UDC 004.89:628.971.6:[004.415/.416:71/72]:005.521

INFORMATION SYSTEM OF STREET LIGHTING CONTROL IN A SMART CITY

Vaskiv R. I. – Post-graduate student of the Department of Information Systems and Networks, Lviv Polytechnic National University, Lviv, Ukraine.

Hrybovskyi O. M. – MSc. of the Department of Information Systems and Networks, Lviv Polytechnic National University, Lviv, Ukraine.

Kunanets N. E. – Dr. Sc., Professor of the Department of Information Systems and Networks, Lviv Polytechnic National University, Lviv, Ukraine.

Duda O. M. – PhD, Associate professor of the Computer Science Department, Ternopil National Technical University named after I. Pulyuya, Ternopil, Ukraine.

ABSTRACT

Context. In the context of the rapid development of technologies and the implementation of the concept of smart cities, smart lighting becomes a key element of a sustainable and efficient urban environment. The research covers the analysis of aspects of the use of sensors, intelligent lighting control systems with the help of modern information technologies, in particular such as the Internet of Things. The use of such technologies makes it possible to automate the regulation of lighting intensity depending on external conditions, the movement of people or the time of a day. This contributes to the efficient use of electricity and the reduction of emissions into the atmosphere.

Objective. The purpose of the paper is to analyze the procedures for creating an information system as a tool for monitoring and evaluating the level of illumination in a smart city with the aim of improving energy efficiency, safety, comfort and effective lighting management. The implementation of a smart lighting system for Lviv will help improve energy efficiency and community safety.

Method. A content analysis of scientific publications was carried out, in which the results of research on the creation of street lighting monitoring systems in real urban environments were presented. The collection and analysis of data on street lighting in the city, such as energy consumption, illumination level, lamp operation schedules, and others, was carried out. Machine learning methods were used to analyze data and predict lighting needs. Using the UML methodology, the conceptual model of the street lighting monitoring information system was developed based on the identified needs and requirements.

Results. The role of data processing technologies in creating effective lighting management strategies for optimal use of resources and meeting the needs of citizens is highlighted. The study draws attention to the challenges and opportunities of implementing smart lighting in cities, maximizing the positive impact of smart lighting on modern urban environments. The peculiarities of the development and use of an information system for controlling street lighting in a smart city are analyzed. The potential advantages and limitations of using the developed system are determined.

Conclusions. The project on the creation of an information system designed to provide an energy-efficient lighting system in a smart city will contribute to increasing security, particularly, ensuring the safety of the community through integration with security systems, reducing energy consumption, through minimizing the electricity usage in periods when the need for lighting is not necessary.

It has been determined that to implement an information system for remote monitoring and lighting control in a smart city, it is advisable to consider the possibility of using a complex lighting control system. Calculations were made on the example of Lviv for the city's lighting needs. The use of motion sensors to determine the need to turn on lighting was analyzed. A conceptual model of the information system was developed using the object-oriented methodology of the UML notation. The main functionality of the information system is defined.

KEYWORDS: information system, lighting system, smart city, remote monitoring, forecasting.

ABBREVIATIONS

IoT is an internet of things;
UML is an Unified Modeling Language;
RNN is a recurrent neural networks;
LSTM is a Long Short-Term Memory;
MQTT is a Message Queue Telemetry Transport.

NOMENCLATURE

D is a distance between measurement points;

S is a distance between lamps in meters;

N is a number of measurement points in the longitudinal direction;

l is a shading coefficient;

E_{zb} is an illumination level with trees;

E_{bb} is an illumination level without trees;

W_r is a width of the road or the considered section;

n is a number of measurement points in the transverse direction;

L is a total number of lamps;

k is a number of lamps at the intersection;

P is a number of intersections;

m is a number of lamps on the street;

n is a number of measurement points in the transverse direction;

V is a number of streets;

E is a total consumed energy;

P is a lamp power;

T is a working time per day;

DOI 10.15588/1607-3274-2024-3-18

$D(t)$ is a lighting dynamics;

$I(t)$ is an intensity of lighting on the street;

k is a positive attenuation coefficient of the lighting intensity;

a is a positive influence coefficient;

$R(t)$ is a traffic level on the street;

x_t is an input vector;

h_{t-1} is a hidden state in the previous step;

f_t is a forgetting vector, which determines which information from the previous state of the cell (h_{t-1}) should be "forgotten";

i_t, o_t are input and output vectors;

c_t is a state of the cell;

W_m are weight matrices;

b_l are displacement vectors;

σ is a sigmoid function;

tanh is a hyperbolic tangent.

INTRODUCTION

A smart city is a concept that is based on the use of information and communication technologies to increase work efficiency, exchange information with the public and ensure better quality of public services and citizens' well-being. The main goal of a smart city is to optimize city functions and promote economic growth, as well as improve the quality of life of citizens with the help of smart technologies and data analysis, in the field of street lighting.

Street lighting is the main part of city infrastructures. In addition to the main function of controlling and regulating street lighting, smart lighting can have other important functions that contribute to the functioning of a smart city. The development of intelligent street lighting systems is one of the topics that interests many researchers around the world. Therefore, the creation of an information system for quality control of street lighting in a smart city is an important and relevant topic.

The **purpose** of the paper is to analyze the procedures for creating an information system as a tool for monitoring and evaluating the level of illumination in a smart city with the aim of improving energy efficiency, safety, comfort, and effective lighting management. The implementation of a smart lighting system for the city of Lviv will help improve energy efficiency and community safety.

The object of research is the street lighting system of smart cities.

The subject of research is methods and means of building a smart lighting system in a smart city.

The scientific novelty of the obtained results lies in the development of a unique system that is a part of a local, wireless, decentralized network for collecting data from sensors on lampposts, processing them to ensure energy efficiency and safety of public lighting, which, unlike existing solutions, provides an opportunity to take into account the features of the urban infrastructure of Lviv and effectively manage the lighting system in the city.

1 PROBLEM STATEMENT

In the context of a smart city, the street lighting management information system plays a crucial role in ensuring the efficiency, safety, and comfort of residents' lives. Formalizing this task involves determining the optimal distribution of lighting resources, taking into account various factors such as energy efficiency, safety, comfort, and economic feasibility.

Input Variables: S; N; E_{zb}; E_{bb}; W_r; n; k; P; m; V; P; T; $I(t)$; k; a; $R(t)$.

Desired outcomes (output variables): D; l; L; E; $D(t)$.

D depends on S and N. For $S \le 30m$ it is $N = 10$, and for $S > 30m$, it is the smallest integer that gives $D \le 3m$.

l depends on E_{zb} and E_{bb}. In turn, D depends on W_r and n. n which is equal to 3 or more and is an integer, which gives $d \le 1.5m$.

L depends on k, P, m, l and V. And E depends on L, P and T.

$D(t)$ depends on k, $I(t)$, a and $R(t)$.

Mathematical modeling of these parameters will allow for the development of optimal solutions for street lighting management in a smart city, ensuring efficient resource utilization and meeting the needs of the population.

2 REVIEW OF THE LITERATURE

Public lighting infrastructure, according to researchers, offers not only smart lighting, but also several other functions and benefits for cities. Using lampposts to integrate sensors from other smart city systems, such as air quality monitoring, Wi-Fi provision, video surveillance for public safety and electric vehicle charging. Researchers believe that high-quality street lighting significantly increases the productivity of smart cities and the quality of life of its citizens. The use of innovative lighting systems is characteristic of smart cities in Europe, Asia, and North America, which have already created the concept of a smart city, many others are developing detailed plans and conducting analysis to reach this stage of development and in the context of the lighting system [1].

The authors of the paper [2] believe that the field of lighting management creates opportunities for the use of sensor technologies with information and communication technologies. This approach contributes to the efficient use of electricity for lighting the city and reducing its negative impact on the environment. Semiconductor light sources, in particular Light Emitting Diode, and LED

DOI 10.15588/1607-3274-2024-3-18

technologies, such as organic LEDs or solid-state light sources, are used to implement the intelligent lighting system. Researchers believe that the development of new relations in this field is mainly focused on the creation of modern lighting control information systems that provide dynamism, controllability and interactivity, adaptability of control procedures. The use of intelligent solutions for lighting ensures automatic detection of failures and efficient use of energy.

Researchers [3] believe that in a smart city, when implementing intelligent lighting systems, it is advisable to combine lighting systems and communication channels with advanced intelligent functions. To ensure lighting control procedures, the authors proposed several IoT usage scenarios [4]. The authors believe that to build an ecosystem of a smart city, it is advisable to use individual systems and solutions taking into account the unique requirements of each city [5], while four conditional categories are distinguished such as citizens, mobility, government and environment [6]. And in order to increase the efficiency of lighting systems, it is necessary to conduct interdisciplinary research to solve many problems, in particular, the features of connecting components using a protocol with IoT support to ensure energy efficiency in a smart city [7].

According to the authors of the paper [1], street lighting is important for ensuring the comfort and safety of road traffic for its participants. At the same time, it is noted that a properly designed and properly executed installation of street lighting will contribute to the creation of safe traffic conditions for drivers, cyclists, and pedestrians in the dark season. In many countries, for economic reasons, the lighting of all streets and roads is not used when there is no traffic on them, but some places and areas are determined that must be lit constantly [8].

A smart lighting system is an automated intelligent lighting control system that involves the use of Internet of Things technologies, devices, and sensors for lighting public places, which are an important part of the urban environment. The use of an intelligent information system of smart lighting contributes to the general feeling of safety and comfort of pedestrian movement in the dark [9, 10]. Factors affecting the feeling of security in the dark time of the day include not only the concept of "illumination", but also other attributes, such as uniformity, light-color transmission, and color temperature of light [11].

Considerable research in the field of neural networks is conducted by Ukrainian scientists. So, there is an intensive search for an evolutionary approach for the structural synthesis of neural networks [12, 13, 14].

3 MATERIALS AND METHODS

A content analysis of scientific publications was carried out, in which the results of research on the creation of street lighting monitoring systems in real urban environments were presented. The collection and analysis of data on street lighting in the city, such as energy consumption, illumination level, lamp operation schedules, and others, was carried out. Machine learning methods were used to analyze data and predict lighting needs. Using the UML methodology, a conceptual model of the street lighting monitoring information system was developed based on the identified needs and requirements.

Using the method of recurrent neural networks (RNN) and Long Short-Term Memory (LSTM), modeling of temporal dependencies in time series was carried out, which made it possible to create a model for predicting street lighting needs.

The project development for the creation of innovative public lighting control systems was carried out by a virtual team consisting of territorially distributed members, among whom are highly co-specialized experts in various fields of knowledge. This approach made it possible to work in different time zones. It is undeniable that managing a virtual team required not only a review of the management strategy, but also ensuring effective interaction between team members, despite their physical distance and dispersion in time zones. The key factors for improving the productivity of members' work were determined to establish team interaction (Fig. 1).

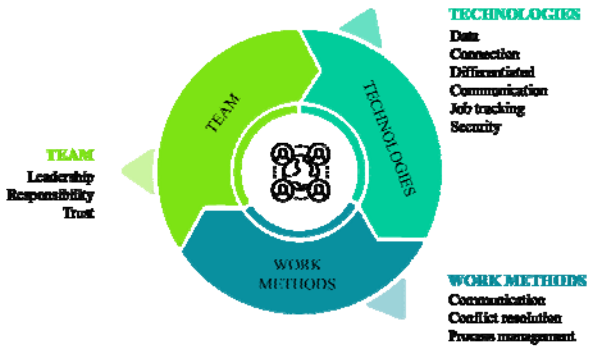

Figure 1 – The key factors to improve virtual team performance

The goals of the project are presented in Fig. 2.

The goals of the project (Fig. 2) in general can be presented as increasing the level of public lighting management, reducing maintenance costs, remote control of each lamp separately, the ability to change the brightness of the light stream depending on the length of a day and weather conditions, energy conservation, due to fluctuating lighting levels depending on traffic, increasing the city's security level, using Internet of Things technologies to improve the city's technological development, the ability to find the safest routes for city residents and guests.

Various algorithms for measuring illumination levels are used for the effective work of the information system, by receiving data from sensors and processing them in real time. Measurements are carried out horizontally on the road surface according to requirements. The location of the measurement points depends on the distance between the lamps and the width of the strip. Illumination measurement in the information system will be carried out on each investigated area, choosing two consecutive lamps in one row in the longitudinal direction, and in the transverse direction it is chosen the width of the area with

DOI 10.15588/1607-3274-2024-3-18

the same illumination class, if the road, adjacent sidewalk or bicycle path have the same illumination class, they can be treated as one area during measurements. The measurement points must be evenly distributed within the measurement field.

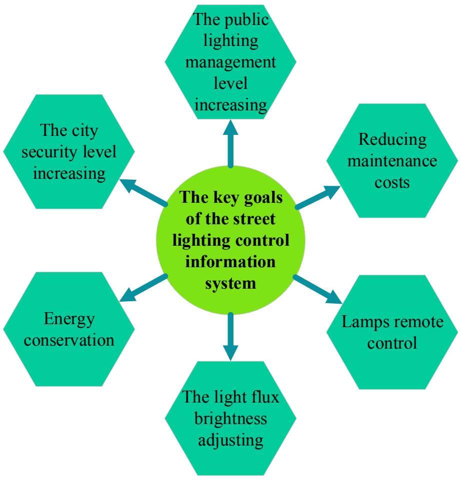

Figure 2 – The key goals of the street lighting control information system

The distance between measurement points (D in (m) in the longitudinal direction should be calculated using the formula 1:

$$D = \frac{S}{N}. \tag{1}$$

In the case of the presence of elements (trees, buildings) that shade certain areas, it is necessary to take this into account when calculating the illumination. It is supposed that there are trees between a light source (like a lamp) and the measurement points. It is advisable to determine how these trees affect the level of illumination at these points by means of computer simulation.

Using light modeling software, it is created a 3D model of our environment with trees and a light source. After that, it is set parameters such as the height and width of the trees, their location from the light source, the light intensity of the source, as well as the properties of the environment (for example, air transparency).

First, it is simulated the illumination at the measurement points without shading by trees. This gives us a baseline light level that will be used to compare with the light level after shading. Then trees are added to our model, and it is restimulated the illumination at the same measurement points. With the help of software, the level of illumination at each point is measured and compared with the base level without shading.

This will determine the shading coefficient. The shading coefficient can be defined as the ratio of the illumination level with trees to the illumination level without trees according to Formula 2:

$$l = \frac{E_{zb}}{E_{bb}}. \tag{2}$$

Therefore, it is obtained the shading coefficient, which reflects how much the trees affect the level of illumination at the measured points. This coefficient is used in the formula to determine the illumination according to your initial formula.

The distance between measurement points D in meters in the transverse direction should be calculated using the formula 3:

$$D = \frac{W_r}{n}. \tag{3}$$

The distance between points and edges of the surface under consideration should be $D/2$ in the longitudinal direction and $d/2$ in the transverse direction.

Territory of implementation of the information system is the city of Lviv and adjacent territories.

The system objects are streetlights and lamps, motion and lighting sensors, a central server for data collection and processing.

Functional capabilities are automated adjustment of lighting brightness, motion detection, adaptation of lighting to the needs of the city at certain hours and its zones, integration with other city systems.

One of the ways to adjust brightness in a smart lighting system can be through setting the optimal number of lighting control sensors. It will be calculated the number of sensors for the city of Lviv, using the following input data:

The area of the city is about 182 square kilometers.

The number of streets and intersections in Lviv is 500 streets and 1000 intersections.

The type of lighting involves the use of LED lamps, which are an energy-efficient and long-lasting option for street lighting.

Lighting intensity is regulated by lighting standards, which may vary depending on the type of streets. Main roads are expected to have a higher intensity of light compared to residential streets. Let's focus on the average lighting intensity of 20 lux.

The working hours of the lighting system will be 10 hours a day (for example, from 6:00 p.m. to 4:00 a.m.).

Sensors and switch-off conditions take into account the possibility of using motion sensors or other conditions to automatically switch off the light in places where there is no traffic.

It will be calculated the approximate number of LED lamps and the energy they will consume for lighting in Lviv. It is supposed that there are LED lamps at each intersection and along each street. Thus, the total number of lamps will be equal to the number of intersections and streets:

DOI 10.15588/1607-3274-2024-3-18

$$L = kP + mV \,. \qquad (4)$$

Taking into account the shading coefficient. The shading coefficient is considered as a multiplier that reduces the number of lamps depending on the level of shade caused by any objects or structures in the city. Thus, the modified formula for calculating the number of LED lamps, taking into account the shading coefficient, will be:

$$L = kP + mV \times l \,.$$

It is supposed that there are 4 lamps at each intersection, and lamps are installed every 20 meters on each street.

$$L = kP + mV = 1000 \times 4 lamps + 500 \times 1000 : 20 \,.$$

Total number of lamps = 4000 + 25000 = 29000 lamps.

The energy calculation will depend on the power of each lamp and the time of their operation. It is assumed that each lamp has a power of 30 W.

$$E = L \times P \times T \,. \qquad (5)$$

$$E = 29000 \times 30 \times 10 = 8700000 Wh = 8700 kWh \,.$$

The information system for monitoring the level of illumination in a smart city is designed to provide comprehensive and effective control of the level of illumination in the urban environment to improve energy efficiency, safety, and comfort of residents. The information system is designed to collect, process, and analyze data on the level of illumination on streets and other public places. The Internet of Things technology and protocols to ensure stable communication are used to implement data transmission in the smart lighting system.

The functional requirements for the lighting control information system in a smart city (Fig. 3) can be presented as follows:

1. Monitoring and data collection. The ability of the system is to measure and record the level of illumination in real time. The ability is to collect data from sensors that measure light levels on different streets and at different times of the day.

2. Dynamic adjustment of lighting. The ability is to automatically adjust the brightness of the lighting depending on the time of a day, weather conditions, the presence of pedestrians and traffic.

3. Energy saving. There is an implementation of energy saving algorithms and modes to optimize the use of electricity.

4. Emergency modes. There is an ability to switch to emergency lighting modes in case of accidents, poor visibility, or other unforeseen situations.

5. Analytics and reporting. Analytical tools are for determining optimal lighting parameters in different areas of the city and at different times of the day. Reports are available on electricity consumption, efficiency, and other parameters.

6. Integration with other systems. There is a possibility of integration with other smart city systems to coordinate lighting with other infrastructural systems.

7. Control of lighting zones. The ability is to group street lighting into different zones and independently control each zone.

8. Remote control. There is a possibility of remote monitoring and control of the system through a web interface or a mobile application.

9. Automated scripts. It is to set up automated scenarios depending on the city's needs and conditions.

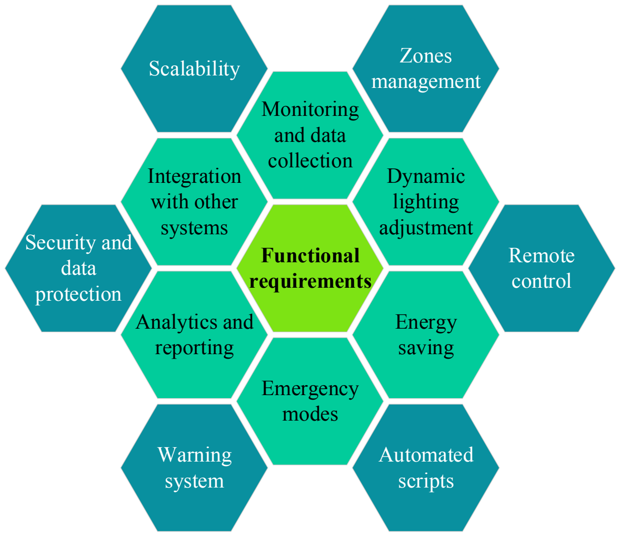

Figure 3 – Functional requirements for the lighting control information system

10. Warning system. There is notification and warning system in case of problems or accidents.

11. Security and data protection. There are mechanisms for protection against unauthorized access and ensuring data confidentiality.

12. Scalability. There is a possibility of expanding the system by increasing the number of sensors and lighting points.

These functional requirements serve as the basis for the further development of a detailed technical task for a system for evaluating the level of illumination in a smart city.

Having decided on the list of functional requirements for the lighting control information system in a smart city, it is created a use cases diagram (Fig. 4). The diagram shows the actor as a user who uses the interface produced by the information system.

After choosing a location, you can evaluate the level of illumination, analyze the results, and use scenarios to control lighting devices. Scenarios make it possible to quickly respond to changes in lighting and to perform specified sequences of actions when pre-defined conditions are met.

DOI 10.15588/1607-3274-2024-3-18

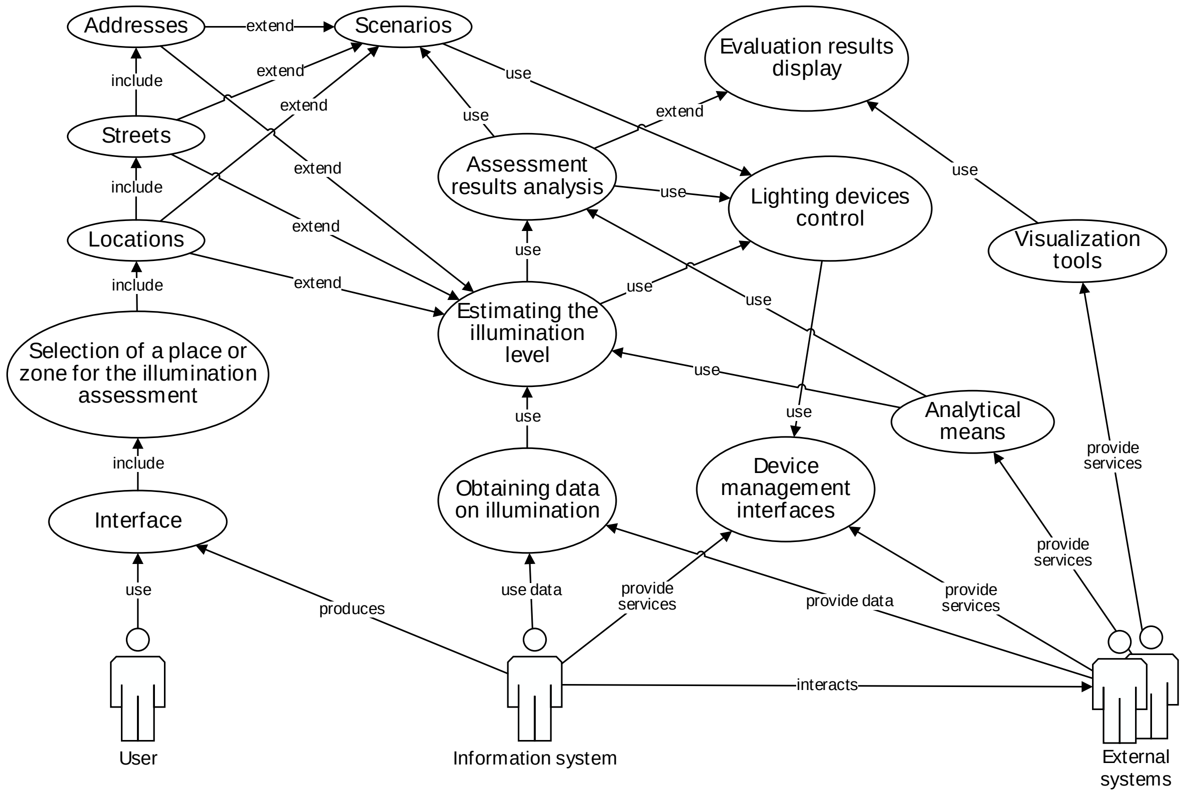

Figure 4 – Functional requirements for the lighting control information system

In this diagram, the Information System is highlighted as a separate actor because it consumes lighting data, produces the user interface, and provides interfaces to lighting control services.

Actors of External systems provide additional interfaces for lighting control services, analytical and visualization tools.

One of the key advantages of the information system is an ability to quickly respond to changes in environmental conditions and adjust lighting, accordingly, thereby ensuring the safety and comfort of citizens.

To achieve the goal of the project, it is envisaged to create and implement an integrated information system for assessing the quality of lighting in a smart city.

The information system for assessing the quality of lighting in a smart city will function with the aim of improving the quality of life of residents and optimizing energy saving management in the city of Lviv. The pro1ject aims to use advanced technologies to create an effective, safe, energy-efficient, and intelligent lighting system that considers the needs of different areas of the city and ensures their integration into the general infrastructure of a smart city.

The information system facilitates the possibility of improving the street lighting system, including different modes of operation, sensors, automation capabilities and other functions. The entire system of interconnected lights allows you to quickly identify areas with faulty lights, which will be immediately displayed in the information system.

The UML Activity diagram for the main flow for an ordinary user is presented in Fig. 5. Launching the system determines the beginning of the assessment of the illumination level and provides that:

– Reading light data involves obtaining relevant data from sensors or other sources.

– Determining the level of illumination includes processing the received data to determine the level of illumination.

– The illumination level is evaluated according to certain criteria.

– Light condition detection determines if the light level is acceptable or if intervention is required.

– Interaction with other systems of a smart city involves the possibility of communication with other subsystems to coordinate actions.

– Starting automatic lighting control modes involves activating automatic modes according to lighting requirements.

– Completing the assessment and saving the results describes completing the assessment process and saving the results for later use.

This diagram illustrates the sequence of steps that the system takes when estimating the illumination level in a smart city.

DOI 10.15588/1607-3274-2024-3-18

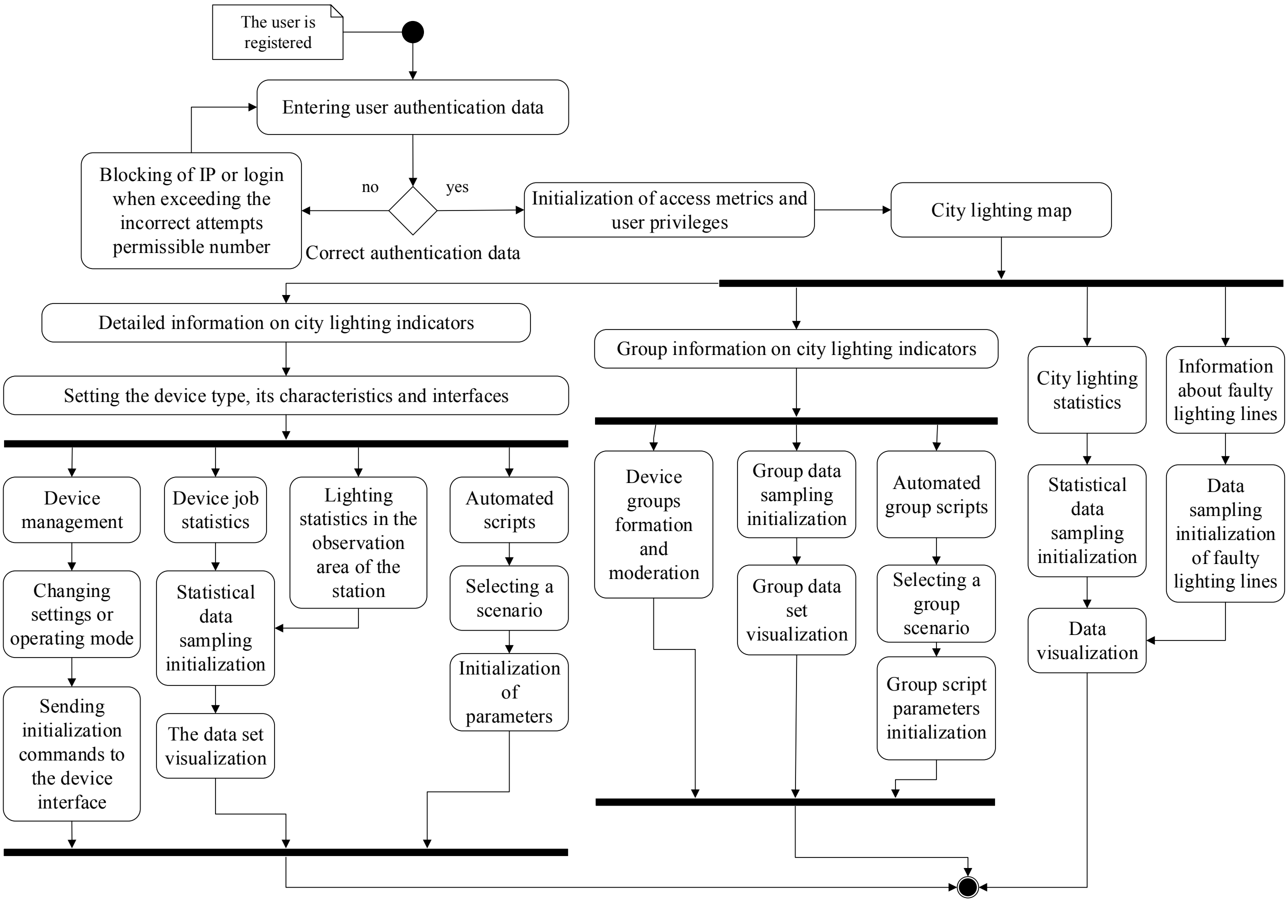

Figure 5 – UML activity diagram of the main sub-processes and actions of the street lighting control information system

To implement an information system for remote monitoring and control of lighting in a smart city, it is advisable to consider the possibility of using a complex lighting control system.

The information system of remote monitoring and control of lighting in a smart city provides for the presence of many elements and several functions.

Sensors and actuators. It is expedient installation of lighting, temperature, movement and other sensors on illuminated objects and areas of the city. Actuators for remote lighting control are used to change the state of the lighting system from a remote location. The information system provides the possibility of turning on and off the lighting remotely. The command to turn on or off is transmitted through the network from the central system to the actuators. The system will allow you to remotely adjust the brightness of the lighting.

To control actuators in smart lighting systems, it is advisable to use general algorithms, such as:

Remote on/off. The algorithm will provide the possibility of turning on and off the lighting remotely. The command to turn on or off is transmitted through the network from the central system to the actuators.

Brightness adjustment. The system will allow you to remotely adjust the brightness of the lighting. The algorithm can consider the parameters specified by the user or automatically react to changes in lighting conditions (for example, a change in the time of a day). To monitor the level of illumination, light sensors are installed that measure the level of illumination in certain areas of the city.

Definition of user parameters. The user can set their own parameters, such as the desired level of illumination, the schedule of changes in brightness during the day, automatic adjustment of illumination. The system automatically adjusts the brightness of the lighting depending on the received sensor measurements and user parameters. If the level of illumination deviates from the one set by the user, the system issues a command to the actuators to change the brightness.

The system will have built-in scripts that respond to certain conditions. For example, there is turning on a bright light in the morning or when natural light is reduced. The user can remotely control the brightness of the lighting through a mobile application or the web interface of the system (Fig. 6). The system can store data about the mode selected by the user and the reaction to various conditions. This data can be used to improve algorithms and train the system. These values may vary depending on specific parameters such as lamp efficiency, light intensity, and other factors. The possibility of using energy saving and optimization technologies to reduce energy consumption is also considered. To adjust the brightness

DOI 10.15588/1607-3274-2024-3-18

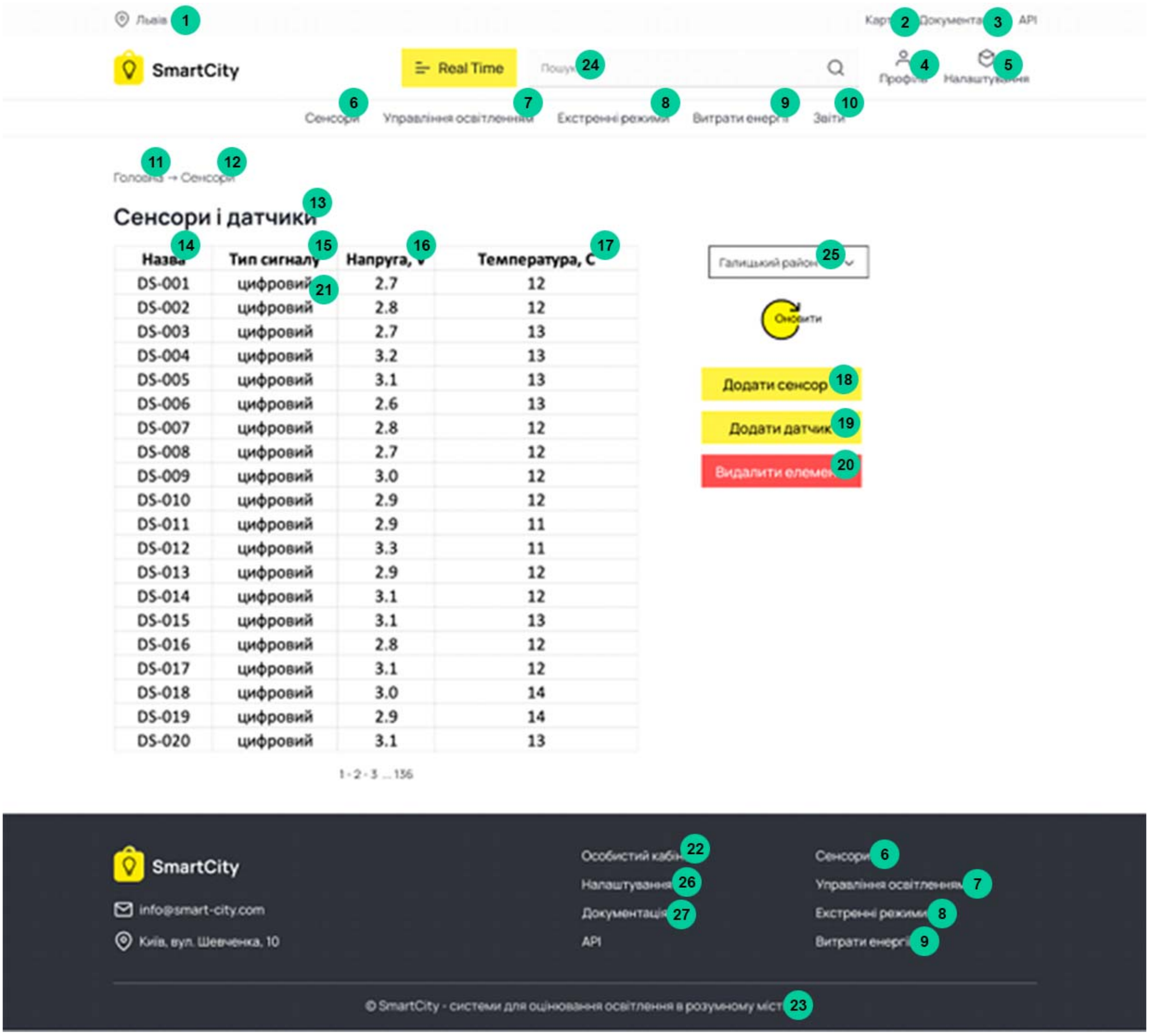

Figure 6 – Information system interface

1 – Lviv; 2 – map; 3 – documentation; 4 – profile; 5 – settings; 6 – sensors; 7 – lighting control; 8 – emergency modes; 9 – energy consumption; 10 – reports; 11 – main page; 12 – sensors; 13 – sensors and transmitters; 14 – name; 15 – signal type; 16 – voltage; 17 – temperature; 18 – add sensor; 19 – add transmitter; 20 – delete element; 21 – digital; 22 – personal account; 23 – a system for evaluating lighting in a smart city; 24 – find; 25 – Halytskyi district; 26 – Settings; 27 – documentation

of the lighting in a smart city, you can set the lighting schedule according to the needs of the city. For example, you can set the brightness to be increased during peak traffic hours and decrease it at night, when there are fewer people on the streets. In addition, it is necessary to consider that weather conditions, seasons, the presence of fog have a direct impact on the formation of lighting schedules.

4 EXPERIMENTS

It will be calculated the lighting schedule in accordance with the needs of the city. For example, you can set the brightness to be increased during peak traffic hours and decrease it at night, when there are fewer people on the streets.

It will be conducted a scenario with variable lighting brightness according to the needs of the city, taking into account peak traffic hours and nighttime.

Lighting schedule:

Peak traffic hours: 18:00 – 22:00 (4 hours).

Night time: 22:00 – 04:00 (6 hours).

Lighting intensity:

Peak hours: 20 lux.

Night time: 10 lux.

Number of lamps:

DOI 10.15588/1607-3274-2024-3-18

Peak hours: 29.000 lamps·20 lux = 580.000 lamps*lux.

Nighttime: 29.000 lamps·10 lux = 290.000 lamps·lux.

Consumed energy:

It is assumed that each lamp has a power of 30 watts.

Energy consumption during peak hours: Energy=580,000 lamps·lux·30 W·4 hours=69.600.000 Wh or 69.600 kWh

Energy consumption at night: Energy=290.000 lamps·lux·30 W·6 hours=52.200.000 Wh or 52.200 kWh hours

Therefore, the total energy consumption per day for this scenario would be approximately 121.800 kWh.

These calculations are used for further optimization and analysis of the efficiency of the lighting system in a smart city and for the development of lighting schedules.

Let's consider an example of the response of the information system to changes in the intensity of traffic using a differential equation. It is supposed that the street lighting intensity $I(t)$ depends on the traffic on the street and reacts to its changes at different times of the year. It can be used the equation to describe the lighting dynamics (Formula 6):

$$D(t) = k \times I(t) + a \times R(t) . \qquad (6)$$

The decrease in lighting intensity depends on the current level of lighting (attenuation) and increases with increasing traffic, the influence of the season, and the presence of fog.

It is appropriate to use Euler's method to solve this equation. Let's consider this on an example.

Initial conditions are $I(0) = 100$ (initial illumination level), $k = 0.01$ (attenuation coefficient), $a = 0.05$ (motion influence coefficient), $R(t)$ is the level of movement that can change over time. $R(t) = [5,10,15,8,12]$ and changes over time. It will be considered the array for saving the lighting intensity values $I(t) = [I,..0], t = 1$ is as a time step. It can be simulated the change in lighting intensity for 5 hours provided changing traffic levels on the street (Fig. 7).

The time of a year and the presence of fog can greatly affect the lighting schedule and the overall light level in the environment. Depending on the season, the factors that affect the duration and intensity of illumination in the dark time of a day change:

Duration of daylight. Depending on the season, the day can be shorter or longer, which leads to a change in the length of daylight and the hours with illumination at night.

Solstice angle. The angle of the solstice in the sky also changes with the season, which can affect how light falls on the ground and objects in the environment.

Light intensity. Sunlight can be more or less intense depending on the season, for example, in winter the light can be less bright due to more clouds or below the setting sun.

The presence of thick fog requires adjustment of the lighting intensity, which consists in the need to consider:

Scattering of light. Fog can scatter light, which leads to a decrease in its intensity and a decrease in the level of illumination in the environment.

Shading. Fog can also obscure lighting objects and reduce the amount of light that reaches the surface.

Lighting schedules are optimized to reduce energy consumption during low-traffic periods. Dynamic changes are displayed in graphs with the ability to adapt lighting schedules in real time based on changes in weather conditions, increase or decrease of activity in the lighting area, etc. The basis of the developed information system is an algorithm for monitoring and analyzing lighting data in different parts of the city, which provides for the continuous collection and processing of data for further improvement of schedules.

5 RESULTS

With the help of one of the methods of deep learning of recurrent neural networks (RNN) [15], particularly the Long Short-Term Memory (LSTM) layer for modeling temporal dependencies in time series made it possible to create a model for predicting street lighting needs. The information system starts forecasting LSTM uses a forgetting mechanism to avoid overloading its memory with unnecessary information.

1. Update login:

Forgetting: $f_t = \sigma(W_{xf} \times x_t + W_{hf} \times h_{t-1} + b_f)$.

Input: $i_t = \sigma(W_{xi} \times x_t + W_{hi} \times h_{t-1} + b_i)$.

Output: $o_t = (W_{xo} \times x_t + W_{ho} \times h_{t-1} + b_o)$.

2. Status update:

State candidate: $c_t = \tanh(W_{xc} \times x_t + W_{hc} \times h_{t-1} + b_c)$.

New state: $c_t = f_t \times c_{t-1} + i_t \times c_t$.

3. Exit Update:

Hidden state: $h_t = o_t \times \tanh(c_t)$,

where tanh is hyperbolic tangent.

An example of lighting calculations in a smart city using LSTM:

Conditional data:

The city is divided into 100 squares.

For each square we have data on:

Time of a day: 0–23 hours;

Day of the week: 0–6 (Sunday-Saturday);

Weather: sunny, cloudy, rainy;

Number of people: 0–1000;

Lighting level: 0–100 (lux).

DOI 10.15588/1607-3274-2024-3-18

Problem is to predict the required level of illumination for each square for the next hour.

LSTM model:

Input data: time of a day, day of the week, weather, number of people.

Output data: predicted lighting level.

Number of layers: 2.

Number of neurons in layers: 128, 64.

Activation function: sigmoid.

Studies:

The model is trained on 70% of the data.

30% of the data is used for testing.

Results:

The model can predict the level of illumination with an accuracy of 90%.

The model can dynamically adjust the lighting depending on the environmental conditions and the number of people in each square.

A calculation example: Square: 50; Check-in time: 22:00; day of the week: 5 (Friday); Weather: cloudy; Number of people: 200.

Projected lighting level is 45 lux.

The conducted experiments demonstrate the effectiveness of the developed information system in planning and managing street lighting for different geographical zones of the city. Energy efficiency indicators and satisfaction levels of the population were balanced to achieve an optimal level of illumination.

We received the lighting schedule.

```
Hour 0: light intensity = 100.00
Hour 1: light intensity = 99.25
Hour 2: light intensity = 98.76
Hour 3: light intensity = 98.52
Hour 4: light intensity = 97.93
Hour 5: light intensity = 97.56
```

Figure 7 – Generated lighting schedule

The experiment results confirm the ability of the information system to effectively manage lighting, leading to a reduction in electricity consumption and promoting sustainable urban development. The experiments validate the improvement in residents' quality of life by providing optimal street lighting levels according to their needs and the time of day. Additionally, a decrease in pedestrian-involved accidents and crimes due to increased visibility on the streets has been observed.

The experimental research also includes an analysis of technical system indicators such as reliability, responsiveness to changing conditions, compatibility with existing city infrastructure, and more. Therefore, the experiment results confirm the effectiveness and benefits of implementing the street lighting management information system in a smart city in terms of energy efficiency, safety, and economic viability.

6 DISCUSSION

The advantages of using LSTM for lighting calculations are the ability to predict the level of illumination with high accuracy; dynamically adjust the lighting depending on the conditions of the surrounding environment and the number of people moving on the street; save energy by using lighting only when it is needed.

Monitoring and data collection takes place with the help of sensors located in different parts of the city to measure energy consumption and collect data on the state of lighting and with the help of the Internet of Things and fog technologies. The implementation of the information system was carried out in the Python language using the library for working with the MQTT protocol.

The written code uses a simple MQTT client to connect to the central system via the MQTT protocol. The client subscribes to the "ligh-ing/commands" topic to receive commands from the central system and publishes lighting status reports to the "lighting/report" topic. The reports contain information about the lighting area and the current brightness level.

7 ACKNOWLEDGEMENTS

The research was conducted within the framework of the R&D project "Methods and Tools for Neuro-Fuzzy Control of a Group of Mobile Robotic Platforms".

CONCLUSIONS

The project on the creation of the information system designed to provide an energy-efficient lighting system in a smart city will contribute to increasing security, in particular, ensuring the safety of the community through integration with security systems, reducing energy consumption, through minimizing the use of electricity in periods when the need for lighting is not necessary.

It was determined that in order to implement an information system for remote monitoring and control of lighting in a smart city, it is advisable to consider the possibility of using a complex lighting control system. Calculations were made on the example of Lviv for the city's lighting needs. The use of motion detectors to determine the need to turn on lighting is analyzed. A conceptual model of the information system was developed using the object-oriented methodology of the UML notation. The main functionality of the information system is defined.

REFERENCES

1. Raskar P., Samant R., Mote R., Patil V., Nighul K. Lighting System for Smart Cities, *International Journal of Science Technology & Engineering*, 2017, Vol. 3, Issue 10, pp. 367–372.

DOI 10.15588/1607-3274-2024-3-18

2. Castro M., & Jara A., Skarmeta A. Smart Lighting Solutions for Smart Cities, *Proceedings: 27th International Conference on Advanced Information Networking and Applications Workshops (WAINA),* 2013, pp. 1374–1379. DOI: 10.1109/WAINA.2013.254
3. Dankan Gowda V., Arudra Annepu, Ramesha M., Prashantha Kumar, Pallavi Singh IoT Enabled Smart Lighting System for Smart Cities, *Journal of Physics: Conference Series 2089 (1): 012037*, 2021. DOI: 10.1088/1742-6596/2089/1/012037
4. Kumar P., Smys S., Raj J.S. Ingenious Lighting System (ILS) for Smart Cities Using IoT, *In book: International Conference on Mobile Computing and Sustainable Informatics, ICMCSI 2020*, 2020. DOI: 10.1007/978-3-030-49795-8_14
5. Gowda D., Kishore V., Shivashankar A., Ramachandra C., Pandurangappa C. Optimization of motorcycle pitch with non linear control, *In 2016 IEEE International Conference on Recent Trends in Electronics, Information and Communication Technology, RTEICT*, 2016, pp. 1656–1660. DOI: 10.1109/RTEICT.2016.7808114
6. Pai G. Naveena, Pai M. Swathi, Gowda Dr.Dankan V, Shruthi M., Naveen B. K. Internet of Things: A Survey on Devices, Ecosystem, Components and Communication Protocols, *2020 4th International Conference on Electronics, Communication and Aerospace Technology (ICECA)*, 2020, pp. 611–616. DOI: 10.1109/ICECA49313.2020.9297458
7. Badgelwar, S. S., Pande H. M. Survey on energy efficient smart street light system, *2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC),* 2017. DOI: 10.1109/I-SMAC.2017.8058303
8. Regulation of the Minister of Transport and Maritime Economy of 23 December 2015 on the technical conditions to be met by public roads and their location, *Journal of Laws of 2016,* item 124.
9. Wu S. Lighting Environment and Perceived Safety. Master's Thesis, Virginia Polytechnic Institute and State University, Blacksburg, WV, USA, 2014.
10. Johansson M., Rosen M., Kuller R. Individual factors influencing the assessment of the outdoor lighting of an urban footpath, *Lighting Research and Technology*, 2011, No. 42 (1), pp. 31–43. DOI: 10.1177/1477153510370757
11. Blobaum A., Hunacke M. Perceived Danger in Urban Public Space: The Impacts of Physical Features and Personal Factors, *Environment and Behaviour,* 2005, No. 37 (4), pp. 465–486. DOI: 10.1177/0013916504269643
12. Subbotin S. The neuro-fuzzy network synthesis and simplification on precedents in problems of diagnosis and pattern recognition, *Optical Memory and Neural Networks (Information Optics)*, 2013, Vol. 22, No. 2, pp. 97–103. DOI: 10.3103/s1060992x13020082
13. Oliinyk A. A., Subbotin S. A. Neural network synthesis based on evolutionary optimization, *System research and information technologies*, 2015, № 1, pp. 77–86.
14. Subbotin S. A. The instance individual informativity evaluation for the sampling in neural network model synthesis, *Radio electronics, informatics, management,* 2014, № 2, pp. 64–72. Access mode: http://nbuv.gov.ua/UJRN/riu_2014_2_12
15. Goodfellow I., Bengio Y., Courville A. Deep Learning, 2016. Access mode: https://www.deeplearningbook.org/

Received 03.04.2024.
Accepted 19.08.2024.

УДК 004.89:628.971.6:[004.415/.416:71/72]:005.521

ІНФОРМАЦІЙНА СИСТЕМА КОНТРОЛЮ ВУЛИЧНОГО ОСВІТЛЕННЯ У РОЗУМНОМУ МІСТІ

Васьків Р. І. – аспірант кафедри інформаційних систем та мереж Національного університету «Львівська політехніка», Львів, Україна.

Грибовський О. М. – магістр кафедри інформаційних систем та мереж Національного університету «Львівська політехніка», Львів, Україна.

Кунанець Н. Е. – д-р наук з соц. ком., професор кафедри інформаційних систем та мереж Національного університету «Львівська політехніка», Львів, Україна.

Дуда О. М. – канд. техн. наук, доцент кафедри комп'ютерних наук Тернопільського національного технічного університету ім. І. Пулюя, Тернопіль, Україна.

АНОТАЦІЯ

Актуальність. У контексті стрімкого розвитку технологій та впровадження концепції смарт-сіті, розумне освітлення стає ключовим елементом сталого та ефективного міського середовища. Дослідження охоплює аналіз аспектів використання давачів, інтелектуальних систем управління освітлення з допомогою сучасних інформаційних технологій, зокрема таких як Інтернет речей. Застосування таких технологій дозволяє автоматизувати регулювання інтенсивності освітлення в залежності від зовнішніх умов, руху людей чи часу доби. Це сприяє ефективному використанню електроенергії та зниженню викидів в атмосферу.

Мета роботи полягає в аналізі процедур створення інформаційної системи, як інструменту моніторингу та оцінювання рівня освітленості в розумному місті з метою покращення енергоефективності, безпеки, комфорту та ефективного управління освітленням. Реалізація системи розумного освітлення для міста Львова сприятиме покращенню енергоефективності та безпеки громади.

Метод. Проведено контент-аналіз наукових публікацій, в яких подано результати дослідження щодо створення систем моніторингу вуличного освітлення в реальних міських середовищах. Проведено збір та аналіз даних про вуличне освітлення в місті, таких як енергоспоживання, рівень освітленості, графіки роботи світильників та інші. Використано методи машинного навчання для аналізу даних та прогнозування потреб в освітленні. З використанням методології UML розроблено концептуальну модель інформаційної системи моніторингу вуличного освітлення на основі виявлених потреб і вимог.

Результати. Висвітлюється роль технологій опрацювання даних у створенні ефективних стратегій управління освітленням для оптимального використання ресурсів та задоволення потреб містян. У дослідженні звертається увага на виклики та

DOI 10.15588/1607-3274-2024-3-18

можливості впровадження розумного освітлення у містах, максимізації позитивного впливу розумного освітлення на сучасні міські середовища. Проаналізовано особливості розроблення та використання інформаційної системи для контролю вуличного освітлення в розумному місті. Визначено потенційні переваги та обмеження використання розробленої системи.

Висновки. Проект із створення інформаційної системи, що покликана забезпечити енергоефективну систему освітлення в розумному місті, сприятиме підвищенню безпеки, зокрема, забезпечення безпеки громади через інтеграцію з системами безпеки, зменшення енергоспоживання, через мінімізацію використання електроенергії в періоди, коли потреба освітлення не є необхідною.

Визначено, що для реалізації інформаційної системи дистанційного моніторингу та управління освітленням в розумному місті, доцільно розглянути можливість використання комплексної системи управління освітленням. Проведено розрахунки на прикладі Львова потреби освітленні міста. Проаналізовано використання давачів руху для визначення необхідності увімкнення освітлення. Розроблена концептуальна модель інформаційної системи з використанням об’єктно-орієнтованої методології нотації UML. Визначено основний функціонал інформаційної системи.

КЛЮЧОВІ СЛОВА: інформаційна система, система освітлення, розумне місто, дистанційний моніторинг, прогнозування.

ЛІТЕРАТУРА

1. Lighting System for Smart Cities / [Raskar P., Samant R., Mote R. et al.] // International Journal of Science Technology & Engineering. – 2017. – Vol. 3, Issue 10. – P. 367–372.
2. Castro M. Smart Lighting Solutions for Smart Cities / M. Castro, & A. Jara, A. Skarmeta // Proceedings: 27th International Conference on Advanced Information Networking and Applications Workshops (WAINA). – 2013. – P. 1374–1379. DOI: 10.1109/WAINA.2013.254
3. Pallavi Singh IoT Enabled Smart Lighting System for Smart Cities / [Dankan Gowda V., Annepu, M. Ramesha et al.] // Journal of Physics: Conference Se Arudra ries 2089 (1): 012037. – 2021. DOI: 10.1088/1742-6596/2089/1/012037
4. Kumar P. Ingenious Lighting System (ILS) for Smart Cities Using IoT / P. Kumar, S. Smys, J. S. Raj // In book: International Conference on Mobile Computing and Sustainable Informatics, ICMCSI 2020. – 2020. DOI: 10.1007/978-3-030-49795-8_14
5. Optimization of motorcycle pitch with non linear control / [D. Gowda, V. Kishore, A. Shivashankar et al.] // in 2016 IEEE International Conference on Recent Trends in Electronics, Information and Communication Technology, RTEICT. – 2016. – P. 1656–1660. DOI: 10.1109/RTEICT.2016.7808114
6. Internet of Things: A Survey on Devices, Ecosystem, Components and Communication Protocols / [G. Naveena Pai, M. Swathi Pai, Dankan V Gowda et al.] // 2020 4th International Conference on Electronics, Communication and Aerospace Technology (ICECA). – 2020. – P. 611–616. DOI: 10.1109/ICECA49313.2020.9297458
7. Badgelwar S. S. Survey on energy efficient smart street light system / S. S. Badgelwar, H. M. Pande // 2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC). – 2017. DOI: 10.1109/I-SMAC.2017.8058303
8. Regulation of the Minister of Transport and Maritime Economy of 23 December 2015 on the technical conditions to be met by public roads and their location // Journal of Laws of 2016. – item 124.
9. Wu S. Lighting Environment and Perceived Safety / S. Wu. – Master’s Thesis : Virginia Polytechnic Institute and State University. – Blacksburg, WV, USA, 2014.
10. Johansson M. Individual factors influencing the assessment of the outdoor lighting of an urban footpath / M. Johansson, M. Rosen, R. Kuller // Lighting Research and Technology. – 2011. – No. 42 (1). – P. 31–43. DOI: 10.1177/1477153510370757
11. Blobaum A. Perceived Danger in Urban Public Space: The Impacts of Physical Features and Personal Factors / A. Blobaum, M. Hunacke // Environment and Behaviour. – 2005. – No. 37 (4). – P. 465–486. DOI: 10.1177/0013916504269643
12. Subbotin S. The neuro-fuzzy network synthesis and simplification on precedents in problems of diagnosis and pattern recognition / S. Subbotin // Optical Memory and Neural Networks (Information Optics). – 2013. – Vol. 22, № 2. – P. 97–103. DOI: 10.3103/s1060992x13020082
13. Oliinyk A. A. Neural network synthesis based on evolutionary optimization / A. A. Oliinyk, S. A. Subbotin // System research and information technologies. – 2015. – № 1. – P. 77–86.
14. Subbotin S. A. The instance individual informativity evaluation for the sampling in neural network model synthesis / S. A. Subbotin // Radio electronics, informatics, management. – 2014. – № 2. – P. 64–72. – Access mode: http://nbuv.gov.ua/UJRN/riu_2014_2_12
15. Goodfellow I. Deep Learning / I. Goodfellow, Y. Bengio, A. Courville. – 2016. – Access mode: https://www.deeplearningbook.org/

DOI 10.15588/1607-3274-2024-3-18