Vehicle lighting equipment and control methods for an adaptive front-lighting system

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Abstract - In 2007, the United Nations Economic Commission for Europe adopted a new headlamp system, called the Adaptive Front Lighting System (AFS), as the rules for the installation of a headlamp system. It is designed to ensure the safety of vehicles in the dark. Practice has shown that cars with this lighting system create less accidents than traditional lighting. Due to the development of the system, it is now possible to distinguish several algorithms implemented in it. Typically, AFS deployment requires a LAN such as CAN. Takes into account the analyzed speed of operations on the CAN network is limited. AFS algorithms and methods for automatically controlling its operation using the CAN network are analyzed. To calculate the load on the network, we use the data of an entire sensor system during the operation of different ASFs. The parameters of the CAN network are calculated: speed, dependence of efficiency on load, probability of errors during the transmission of commands. Alternative ways of organizing ASF are considered, in particular using the modulation of the pulse width of the light bulb under the control of Ardyino system. This system can be combined with a number of other sensors.

Keywords - vehicles, road, traffic safety, headlights, adaptive lighting, focal vision distance, CAN network, network efficiency.

I. INTRODUCTION

The efficiency of transport operation is inextricably linked with the development of modern electronic and computer technologies that control electromechanical systems. The development of scientific directions of mechatronics and electromechatronics is one of the main directions of modern vehicles development and making wide use of such systems in vehicles. Modern electronic mechatronic systems and mechatronic modules make possibility to solve a number of problems in electric transport, problems about energy saving in life safety, and the global problem of human influence on the ecology of the environment. Using transport, especially in the darkness, is associated with the risk of accidents. For traffic safety at night, the front light system has developed and it makes high-quality road lighting. It was adopted by the United Nations Economic Commission for Europe (EEC) in 2007 under the name "Adaptive Front-lighting System" (AFS), regulation No. 123 [1-3].

In 2007, these rules were accepted in Ukraine without any comments. According to the regulation 123, which accepted the rules of arrangement the vehicle lighting system, the scientific basis for the organization of the lighting system and methods for managing such systems are being developed. The relevance of the work determines the complexity of the electrical equipment of the vehicle, increasing the speed of movement, to ensure the necessity of traffic safety on the road and create a comfortable working environment for drivers.

II. ANALYSIS OF LAST RESEARCHES AND PUBLICATIONS

The front lighting systems of the vehicle can be different types and for different functional purposes, but all of them are called "Adaptive front light system". At the beginning, it was installed on luxury cars and gradually implemented on all vehicles. Experts from European insurance agencies say that cars with an adaptive lighting system make the emergency situations in the darkness less than cars with a traditional light by 40%. [3].

The AFS operates according to the headlight turning control algorithm, in accordance with the position of the steering wheel. Over the period since the rules were accepted, the system has developed and improved. Now, based on different points of view of implementation, four categories of algorithms are used [4]:

1 – <u>algorithm of regulation</u> No. 123, which takes into account the angle of rotation of the steering wheel of the vehicle;

2 – <u>algorithm of safety</u> based on safety braking and considering the braking distance of the vehicle. It ensure that the enough road section is lightened for braking;

3 – <u>algorithm of contrast</u>, high-quality lighting is provided by the requirements of traffic safety. The basis is taken lighted road section, time of movement along which is carried out for 3 s. The contrast algorithm is safe enough and time-tested;

4 – <u>algorithm of preliminary inspection</u>, based on the peculiarities of the driver's observation the road in front of the vehicle, does not consider characteristics of his/her visual acuity.

Algorithm of preliminary inspection was developed on the basis of algorithm of contrast and is based on the study of the work of the driver's eyes, namely, determining the distance at which his eyes are concentrated [4]. This algorithm is an attempt to develop a dynamic system that fully consider the peculiarities of the driver, and allowed to provide high-quality lighting of the road. According to the algorithm, a section of the road is calculated that the driver can see while his/her and the headlights of the vehicle are automatically controlled. The distance of the previous review (the distance of the driver's focused attention) was calculated theoretically and measured experimentally. During the research, the movement of the driver's eyeball was fixed. The fixation frequency was 60 measurements per second. The place of focused attention (point of view) on the road was determined by a special computer program for analyzing eye movement, with a parallel reproduction of a video image of a car's pathway. Researches were conducted both in the light and in the dark period of time, while driving on roads with a radius of curvature of 20, 30, 40 m at a speed (20, 30, 40 km/h). According to the results of theoretical and experimental researches, empirical dependencies of distance and time of preliminary inspection on the speed and turning radius of the road were obtained.

The distance of the focused vision d_p and the time t_p of the preliminary examination depends, first of all, on the speed v of the vehicle and the radius of rotation. Driving the road with a radius of rotation r = 20 m, these quantities are described by the following formulas [4]:

$$\delta_\pi = 0{,}025\ \varpi + 9{,}358, \quad (1)$$

$$\tau_\pi = 0{,}09 + 33{,}689/\varpi, \quad (2)$$

here, v – the speed in km/h, d_p – the distance in meters, time in seconds.

When the vehicle is moving, dynamics of the road illumination was simulated. The illuminated area is highlighted by the line of isoluks headlights and its movements are considered while the vehicle is moving along the road with turns. It is shown that the optimum rotation angle of the headlights is less than when we use algorithm of contrast. The maximum value of the rotation angle was 15^0. This angle quickly changes while entering a turn and remains almost constant while moving in a turn.

The task of the AFS system is to provide high-quality road lighting with various driving conditions. AFS is implemented by a number of measures, including computer-controlled operation of headlights. High-quality lighting is provided by the choice of efficient light sources and regulation the distribution of their light flux.

The luminous flux of the headlights is adjusted by switching the lamps and mechanically moving their optical elements. Nowadays, in almost all modern vehicles, manufactured in Europe, the AFS system is used with mechanical drives. The headlights are made in the form of mechanotronic modules, which contain a stepping motor and a microcontroller work manager.

The implementation of the AFS system involves using local area network (vehicles), which, as a rule, is used by the CAN network. The computer network is necessary because the operation of the AFS system is connected with the steering, depending on the speed of movement, the position of the brakes, the accelerator and the condition of the other vehicle equipment.

Analysis of the sources [4-6] shows that the problem of introducing AFS is being solved in various ways now. In [5], it was proposed to use the ARDUINO controller system to control the operation of AFS without using an electromechanical drive. It works on the basis of pulse-width regulation (PWM) of the lamps. The headlights have 4 sections and there are different lamps in each. With the help of ARDUINO electronics, connection is provided between: the steering wheel, the right and left headlights of vehicle. The control system allows you to adjust the brightness of each lamp on the levels. The lamp brightness is programmed in the ARDUINO system according to the position of the steering wheel. The authors [5] argue that the proposed control system for the luminous flux of headlights is more efficient than using mechanical system of CAN network. Its advantages are: energy cost is lower, speed is more. Using the electromechanical drive in the AFS system, according to the authors, slows down the work of the headlights and does not allow the lighting to qualitatively track changes in the position of the vehicle.

Another point of view is shared by the authors in [6]. They also note that due to the delayed response time of the mechanical transmission, which is estimated to be 40 ms, and the network of CAN controllers, the AFS system at the corners of the road lags behind the rotation angle of the vehicle. As a result, the system does not meet the requirements about active safety of the car. According this, control algorithms with feedback correction, which is implemented via the CAN network, are proposed. The authors believe that the problem has been solved to a certain extent, and its implementation is based on high-tech equipment instead of being solved using a predetermined algorithm [6].

After analyzing, we can see that the issue about compliance of the CAN network with the requirements of adaptive lighting is relevant. Therefore, in this work, the processes of signal transmission in the CAN network and the processes of controlling the lighting of the vehicle in accordance with the AFS system are analyzed.

III. Work analysis and calculation of CAN network parameters in accordance with the requirements of AFS

CAN networks, operating in the AFS system, must meet the requirements of speed and reliability of their work. The scheme of connecting the vehicles nodes to the CAN tire is shown in fig 1.

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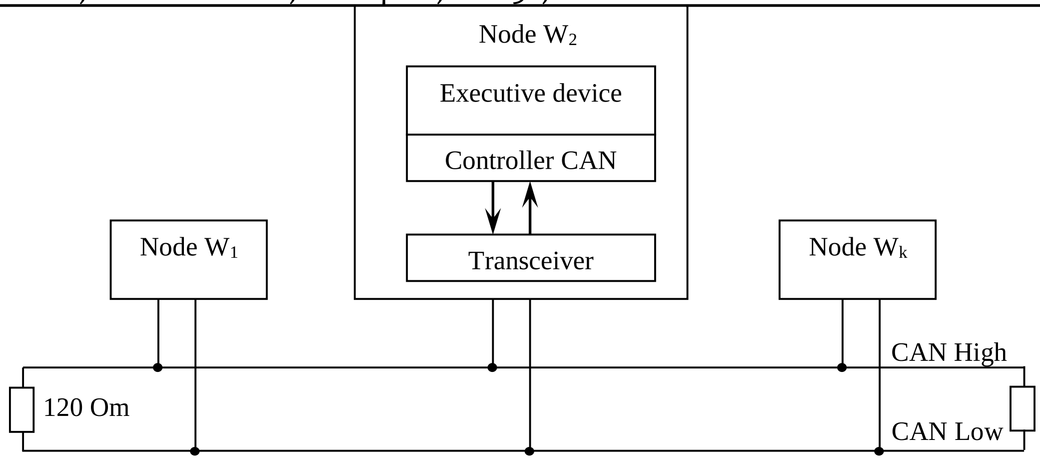

Fig. 1. Scheme of connecting nodes to the CAN tire

Each device that is connected to CAN network presented like its node and should have: a transceiver, a CAN network controller and an actuation device. The transceiver receives signals transmitted in the network, the controller processes them and transmits a command to the actuator. The network used packet data. Information packets (in the CAN network they are called frames) are transmitted to the network and received by the nodes, according to the protocols of the physical and link layer of the Internet [7-9].

A feature of the CAN network is that the speed of operation is limited by the method of arbitration (regulation of access to the network). During access to the network, the node that started the data transfer should receive information from another node that simultaneously with it (within the bit duration) also started the data transfer. This node can be the most remote node in the network. Transmitted bit of information must go through the whole network, be accepted processed by the farthest node, and a signal about the value of the bit that the remote node transmits should come to the node that transmitted this bit [7, 8]. As a result of the comparison, the node can transmit the next bit of information or stop the transfer. Thus, the arbitration method imposes limitations on the bit rate of information and the network length (taking into account the speed of electronics devices). Between these values should be the ratio:

$$v \leq \frac{1}{2(\frac{l}{c} + t_{\Pi} + t_{K})} \tag{3}$$

where: v – network speed, bit/s; l – the length of the network, m; c – the speed of the signal along the network, m/s; t_n – time of transceiver operation, c; t_k – is the signal processing time by a comparator.

Given this ratio, the length of the network is l, with its given speed – v is limited. There are different lengths with different speed v in networks [10]. In this article, only networks with speed of 1 Mbit/s with a length of 40 m and 500 kbit/s in length of 100 m are calculated.

As we said before, frames transmit the information on the network, and when we are sending the frame, it is necessary to receive an answer from the node that adopted it. Moreover, this information must contain data; the frame is accepted without any errors. Only after that, the frame is considered to be transmitted.

During operation in the AFS system, a message should be sent to each transmitted command about the outcome of its execution. So, network analysis needs to be performed on three levels: bit level, frame level and command level, and their execution.

The frame length is standard G = 134 bits, that is, 500 kbit/s in the network to transfer the frame we need to spend 238 microseconds, and transmission command 576 microseconds of time. Besides this, a certain time interval is set in the network and there are cases of re-transmission of the frames, if it is damaged. Damage during reception of a frame, appear on the method of calculating its checksum. In this way, the command time is increased. The performed analysis shows that the average frame transmission time, taking into account the probability of re-transmission of the network 40 m, does not exceed 300 microseconds, and on the network 100 m – 600 microseconds.

IV. Managing the work of AFS using a computer CAN network

To ensure the management of the work of AFS, must be taken results of researching works, which justify the system requirements in the works [4, 6], and the results of the CAN network analysis. Taking into account the formulas (1) and (2), the value of the distance and time of the previous review of the driver's path while driving on a turn with a radius of 20 m is calculated in the table.

TABLE I. Value of distance d_p, and time T_P of the previous review

v, km/h	10	15	20	25	30
t_p, s	3,489	2,336	1,774	1,438	1,213
d_p, m	9,608	9,733	9,858	9,983	10,108

As we can see from the given data, when riding on the road with the steepest turn, the time of the preliminary survey is in the range of 3.5 – 1.2 s depending on the vehicle's speed. The distance from the previous survey is practically unchanged and is within the range of 9.6 - 10.1 m. Considering distance value, it can be assumed that for a smooth change in the illumination of the road it is enough to provide a change in the position of the headlamps through every 0.5 m of the way, that is, through 1/20 interval. In this case, the control signals must be given with an interval of t = 60 microseconds.

The above frame transmission time in the CAN network is 0.238 microseconds and 0.576 microseconds for a network of 40 and 100 m, respectively. However, it should be noted that the work of the computer network in the control system is significantly different from the operation of the electrical network. The signals transmitted in the electrical network cause a single change in the output quantities. The work of the computer network is more complicated. It contains data packets, information. They spread along the network, nodes accept it, process it. Depending on the content of the information and the specific situation, certain actions are performed, intelligent management is carried out.

There is no obvious connection between the network speed and the frame rate. At the time of the frame transfer, the following factors are affected:

– the size of the frame, we have fixed it;

– load of the network;

– conflicts in the network and the time of their solution;

– lack time before the transfer;

– damage files and their re-transmission.

One of the important characteristics of the network is its productivity. Network productivity is the ratio of the actual frame rate transfer to the maximum. It is determined according to the formula [11]:

$$\mathrm{Pr}(k) = \frac{\mathrm{V}(k)}{\mathrm{V_G}}, \quad (4)$$

where: k – network load, which is determined by the average k attempts to transmit the frame during its duration.

The performance of different networks is different, and is determined by the method of access to the network. There are networks in which the maximum productivity is only 17%, while in others it reaches almost 100% [11]. Theoretically CAN network productivity can also reach 100% since the access method allows you to transmit data without losing time and information. In practice, it is smaller because of the necessity taking some time before the frame is started. Insofar as, the calculation of network productivity is the subject of another article [12], we restrict ourselves only to the results of calculating the number of commands that can be guaranteed per unit time on the network, namely: 3260 and 1620 commands per second, respectively, for networks of 40 and 100 meters length. Probability of mistakes in command transfer $4.7 \cdot 10^{-11}$ [10].

As a result of the performed analysis it has been shown that for quality control of the work of AFS it is necessary to ensure the transfer of control commands at intervals of 60 microseconds, that is, at a speed of $V = 17$ 1/s. As shown in [13] the eye distinguishes the object for 0.1 s, and taking into account the driver's mechanical response [14], the response time is 0.3 s. CAN 500 kbit/s provides transmission time and receive response from the host node, it provides a transmission interval of 1.2 microseconds. However, we should take into account a number of other factors:

variation of signal reception time;

magnitude and influence of the load on the network.

During CAN network work, we cannot guaranty that the frame will be immediately accepted by the destination node. In [15], it has been shown that there are fluctuations in delivery time on the network. They are determined of waiting for the start of transmission and possible retransmissions through obstacles. The mathematical expectation of delay is 0.1 times of the frame transmission, or 0.06 microseconds.

To calculate the network load, it should be noted that during the operation of different AFS we use the data of an entire system of sensors: turning the steering wheel, speed, road resistance, sensors of the current position of the headlights, position of brakes, accelerator, pressure in the hydrosystem, etc. Modern AFS systems also use camcorder displays, processed by the computer image recognition system [12], and data obtained from the satellite GPS navigation system. The last ones allow the driver to predict the next turn on the road and their subsequent actions. Sensors, executive organs, and computers are connected to the CAN network like its nodes: W1, W2, ... Wk (look Picture 1). Each node can transmit information to the network. To determine the network load, we describe the node as the average value of the time interval Ti with which it sends a message to the network. Given that there are n nodes in the network, the network traffic is calculated according to the formula:

$$k = \frac{2G\sum_{i=1}^{m}\frac{1}{T_i}}{\lambda\,\mathrm{Pr}(1)}, \quad (5)$$

Here λ is the network speed, bit/s. To estimate the network load, we will assume that 20 nodes are working on the network. Each node transmits data with the frequency that is defined for AFS, that is, with a time interval. $t_i = 60$ microseconds. Loading according to (5) will be:

$$k = \frac{2\cdot 135\sum_{i=1}^{20}\frac{1}{60\cdot 10^{-3}}}{0{,}5\cdot 10^{-6}\cdot 0{,}9} = 0{,}2, \quad (6)$$

The network, under such conditions, will work at a load of $k = 0.2$. In this case, we see that the network is not fully loaded and there is a reserve to use its capabilities.

Returning to the proposed method for managing the work of AFS using PWM using the ARDUINO system, it should be noted that this is an electronic controller system with all their advantages and disadvantages [5]. The performed analysis shows that modern AFS systems are intelligent systems in which control is carried out under the control of a computer and in which, in addition to the steering position, the impressions of different types of sensors are taken into account, as well as the results of computer processing of the image of the road and the displays of the satellite navigation system taking into account the electronic terrain maps. The system based on ARDUINO takes into account only the steering wheel position. Of course, you can combine it with a number of other sensors, but it's not possible to get an intelligent control system, which provides control using CAN network. Another solution is possible, namely connecting ARDUINO to CAN network, then it will work as one of the nodes. Using ARDUINO as an alternative to the CAN network for advanced AFS systems is not possible.

In the first part of the article we looked through the functions of adaptive lighting and auxiliary equipment, that operate the AFS need to use a local computer network of vehicle,

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and the specified ARDUINO system in its functional capabilities cannot ensure the operation of such system.

V. Conclusions

The analysis of systems of adaptive front lighting (AFS) and methods of automatic control of their work are executed. It is shown that the system is intensively developed and implemented in the vehicles of the most advanced companies. The most widely using of the system is based on the algorithm of the pre-inspection of the road by the driver.

Using the CAN network of vehicles to control the work of the AFS and its prevalent. Alternative systems do not allow to issue the management question fully.

The network demands that are required to implement the AFS control system are calculated. It is shown that in order to ensure good management, it is enough to submit commands to the electromehatronic module of headlights with a minimum interval of 60 microseconds.

The CAN network parameters are calculated: speed, dependence of productivity on load, probability of errors during transfer of commands. It is shown that under all conditions, the network at a speed of 500 kbps ensures the transmission of control commands for 2 microseconds, and the probability of transmission error does not exceed 10^{-10}.

VI. Referenses

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Обладнання для освітлення автомобіля та методи управління адаптивною системою переднього освітлення

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У 2007 році Європейською Економічною комісією Організації Об'єднаних Націй, було прийнято нову систему переднього світла під назвою "Адаптивна система переднього освітлення" (AFS), як правила встановлення системи переднього світла. Вона розроблена для забезпечення безпеки транспортних засобів у темний час доби. Практика показує, що автомобілі з цією системою освітлення сприяють створенню аварій менше, ніж з традиційним освітленням. У зв'язку із розвитком системи, на даний час, можливо виділити декілька алгоритмів, що реалізовуються в ній. Як правило, для впровадження системи AFS передбачає використання локальної мережі, такої як CAN. Враховується аналізуються швидкість операцій в мережі CAN обмежена. Проаналізовано алгоритми роботи AFS та методи автоматичного керування її роботою, використовуючи CAN-мережу. Для обчислення навантаження на мережу, під час роботи різних АЧС ми використовується дані цілої системи датчиків. Розраховані параметри роботи мережі CAN: швидкість, залежність ефективності від завантаженості, ймовірність помилок під час передачі команд. Розглянуто альтернативні способи організації АЧС, зокрема з використанням модуляції ширини імпульсу яскравості лампочки під управлінням системи Ardyino. Цю систему можливо комбінувати з низкою інших сенсорів.

Ключові слова - транспортні засоби; дорожній рух; безпека руху; фари; адаптивне освітлення; фокусна відстань; мережа CAN; ефективність мережі.