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Methodological Assessment of Street Lighting With the Effect of Light Scattering in the ITSGIS Intelligent Transport Geographic Information System Personified Approach

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***Abstract*— From the position of system analysis, among the tasks that are solved in the framework of managing the functioning of the transport infrastructure, the tasks of monitoring the characteristics of the road network, traffic flows, and traffic control equipment stand separately. The solution of such problems requires tools that provide these processes with universal means of creating and dynamically modifying objects. Intelligent transport GIS "ITSGIS" is based on modern evolving information technology, combining the ability to create thematic layers of an interactive map, work with a database, with objects of transport infrastructure, with visualization of data in the form of interactive geo objects on a geographical map. The article discusses the methodological assessment of street lighting with the effect of light scattering in the ITSGIS intelligent transport geographic information system. The personified approach is implemented on the thematic layers of an interactive electronic map with visualization of the location of lighting geo-objects with modeling at night. Visualizing the illumination uses a new algorithm for calculating the scattering coefficient, based on calculating the deviation between the ratio of the distances from the current point to the focus and to the directivity and the eccentricity of the curve.**

Keywords—Intelligent transport geographic information system, "ITSGIS", lighting, modeling.

I. Introduction

The relationship of people to the transport infrastructure, nature, road safety, the software created by them, is characterized by a complex combination of interactions and contradictions, which are reflected in the functionality of the transport infrastructure, including the level of social significance, complex the scheme of the organization of road traffic, the effectiveness of transport relations, relationships, processes. The socio-economic development of national structures dictates the need to solve problems with the contradictions between the needs of the population in movement and their security and optimal functionality of the transport infrastructure [1, 2].

Comprehensively linking various types of functional transport infrastructure, geo objects of an interactive electronic map of an intelligent transport geographic information system, transport processes have a number of factors that affect the living standards of cities, the economic activity of society, its cultural and social development [3, 4].

When developing a methodology for improving security and the social significance of transport infrastructure, it is important to increase the reliability of transport services for the population by individual and public transport, which depends on a number of indicators. At the same time, by individual automobile transport is meant a passenger transport of individuals, performing a certain volume of passenger traffic, by public transport - passenger vehicles that provide official transportation of the population. The relevance of studying the problem associated with the functional transport infrastructure, taking into account transport processes based on geo objects and automobile transport, is associated with a high share of individual automobile transport in the total volume of traffic (15% or more) relative to all types of mass passenger transport, despite the fact that its share in the traffic flow exceeds 80% [5].

II. Methodology Of Developing Integrated Schemes Of Organization Of Road Traffic In ITSGIS

The methodology for the development of integrated traffic management schemes, taking into account the functionality of the transport infrastructure in the settlements, is based on principles that take into account strategic directions for the development and improvement of activities in the area of traffic rules in the study area, and is aimed at ensuring complexity in solving problems of organizing traffic and pedestrian flows with complex visualization of the solved problems on an interactive electronic map on various thematic layers Predictive trans tailor geoinformation «ITSGIS» system [6].

As a methodological and informational basis for constructing an intelligent transport geo-information system for managing the functioning of transport infrastructure, taxonomy models are used that underlie object-oriented construction of instrumental environments focused on the development of complexly organized systems [7, 8, 9, 10]. Intelligent transport geo-information system "ITSGIS" is a tool for storing and processing geodata, combines the ability to create thematic layers of an interactive map, work with a database, with transport infrastructure objects, with visualization of data in the form of inter-active geo objects on a geographical map [11, 12] and has high potential in the field of intellectual decision support. Fields of application of ITSGIS are based on network-centric management tasks.

The geo-information component of ITSGIS records geo-objects (polygonal, linear, point) of an electronic map with their semantic filling (geo-object purpose, organization affiliation, scanned documents, contacts for communication with the population, etc.).

One of the subsystems (plug-ins) of ITSGIS is a system of expert deployment of technical means of organizing traffic on thematic layers with their visualization on an electronic map, designed to verify the correct installation of road signs, traffic lights and other geo objects of the transport infrastructure [12-15].

One of the ITSGIS plugins designed to solve the problems of network-centric management of transport infrastructure facilities is the subsystem of dynamic modeling of street lighting [16, 17]. It is designed to solve the problems of the location of lighting geoobjects on special thematic layers, the design and reorganization of outdoor lighting parameters, the tasks associated with monitoring the quality of automatic work and real-time control of street lighting facilities within the framework of the Smart City program and the concept of the Internet of things.

The article discusses a street lighting model developed and implemented by the authors, based on the geometric and physical properties of light, including a new model of light scattering in the vicinity of a light spot.

The role of controlled geo-objects - lighting sources - in the model is performed by lights installed on light poles. It is assumed that the lantern consists of a lamp and a reflector in the form of a truncated straight circular cone, inclined at a given angle to the axis of the support. For each such source, all parameters of the illuminated zone on the electronic map are calculated, and the total illumination of each point is summed up over all sources acting on it.

Below is a description of the operation of the algorithm for a single source.

The initial parameters are set by the following (mutable) constants:

A – lamp angle ($A \in [0, \pi/2)$), zero angle corresponds to the direction of the axis of the cone of light vertically downward);

B – horizontal angle of rotation of the lamp ($B \in [0, 2\pi]$, at B = 0, the axis of the light cone is orthogonal to the axis OY for any A);

θ – cone angle;

H - the height of the light source;

Φ – preset luminous flux (in lumens, lm).

III. Definition Of The Light Spot Equation

The equation is constructed in a two-dimensional coordinate system with the origin at the base of the projection of the point of location of the light source on the plane of the map surface under the assumption that the light rays pass inside a straight circular cone. Thus, having written the cone equation taking into account the corresponding linear transformations, it is easy to find its intersection with the OXY plane. The resulting border of the light spot is a second-order curve.

$$a_{11}x^2 + 2a_{12}xy + a_{22}y^2 + 2a_{13}x + 2a_{23}y + a_{33} = 0,$$

with coefficients

$$a_{11} = c_1\cos^2 B + c^2\sin^2 B$$

$$a_{12} = \sin B\cos B(c_1 - c^2)$$

$$a_{22} = c_1\sin^2 B + c^2\cos^2 B$$

$$a_{13} = -\frac{1}{2}\,c_2\cos B,\quad a_{23} = -\frac{1}{2}\,c_2\sin B$$

$$a_{33} = -H^2(\cos^2 A - c^2\sin^2 A),$$

where

$$c = \tan^{-1}\frac{\theta}{2},$$

$$c_1 = c^2\cos^2 A - \sin^2 A,$$

$$c_2 = 2H\sin A\cos A(c^2 + 1),$$

IV. Determination Of The Light Quantity

To determine the illumination of each point inside the light spot limited by the obtained curve, the light intensity is calculated (in candelas, cd)

$$I = \Phi/\gamma,$$

where γ is the solid angle at the apex of the straight circular cone

$$\gamma = 2\pi\left(1 - \cos\frac{\theta}{2}\right).$$

The amount of illumination (in lux, lx) at each point in a predetermined area of the screen (inside the light spot) is

$$E = \frac{I}{R^2}\cos\beta = \frac{I}{R^2}\cdot\frac{H}{R} = \frac{IH}{(x^2+y^2+H^2)^{3/2}}. \quad (1)$$

Here R is the distance from the light source to the current point on the surface;

β – is the angle between the ray of light directed to the corresponding point and the normal to the surface;

(x, y) - coordinates of the surface point (in meters) relative to the projection of the light source (calculated based on the coordinates of the corresponding point on the screen, the coordinates of the source itself and the map scale currently being used).

V. Modeling Of Scattered Light

In order to achieve physical realism in calculating the final gradation of the brightness of a point on the screen, a scattering algorithm was developed and implemented that blurred the border of the light spot. The calculation of the scattering coefficient is based on the deviation of the distance ratio from the current point to the focus and to the directrix from the eccentricity.

First, the coordinates of the curve vertex closest to the source are sequentially calculated

$$x_v = H\tan\left(A - \frac{\theta}{2}\right)\cos B$$

$$y_v = H\tan\left(A - \frac{\theta}{2}\right)\sin B$$

and curve invariants

$$I_1 = a_{11} + a_{22}$$

$$I_2 = \begin{vmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{vmatrix},$$

$$I_3 = \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{12} & a_{22} & a_{23} \\ a_{13} & a_{23} & a_{33} \end{vmatrix}.$$

Further calculations depend on the type of curve. In the case of an ellipse or a hyperbola ($I_2 \neq 0$) the square of the major semi-axis (ellipse) or the square of the real semi-axis (hyperbole) is calculated

$$a_{qu} = \frac{1}{4} H^2 \left(\tan\left(A + \frac{\theta}{2}\right) - \tan\left(A - \frac{\theta}{2}\right)\right)^2,$$

and the square of the minor semi-axis (ellipse) or the square of the imaginary semi-axis with a minus sign (hyperbole)

$$b_{qu} = -\left(I_1 I_2 / I_3 + a_{qu}^{-1}\right)^{-1}.$$

For curves of both types, we calculate the eccentricity as

$$\varepsilon = \sqrt{1 - \frac{b_{qu}}{a_{qu}}},$$

as well as the distance from the focus to the nearest vertex (perifocal / pericentric distance)

$$d_{fv} = \sqrt{a_{qu}}\,|1 - \varepsilon|$$

For a parabola, respectively, the last two values are equal

$$\varepsilon = 1, \quad d_{fv} = -\frac{1}{2} \frac{a_{13}\cos B + a_{23}\sin B}{I_1}$$

Then the coordinates of the focus (the nearest, if there are two) for all types of curves are equal

$$x_f = x_v + d_{fv}\cos B, \quad y_f = y_v + d_{fv}\sin B$$

and the directrix point closest to the vertex is

$$x_{dir} = x_v - \frac{d_{fv}}{\varepsilon}\cos B, \quad y_{dir} = y_v - \frac{d_{fv}}{\varepsilon}\sin B.$$

To determine the scattering coefficient for a point with coordinates (x, y) relative to the projection onto the plane of the map of the light source, the distances from it to the focus and to the directrix are calculated

$$d_f = d_f(x, y), \quad d_{dir} = d_{dir}(x, y):$$

$$d_f^2 = (x - x_f)^2 + (y - y_f)^2, \quad d_{dir} = |(x_{dir} - x)\cos B + (y_{dir} - y)\sin B|.$$

Further, for points outside the light spot, i.e. such that

$$d_f / d_{dir} > \varepsilon$$

the scattering coefficient f is assumed to be equal to

$$f = \begin{cases} 1 - 2z^2, & 0 < z < \frac{1}{2} \\ 2(z-1)^2, & \frac{1}{2} < z < 1 \\ 0, & z > 1 \end{cases}, \qquad z = \frac{d_f}{\varepsilon \cdot d_{dir}} - 1$$

(note that for all points of the boundary, z = 0 and f = 1, and outside the boundary, z> 0 and 0 <f <1). For points inside the illuminated zone, we set f = 1.

Finally, the value of the gradation (0–255) of the brightness of a point on the screen (when illuminated by a single source) is set equal to

$$e = \min\{f \cdot K \cdot E,\ 255\}, \qquad (2)$$

where the illumination value E is calculated by the formula (1) (as if this point was inside the illuminated zone), K = 1.5 is an experimentally selected constant.

Thus, inside and at the border of the light spot, the brightness value depends only on the illumination e, while outside the border it gradually decreases. In this case, one can observe the effect of light scattering when moving along the border of the light spot

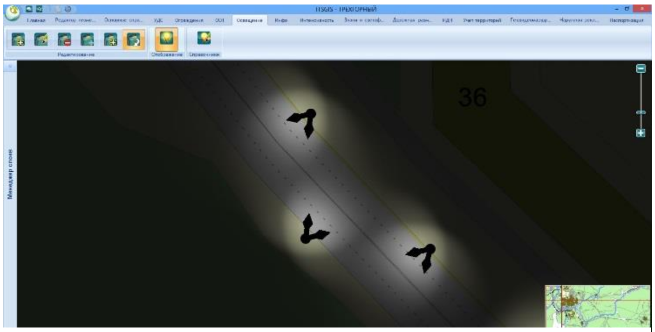


Figure 2

Figure 1

from the source (Figure 1).

When illuminating a single point with several sources, the corresponding gradation values are added up (Figure 2). Note that in order to save computational resources, the scattering coefficient f for each source in the ITSGIS system was calculated, being limited only to the points of the region $x^2 + y^2 < D^2$, where

$$D = 2\sqrt{\left(\frac{IHK}{5}\right)^{2/3} - H^2}.$$

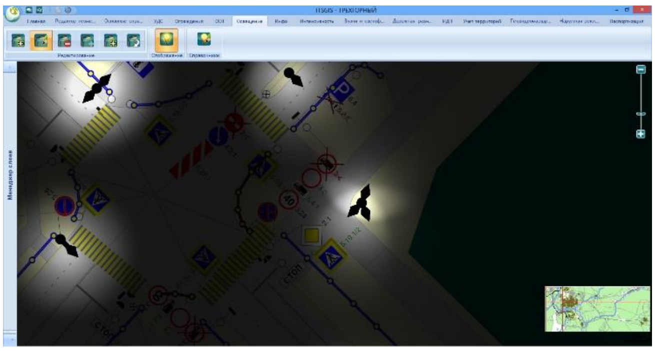


Figure 2

VI. Implementation Of Lighting Tasks

Application of lighting technology is used to solve various problems.

Events to improve the conditions of pedestrian traffic, presented in the ITSGIS database, are displayed on thematic layers of the integrated traffic management scheme. New sidewalks, pedestrian and bicycle paths were proposed, the corresponding road signs 5.19.1, 5.19.2 "Pedestrian Crossing", pedestrian fences, special lighting were displayed on them. All new geo objects of transport infrastructure have the status: "Required".

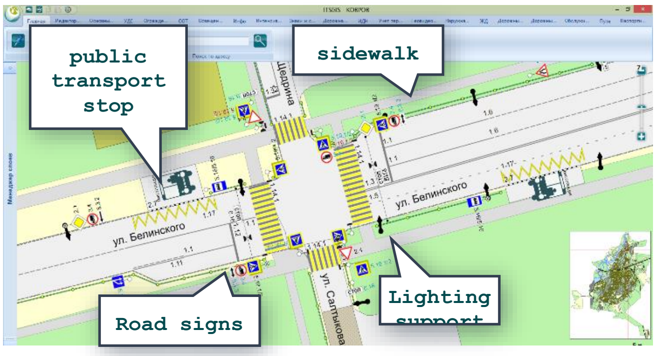
Traffic signs have a green signature, sidewalks, lighting, pedestrian fences have a blue tint in the display of symbols when visualizing objects on an electronic map (Figure 3).

The following typical tasks of organizing the movement of pedestrians [18]:

– providing independent ways for people to move along streets and roads;

– equipment of pedestrian crossings with traffic signs with internal lighting in order to improve visibility, in particular, unregulated pedestrian crossings, especially at night, traffic signs 5.19.1 or 5.19.2 with internal lighting and a reflective surface "Pedestrian crossing" in accordance with GOST 52290 - 2004.

Figure 3

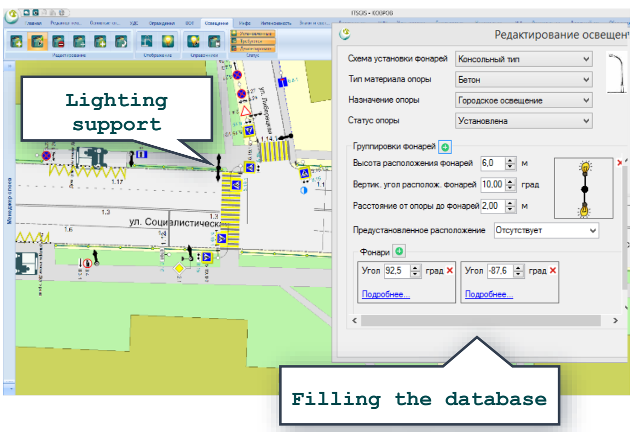


VII. Conclusion

Dislocation of artificial lighting with lighting simulation

Visibility conditions play a big role in ensuring safe driving. In the dark, contrasts, details and movements along the road are perceived by the driver much worse than in the daytime. It is for this reason that the likelihood of accidents in the dark increases. For vehicles, the risk of accidents in the dark is 1.5-2 times higher than in daylight. This statement is also true for pedestrians. On average, about 20 - 25% of the time, the movement of vehicles is carried out in the dark. At the same time, in the dark, about 35% of accidents occur. This figure applies to accidents both in settlements and beyond. Most accidents in the evening and at night are associated with the participation of pedestrians or with the exit of the car from the road. Road lighting reduces the risk of accidents by facilitating the perception of the road and its immediate surroundings, as well as the timely detection of other road users.

Figure 4



Road lighting is any artificial lighting of roads, streets, intersections and pedestrian lanes. In settlements, roads and streets are generally more or less lit.

Road lighting reduces the number of fatal accidents by about 65%, the number of accidents with injuries by 30% and the material damage from accidents by about 15%. These results were obtained as a result of a large number of studies conducted over a long time in many countries. Road lighting has a stronger effect on the number of accidents with pedes-trians (a decrease of about 50%) than other types of accidents.

A comprehensive traffic management scheme taking into account the dislocation of artificial road lighting was made on the appropriate thematic layers of the ITSGIS interactive elec-tronic map.

Aggregate lists of artificial road lighting in the streets are present in the database (Figure 4). The summary statements contain [18]:

– status of artificial road lighting (Installed, Required, Dismantled);

– lamp installation scheme - console type;

– type of support material (concrete, metal, wood);

– purpose of support (city lighting, power transmission line);

– grouping of lamps (support height, angle, number of lamps on the support, type of location);

– coordinates of the binding of lighting to the city map, the number of piers of artificial road lighting.

Supports with artificial road lighting are not covered at the carriageway, at sidewalks, in parks, near educational institutions, etc.

In the environment of the intelligent transport geographic information system ITSGIS, night illumination level modeling is carried out based on the data collected on the survey of the road network of the location of street lighting objects. Simulation is carried out at different scales of the city map in order to view sections of the road network that are not equipped with the necessary lighting facilities, with the goal of planning the installation of new artificial road lighting facilities [19, 20].

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