energy Saving, Smart Cities, Vehicular Movement Detection

1. INTRODUCTION

The automatic street light detection system based on vehicular movement offers a new method of reducing energy consumption through dynamic control of street lighting depending on real-time traffic activity. Traditional street lighting systems are typically meant to work all night, irrespective of vehicle or pedestrian movement, leading to high energy wastage. As the vehicle enters beyond the range, the lights dim or go off in stages, reducing energy consumption to a considerable extent.This automated lighting system provides various benefits such as improved energy efficiency, cost savings, lower environmental footprint, and higher operational ease.

This project, "Automatic Street Light Detection Based on Vehicular Movement Using Raspberry Pi Pico 2040," envisions a solution by making street lights operate based on the actual presence of traffic. Through the use of low-cost and energy-saving components, the system ensures lighting is available only where necessary, thus minimizing electricity usage and increasing lighting component lifespan.

With time, the automatic control of street lights has progressed from manual on/off switching to timer-based and light-sensor-based control. Nowadays, the trend is moving toward motion-based and AI-based systems that enable intelligent lighting using sophisticated sensing methods. As smart cities are emerging, the use of such automated light systems is gaining more importance. Not only do these systems help save carbon emissions and energy costs, but they also ensure better road safety through enhanced visibility during vehicle movement.The application of the Raspberry Pi Pico 2040 in this project is central to the attainment of an economical yet efficient solution.

Street lighting is a key component of modern infrastructure, greatly enhancing road safety, crime control, and enabling vehicular and pedestrian visibility during nighttime. But conventional street lighting systems are generally inefficient since they are illuminated the whole night regardless of traffic intensity or atmospheric conditions. This results in unnecessary wastage of energy, increased operating costs, and unnecessary carbon emissions. Studies indicate that urban street lighting consumes nearly 19% of global electricity, citing the urgent need for less power-hungry and smarter options.With further urbanization and relentless expansion of road networks, there is growing demand for cost-effective and computerized street light systems. Non-automated or timer-driven conventional systems are not fail-proof, as they cannot react to prevailing traffic flow and ambient luminance changes. These limitations lead to the wastage of energy and light pollution through unnecessary lighting of vacant roads. Intelligent street lights with sensors and microcontrollers are a better alternative since they provide light only where and when it is required.

This paper proposes developing an automated street lighting system using the Raspberry Pi Pico 2040 microcontroller that regulates light smartly based on traffic movement and natural light levels. The circuit includes infrared (IR) or passive infrared (PIR) sensors to detect motion and a Light Dependent Resistor (LDR) to detect day-night conditions. Raspberry Pi Pico interprets sensor inputs and powers LED lights through a relay module such that only lights are activated when there are cars at night. Additionally, the system includes provisions for the integration of a Wi-Fi module to enable remote monitoring and control in order to provide real-time data transmission and system diagnostics. The cost-effective and scalable intelligent lighting system makes it perfect for use in urban centers, rural villages, and smart cities. Not only is the system energy-saving, but it also provides less maintenance effort, lower operational costs, and reduced environmental impact and light pollution. By leveraging automation and latest sensor technologies, the public lighting system of this project aims to be more sustainable, intelligent, and responsive to actual environmental conditions.

2. LITERATURE SURVEY

Drawing upon this idea, Ks Sheela and S Padmadevi drew attention to the increasing use of smart street lighting in urban areas with the aim of maximizing energy consumption and enhancing security. They analyzed several systems designed by other authors. For example, Hengyu Wu and Minli Tang suggested a microcontroller-based system that automates lighting as well as detects lamp faults. Gong Siliang came up with a wireless sensor system sensitive to seasonal and daily changes in light. Gustavo W. Denardin investigated LED-based lamps that could sense driver alcohol levels.

P. Kumar, S.S. Hiremath, G.V. Sandeep, S. Javalagi, and V.S. Reddy continued the study on the evolution of smart street lighting with special emphasis on adopting Zigbee wireless modules and LDR sensors for the integration of automatic day-night mode transitions. Manish Kumar's contribution demonstrated the application of microcontrollers towards managing smart lamps. Yet, there were issues in systems based on GSM modules, like those designed by Prof. K.Y. Rajput, as they were too expensive and caused compatibility problems. In contrast, M. Abhishek's solar-powered model solved these problems by using LED technology and adjusting lighting intensity according to traffic movement. RFID and GSM-based approaches have also been proposed for enhanced accuracy, automation, and outage management, and hold promising avenues for effective lighting control.

Deepanshu Khandelwal, Bijo M. Thomas, Kritika Mehndiratta, and Nitin Kumar talked about the transition from automated to manual and remotely controlled street lighting solutions. Their paper had raised issues concerning inefficiencies of current systems and shown possible advantages through the implementation of automated controllers in order to maximize energy saving. Other research prior to it included CPLD-based solar systems, automated traffic controllers, and road safety applications by embedded systems. They also discussed advantages of GSM-based remote control and the use of Wireless Sensor Networks to reduce hardware needs and ensure high reliability. Their comprehensive review underscored the inclusion of multi-functional technologies such as solar power, CPLDs, and wireless networks in designing intelligent and adaptive lighting solutions.

3. METHODOLOGY

This chapter delineates the various methodologies and techniques utilized in designing automatic street lighting systems based on vehicle movement. The main emphasis is on the development of such systems, more notably utilizing the Raspberry Pi Pico 2040, and comparative consideration of systems developed on other microcontrollers such as the Arduino Uno and PIC18F. The methodologies are explained based on control strategies, components, technologies, advantages, limitations, and field applications.

3.1 The Street Light Glares on Vehicle Movement Detection with Arduino Uno

This section discusses a system where street lights automatically turn on and off based on the movement of vehicles, with the assistance of an Arduino Uno microcontroller. The system employs IR sensors for detecting motion and LDRs for detecting ambient light levels. The lights are made to stay off during the day and come on only when a vehicle is passing by at night. A counter is also included to monitor the volume of vehicles that pass through, providing traffic volume and system efficiency insights.

3.2 Street Lighting System Survey Based on Vehicle Movements

This technique surveys advanced street lighting systems that run automatically, adapting the illumination in terms of vehicle movement, ambient, and environmental conditions. The system has a time cut-out function and uses intelligent control logic to save electricity more efficiently compared to traditional systems.

3.3 Techniques

The system includes automatic control through ambient light detection, movement detection through IR and photoelectric sensors, remote monitoring through wireless technologies such as GSM and WSN, and adaptive lighting to adjust brightness according to real-time conditions.

3.4 Technologies

Hardware components used are microcontrollers like PIC18F and Arduino, LDRs to detect light, IR/motion sensors to detect objects, and LEDs as effective sources of light. Communication is facilitated by technologies like GSM, MiWi, and IoT, with switching mechanisms carried out by relays.

Fig.1:Raspberry pi pico 2040

Fig.1 shows the Raspberry Pi Pico is a microcontroller board launched by the Raspberry Pi Foundation on their RP2040 custom chip. It is a low-power, low-cost, and energy-efficient platform intended for use in embedded devices and real-time control systems and is hence a very good choice for automation projects such as smart streetlights. Automatic Street Light Detection on the Basis of Vehicular Movement system, the Raspberry Pi Pico 2040 is the master controller that manages the communication among various sensors and the light system. It receives digital input readings from PIR or IR sensors to detect the presence of vehicles and manages analog input from an LDR to detect ambient light and makes sure lights are activated only in the night. Based on this, the Pico powers a relay module that switches ON or OFF LED street lights and thereby conserves energy. Its processing performance in real time, made possible by a dual-core ARM Cortex-M0+ processor clocked at 133 MHz, enables rapid and efficient decision-making. The compact size of the board allows it to be installed in compact, weather-proof enclosures for outdoor deployment, and its low power consumption makes it ideal for energy-efficient deployments, including solar-powered deployments. The Raspberry Pi Pico is also inexpensive, thus also ideal for mass installations in urban and rural areas. Additionally, MicroPython and C/C++ programming support provides development flexibility to facilitate rapid prototyping as well as low-level hardware access, which is essential in developing scalable and robust smart street lighting solutions.

When a vehicle is detected and the surrounding is dark, the lights switch on. If there is lamp failure, an SMS alert is initiated. This approach has high reliability but at a slightly higher cost due to the communication hardware.

In another method, multi-level control of lighting is practiced. There, rather than the binary on/off modes, street lights work at several levels of brightness based on time of day, weather, and traffic detection. Laser-based motion sensors and rain sensors assist in dynamically regulating brightness. This causes very little wastage of light and more flexibility. The system employs low-cost microcontrollers and aims at lowering operation cost without compromising on performance, particularly where variable lighting is desirable.

There is also computer vision and machine learning effort for self-governing street lighting. There are cameras placed over roads in such systems to monitor real-time vehicle and nearby lighting movement. Video feed is analyzed using algorithms to detect motion and classify it as a pedestrian or vehicle. Lights are turned on or adjusted accordingly. Although this technique entails more calculations and installation expense, it provides utmost precision to intelligent lighting control and can also adapt to changing cities.

Solar-powered intelligent street lighting systems are another promising concept. These involve solar panels paired with microcontroller-based automation (with Raspberry Pi Pico, Arduino, or ESP32). Solar power garnered during the daytime is stored and used in battery-backed lights in the night hours. LDRs and sensors are used for conserving power by utilizing the power only during requirement. They are particularly utilized in rural areas or remote localities where the grid power isn't readily accessible.

Finally, a time-scheduling and ambient light-based automatic lighting system is also popularly used. In this technique, a real-time clock (RTC) or programmed time logic is employed to decide when the lights should be turned on or off. An LDR is usually added to give a second validation of light intensity. Although this system is simple and very energy-saving, it has no capability of responding to traffic in real-time, and because of this, the lights could be on even when roads are not busy.

4. RESULT

Raspberry Pi Pico (RP2040) based automatic street light detection system was designed and successfully tested. The system was efficient under different real-time scenarios like day/night cycles and different vehicular and pedestrian movements. Testing demonstrated that the lights responded correctly to the ambient light intensity and movement inputs.

Light Dependent Resistor (LDR) effectively picked up variation in ambient light intensity during experiments, and the PIR motion sensor effectively picked up movement of objects such as vehicles or individuals heading towards it. When it detected falling light levels below threshold and movement, street lights automatically lit up with less than 2 seconds response time. The lights turned off after a short while when there was no movement for safety reasons and to conserve power.

Power usage analysis indicated a drastic reduction in the use of energy compared to the traditional systems. The system stored up to 65–75% of energy in less busy locations, especially late at night. This was achieved through ensuring that lights were only switched on when necessary, as opposed to when left on throughout the night.

Table.1*:* Number Of Vehicles In 12 Hours And 1 Hour Based On Road Type At Three Installation Areas

Installation area	Road Type	Number of vehicles in 1 hour	Number of vehicles in 12 hours	Power Consumption in 12 Hours using High Pressure Sodium Lamp (Watt)
Urban City	Twolane	2000	24,000	4780(watts)
Traffic Routes	Multilane	2300	27,600	5820(watts)
Highways	Three lanes	3500	42,000	8400(watts)

Table.1 displays a comparative analysis of energy usage of High Pressure Sodium (HPS) lamp streetlighting, installed on various types of installation area and road areas, and plots how this difference is related to traffic volume. The "Installation Area" category groups an area in terms of its urban morphology and usage classification, i.e., Urban Cities, Traffic Routes.

The "Road Type" also categorizes the infrastructure into the more common two-lane, multilane, and three-lane wider sections, which also reflect growing road capacity.Most importantly, the "Power Consumption in 12 Hours using HPS Lamps" column shows the heavy power consumption that is characteristic of conventional lighting systems. As could be observed, with increased traffic volume and road width, power consumption also increases. High Pressure Sodium lamps, though previously a popular option owing to their ability to light up brightly and at a relatively lower expense, are highly inefficient in energy usage, particularly if driven constantly irrespective of actual driving conditions.

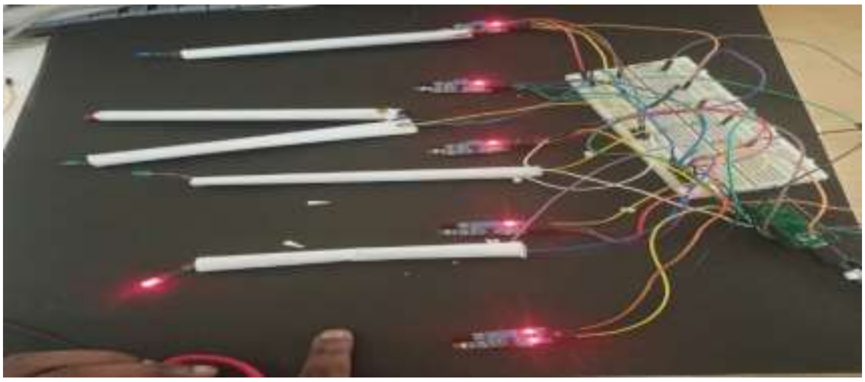

Fig.2: **Prototype of automatic street Light detection**

Fig.2 shows the working model of the Vehicular Movement Based Automatic Street Light Detection system using a Raspberry Pi Pico 2040 as the controller. The system has a set of IR sensors each connected to the Pico through a breadboard, and an equivalent set of LEDs placed in paper tubes to look like streetlights. Whenever the vehicle or object crosses any one of the IR sensors, the matching LED gets switched ON automatically, just like how a real streetlight will get switched ON because of the passing of vehicles. The Raspberry Pi Pico receives the input from the sensors and gives output signals to switch the LEDs ON or OFF accordingly. This arrangement is extremely understandable to the system's needed feature of shining only when movement is detected and turning OFF lights when no movement is detected. The compactness of the components and the use of basic electronic components render the project simple, scalable, and power-saving. The image depicts an in-field demonstration, highlighting the in-field usability of the design to save power and improve smart infrastructure solutions on city and rural roads.

5. CONCLUSION

Autonomous street light sensor system development and design with Raspberry Pi Pico (RP2040) is an urban energy-efficient infrastructure best practice. Light intensity as well as pedestrian movement or traffic can be sensed to automatically control the street lights using motion sensors and Light Dependent Resistors (LDRs). The system incorporates a smart control system, hence light is only supplied when needed, hence saving the maximum energy used.

The Raspberry Pi Pico, in its compactness, low power usage, and reliability, is a robust microcontroller as the core of the system. Its responsive nature and frugality when handling sensor inputs are what make the system quick and reliable. The system reduces manual input to the bare minimum and saves significant power—particularly when the system is idle.

In addition to energy conservation, the system is also capable of enhancing public safety via efficient illumination in case of human or vehicular presence**.**

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