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A MODEL OF AN AUTONOMOUS SMART LIGHTING SYSTEM USING SENSORS

Abstract. Traditional street lighting systems receive data about daylight levels and adjust the lighting. However, in such conditions, energy consumption increases since the sensors of such systems receive data on only one indicator, which is daylight. Therefore, a suitable automated intelligent lighting system model is needed. Intelligent lighting systems can adjust the brightness of the light not only based on natural data but also based on the movement of vehicles and people. This paper describes the development, implementation, and testing of a smart lighting system model to increase energy efficiency and high reliability. This system is controlled by a microcontroller programmed to control the lighting and receive data from sensors for processing with good efficiency. Distributed sensors record environmental conditions such as daylight and traffic. Photoresistors change resistance in daylight to light up the streets at night. The HC-SR501 infrared motion sensor detects objects emitting infrared radiation (heat) in the controlled motion zone and sends a signal to the microcontroller. The intelligent lighting system uses LEDs, which consume less energy and achieve high efficiency. Calculations show that the efficiency of using these lamps is almost 70%, compared to what is used in conventional street lighting systems.

Keywords: street lights, automation, smart technologies, optimization, modeling, data collection and processing algorithms.

Introduction

Street lighting enables people to illuminate streets, roads, and pedestrian crossings. It helps reduce the number of accidents on the roads and provides light for pedestrians and drivers at night [1]. In the traditional version of street lighting, sensors work only during darkness, but energy is expended on the light when lighting is not needed. This causes irrational electrical energy consumption, which does not go hand in hand with economy and environmental friendliness. In addition, such systems require regular monitoring and replacement of system components, such as lamp bulbs [2]. It takes time to indicate the errors in the whole device, and it would be better to automate the lighting system to a new version. In this case, an intelligent lighting system is needed, which allows people to reduce electricity costs and make data usage convenient.

A smart streetlight is a traditional lighting system with special sensors and functions. A smart version of such a system allows a microcontroller to control the illumination level at a given moment and create conditions for saving energy [3]. LED bulbs, photoresistors, and motion sensors are used for this model, and these components make up the entire automated lighting system.

The implementation of intelligent lighting helps young countries, such as Kazakhstan, maintain an ecological balance with non-renewable energy sources. The total street lighting coverage in the capital of Kazakhstan, Astana, is about 98% and equipped with high-pressure sodium (HPS) and high-pressure mercury (HPM) lamps. Street lighting has been installed on almost all streets of Astana, with a length of 1,505 km [4]. Two types of lamps are most commonly used in this city, so energy consumption in one region differs from another. For example, statistics show that 70% of all streetlights are HSP lamps, consuming 82% of all street energy, while LED lamps account for 30% and consume only 18% of electricity. Assuming that there are an equal number of two types of lamps for street lighting, it can be inferred that the consumption of LED-based lamps causes an efficiency of 51.2% [5]. Building a model and creating a platform based on a system with LED lamps for city streets can save a large number of electricity costs.

The objective of the project

The aim is to examine the integration of intelligent lighting into the concept of smart energies and smart cities.

Motive and analysis hypothesis

Most of the world's energy consumption is based on non-renewable energy. Until these changes are made, it is necessary to look for opportunities to save and use energy efficiently. Today's cities are increasingly adopting the concept of smart cities, and effective energy management is one area of focus. One element of smart cities that is being implemented by cities is smart energy. Within this framework, the popular idea is to replace traditional lighting with LED (Light-Emitting Diode) lighting, which can save energy and costs, reduce pollution from artificial light in the sky, and improve the effectiveness of urban lighting.

Literature review

In accordance with other studies on street lighting from IEEE Photonics Journal, C. -C. Sun et al., "Design of LED Street Lighting Adapted for Free-Form Roads", It was discovered that street lighting, which is a major contributor to energy waste and nighttime light pollution, still faces the challenge of efficiently lighting streets with curved and winding shapes [6]. Older street lighting technologies, such as high-pressure sodium or high-pressure mercury luminaires, emit light in all directions, making it difficult to control the distribution of light. These luminaires often have shortcomings such as glare, uneven light distribution, light that is reflected upwards, pollution arising from light, and energy waste. In this scientific research, it was found that a newer lamp model – LED – is more efficient than the previous ones, as the lamp LED has no deficiencies in light emission and pollution, and is also more profitable for commercial purposes, as it reduces energy consumption, which leads to a reduction in the financial costs of street and house dedication [7].

Research methodology

Methods suggest how to solve a problem from different perspectives by specifying a problem, how to work with data related to the problem, and which way is suitable for the end result. The first method used in this article is the qualitative methodology, which provides research-

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ers with trustworthy content and tools to study complex phenomena in their context. The case study research was used for qualitative research. This method is used when the computational capabilities of other methods are limited and a thorough study of the behavioral components is required [8]. This method uses various sources such as research papers, newspapers, books, and images to confirm the information's accuracy [9]. The Quantitative Method was used for calculations and work with statistical data. Because it builds on existing theories, quantitative research is specific in the experiments and surveys it conducts. It is used individually by each researcher, and the result is dependent on relevant data for calculation [10].

The analysis of scientific research papers on the implementation and design of intelligent lighting systems aims to recognize the general picture of intelligent technologies in cities and introduce hypotheses and theories.

The novelty of this project lies in the development of smart lighting adjustable using portable devices. Thanks to the automatic control of consecration and other devices, it is possible to reduce energy consumption over a vast territory significantly. In addition, this article outlines the implementation of cost reductions for equipment and materials for the implementation of the project [11].

This work aims to expand the lighting system's efficiency by implementing a context-sensitive control algorithm. In order to attain the objectives, it's required to analyze existing commercial solutions in the field of managing the parameters of the bright residence system and, based on the analysis, to expand an algorithm for controlling the lighting system based on an artificial neural network, as well as to carry out the hardware implementation of an intelligent system for lighting control.

Management System

The management system of an autonomous lighting system can be divided into Hardware and Software.

The architecture of the autonomous lighting system consists of a microcontroller, LED lamps for illumination, photoresistor, and infrared motion sensors. In this work, the main components of device workability are the HC-SR501 sensor for motion recognition that transforms signals to a microcontroller, the photoresistor for daylight monitoring, and energy saving Light-Emitting Diode lamps (Figure 1).

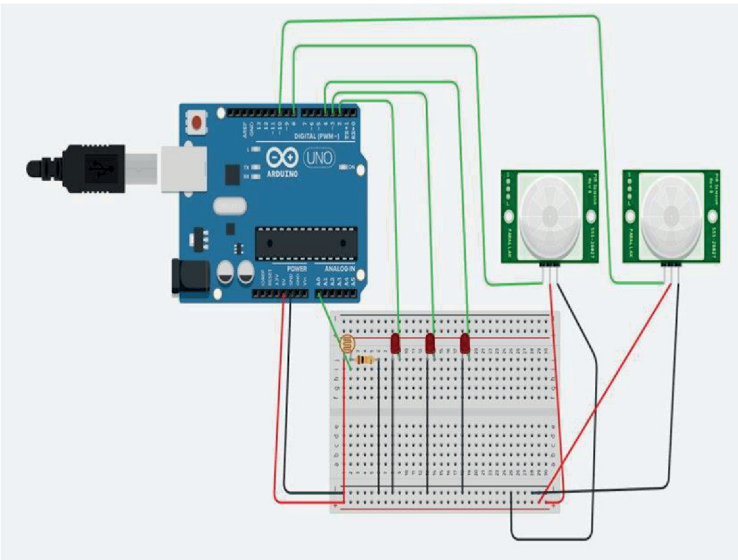

Figure 1. Schematic diagram of the project

A power source is a device that supplies electrical energy to systems. The 220-240 V source voltage is lowered to a more suitable voltage value in the range of 5-12 V. The board is charged using the connector for connecting an external port on the Arduino shield [12].

The microcontroller controls the smart lighting control system. Arduino Uno shield was used as a microcontroller for this project because of its preferential usability [13]. It can connect to the PC and send data to analyze energy consumption. The USB port on the circuit board is used for connection via a PC. This is usually done to upload the code to the board or to control the board without using a wireless network when not required [14]. This microcontroller board is based on the ATmega328P, which consists of 28 pins. There are specific purposes for each pin: 14 digital input/output pins, six analog inputs, three ground pins, one power input pin (V), two power output pins (3.3V and 5V), an AREF (Analog Reference) pin, and a reset pin. The board also consists of a 16MHz quartz crystal wired to its clock pins, a power jack, an ICSP (In-Circuit Serial Programming) header, and a reset button [15]. Each of the 14 digital pins on the Uno runs at 5 volts and can be configured as either an input or an output using a variety of functions. The recommended operating condition for each pin is 20−50mA, and each pin has a 20−50k ohm internal pull-up resistor. In order to prevent permanent harm to the microcontroller, no I/O pin may have a current value greater than 40 mA [16].

The photoresistor determines the time of day and instructs the module to turn on the bulbs only at night. Figure 2 shows data received from this sensor to analyze processability. In bright light, resistance to daylight increases. The program has been structured to retrieve and understand the resistance using a photoresistor measured in lx. The analysis was based on indicators based on the following criteria as in Table 1:

Table 1. Processability analysis

Scale	**Description**
more than 800 lx	“Very Bright”;
500−800 lx	“Bright”
200−500 lx	“Light”
10−200 lx	“Dim”
less than 10 lx	“Dark”

The HC-SR501 motion sensor detects movement and switches on the nearest light bulb. After passing the next sensor, the speed of the passing sensor is determined so that the module understands how fast the object is moving and smoothly turns on the next bulbs and turns off the previous ones [17].

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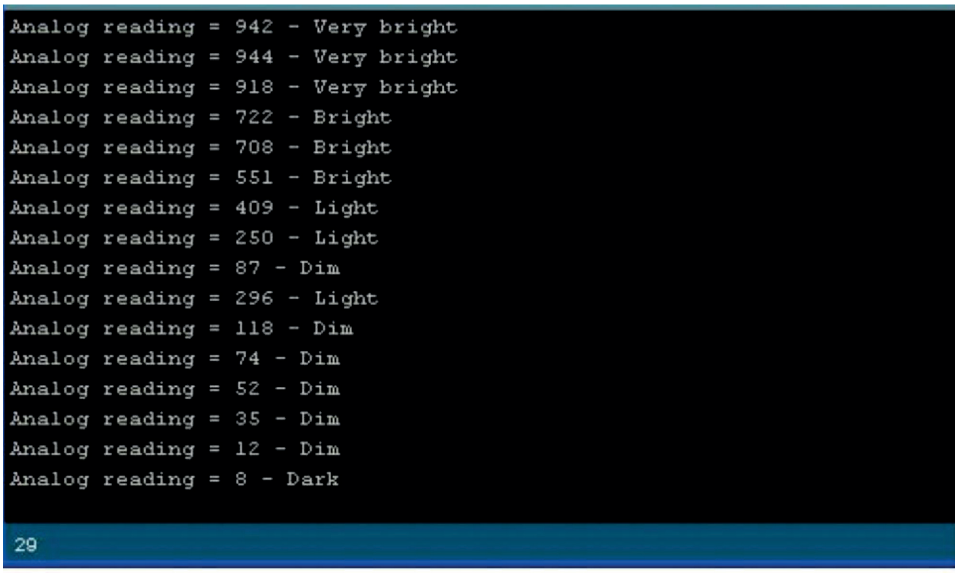

Figure 2. Receiving Signals from Photoresistor

Electrical Circuitry

The system consists of a resistor, LEDs, a power supply unit, two HC-SR501 motion sensors, and an Arduino Uno microcontroller board. The system shown in Figure 3 is supplied by a 220 V power supply unit source, which is additionally lowered and converted to the corresponding nominal voltages to microcontroller [18]. After regulation, voltage outputs are routed to supply the components. The 5V voltage feeds the proximity HC-SR501 sensor and photoresistor. The LEDs react to the commands of the microcontroller.

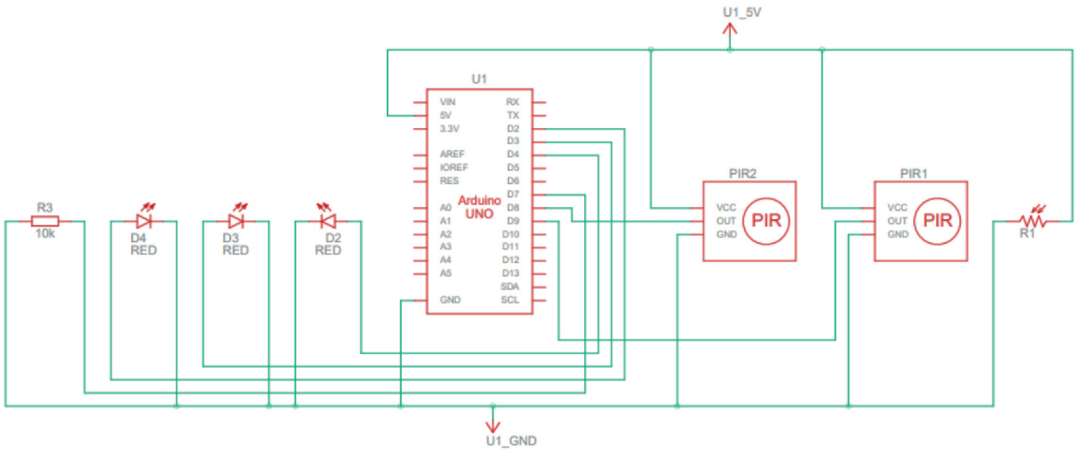

Figure 3. Circuit Diagram of the System

The value of the resistor used to protect the LED is found from this equation 1:

$$R = \frac{(V - V_{led})}{I_{led}} \quad (1)$$

where,

V – Voltage of power supply unit;

V_{led} – Voltage to LEDs;

I_{led} – Current flow does through LEDs.

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Microcontroller Programming

The Arduino IDE platform is used for programming [19]. This platform has installed libraries for connecting to sensors. The object-oriented programming language C was used for the automation of the system.

Two functions are used for the code: setup() and loop().

setup() function initializes and sets the initial values for the program.

loop() function contains the commands that the program executes when the program is running.

```
#define photoresistor A0
int PIRpin = 8 ; // motion sensor is connected to the 2nd digital output
int ledpin = 4; // the LED is connected to the 3rd digital output
int light;

void setup() {
  pinMode(ledpin, OUTPUT); // output
  pinMode(PIRpin, INPUT);  // input
}

void loop() {
 svet = analogRead(photoresistor);
  // the LED does not light if there is no movement
  if(light < 50) {
    if(digitalRead(PIRpin)==LOW) {
    digitalWrite(ledpin,LOW);
    } // the LED lights up if the movement is fixed
    else {
    digitalWrite(ledpin,HIGH);
    }
  }
  else {
    digitalWrite(ledpin, LOW);
  }
}
```

Figure 4. Code for Processing of the System

Figure 4 shows the program code for the operation of the device. It is written in C, in the Arduino IDE. For the work of consecration, first of all, libraries were used on a photoresistor and motion sensors. Next, three variables are inherent to the LED, the motion sensor, and the photoresistor. The concept of work was previously described in the Management system in this article. In the void loop, a condition is made under which if the photoresistor gets a value of fewer than 50 ohms, then there is a street light at this point, otherwise, if it is more than 50 ohms, then there is no daylight and the LEDs must be turned on. In any other case, the LEDs will be off to conserve power.

Research results

During the implementation of the project, the real EXPO territory was modeled, which is a three-dimensional object of a digital model. A three-dimensional model was created in a special program called Autodesk Fusion 360, and each part, including the base of the structure, was modeled separately and then superimposed on each other. The finished model was sent to the 3D printer, which proceeded to create a sample by layering the filament in layers. As a result, the 3D printer printed the finished model of the expo in the ratio of 1:533.333 centimeters.

The process of modeling the territory of the expo is shown in Fig. 5 and Fig. 6.

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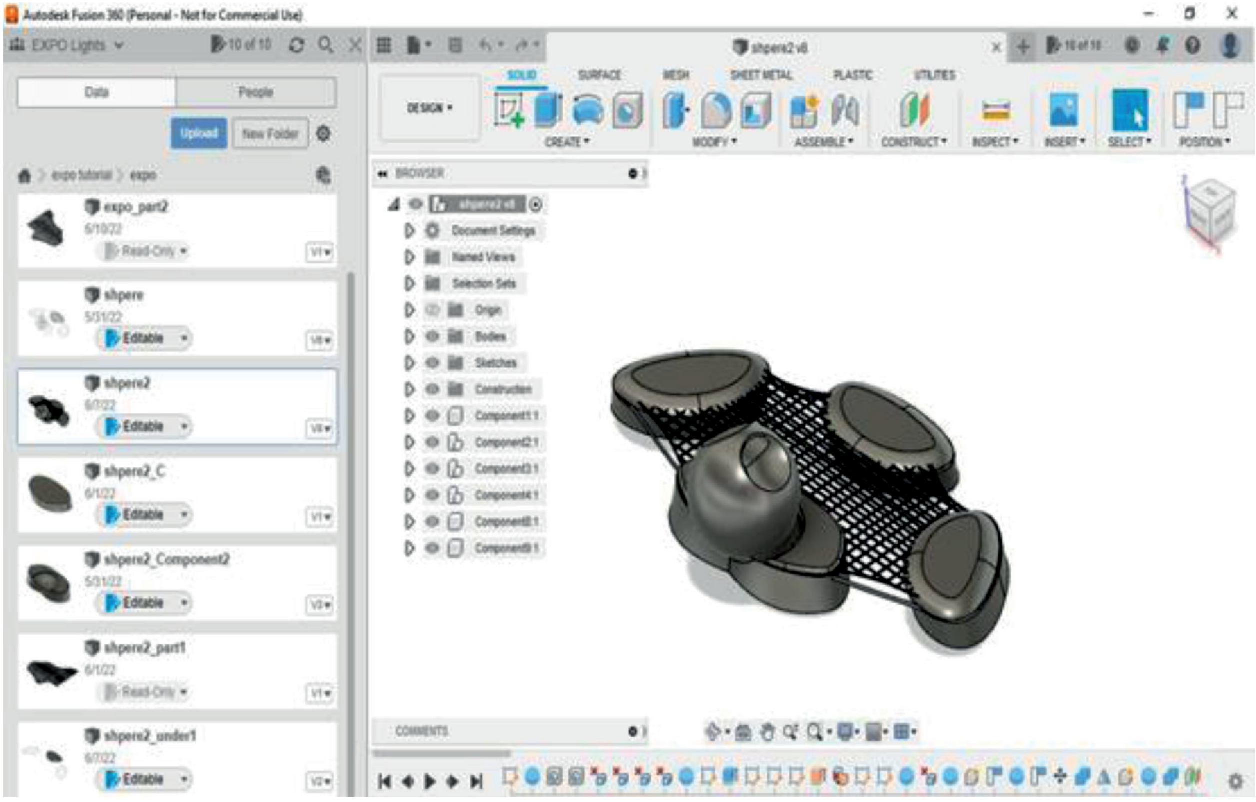

Figure 5. Creating an expo model on the program Autodesk Fusion 360

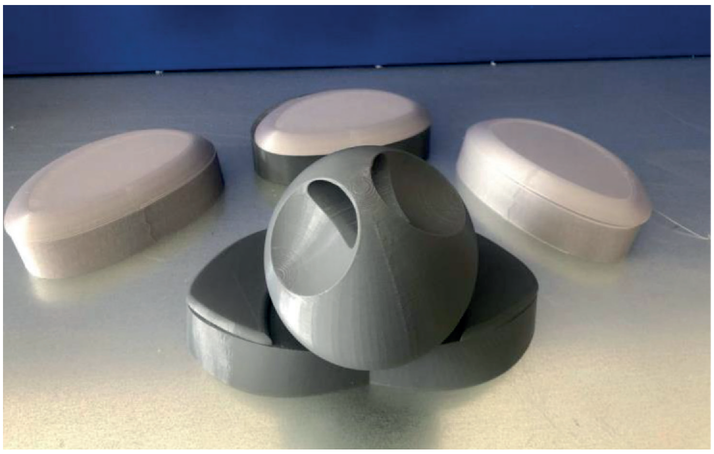

Figure 6. The result of modeling on a 3D printer

The study compared two common lamps (HSP lamps and LED bulbs) in the territory of the city of Nur-Sultan. Table 2 shows the main characteristics that affect energy consumption.

Table 2. Comparison of lamp types of street lighting system.

	Light-Emitting Diode (LED)	High-Pressure Sodium (HPS)
Power Consumption (W)	6	60
Voltage (V)	90–240	200-230
Lifespan (h)	>10’000	5’000
Color Temperature	6500	2200

A comparison of two types of street lighting lamps shows that the consumption of LEDs leads to energy savings due to their performance characteristics. As part of the experiment, the energy consumption of these lamp types was measured at different time intervals. It is noted that the power output of LEDs is much more efficient due to the saving of a non-renewable energy source. The energy consumption of the LED is in Table 3.

Table 3. Energy consumption of LED

Time Frame	LED (kWh)	HSP (kWh)
6:00 – 14:00	0.3	9
14:00 – 22:00	0	4
22:00 – 06:00	0.9	9

As described in Table 1, one LED lamp uses 6W of energy. Table 2 shows the indicators of energy consumption of a LED lamp, which, when calculated for three lamps, leads to the following equation 2:

$$3 \times 6W = 18W \quad (2)$$

In the traditional city street lighting, only one HSP lamp is used, so the energy consumption is equal to equation 3.

$$1 \times 60W = 60W \quad (3)$$

Calculations show that the efficiency of using these lamps is almost 70%, compared to what is used in conventional street lighting systems.

High-performance LED driver IC's are designed to help accelerate the development of intelligent LED lighting systems. These ICs may include non-flashing light dimmers and even a system for remote control to meet color quality requirements and increase product prices. The innovative development of LED production technology, color, and packaging is considered promising in the current market. LEDs have a major advantage over other types of light sources because of their energy savings and long lifespan. The approach used is a self-tuning weighted algorithm that is based on a neural network. The self-adaptive weighted merge algorithm is an algorithm that determines the weights of measured data adaptively in order to optimize the data.

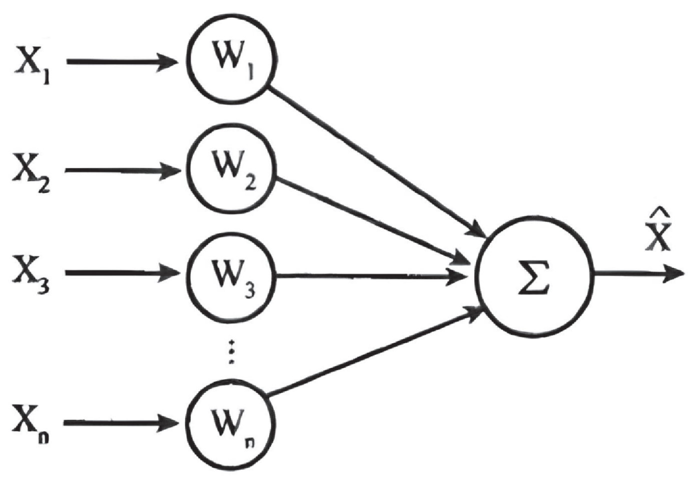

Figure 7. A data fusion model for a self-adaptive weighted algorithm

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Assume that given the area of observation, there are clear data, such as LED 1, LED 2, LED 3, etc. As shown in Figure 7, P_{ij}, i = 1,2,3 … r, j = 1,2, 3 … r, represent the data found about object j by sensor i, r is the number of objects that are fuzzy, and the variances of the data perceived by each node are represented as σ1, σ2, … σ_r :

$$\begin{cases} P_j = \sum_{i=1}^{r} W_i P_{ij} \\ \sum_{i=1}^{r} W_i = 1, 0 \leq W_i \leq 1 \end{cases}$$

(where P_j is the ultimate goal, j is the observation, r is a number of objects, σ are data variances, W is a weight vector, X is a vector of input signals)

The ultimate goal of observations P_j shows dependence only on the data, measured by each sensor for a given squared error. One more point worth mentioning is that a weighted estimate and scores in games can be expressed in exactly the same form, with the only the difference is that in the first case, the scales are assigned to each sensor, and in last – average data is processed as an update, after whereby the arithmetic mean is defined as:

$$\sigma_1^2 \times (\sigma_2^2)^{-1} = \left(\frac{1}{r^2}\sum_{i=1}^{r}\sigma_i^2\right) \times \left(\sum_{i=1}^{r}\frac{1}{\sigma_i^2}\right) \geq \frac{1}{r^2}\left(\sum_{i=1}^{r}\sigma_i \times \frac{1}{\sigma_i}\right)^2 = 1 \rightarrow \sigma_1^2 \geq \sigma_2^2$$

This suggests that there is low variation in this work, data fusion, that is, high stability.

Discussion

The model of an autonomous smart lighting system is investigated using efficient sensors to minimize energy consumption. This work aims to reduce the cost of energy consumption for streetlights. The system conserves energy and increases the efficiency of the streetlight network. If the system is widely implemented in the country's streetlight network, it will significantly reduce energy consumption from the grid. Analysis has shown that implementing a smart street lighting system has many benefits. The system can be further enhanced by incorporating a hybrid energy generation system in addition to relying on the grid for power. In addition, the best solution in improving and promoting the Smart City project in the scientific community will be the development of a system that controls not only traffic and energy consumption but also the involvement of important objects of visit, such as pharmacies or shops. It would also be a good scientific component to create mobile devices that control various daily or production processes.

Conclusion

As a result of the work done, it is possible to sum up the successful implementation of the project. During the analysis of scientific literature in the field of electricity, conclusions were drawn about the huge financial costs of consecration, while there is one solution – the transition to smart technologies that control the operation of the device system remotely or using mobile devices. We considered a new concept of an adaptive automated street lighting system using the EXPO territory as an example. Thanks to the constructed model control system, the participation of human forces in the control of illumination and energy consumption is no longer required, since all sensors, photoresistors, and LEDs are connected to a single module that controls the entire process, which helps to significantly decrease the financial costs of energy consumption, as well as reduce harmful emissions into the environment. An autonomous system model can help conserve energy and increase the efficiency of a streetlight network. If this system is widely implemented in the country's streetlight network, it will significantly reduce the amount of energy consumed from the grid, resulting in cost savings.

The research material for the project was the scientific work of other scientists published in IEEE journals. Thanks to the data presented in these works, a hypothesis was put forward for this article.

In conclusion, we can say that our project is simple and effective, and it is optimal in that it provides the most budgetary and, at the same time, accurate results for solving the problem of enormous energy consumption in the city and huge damage to nature due to unnecessary harmful emissions into the environment.

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