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Microcontroller Based Wireless Communication System Design for Smart Streetlights

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Abstract

Street lighting accounts for a large part of the total energy consumption in cities. This study focused on reducing energy consumption in light-emitting diode (LED) street lighting and detecting defective LED streetlights. For this purpose, a microcontroller-based wireless communication system has been designed for smart LED streetlights. In the designed system, the light intensity of the LED streetlight, the air temperature and humidity, and the number of movements around the streetlight were observed. The developed module consists of an embedded system in which the observed values are analyzed, and the brightness of the LED luminaire is controlled according to the output. The microcontroller used in the embedded system is programmed with the C programming language to enable the communication of the sensors and data transmission. A human-machine interface has been developed for observing the measured values. Long-range (LoRa) technology is used to transfer the data received from the sensors to the computer environment. LoRa technology consists of an end device, gateway, server (Chirpstack), and human-machine interface. After sunset, the motion sensor was activated and the number of environmental movements was detected. The environment was described as crowded or secluded according to the number of detected movements. The brightness of the LED streetlight was determined automatically after midnight according to the ambient conditions. The effects of the developed system on energy consumption were analyzed, and the results were presented.

Keywords: LoRa, Microcontroller, Fault detection, Energy saving, Smart streetlight.

Akıllı Sokak Lambaları için Mikrodenetleyici Tabanlı Kablosuz Haberleşme Sistemi Tasarımı

Öz

Sokak aydınlatması şehirlerdeki toplam enerji tüketiminin büyük bir kısmını oluşturmaktadır. Bu çalışma, ışık yayan diyot (LED) sokak aydınlatmasında enerji tüketimini azaltmaya ve arızalı LED sokak lambalarını tespit etmeye odaklanmıştır. Bu amaçla akıllı LED sokak lambaları için mikrodenetleyici tabanlı kablosuz iletişim sistemi tasarlanmıştır. Tasarlanan sistemde LED sokak lambasının ışık şiddeti, hava sıcaklığı ve nemi ile sokak lambasının etrafındaki hareket sayısı gözlemlenmiştir. Geliştirilen modül, gözlenen değerlerin analiz edildiği ve çıkışa göre LED armatürün parlaklığının kontrol edildiği gömülü bir sistemden oluşmuştur. Gömülü sistemde kullanılan mikrodenetleyici, sensörlerin iletişimini ve veri iletimini sağlamak için C programlama dili ile

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programlanmıştır. Ölçülen değerlerin gözlemlenmesi için bir insan-makine arayüzü geliştirilmiştir. Sensörlerden gelen verileri bilgisayar ortamına aktarmak için uzun menzilli (LoRa) teknolojisi kullanılmıştır. LoRa teknolojisi, bir uç cihaz, ağ geçidi, sunucu (Chirpstack) ve insan-makine arayüzünden oluşur. Gün batımından sonra hareket sensörü devreye girmiştir ve ortam hareketlerinin sayısı tespit edilmiştir. Tespit edilen hareket sayısına göre ortam kalabalık veya tenha olarak tanımlanmıştır. LED sokak lambasının parlaklığı, ortam koşullarına göre gece yarısından sonra otomatik olarak belirlenmiştir. Geliştirilen sistemin enerji tüketimi üzerindeki etkileri analiz edilmiş ve sonuçlar sunulmuştur.

Anahtar Kelimeler: LoRa, Mikroişlemci, Hata tespiti, Enerji tasarrufu, Akıllı sokak lambası.

1. Introduction

Electrical energy consumption is overgrowing with population growth and urbanization (Satterthwaite, 2009). The increase in energy consumption brings with it types such as environmental, noise, and light pollution (Gallaway, Olsen, & Mitchell, 2010). Reasons for light pollution; are street lighting, vehicle lighting, and lighting made to decorate parks and gardens (Korkmazer et al., 2019). Street lighting illuminates the environment at night, increases the viewing distance, creates a sense of trust, and decorates the environment (Douglas & Douglas, 2004). However, unconscious and excessive lighting negatively affects nature and electrical energy consumption (Abdou, 1997). Street lighting can be divided into classical and light-emitting diode (LED) lighting (Lagorse, Paire, & Miraoui, 2009). In classical lighting, the preferred luminaire type is sodium vapor street luminaire (Rustemli & Demir, 2021). The sodium vapor streetlight is monochrome, relative to the color visible during the day, and shows objects as shaded black (Owens & Lewis, 2018). Besides, sodium vapor fixtures require warm-up time (Peck, Ashburner, & Schratz, 2011). Sodium vapor fixtures cannot operate at full power during the warm-up period and glow pink/red (Xie et al., 2011). Sodium vapor armatures have a life of 9000 - 12000 hours (Sanford, 2004). With the emergence of LED street fixtures, sodium vapor fixtures are no longer preferred (Minnaar et al., 2015). LED technology has high energy efficiency, low cost, and long life, and therefore it has been used in many interior and exterior lighting areas, especially street lighting (De la Obra et al., 2017). LED luminaires are more advantageous than traditional lighting with their features such as providing the same light power with lower energy, saving a large amount of energy, long-lasting around 50,000 hours without maintenance, and not changing color when the light is dimmed/turned on (Taguchi, 2008). LED street luminaires are available in different colors (Davidovic et al., 2019). In addition to converting street luminaires from sodium vapor to LED luminaires, the adverse effects can be reduced by making systems intelligent (Yoomak et al., 2018). Also, making systems smart increases energy savings and social welfare (Sharma et al., 2021). Intelligent systems realize features such as using electrical energy at the desired level and passivation by adapting to environmental factors at certain times (Goodenough, Abruña, & Buchanan, 2007).

In this study, designed a system to reduce energy consumption by making the LED streetlight smart and detecting faulty streetlights. There are sensors in the system that measure the light intensity, humidity, and temperature of the environment and detect the movement in the environment. These variables are the light-dependent resistor, which measures the light intensity of the LED streetlight, the motion sensor that captures the movement in the environment, and a temperature and humidity sensor that measures the temperature and humidity of the environment. In the designed system, a Long-range wide area network infrastructure was used for data transfer to the server and the processes reaching the processor from the server. Inversely proportional to the number of detected movements, the brightness of the streetlight decreases at specific rates after midnight. The streetlight was not completely turned off to not create a security gap and not disturb the welfare of society. At sunrise, the streetlight is completely turned off. The system checks whether the streetlight is off. If the streetlight is not turned off, the server is informed that it is not turned off. All variables can be monitored with the designed human-machine interface.

The declaration's content is as follows: the equipment used and the communication protocol are mentioned in Section 2. the results obtained in the designed project are given in Section 3. conclusions are presented in Section 4, and future research directions are outlined.

2. Material and Method

The designed system consists of a light-dependent resistor for light-emitting diode (LED) luminaire, temperature and humidity sensor for ambient temperature and humidity, motion sensor for human density, in-plane switching display, and LED street luminaire, power supply, L298N motor driver, and, STM32L053R8 microcontroller. It also consists of a Long-range (LoRa) end device, LoRa gateway, server, and application that enables the system to exchange information, retrieve information such as time and date, display broadcast information, and store sensor data. Voltage control on the L298N is done by pulse width modulation. The workflow diagram of the designed system is given in Fig. 1.

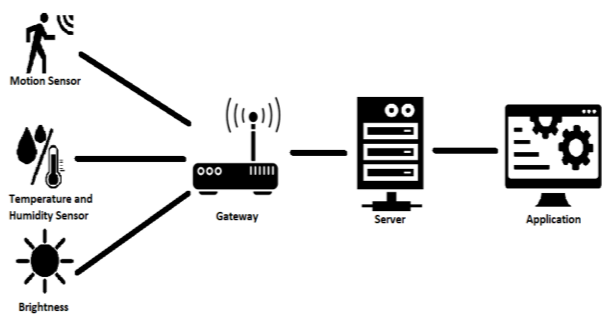

Fig. 1. Workflow Diagram

2.1. Peripheral Units

The designed system uses a light-dependent resistor (LDR) to measure the light intensity emitted by the light-emitting diode (LED) luminaire. The operating temperature range of the LDR is between -30 °C and 70 °C, and it is an analog sensor. A 100nF capacitor is connected in series with the LDR to prevent noise in the measurement. In the proposed work, an analog to digital converter (ADC) system converts analog signals from the temperature sensor to digital signals. The resolution of the ADC is 12 bits. The LDR is calibrated to lux. Thanks to its wide input voltage between 3.5 and 5 volts, it is also used in many applications and industrial projects. LDR is placed in the closest position to the LED luminaire as it is aimed to get maximum efficiency from the operation. The LDR used in the designed system is shown in Fig. 2.

Fig. 2. Light Dependent Resistor (Putri & Aryza, 2018)

In the designed system, the DHT-11 temperature and humidity sensor was used to create a new data set, use it in other studies, and create a more prosperous environment. The sensor is digital output and calibrated. The operating voltage range is between 3.5 and 5 volts. Over and above, the operating temperature is between 0 °C and 50 °C. The sensor uses a single bus format for communication. A communication process is approximately 4 ms. Data transmission is a combination of significant and insignificant bytes, totaling 5 bytes. The temperature and humidity sensor is preferred for anti-interference, fast response, small size, low energy consumption, and signal transmission up to 20 meters. The temperature and humidity sensor used in the designed system is shown in Fig. 3.

Fig. 3. Temperature and Humidity Sensor (Yuen et al., 2018)

Motion module HC-SR501 is used to detect movements around the LED luminaire. The motion module detects motion thanks to its infrared sensor. The module has an adjustable motion detection distance of 3 to 7 meters. The module has a digital output, and how long the result stays high can be adjusted. It gives 3.3 volts. The input voltage is between 5 and 20 V. It is aimed to detect the maximum number of movements by minimizing the duration of the output being high. The motion sensor used in the designed system is shown in Fig. 4.

Fig. 4. Motion Sensor (Shiraki et al., 2021)

The LED luminaire used in the system contains 16 LEDs and has a square structure. It has an operating range of 12 - 24 V. It consumes 48 watts of energy at 100% brightness. It has been used in the recommended system due to its waterproof and long life. The LED luminaire in the designed system is shown in Fig. 5.

Fig. 5. LED Luminaire

In-plane switching (IPS) thin-film transistor (TFT) display module is placed in the system to see the data received from the sensors instantly. The dimensions of the IPS screen used are 13.5 mm x 27.95 mm x 1.5 mm. Its resolution is 80 x 160 pixels. It also communicates with the microcontroller via serial peripheral interface protocol. It is placed inside the box that protects the module, preventing it from being affected by adverse weather conditions. The 0.96" 80x160 IPS TFT display module used in the designed system is shown in Fig. 6.

Fig. 6. 0.96" 80x160 IPS TFT Display Module

STM32L053R8 microcontroller has a 64 KB flash 32-bit ARM cortex M0 core. In this project, the microcontroller Long-range LoRa module will transfer the data and fault information from the motion, LDR temperature, and humidity sensors to the relevant institutions. LDR will use it to control the light level of the system. Unlicensed frequency channels are used in the industrial, scientific medical band (ISM). Otherwise, the radio frequency output power is designed not to exceed the value that can be used without the need for a license. In this way, the cost of the system has been dramatically reduced. This system is used in the ISM band with 868 MHz. It first sends a media access control command to the server when the system boots up. The server sends the system's hour, minute, second, and date information. Time-based transactions are easily performed under the auspices of the time data received from the server. The (a) STM32L053R8 Microcontroller and, (b) SX1276M1MAS LoRa End-Device used in the designed system is shown in Fig. 7.

(a) (b)

Fig. 7. (a) STM32L053R8 Microcontroller and, (b) SX1276M1MAS LoRa End-Device

These devices use wireless, cellular sharing technologies, and TCP/IP protocol to transfer data from LoRa nodes to the server. The LoRa gateway will transfer the data coming from the LoRa communication module connected to the smart streetlight to the server in the proposed system. Additionally, it transmits data from the server to the LoRa end device. The LoRa gateway used in the designed system is shown in Fig. 8.

Fig. 8. LoRa Gateway (Widianto, Pakpahan, & Septiana, 2018)

2.2 Proposed Smart Streetlight System

A motion sensor was used to detect the number of movements around the streetlight from sunset to 00:00. The variable value of the motion sensor increases by one each time it detects motion. When the variable reaches 60, the environment is considered crowded, and the brightness of the light-emitting diode (LED) luminaire remains at 100%. If the amount of motion detected due to the measurement is between 30 and 60, the brightness is 25%, and when less than 30% motion is detected, the brightness decreases by 50%. The brightness ratio remains at 50% when there is no motion. The brightness of the LED luminaire is not turned off completely, as completely turning off the LED luminaire will cause a decrease in environmental safety and an uncertain environment. When the LED luminaire works, its average temperature is 60 °C. Light-dependent resistor (LDR) continuously measures the luminous intensity of the LED street luminaire. When the value received from LDR falls below a specific value, it is understood that the streetlight does not work. The temperature and humidity sensor measures the temperature and humidity of the environment. A liquid-crystal display panel is placed inside the module so that the data received from the sensors can also be seen on the module. The measured temperature and motion data, erroneous or non-defective information, and brightness information are transmitted by radio frequency to the Long-range (LoRa) gateway by the LoRa end device. LoRa gateway has internet access. In this way, the data is transferred to the server. Radio LoRa broadcasts were made every 1 hour. It also informs the relevant institutions by broadcasting when the streetlight does not give light. 868 MHz is broadcast according to European standards. A Long-range wide area network (LoRaWAN) default end node class port is defined as Class C. LoRaWAN adaptive data rate is on. The LoRaWAN activation type is authentication by personalization. The flowchart of the system is given in Fig. 9.

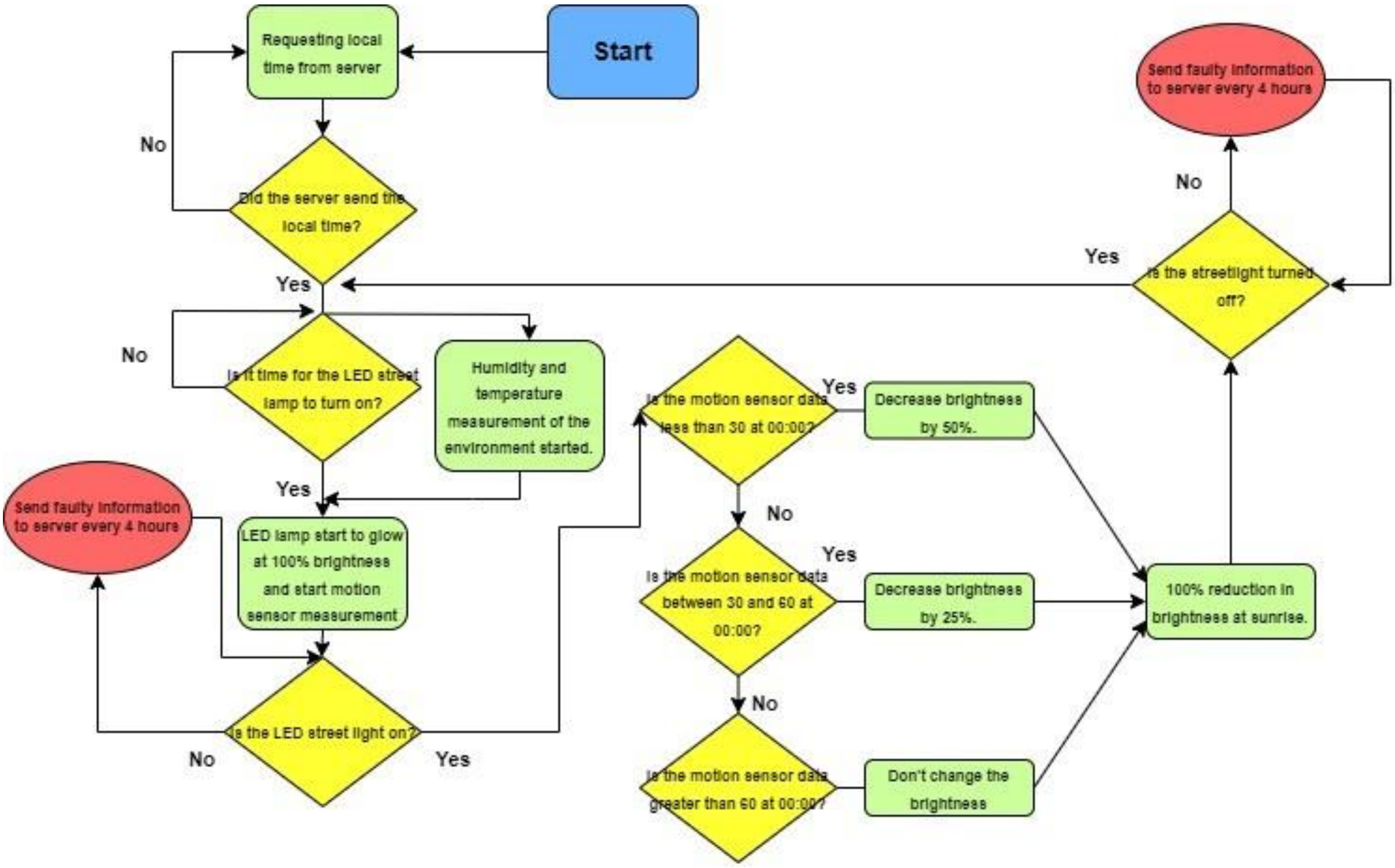

Fig. 9. Flowchart of The System

The overview of the system is given in Fig. 10.

Fig. 10. System Overview

3. Results and Discussion

This system, it is aimed to examine the relationship between the amount of energy consumed by the light-emitting diode (LED) streetlight in different modes and the amount of energy consumed by the sodium vapor streetlight in different periods, and the amount of energy consumed. To speed up troubleshooting/repair phases with an LED streetlight. There are sensors in the system that measure the value of 4 variables. These variables are the light-dependent resistor (LDR), which measures the light intensity of the LED streetlight, the motion sensor that captures the movement in the environment, and a temperature and humidity sensor that measures the temperature and humidity of the environment. LDR and motion sensor are active when the LED streetlight is turned on to save energy. The temperature and humidity sensors are always busy. In the designed system, a Long-range wide area network infrastructure was used for data transfer to the server and the processes reaching the processor from the server. When the system starts, it sends a media access control (MAC) command to the server to learn the local time. The server checks local time information to determine whether a downlink is made or not. If the local time does not reach the system, the MAC command is repeated at certain time intervals. When the local time goes to the processor, it is controlled when the LED streetlight will turn on according to the month and day. When the LED streetlight is on, it lights up at 100% brightness, and at the same time, the motion sensor and LDR sensor start to measure. When the light intensity falls below a specific value, the streetlight sends the LoRa terminal device to the server with the information that the streetlight is malfunctioning. When the time is 00:00, the number of detected motions is evaluated. If the total number of detected movements is more than 60, the streetlight continues to glow at 100% brightness. If the total number of seen motions is between 30 and 60, the streetlight will turn on at 75% brightness, and if less than 30, at 50% brightness. In order not to create a security gap and not to deteriorate the welfare of society, the streetlight was not completely turned off. At sunrise, the streetlight is completely turned off. The system checks whether the streetlight is turned off. If the streetlight is not turned off, the server is informed that it is not turned off. An example view of the designed computer interface is shown in Fig. 11.

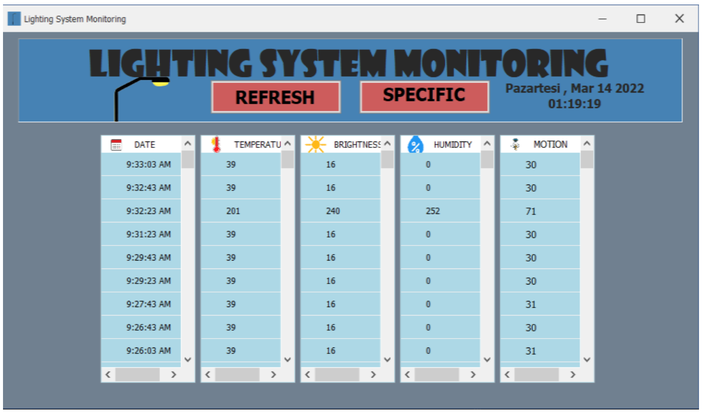

Fig. 11. Designed Interface

As a result of the measurements, the data presented in Table 1. are presented in terms of the current drawn by the streetlight at different brightnesses in amps, the voltage used in volts, and the total power consumed in watts.

Table 1. Total Power Consumed at Different Brightnesses

Brightness	**Current (A)**	**Voltage (V)**	**Total Power Consumption (W)**
100% Brightness	0.565 A	10.26 V	5.80 W
75% Brightness	0.493 A	9.15 V	4.51 W
50% Brightness	0.410 A	7.24 V	2.97 W
25% Brightness	0.224 A	3.34 V	0.75 W

The amount of energy consumed by the streetlight at different brightnesses is shown in Fig. 12 every month.

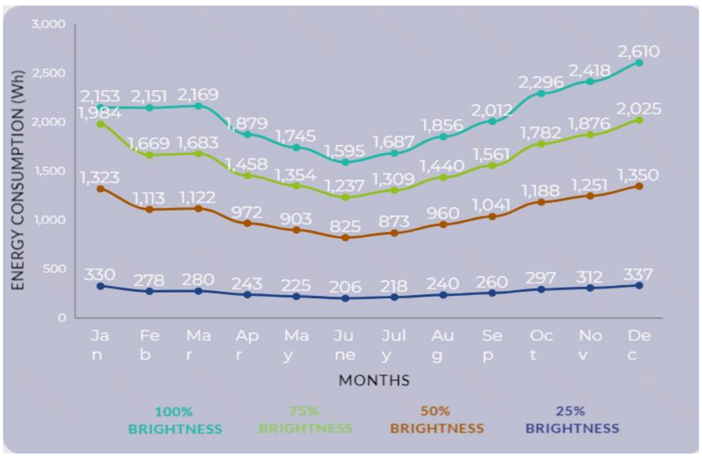

Fig. 12. Energy Consumption of Streetlight by Month

4. Conclusions and Recommendations

This study designed and tested a light-emitting diode (LED) street luminaire system with communication protocol instead of a sodium vapor street luminaire. The brightness of the LED streetlight should be checked by examining the data received from the sensors connected to the system. The transfer of data to the server was performed by the long-range (LoRa) end device, the LoRa gateway. The long-range wide area network protocol can be quickly and successfully applied to transmit data and multiple systems. The data reaching the server can be easily examined thanks to the prepared interface, and the authorized person is automatically informed via e-mail in case of unintentional data changes. Sodium vapor street fixtures consume 70-400 Watts of power. Thanks to the designed system, energy consumption has decreased considerably, and significant energy saving has been achieved. The LED streetlight malfunctioned cases were determined, and the malfunction information was sent to the server. The system was implemented, the application details were explained, and presented the results. Based on the results given, no problems were encountered in the communication and stability of the system, and it has been shown to perform adequately. Machine learning methods can be used to improve wireless communication in case the proposed work is continued or similar in the future.

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