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SIMULATION OF AN INTELIGENT-ADAPTIVE FRONT-LIGHTING SYSTEM

BY

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Abstract. Advanced Frontlight System (AFS) is an intelligent system that optimizes the illumination of road curves during the night, on the basis of signals representing several quantities such as speed, steering angle and yaw rate of the car. A vehicle equipped with intelligent headlight gives the driver an optimal illumination of the road even in curves. The goal of this paper is to present the operation of such an AFS through its simulation of data exchange in terms of messages flowing through in-vehicle controller area network (CAN).

Key words: CAN bus; bending lights; headlamp; steering wheel angle; vehicle speed.

1. Introduction

A vehicle lighting system consists in integrated lighting and signaling, using devices mounted in front, side, rear, and in some cases on top of the vehicle. The purpose of this system is to provide illumination for the vehicle driver to operate safely in the dark. It serves to increase the vehicle visibility, and to display information about the presence, position, size, and direction of travel of the vehicle, as well as the driver's intentions regarding the vehicle

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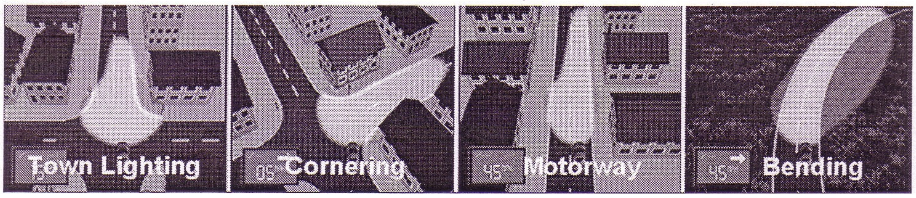
direction and speed. An Intelligent Lighting System (Bending Light) optimizes the illumination system operating during the night in curves, using a directional control system of the vehicle headlamps.

Valeo, the world leader in automotive lighting technology, first made intelligent headlight systems (Makowitz & Temple, 2006; Semiconductor Comp. Ind., 2008). Valeo developed a technology for lamps, which is called *Bending Light*. This technique automatically directs the lights in accordance with the road, in order to optimize vision at night. This technology brought a significant contribution to comfort and convenience by reducing the driver fatigue. Headlight System (Light Bending System) consists of a Bi-Xenon projector or reflector headlamp that can rotate from its normal position. An additional projector or reflector, or a combination of both, can be used to provide more light on a curved road. Commissioning of the motors from the lighting unit attached to each lamp is controlled by an electronic control unit that receives signals from the steering wheel, speed, yaw rate, and vehicle state.

Intelligent Light System is the first next-generation adaptive front lighting system. The range includes three different types of lighting, presented in Fig. 1 namely

a) Lighting highway – usually above 80 km/h (50 mph). The reduction function of the light intensity beam is based on a signal received from the speed sensor and acting on a self-leveling system, thus increasing the driver visibility at high speeds (Figs. 1 *c*, *d*).

b) Lighting in the city, in urban areas, where the exterior light is sufficient, the light beam is reduced and the light side is increased, to improve the visibility of the foot passengers, cyclists, and the other road users to reduce glare (Figs. 1 *a*, *b*).



a *b* *c* *d*

Fig. 1 – Types of lighting of AFS : *a*, *b* – lighting in the city; *c*, *d* – lighting highway; *a*, *b*, *c*, *d* with hash weather conditions – lighting in adverse weather conditions.

c) Lighting in adverse weather conditions provides in harsh conditions of low visibility (fog, rain and snow), additional lighting, to increase the visibility of the road edges, while the light is removed from the foreground to reduce the reflections on the wet road. This function is available for all the road conditions presented in Fig. 1.

AFS (Advanced Frontlight System) represents a general term for the intelligent lighting functionality.

In Fig. 2 is presented the difference between the illumination beam of an inteligent light system and a fixed light system.

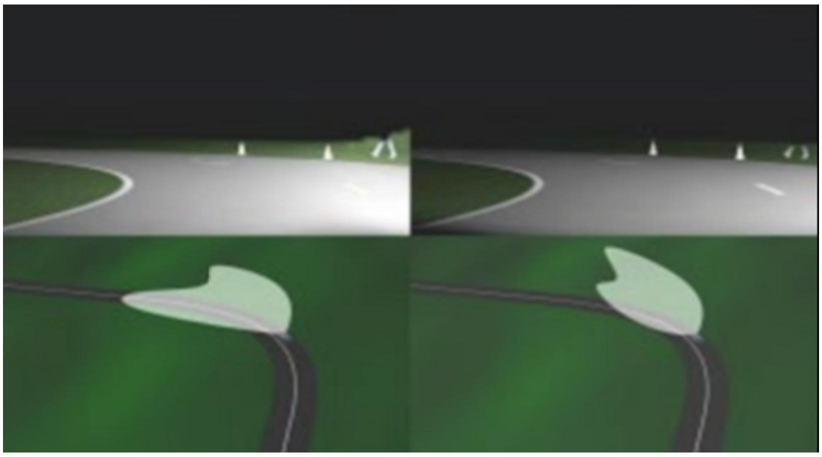


Fig. 2 – The intelligent lighting (left) and normal lighting (right).

Another company which developed an AFS is Visteon. The system uses the inputs from steering wheel, speed and axle sensors to precisely tailor the lighting pattern according to vehicle speed and road configurations. Visteon offers dynamic and static systems using halogen, High Intensity Discharge (HID)/Xenon and Light Emitting Diode (LED) sources.

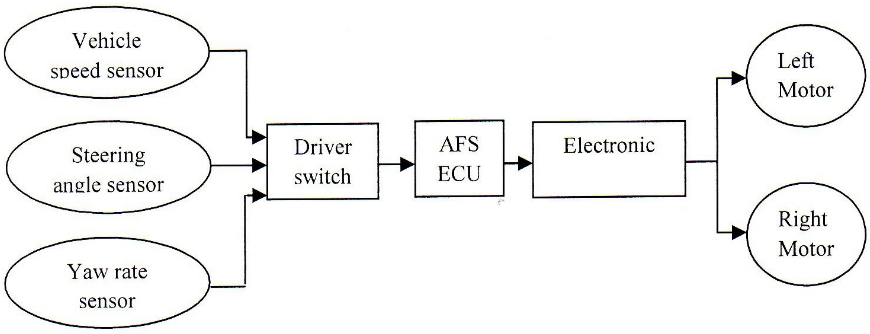


Fig. 3 – The block diagram of an AFS system.

Fig. 3 presents a block diagram of an AFS system. Each system is equipped with sensors that detect changing conditions, a driver-controlled switch, an electronic control unit which processes the data received from sensors and finally the electronics driving the motors that move the headlights. The central processor receives inputs from the yaw rate sensor (to measure the wheel angle), the speed sensor and steering angle sensor indicating (Hacibekir *et al*., 2006).

Because there are many issues that can appear in the AFS development chain, a previous simulation of the system may save costs by fixing the problems identified after the hardware and software implementation.

OKTAL is a major provider in innovative and durable simulation software and systems. The SCANeR Headlight is an interactive headlight simulation software which is used for headlight systems design and realistic night drive experiments. The simulation developed by OKTAL has the following features:

a) Photorealistic rendering (BRDF): advanced shading model for real time 3-D reflectance (wet road, snow, road marking…).

b) Illumination measurement on ground/wall/traffic *via* virtual sensors.

c) Mechanical data adjustable for each lamp (road height, cross car spacing, driver eye position…).

d) Advanced front lighting system benchmarking (AFS analysis tool).

e) Generation of user's own AFS strategy using SDK interfaces.

In this paper is presented an AFS system simulation, which contains the entire process: sensors, electronic control unit (ECU), and electronic drives of the headlights. Unlike the SCANeR simulation which is based on illumination measurement and reflectance, this simulation is based on the messages vehiculated on the CAN between sensors and ECU, and between ECU and motors of headlamps (Wu *et al*., 2009). This simulation can be used at the system validation phase, before the start of production, to hightlight the problems that can appear when the AFS component is integrated in the entire car system.

2. Presentation of the Proposed System

This paper is focused on presenting the operation of an intelligent lighting system by simulating of the message exchange through in-vehicle CAN. Fig. 4 shows the interconnection of elements that are part of an in-vehicle

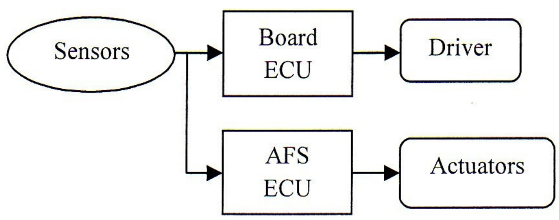


Fig. 4 – In-vehicle communication.

communication. The signals delivered by the sensors are received by the ECU to which the sensors are connected. At this level the signals are decoded and processed in order to be displayed to the driver or to be used by other ECUs.

The AFS functionality involves collecting information from three sensors: a vehicle speed sensor, the steering wheel angle sensor and the sensor that measures the yaw rate. In addition to these three inputs, the AFS ECU receives other two signals from the dashboard ECU, namely intelligent headlamp activation signal and the signal provided by contact (vehicle mode).

Fig. 5 shows the functional diagram of the AFS. The central unit of the system has five inputs and two outputs. The five inputs are received from sensors and from driver input commands and the outputs are the commands to the headlights motors. “Bending Enable” and “Vehicle Mode” are legitimated general inputs received from the driver. These signals are processed by the dashboard control unit and sent to the AFS ECU.

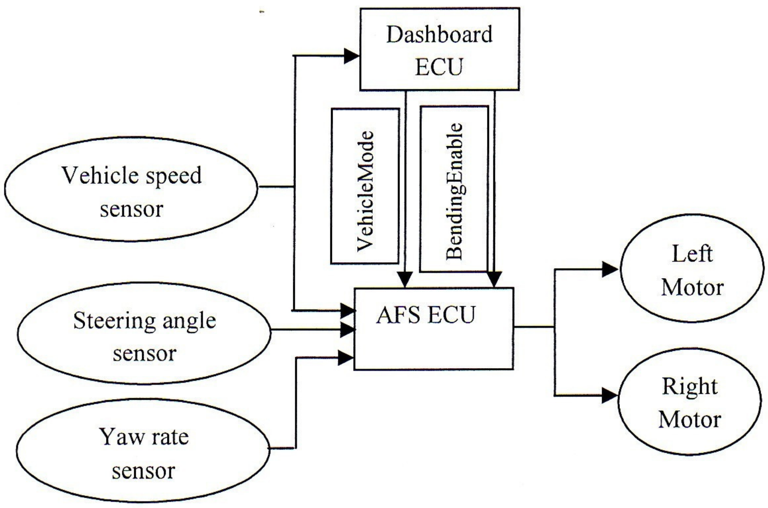


Fig. 5 – Intelligent headlight diagram.

The entire simulation is developed in LabView programming environment, because LabView offers the possibility to create a graphical program, using functions already built. The simulation is created on an hierarchy of 18 sub-VIs on five levels, which is presented in the Fig. 6.

Each sensor which send the value to the ECU is simulated using a VI. In the Fig. 6, the VIs which simulate the sensors are „Steering Angle”, „Vehicle Speed” and „Yaw Rate”. Also the inputs from the driver are simulated in different VIs, named „Bending Enable” and „Vehicle Mode”. The VIs which are used for simulating the CAN communication are „RX Driver”, „Write Msg”, „Write Msg CAN” and „CAN Card”. The „Move Algo” represents the VI which calculates the motors positions and the movement speed of the motors. „Lamp motors” simulates the motors of headlamps and „Move comm” simulates the commands sent by ECU to the motors.

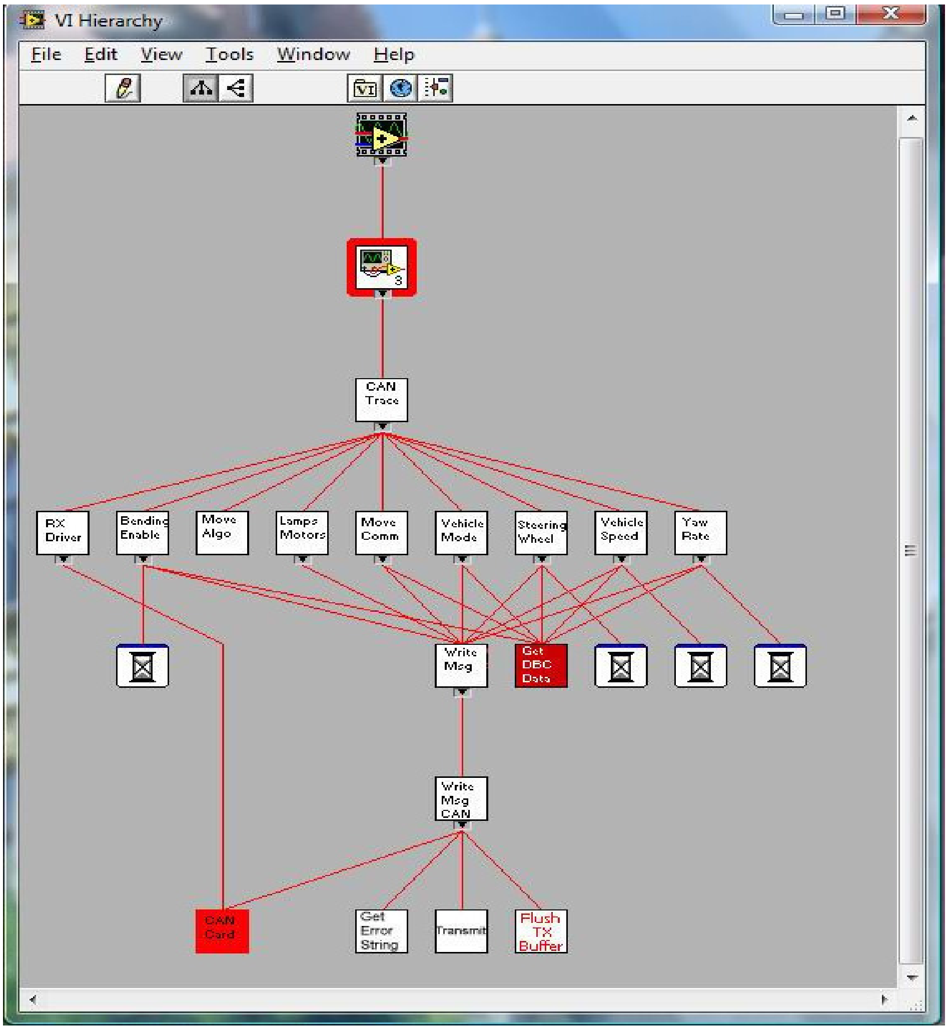


Fig. 6 – The hierarchy of the VIs which are used in the AFS simulation.

2.1. The Simulation of the Input Signals for the AFS ECU

All the necessary inputs for the functioning of intelligent lights, are presented in Fig. 7.

In this panel, Vehicle Mode can be: 0 – Hibernate, 1 – Parking, 2 – Stationary, 3 – Accessories, 4 – Pre-Running, 5 – Cranking, 6 – Running. First, if the vehicle mode is different from „Running" (value 6), the other inputs can not be taken into account.

Vehicle speed value is sent to the driver (on board) by the speed sensor, being used for calculating the rotation angle (relations (2) and (3)) and the rotation speed of the headlights (relation (1)). In the present simulation, the speed is entered by the designer, using the control "Vehicle Speed". The control "Bending Enable" is activated by the driver when he wants to enable the AFS option. If the option is not activated the lights remain stationary in any road conditions. The relation (1) is used for calculating the movement speed of the headlamps. The value received from the sensor that measures the yaw rate is used in that formula for calculating the rotation speed of the headlights. This sensor sends the value directly to the central ECU, but in this simulation the sensor receives the value from the designer by using the "Yaw rate" control. Steering wheel angle indicates the direction of the vehicle and is also used to calculate the effective rotation angle of the headlights. Angle value is entered by the designer using the control "SteeringWheelAngle". Valid values are ranged between –3.2 and 3.2 radians. The interval [–3.2, 0] indicates that the wheel is rotated to the left and the values between [0, 3.2] indicates that the wheel is rotated to the right.

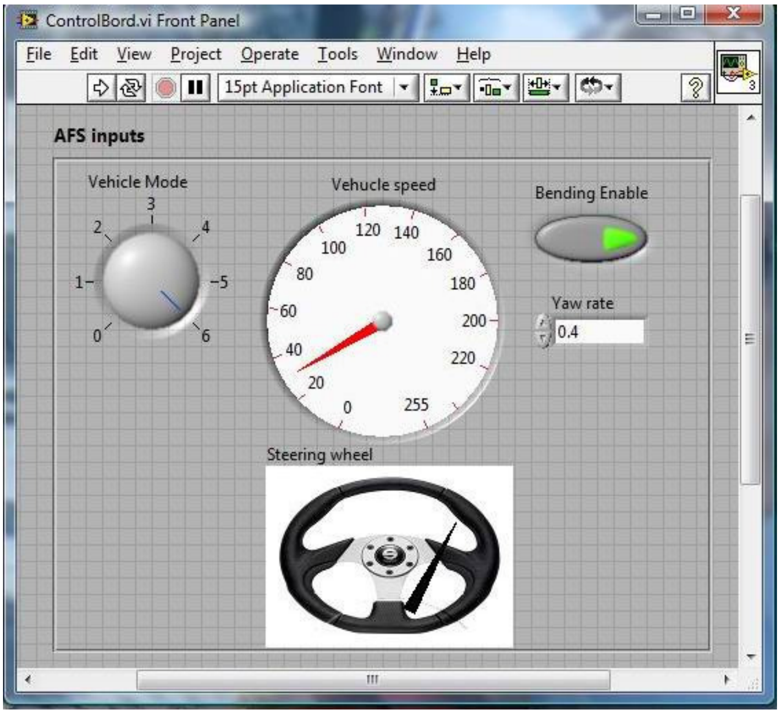


Fig. 7 – User interface for entering the input signals to the simulator.

2.2. The Simulation of the Output Signals for the AFS ECU

The following formula is used to calculate the speed of headlamps movement:

$$\text{movement\_speed} = \text{YawRate} + C1 \times \text{VehicleSpeed}, \qquad (1)$$

where $C1 = 0.054$; both headlamps have the same movement speed.

$C1$ represents a constant that depends on the vehicle type, which includes the type of headlights and the type of the stepper motor. $C1$ is fixed by the car manufacturer and is used in the movement algorithm.

Each motor position is calculated according to the different ranges of movement

$$\text{LeftPosition} = \text{SteeringWheelAngle} \times C2; \tag{2}$$

$$\text{RightPosition} = \text{SteeringWheelAngle} \times C3, \tag{3}$$

where $C2 = 0.68$; $C3 = 0.75$.

The constants $C2$ and $C3$ are different because the range of movement are different for each motor.

Range of motion for the left motor is [–24, 22] and for the right motor is [–22, 24]. These values are expressed in radians × 10. On the left, the angle has negative values, on the right the angle has positive values and 0 represents the default position. The AFS option is activated by the driver, using the Bending Enable switch. If the option is not activated, the headlamps are fixed in zero position.

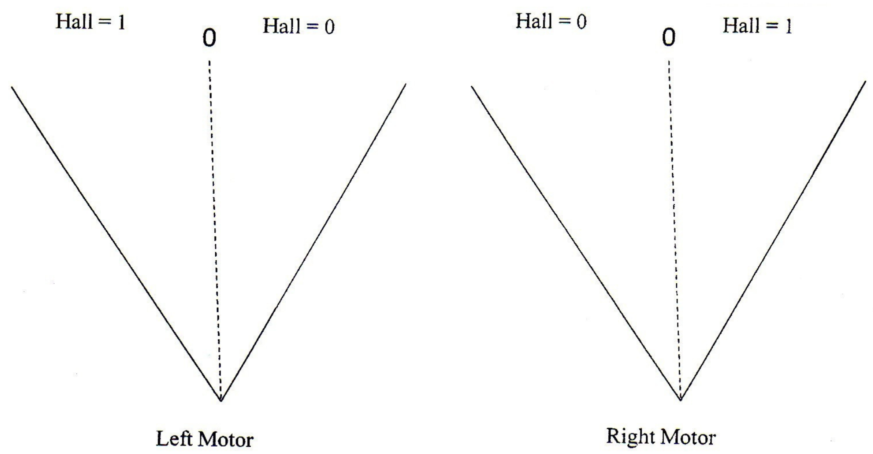


Fig. 8 – Hall sensors working for the left and the right motors.

Each stepper motor has attached a Hall sensor which indicates the lamp position (to the left or to the right). In this case the Hall sensor has not a classic operation, but works as a flag, when the motor is passing through the zero position. If the motor is moving from zero to outside of the vehicle (the right motor to the right) then the sensor value changes from 0 to 1. If the motor is moving from 1 to an inner position (the left motor to right) then the sensor value changes from 1 to 0. A sensor problem appears when both sensors have the same value. Fig. 8 explains how the Hall sensor works for each motor.

2.3. The Interface for Monitoring the CAN Bus Messages

The input signals for the AFS option activation, the commands to the motors and the responses of the motors are sent *via* in-vehicle CAN. The simulation presents an interface for viewing the messages from the sensors to the AFS ECU, the messages from the AFS ECU to the motors and the messages sent by the motors to the AFS ECU. Fig. 9 shows all the messages sent on the CAN bus and the interpretation of each message.

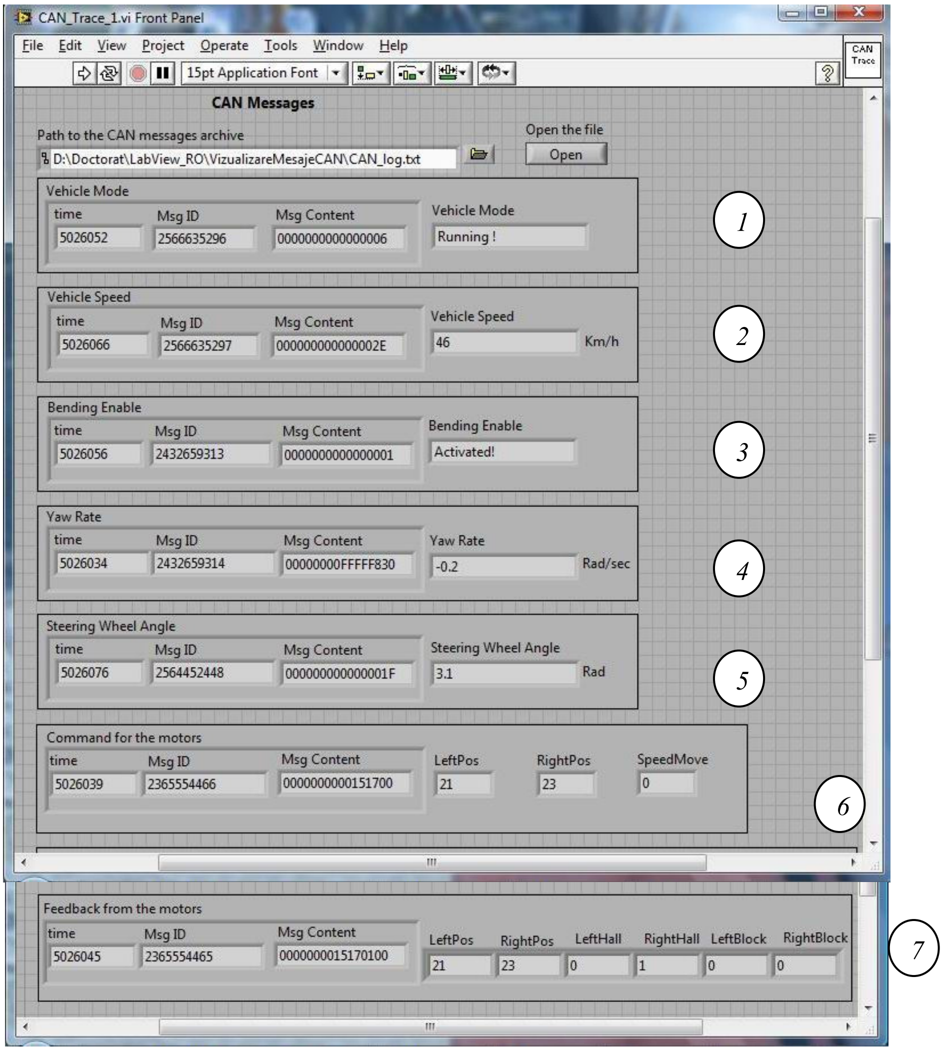


Fig. 9- The interface for messages view during CAN commuication.

Each panel represented in Fig. 9 contains the following information about the message: the time when the message is vehiculated on the bus, the message identifier (Msg ID), the message content (Msg Content) and the interpretation of the message content. The panel *1* contains the „VehicleMode" message. This message is sent from the control board to the AFS ECU. Message content is modified by the driver/designer, by changing the contact state. The data message contains 8 bytes and the last byte represents the Vehicle Mode in hexadecimal. If the Vehicle Mode is 6 (motor running), then the message content converted in hexadecimal number is 0x0000000000000006.

The panel *2* contains the "Vehicle speed" message which is sent by the speed sensor to the AFS ECU. This value is sent also to the control board to be displayed to the driver. The message contains the speed value converted in hexadecimal number. If the sensor value is of 120 km/h, the message content is of 0x0000000000000078. The valid values for the vehicle speed are situated between 0 and 255 km/h.

The "Bending Enable" message is presented in the panel *3* and is sent from control board to the AFS ECU. Message content is modified by the driver, by switching on/off the Bending Enable button. When Bending Enable switch is on, the message content is of 0x0000000000000001 and when is off, the message content is of 0x0000000000000000.

Panel *4* shows the "Yaw rate" message. This message is sent by the yaw rate sensor to the AFS ECU. The valid values for yaw rate are ranged between –0.4 and 0.4 rad/sec. The message from the sensor contains the yaw rate value, multiplied by 10, converted in hexadecimal number. If yaw rate is 0.4, then the message content is of 0x0000000000000004.

"Steering Wheel Angle" message is presented in panel *5* and is sent by the sensor which measures the steering angle, to the AFS ECU. The steering wheel angle is measured in radians and the values are situated between –3.2 and 3.2 rad. The negative values are from 0 to the left, and the positive values are from 0 to the right. The message content for –3.2 rad is of 0x00000000000000E0 and for 3.2 rad is of 0x0000000000000020.

The panel *6* presents the "Motors Command" message which is sent from the AFS ECU to the motors of the headlamps. The message contains the command position for the left and the right motors, and also the motors movement speed. The values for the motors speed and for the motors position are calculated by ECU, based on the inputs values from vehicle mode, bending activation, vehicle speed, steering angle and yaw rate messages. The message contains three bytes: one byte for the movement speed, one byte for the right motor position and one byte for the left motor position. The message 0x0000000000151702 means that the left motor position is of 2.1 rad , the right motor position is of 2.3 rad and the motors speed is of 0.2 rad/s.

The "Motors response" message is shown in panel *7*. The message contains the current position of the left motor, the current position of the right motor, the Hall sensor value of the left motors, the Hall sensor value of the right motor, the block detection for the left and right motors. If the position commanded by the message “Motors command” is not the same as the current position from the message “Motors response”, it means that the motors have encountered a problem either at Hall sensor or were blocked by various external factors or by internal electrical issues. The occurrence of the motors blockage of all kinds, due to sensors malfunction or due to other internal/external factors, is indicated by the last byte of the message. The nibble BlockLeft indicates a failure occured on the left motor (0 – no errors, 1 – error), and the nibble, BlockRight indicates the appearance of a defect to the right motor (0 – no errors, 1 – error). The response message (0x0000000015170100) indicates that the left motor position is of 2.1 rad (0x15), the right motor position is of 2.3 rad (0x17), the Hall sensor for the left motor is 0, the Hall sensor for the right motor is 1, the left motor is not blocked and the right motor is not blocked too.

3. Results and Discussion

Table 1 shows different situations and operation modes of the intelligent headlights. Not all the types values from the table have measuring units.

Table 1
Intelligent Lighting Operation

No.	1	2	3	4	5	6	7	8	9
Vehicle mode	6	6	6	6	6	6	6	6	6
Bend enable	1	0	1	1	1	1	1	1	0
Vehicle speed km/h	20	20	0	10	10	100	220	0	0
Yaw rate rad/s	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.0	0.4
Steering angle, [rad]	3.0	3.0	2.0	–2.0	–1.5	2.0	–3.0	3.0	–2.0
Left motor rad	2.0	0	0	–1.4	–1.0	1.4	–2.0	2.0	0
Right motor rad	2.2	0	0	–1.5	–1.1	1.5	–2.2	2.2	0
Left Hall	0	0	0	1	1	0	1	0	1
Right Hall	1	1	1	0	0	1	0	1	0
Motor speed rad/s	1	0	0	0.2	0.3	0.7	0.2	0	0
Left block	0	0	0	0	0	0	0	0	0
Right block	0	0	0	0	0	0	0	0	0

Table 1 shows the motors responses according to the AFS ECU commands. The first column (No.) indicates the number of case study. The second column (Vehicle mode) means the contact position. If the engine is not running (the value is different from 6), the AFS option is disabled, and the motors remain to zero position regardless of steering angle. The column “Bend Enable” contains the value from Bending Enable switch, entered by the driver. If the switch is not activated, the value for Bending Enable is 0 and the motors remain fixed in the central position, even if the engine is started and the steering wheel angle is different from zero. So the conditions for dynamic headlights are: engine running (the value is 6) and bending option enabled (the value is 1).

The column “Vehicle speed” contains different values of vehicle speed and the column „yaw rate” contains values of yaw rate received from the sensor. The speed values of the motors are listed in the “Motor speed” and are expressed in radians per second. Steering angle values are present in the “Steering angle” column. For each of the five inputs, the AFS ECU receives a message. The motors respond with a single message by sending information about their current status. The columns “Left motor” and “Right motor” represent the positions for the left and right motors, calculated by the AFS ECU, according to the input values. “Left Hall” and “Right Hall” columns contain the values of the Hall sensors for the left and right motors. The movement speed of the motors is calculated also by AFS ECU and it is presented in the “Motor speed” column. In case of motors errors or blocks, for each motor is set a flag. The last two columns, “Left block” and “Right block”, indicate the values of these flags.

In the case No. 6 from the Table 1, the inputs signals, sent by the designer, are: Vehicle Mode is 6 (motor running), Bending Enable is 1 (the option AFS is activated), Vehicle Speed is 100 km/h, yaw rate value is 0.3 rad/s, and steering wheel angle is 2 rad. Acording to these inputs, the AFS ECU calculates the motors positions. In this case the motors are moving to the right because the steering wheel angle has a positive value. The left motor is moved to the position 14 (is moved to the right with 1.4 rad), the right motor is moved to the position 15 (is moved to the right with 1.5 rad) and the movement speed of the motors is of 0.7 rad/s which is the maximum speed. The motors feedback contains four flags: Hall value for the left motor is 0 (the left motor is moved to the inner side), Hall value for the right motor is 1 (the right motor is moved to the outer side), and the block detection flags are 0 for both motors because no blockage is occured.

4. Conclusions

Currently, more and more vehicles are equipped with an AFS option which requires an evaluation stage of development, testing and validation of functionality. Presented simulation can be used at this stage of product development to analyse and predict the operation errors that may occur. The simulation was performed only for horizontal movement of the headlights but the working can be extended to change the headlight level (vertical motion) and the beam intensity(forward and backward movement of the headlamp). In this case each headlamp needs three motors: a motor for horizontal movement, a motor for vertical movement and a motor for back and forward movement. The main advantage of the proposed simulation is that it offers the possibility to modify the original draft before it is implemented, without substantial cost.

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SIMULAREA UNUI SISTEM DE FARURI INTELIGENT-ADAPTIVE

(Rezumat)

Sistemul avansat al luminilor frontale (AFS) este un sistem inteligent care optimizează iluminarea traseelor curbate pe timpul nopții pe baza semnalelor ce reprezintă viteza, unghiul de direcție şi viteza de deviație a autovehiculului. Un vehicul echipat cu sistemul de faruri inteligente oferă conducătorului auto o iluminare optimă a traseului, chiar şi în curbe. Scopul acestei lucrări este de a prezenta modul de operare a unui astfel de sistem (AFS), prin simularea schimbului de mesaje prin rețeaua Controller Area Network (CAN) folosită în interiorul autovehiculului.