The quality monitoring of outdoor lightning using IoT technologies

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Abstract. This paper discusses the various aspects of the instrumental quality monitoring of city outdoor lighting using IoT technologies on the example of the central area of Perm city, such as selection of the monitored parameter and its measurement methods, methods of processing measured data, the applicability of the results of measurements for various applications using Big Data.

1. Introduction

Dark time in the middle zone of Russia is about 40% of the day time, with about half of this time falls on the evening and the morning, ie, time of increased business activity of the population [1].

Currently, the quality monitoring of outdoor lighting in most Russian cities insufficient attention is given. And this is despite the fact that the quality of outdoor lighting defines such important parameters of the urban environment at night, such as: security, energy efficiency, ergonomics and presentable. At the same time in most operating companies the quality monitoring process of outdoor lighting is based on outdated methods and measuring instruments [2].

This work aims to develop a prototype of an automated system for controlling the quality of outdoor lighting and assessing the possibility of replacing manual measurements with automated ones.

2. Development and testing of the system prototype

2.1. Selecting the monitored parameters

As the parameters for measuring and monitoring can be used illuminance and luminance [3]. Both parameters characterize the quality of the lighting system and have comparable values in the regulations. Both parameters can be measured with manual and automated tools. But these parameters have a number of differences in their use from a practical point of view.

The disadvantages of the luminance measurement:

- Non-Proliferation of luminance monitoring procedure (and no devices) in the majority of cities in Russia;

The high cost of equipment for the automated measurement;
- The high labor intensity of processing of measurement results.

The main disadvantage of illumination measurement is that the measurement and monitoring of the luminance (but not illuminance) are used in the European standards as the main normalized parameter [4, 5]. However, by aggregate value (low-cost measuring devices, simple processing of measurement results, the presence of norms, accurate description of the state of the lighting of the lighting installation, minimal impact on the accuracy of measurement from surrounding vehicles) the illuminance was chosen as the monitored parameter.

Illuminance measurement is possible to produce manually or automatically. Manual measurements are widespread at the moment, but are rarely made, because typical illumination measurement in one area takes about 3 hours at a midnight (least vehicles which can interrupt measurement) and require a change operating mode of lighting system in the full (evening) mode. Quality lighting monitoring in the city at a frequency at least 1 time in 12 months with handheld devices is not possible because of the very high complexity of the method.

2.2. Development of a measuring device

For the automated control of illumination with use of the car the mobile sensor of illumination working in an automatic mode has been developed. The device contains an ambient light sensor, a GPS receiver, a device for storing the readings of sensors, a microprocessor and a modem for transmitting readings to the server (Figure 1).

The characteristics of the device are given in Table 3. This device is placed on the roof or on the vehicle trailer, which is moving through the streets so as to pass all its lanes. To increase the accuracy of measurements can be used several devices in different parts of the vehicle roof [6]. To perform accurate measurement created devices were calibrated using an illuminance meter attorney LXP-1 as a standard.

![Figure 1. The operating principle of mobile measurement device of illumination.](image)

2.3. Selection of urban area with outdoor lighting

The main criteria for the choice of the site of the city: the high traffic, large number of road accidents, the presence in the site of different types of outdoor lighting systems in different states and the relative compactness of the site. The central planning area of Perm meets these requirements (Table 1).

| Parameter                  | Value       |
|----------------------------|-------------|
| The area of the selected site, km² | 5,2         |
| The length of the streets, km. | 49          |
| Streets categories         | B1, B2, V1, V2 |

Table 1. Characteristics of the selected site of Perm.
Also, several smaller sites were selected for more detailed research on specific criteria (Table 2).

Table 2. Characteristics of the selected site of Perm.

| Address Study                                      | Study                                      |
|----------------------------------------------------|--------------------------------------------|
| Ekaterininskaya str. 170 - 190                      | Analysis of the quality of repair of lighting installations |
| Okulova str. 14 – 75 k3                              | Data collection on the site with old equipment |
| Lenina str. 74 – 100                                | Analysis of the impact of lighting on the vehicle accidents |
| Uinskaya str. 5 – 13                                | Analysis of the proposed method of processing measurement results |
| Marshala Rybalko str. 11 – 111                      | Analysis of the impact of lighting on road accidents involving pedestrians |

2.4. Development of a method for calculating the average illumination of a plot

Measurements of illumination according to standard [2] are performed manually at grid nodes applied to the monitored section of the street with uniform pitch (Figure 2). Further, the average illumination is calculated from formula (1) [7].

\[
E_{avg} = \frac{\sum_{i=1}^{M} E_i}{M}
\]  

When using automatic measurements from a vehicle, in general, it is impossible to ensure a uniform distribution of measurements over the area of the monitored section of the street (Figure 3, 4). In this case, the calculation of the average amount of illumination at the site by the method of [7] and formula (1) will give us the wrong result.

A new iterative calculation technique was developed. At the first step, the analyzed road segment is divided into a large number of rectangles of equal size. The recommended size of the rectangle is at least 1x1 m, and no more than 3x3 m (the smaller the size of the original rectangle, the higher the accuracy). For each rectangle, the average illumination is calculated from the formula (1) among all points that fall in this rectangle.

At the next step, the plot is divided into larger rectangles, so that at least four rectangles from the previous step get into each of them. For each enlarged rectangle, the average illumination is calculated from formula (1).

Then again, the plot is divided into larger rectangles with the appropriate calculation, and so repeats until you get one rectangle, which includes the entire study section of the road.

The figure obtained from the automatically collected data according to the developed method corresponds to the figure calculated according to the procedure [7] based on the results of manual measurements at the same site by the method [2].

Table 3. Features of the device.

| Parameter                                      | Measurement accuracy |
|-----------------------------------------------|----------------------|
| Time                                          | 10 ms                |
| Illuminance                                    | 0.5 lx               |
| Latitude, longitude in WGS84 system            | 2 m                  |
| The frequency parameters fixing                | 8 Hz                 |
| The allowable range of the carrier vehicle speeds | 5-60 km/h          |
| Data transfer channel to the server            | 3G                   |
| Data transfer protocol                         | MQTT                 |
2.5. **Software development for data processing and visualization**

To automate the collection, processing of data and their visual representation, an application program was developed in C++.

The program operates in a 24/7 mode on a server connected to the Internet, receives data from the devices using the MQTT protocol and stores them in a database implemented in the ORACLE DBMS. Data analysis uses SQL queries and visual representation of data in 2D or 3D.

2.6. **Organization of data collection**

In the dark, two cars with instruments traveled the streets of the area under investigation at a speed of 10-40 km/h, so as to measure the illumination on each lane. The measured data from the devices through the 3G connection were transmitted to the server, where they were stored in the database. As a result, for about 70 days, about 0.5 million illumination measurements were collected.
In addition to illumination, for each area under study, additional necessary indicators were collected: by the number and types of accidents [8], the illumination standards [3]. This data was also uploaded to the database.

3. Analysis of collection data
At the study site it was revealed the whole range of problems with lighting systems:

- Insufficient average illuminance;
- High illuminance non-uniformity;
- Overstated average illuminance;
- Insufficient illuminance at pedestrian crossings;
- Insufficient illuminance at crossroads.

Error in the design or design for understated (overstated) standards is a main reason of deviations from the norm. Defective equipment (lamps, ballasts) is reason for a small number of identified problems.

It is known that the multiplication at 2 - 5 of the original illuminance level, leads to reduction of the number of accidents in the dark for about 10%. When the illuminance level is increased more than x5 from the original level, the number of fatal accidents and injuries is decreased by 30% [8]. Within the framework of the research, the dependence of the number of accidents on the fixed amount of illumination was analyzed.

Over the period 2015-2016 was officially registered about 4,000 traffic accidents (30% of them at night). About 500 traffic accidents were registered in the investigated site (12% of the total). From them, 250 traffic accidents were in dark (50% of the accidents at the site). The biggest count of the road accidents in investigated site were registered at road intersections and pedestrian crossings [8]. Analysis of identified problems with lighting and statistics of accidents at night on the site in question, gives grounds to believe that these facts depend.

4. Conclusions
As a result of the research, practical tasks were solved, which were solved with the help of instrumental illumination monitoring by the proposed method.

![Figure 5. Street site with low illuminance level.](image)

It is possible and economically effective to replace the virtually absent manual pedestrian illumination measurements with automated ones from the vehicle for an express assessment of the state of lighting equipment.
Such measurements make it possible to quickly identify (15 minutes to 3 hours) the problems of not matching real street lighting with existing regulations and, if necessary, produce tad-cost manual legally significant measurements already in a clearly defined place.

The measurement of illumination by the proposed method makes it possible to control illumination in all points of a large city more than twice a year using only one car.

The proposed instrumental monitoring method allows you to identify and control situations [9]:

- Insufficient average illuminance;
- High illuminance non-uniformity;
- Overstated average illuminance;
- Insufficient illuminance at pedestrian crossings and crossroads;
- Facts of untimely switching of lighting.

![Figure 6. The distribution of accidents that occurred in the dark in the city of Perm in the period 2015-2016. by time of day.](image)

The developed prototype of the automated system allowed to quickly and effectively solving the tasks assigned to its: collecting, storing, processing, analyzing and visualizing large volumes of raw data [10]. Prototype has been tested and patented successfully [11]. This research is also helped at implementation of a new Master’s program "Conceptual design and engineering to improve energy efficiency" for preparing of engineering and administrative skills for new generation’s master’s students [12].

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