Research on Intelligent LED Headlamp System Based on Multi-Sensor Fusion

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Abstract. This paper researches on automobile headlamp system. Multi-sensor fusion technology is used in the system, which can realize for data acquisition of full automation, including the road conditions and the vehicle’s own operating status. On this basis, the deflection angles of headlamp at bend and ramp are calculated in real time, and the illumination angle and the illumination distance of the headlamp are adjusted accordingly. Finally, the research on intelligent LED headlamp system with the functions such as intelligent switching of low beam and high beam, bend adaptive lighting and ramp adaptive lighting is completed. The test results show that the system performance meets the basic requirements of automobile adaptive lighting.

1. Introduction
With the improvement of people's consumption ability and the rapid development of science and technology, more and more people pay attention to the driving safety and environmental protection of vehicles. As one of the important parts of future automobile driving plan, headlamp is also invested by more and more automobile companies and research institutions.

In the world, the intelligent research on automobile headlamps began in 2003. In 2005, HELLA announced that it has produced the AFS system, in which the headlamps can be automatically adjusted based on the road conditions and the external environment [1]. In 2013, new Audi A8L was equipped with matrix LED headlamps with dynamic steering function realized by changing the lens and reflector to illuminate the bend ahead of time [2, 3]. In 2015, laser headlamp technology, which not only realizes the functions of the traditional AFS, but also makes the headlamp illumination distance from 300 meters to 600 meters, was demonstrated on a new generation of BMW 7 Series vehicles codenamed G11/G12 [4]. There is also an AFS system based on GPS positioning system developed by Visteon, the headlamps are adjusted in time through precise GPS positioning and map data [5].

China's intelligent headlamp research started later than the international. In early 2007, Shenyang North Automobile Headlamp Auto-steering Factory successfully developed automobile automatic steering headlamps, which broke the monopoly of foreign companies in this respect [6]. In July 2009, the new Lacrosse equipped with a follow-up xenon headlamp developed by HiRain Technology, was officially launched. The headlamp has the functions of following-up turning at bends, automatically enhancing near light intensity at low speed and automatically increasing light distance at high speed [7]. In the same year, Jilin Dongguang Ruibao Automobile Lamp Co., Ltd. successfully developed the first full LED headlamp in China [8].
The above are the research status at home and abroad. In summary, at present, the research can be regarded as three operations for high beam and low beam, including on-off control, brightness adjustment and direction adjustment.

2. System structure

2.1. System function description

The intelligent research on automobile headlamp in this paper is divided into three parts as follows.

(1) Intelligent switching of low beam and high beam
    After the light AUTO key is pressed, the headlamp can be automatically turned on or off according to the ambient illumination. With the headlamp turned on, the high beam and low beam can be automatically switched according to the speed of the vehicle.

(2) Bend adaptive lighting
    By real-time acquisition of steering wheel angle and vehicle speed, the illumination angle of the headlamps is automatically adjusted, and the light intensity inside the curves is enhanced.

(3) Ramp adaptive lighting
    The illumination distance of the headlamps is automatically adjusted based on real-time information such as vehicle speed and body inclination.

There are two requirements for the opening of bend adaptive lighting and ramp adaptive lighting. One is that the AUTO key of the headlamp has been pressed, and the other is that the headlamp has been turned on.

2.2. System structure

According to the three functional requirements of automobile intelligent headlamp, there are some requirement analysis of hardware system as follows.

The intelligent LED headlamp system based on multi-sensor fusion consists of three key points: 1) LED headlamp; 2) AFS system; 3) multi-sensor fusion.

The first and second key requires that the hardware platform needs an LED headlamp with low beam, high beam and a mechanical rotation structure that adjust the beam in two axes. The hardware platform is also required to have LED drive unit and motor drive unit respectively. As for the third key, there are many sensors needed by the hardware platform, including photosensitive sensor, speed sensor, steering wheel angle sensor and six-axis sensors, and possibly image sensors. The control and data communication between the driving units and the sensors require that there is main control unit, referred to as MCU, needed in hardware platform.

![Figure 1. The hardware platform framework.](attachment:image.png)
Figure 1 shows the hardware platform framework of this paper. Figure 2 shows the communication relationship between MCU, driver units, sensors, motor and LED headlamp.

![Figure 2. Working block diagram of hardware system.](image)

The analog input of hardware system includes body inclination. The digital inputs include ambient illumination, vehicle speed, steering wheel angle, etc. The digital outputs include horizontal motor adjustment state, vertical motor adjustment state, near-light intensity, far-light intensity, near-light extinction, far-light extinction. There is no analog output in this hardware system. There is a LIN communication interface, a CAN communication interface, a serial peripheral interface, three analog I2C communication interfaces and a pulse capture interface in the MCU with MC9S12P128 as the core.

From the requirement analysis of the hardware system, to the selection of components, to the design of the assembly circuit board, then to the installation and debugging of the hardware platform, the hardware platform of the intelligent LED headlamp system based on multi-sensor fusion is completed finally.

3. System control strategy

3.1. System working constraints

The working constraints of intelligent LED headlamp system based on multi-sensor fusion are as follows:

1. The horizontal adjustment range of automobile headlamp is that the left headlamp adjustment angle is \(-15^\circ\)~\(8^\circ\), and the right headlamp adjustment angle is \(-8^\circ\)~\(15^\circ\) [9, 10].

2. Conditions for headlamps to be turned on are that ambient illumination is less than or equal to 200 lux, and detailed data analysis is shown in Figure 9.

3. Relevant traffic regulations for the intelligent switching of high beam and low beam in the case of low visibility [11]:

1) Within 150 meters from the vehicles coming in the opposite direction, the vehicle is required to change to low beam instead.

2) When meets with non-motorized vehicles on narrow roads or narrow bridges, the vehicle is advised to use low beam.
3) When the vehicle is driving at close range in the same direction with other vehicles, no high beam shall be used.

4) When passing through sharp bends, slopes or intersections without traffic lights, the vehicle is recommended to alternately use high beam and low beam to indicate.

(4) In the case of low visibility, it is recommended to use a low beam when the vehicle speed is lower than 30 km/h, otherwise the high beam can be used. Vehicles are recommended to use low beam at night through a section with good lighting conditions.

3.2. System Control Strategy
The three important research stages of this system are: 1) building the hardware platform environment; 2) formulating the system control strategy and compiling the bottom program and control program of the software system; 3) verifying the feasibility of this system in accordance with the national standard of automobile headlamp and the working constraints of this system. This section mainly introduces the control strategy of the system.

![Flowchart](image)

**Figure 3.** Working block diagram of hardware system.

The main program flow chart of this system is shown in Figure 3. The main program workflow mainly includes system fault detection and alarm processing module, the intelligent switching module of high beam and low beam, bend adaptive lighting module and ramp adaptive lighting module.

The working principle of the system will be described in the following two paragraphs.
There are three initialization steps before starting the system. Firstly, checking whether the car key is in ON gear is needed. Secondly, the headlamp fault detection is needed, and if the faults are detected, the alarm will be issued and the system will exit. Thirdly, it is necessary to detect whether the driver has pressed the AUTO key of the lamp. If not, it means that the system is not started.

After the system is started, first of all, the ambient illumination is automatically detected. If the illumination is not greater than 200 lux, the headlamps are automatically turned on. Next, the intelligent switching module of high beam and low beam is entered, and high beam and low beam are switched according to the speed of the vehicle. Then, the bend adaptive lighting module is entered, the horizontal motor drive the lamp to the position which is calculated according to the specific bend follow-up algorithm, and the light intensity inside the curves is enhanced in the same time. After that, the ramp adaptive lighting module is entered, the vertical adjustment angle of the lamp is calculated with the specific ramp adjustment algorithm, and the illumination distance of the headlamps are adjusted accordingly. Finally, the above process is cycled until the car key is in the OFF position. If the driver turns the car key to the OFF position, the system will exit after the motor returns to the home position.

![Flow chart for the intelligent switching module of far and near light.](image)

**Figure 4.** Flow chart for the intelligent switching module of far and near light.

![Flow chart for bend adaptive lighting module.](image)

**Figure 5.** Flow chart for bend adaptive lighting module.
4. Experimental result

In this system, the NCV78663 chip is used as the main chip of the LED headlamp driving unit. The two schemes of adjusting headlamp brightness are: 1) setting dimming duty factor of LED strings; 2) controlling the current setting ratio of LED strings. In this paper, we test the data for these two schemes, and the obtained data is fitted by first-order linear fitting. The test object is 1W lamp beads.

The current and voltage parameters of each lamp bead are measured by changing the number of lamp beads in series or the dimming duty factor while the other parameters remain the default state. The dimming duty factor can be abbreviated as DDF. The measurement data are shown in Table 1, and the relationship between the working parameters of the beads and the DDF is shown in Figure 7.

Table 1. Measurement data by changing the number of lamp beads or the DDF.

| DDF  | Lamp beads*1 | Lamp beads*2 | Lamp beads*3 | Lamp beads*4 |
|------|--------------|--------------|--------------|--------------|
|      | V/V          | I/mA         | V/V          | I/mA         | V/V          | I/mA         | V/V          | I/mA         |
| 0.00%| 2.61         | 20.09        | 5.39         | 43.50        | 8.12         | 40.79        | 10.84        | 42.62        |
| 10.00%| 2.59         | 18.16        | 5.33         | 39.17        | 8.05         | 39.39        | 10.75        | 38.24        |
| 20.00%| 2.58         | 16.60        | 5.30         | 35.61        | 8.00         | 33.29        | 10.68        | 34.91        |
| 30.00%| 2.56         | 14.75        | 5.24         | 30.76        | 7.92         | 28.87        | 10.58        | 30.12        |
| 40.00%| 2.54         | 12.10        | 5.20         | 25.89        | 7.85         | 24.30        | 10.48        | 25.45        |
| 50.00%| 2.52         | 11.90        | 5.14         | 24.40        | 7.76         | 23.90        | 10.39        | 23.60        |
| 60.00%| 2.50         | 8.04         | 5.08         | 16.16        | 7.69         | 15.21        | 10.28        | 15.80        |
| 70.00%| 2.47         | 5.48         | 5.03         | 11.52        | 7.61         | 10.72        | 10.18        | 11.40        |
| 80.00%| 2.45         | 3.48         | 4.97         | 6.81         | 7.53         | 6.32         | 10.07        | 6.40         |
| 90.00%| 2.44         | 2.03         | 4.92         | 3.08         | 7.46         | 2.97         | 9.99         | 3.11         |
| 94.14%| 2.43         | 1.34         | 4.91         | 1.71         | 7.44         | 1.43         | 9.96         | 1.53         |
| 94.53%|              |              |              |              |              |              |              |              |

The lamp beads can't be turned on.
As shown in Figure 7, when the number of 1W beads in series is greater than 1, the relationship curves between the output parameters and DDF basically coincide. With the increase of DDF, the beads’ current decreases linearly and rapidly, and the voltage decreases in a very small range.

Changing the number of lamp beads in series or the current setting while the other parameters remain the default state is to measure the data of the current and voltage parameters. The obtained data are shown in Table 2, and the relationship between the working parameters of the beads and the current setting is shown in Figure 8.

The relationship curves between the output parameters and the current setting basically coincide. With the increase of current setting ratio, the output current of the beads increases linearly and rapidly, and the voltage increases in a small range.

### Table 2. Measurement data by changing the number of lamp beads or the current setting.

| Current setting | Lamp beads*1 | Lamp beads*2 | Lamp beads*3 | Lamp beads*4 |
|-----------------|--------------|--------------|--------------|--------------|
| 0.00%           | 2.64 V/V     | 22.4 I/mA    | 5.46 V/V     | 49.3 I/mA    | 8.10 V/V     | 48.2 I/mA    | 10.80 V/V    | 48.1 I/mA    |
| 20.00%          | 2.89 V/V     | 176.0 I/mA   | 5.88 V/V     | 259.0 I/mA   | 8.67 V/V     | 262.4 I/mA   | 11.70 V/V    | 257.7 I/mA   |
| 40.00%          | 3.10 V/V     | 432.0 I/mA   | 6.17 V/V     | 459.0 I/mA   | 9.24 V/V     | 459.0 I/mA   | 12.42 V/V    | 459.0 I/mA   |
| 60.00%          | 3.28 V/V     | 682.0 I/mA   | 6.48 V/V     | 678.0 I/mA   | 9.62 V/V     | 670.0 I/mA   | 12.82 V/V    | 664.0 I/mA   |
| 80.00%          | 3.41 V/V     | 898.0 I/mA   | 6.61 V/V     | 837.0 I/mA   | 9.67 V/V     | 803.0 I/mA   | --           | --           |
| 100.00%         | The lamp beads burned quickly. |
Table 3. Measurement data of ambient illumination at different times.

| lux | ratio | lux | ratio | lux | ratio | lux | ratio |
|-----|-------|-----|-------|-----|-------|-----|-------|
| 287 | 0.50  | 617 | 0.25  | 747 | 0.30  | 247 | 0.50  |
| 169.2 | 0.50 | 452 | 0.40  | 385 | 0.45  | 207 | 0.65  |
| 156 | 0.75  | 360 | 0.30  | 312 | 0.35  | 157.2 | 0.55 |
| 114.6 | 0.80 | 320 | 0.30  | 265 | 0.40  | 133.2 | 0.65 |
| 77.3 | 0.85  | 168.1 | 0.35 | 159.3 | 0.55  | 101.2 | 0.65 |
| 76.6 | 0.75  | 132.5 | 0.50 | 121.9 | 0.50  | 77.6 | 0.65 |
| 62.1 | 0.90  | 116.3 | 0.65 | 89.7 | 0.55  | 59.6 | 0.85 |
| 53.9 | 0.75  | 102.6 | 0.50 | 66.9 | 0.70  | 33.8 | 0.95 |

In the research of intelligent automobile headlamp system, the threshold of ambient illumination is an important factor affecting system quality. Therefore, we measured and counted the headlamp opening situation and ambient illumination at dusk for 5 days. For each calculation of the headlamp opening situation of 20 vehicles, we record the ambient illumination at that time. After screening out the data with larger errors, the remaining reasonable data are shown in Table 3.

Fitting the data with a third-order polynomial, the relationship curve is obtained as shown in Figure 9. The expression of the relationship between the ratio of car lights on and the ambient illumination can be listed as equation (1).

\[
y = -2976.92x^3 + 6773.55x^2 - 5321.44x + 1531.20
\]  

(1)

Generally, the proportion of automobile lights on that reaches more than 1/2, means that the ambient illumination at that time is the threshold of the system headlamp on. By substituting \(x = 0.5\) into equation (1), the result is \(y = 191.76\) lux. Therefore, this paper takes 200 lux as the threshold of ambient illumination.

Figure 9. The Relationship between illuminance and headlamp turn-on ratio at different times.

In this paper, a closed-loop feedback control system is composed of LED driver, motor drivers, sensors and MCU. There are two fault detection mechanisms in the system, one is active feedback mechanism, and the other is passive feedback mechanism.

The active feedback mechanism of fault detection refers to actively using a specific I/O to feed back its fault information to MCU after a fault occurs in the drivers or sensors. The passive feedback
mechanism of fault detection refers to that when it’s necessary to know whether a driver or sensor has a fault, the MCU sends corresponding instructions to the fault detection object by in a specific communication protocol. After receiving the instructions, the detecting object feeds back the fault information to the MCU. In this system, the active feedback mechanism is used as the fault detection mechanism of hardware units such as LED driver, steering wheel angle sensor, speed sensor, etc. And the passive feedback mechanism is used as the fault detection mechanism of the hardware units including LED driver, motor driver and photosensitive sensor.

The fault detection types and treatment measures of the system are briefly summarized in Table 4. As we see, there are three levels of alarm mechanism in Table 4 for fault diagnosis. The treatment measure of level 1 alarm is that red warning light is turned on and the system is forced to exit, as well as the car is recommended to park overhaul immediately. The treatment measure of level 2 alarm is that orange warning light is turned on, the system is forced to exit and the car is recommended to repair when idle. The treatment measure of level 3 alarm is that the yellow warning light is turned on, but the system is still working, and the car is suggested to repair when idle.

| Alarm Level | Fault Diagnosis Types                                           | Treatment Measures         |
|-------------|-----------------------------------------------------------------|----------------------------|
| 1           | Level 1 alarm                                                  | LED string open circuit    | Parking overhaul           |
| 2           | Level 1 alarm                                                  | LED string short circuit   | Parking overhaul           |
| 3           | Level 1 alarm                                                  | Individual LED shorted     | Parking overhaul           |
| 4           | Level 1 alarm                                                  | LED string over current    | Parking overhaul           |
| 5           | Level 2 alarm                                                  | The LED driver communicates abnormally with the MCU | Exit system forcibly |
| 6           | Level 2 alarm                                                  | Horizontal motor or vertical motor works abnormally | Exit system forcibly |
| 7           | Level 2 alarm                                                  | Photosensitive sensor works abnormally | Exit system forcibly |
| 8           | Level 2 alarm                                                  | The steering wheel angle sensor works abnormally | Exit system forcibly |
| 9           | Level 2 alarm                                                  | Speed sensor is working abnormally | Exit system forcibly |
| 10          | Level 2 alarm                                                  | Six-axis sensor works abnormally | Exit system forcibly |
| 11          | Level 3 alarm                                                  | LED driver booster is under voltage | Indicator light alarm |
| 12          | Level 3 alarm                                                  | LED driver issues a thermal warning | Indicator light alarm |
| 13          | Level 3 alarm                                                  | LED driver booster reaches maximum duty cycle | Indicator light alarm |

5. Conclusion

In this paper, the multi-sensor fusion technology is adopted in this intelligent LED headlamp system. Acquiring data such as the road conditions and the vehicle’s own operating status at the same time by multiple sensors, improves the sensitivity of the system. Compared with most intelligent headlamp in the current market, this system adds the ramp adaptive lighting function, which enables the vehicle to automatically adjust the illumination distance of the headlamp at the ramp. The ramp adaptive lighting function improves the intelligence and security of the system. All in all, this paper completes the research and implementation of intelligent LED headlamp system based on multi-sensor fusion, which increases the reliability and efficiency of the system.

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