FPGA-based led intensity controller for power consumption efficiency in motorcycle

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Abstract. Improper beam patterns on vehicle lights have major implications for the level of driving safety. This beam pattern control technique has been developed to improve driving safety. Most of them use additional components that increase power costs. In LED-based light sources, the design of LED arrays can increase the level of lighting and expand the transmission area. A large transmitting area is needed, but in a turn of the road, conditions are only needed based on the direction of the vehicle. Therefore, in this study, a system was designed to regulate LED beam patterns based on the direction of the vehicle. The main objective is to reduce power consumption so that it is more environmentally friendly and supports green technology programs. The control process was done by adding control components that work based on the direction of the vehicle that is read by the direction sensor. The digital control algorithm was implemented on the Altera DE-0 Nano FPGA with controls using fuzzy logic. The memory resources needed for implementing this system are 145 logic in the form of the loop up tables and 102 registers with a total power of 2 mW. This control module is able to provide a better focus of lighting and power efficiency up to 53% compared to a system without control.

1. Introduction

Since 2009, the Indonesian government has implemented an obligation to motorcycle to turn on the headlights during the day or what is known as Daytime Running Lights (DRL). The purpose of this new rule is to reduce the level of accidents in driving. This rule is proven to reduce the number of accidents by up to 20% [1]. Even so, there are negative impacts caused by increasing energy consumption and decreasing the lifetime of lamp components due to high temperatures. The use of the main motorcycle headlights is designed as a source of lighting, especially at night. During the day, of course, it can be considered as something inefficient. This condition is in stark contrast to the green technology program that is being heavily socialized.

The other thing that becomes a problem is the lack of efficiency in the use of energy in vehicles is an inappropriate beam pattern. Beam patterns on vehicle lights have major implications for energy saving and for safety driving [2]. The technique for controlling beam patterns is mostly done to improve driving safety, most of them use additional components that actually increase power requirements. On lamps based on LED lights are used a lot to increase the level of lighting and expand the beam area. Not only the wide beam area but also the focus of lighting is needed based on the direction of the vehicle's steering. In this study, control of the LED lights will be carried out based on the direction of the vehicle's steering. The main goal is to reduce power consumption so that it is more eco-friendly.
In 2019, the number of motorbikes in Indonesia was 137.7 million [3]. The use of massive motorbikes will have a significant impact on increasing energy consumption. As an illustration, if the number of active motorbikes during the day is 50%, 1 hour driving time and the lights used are types of LEDs with a power of 20 watts, the power consumption every day is 2.3 billion watts. This consumption is very large and affects the decreasing lifetime of the lamp. Therefore, it is very important and urgent research effort that is focused on overcoming this problem.

LED is one of the solutions as the most energy-efficient type of lamp. Motorcycle manufacturers began to replace conventional lights with LEDs. At the moment, the beam LED's capabilities can reach efficiency levels of up to 100 lumens/watt [4], which means it is far more efficient than ordinary incandescent lamps that are only 10-17 lumens/watts even halogen lamps that have 12-22 lumens/watt efficiency [5]. However, LEDs have limited transmission patterns compared to halogen lamps. So it takes an array that is arranged in an array to get a wide beam. The LED array of course requires large power and a wide beam pattern is not always needed in driving. Therefore, in this paper a beam pattern control is implemented, where not all LED segments must glow optimally, but only a few LEDs that are needed. For example, when the vehicle is going straight, the LED that lights up is maximum enough that the LED has a straight forward beam pattern, while the LED that illuminates laterally will gradually become dimmer. Likewise, when turning right, the LED that lights up optimally is the right LED segment.

Some research has been carried out in LED intensity control and some of them aim for efficiency. Ponniran et. al., implemented an LED intensity control system based on the level of light brightness [6]. Research by Wang et. al., designed a vehicle light control system that can work adaptively according to the geographical conditions of the surrounding environment [7]. Research by Kim et. al., designed a module control in the Multi-LEDs application using PWM [8]. But Kim's research did not show specific goals and was limited to simulations. The automatic lighting energy efficient control technique has also been successfully applied to LED-based street lights [9-10]. LED control simulation by adopting the Pulse Width Modulation method proposed by Umar et. al. [11], it is enough to provide evidence that LEDs can work optimally in efficient current. The LED dimming system has been implemented by Yang et. al. [12], but the switching process is done manually. Some of the literature studies described provide enough knowledge that LED control systems will have a positive impact on energy efficiency. But some of them have not discussed the details of the efficiency produced, still working manually or still in simulation. Therefore, in this paper an LED control on two-wheeled vehicles has been designed and implemented for energy efficiency. This control is to regulate the intensity of the LED beam based on changes in the steering angle with the FPGA as the main controller of the digital system. Comprehensive analysis regarding the efficiency of LEDs and processor resources is also discussed.

2. Beam Pattern Control Algorithm
The purpose of this proposed research is to get energy efficiency by emitting light in the effective area according to the direction of the vehicle. This explanation is illustrated in Figure 1.

Figure 1 Comparison of effective vehicle lighting and actual lighting [13]

There is research that has realized the control system by adding mechanical systems to adjust the beam pattern based on the direction of the steering wheel [14]. This method may be difficult in the
installation and of course requires more power to make it work. Thus energy efficiency cannot be achieved. Another method is to expand the beam area of the lamp by modifying the reflector [15]. The consequence of this method is that the size of the reflector can be larger or the current to the LED becomes larger which can cause high heat so that the LED is damaged. An alternative technique is to increase the number of LEDs used. However, power control is needed so that the intensity of each LED is effective in accordance with the direction of the vehicle. This method is the focus of the implementation and analysis of this proposed research.

This study adopted the beam forming method to set beam patterns in LED arrays. Beam forming is a method of forming a transmit pattern by arranging the transmission sequence following a certain transmitting pattern such as an ultrasound transducer. The ultrasound transducer has a narrow transmission pattern, so to form a large transmit pattern the transducer will be formed into an array consisting of several transducers. Then to get the desired transmission pattern, the transmission process is set with different delays for each transducer (Figure 2). This technique is the basis for setting the beam pattern on the LED array. However, the configuration of the LED array is done by adjusting the light intensity of each LED using Pulse Width Modulation to obtain an effective beam pattern. It also adjusts to the effective view of the human eye which ranges from only 94 to 104 degrees (Figure 3).

![Figure 2 The process of beamforming on an ultrasound transducer [16]](image)

![Figure 3 Limitation view of human eye [17]](image)

3. Design and Implementation

3.1 System Design

The main components of this system are directional sensing (angle sensor), decision maker (controller), dim light regulator (dimmer) and LED lights. The sensing component consists of a handlebar and a
potentiometer as an angle sensor. The decision component serves to synthesize information from the angle sensor to determine the prediction of the current vehicle position. This information will be the basis for determining the rate of the dimmer which in this case uses pulse width modulation (PWM). The decision circuit is implemented by the FPGA processor. Finally the PWM will drive the current towards the LED array that has 3 LED segments. The selection of LED arrays is based on usage commonly used on motorbikes so that this design is expected to be universally applied. The system design and LED components are shown in Figure 4 and Figure 5.

![Figure 4 System Design](image)

![Figure 5 LED components with 3 segments](image)

This research is a development from previous research [18] with the aim of obtaining higher power efficiency. In this study, the direction of the vehicle was divided into five groups, they were Straight, Right_1, Right_2, Left_1 and Left_2. At the beginning of the operation, a calibration is carried out, namely the initial measurement, where the input from angle sensor will be stored as an initial reference that the condition of the vehicle is facing straight ahead. So that the workflow of this decision-making component will be seen as a flowchart in Figure 6.

The position of the steering angle that changes will be followed by a change in the potentiometer resistance so that the main control component detects changes in steering direction. During calibration, the value is then stored by assuming the vehicle is in a straight position. Then after the value is stored as a reference, if the voltage read by the ADC decreases, a decision is taken that the direction of the vehicle is to the right. When the voltage increases, the direction of the vehicle is left. The process of determining
this direction uses fuzzy logic as a control with the learning process carried out first to determine the threshold for each direction.

![Workflow of the proposed system](image)

**Figure 6** Workflow of the proposed system

Rotating radius of a motorcycle has a limitation which is around 120 degrees. This condition then allow us to ignore the other degrees. Due the use of fuzzy logic as the controller, we define five turning regions and four additional regions as the transition area such as shown in Figure 7.

![Nine regions representing the motorcycle movement based on the handlebars angle](image)

**Figure 7** Nine regions representing the motorcycle movement based on the handlebars angle

In calibration process, the straight position is determined form $0^\circ$ which cover $-15^\circ$ to $+15^\circ$. There are two transitions area covering the next $10^\circ$ in both sides. “Right_1” position covers $20^\circ$ from $25^\circ$ to $45^\circ$, and vice versa for “Left_1” position. “Right_2” and “Left_2” position is located $10^\circ$ after the transition area, covering $50^\circ$ to $60^\circ$ for both sides.

3.2 Composition of Light intensity based on direction
This research used three segments of LED which called as “Left LED”, “Center LED”, and “Right LED”. The light intensity (in percent) from each LED determined according to the direction of the handlebars showed in Figure 8.
Based on the rotating region area, and the light intensity from each LED, we create a fuzzy diagram that used as the main reference for the developed system. The fuzzy logic chart is shown in Figure 9.

The fuzzy logic graph shows the LED intensity to handlebars direction angle. The yellow line shows the average intensity value which spreads around 36.7% to 53%. This value represents the total power consumption needed by the system, which means the energy consumption can be reduced by 47% to 63%.

Figure 8 Light intensity of LED segments (a) Straight; (b) Right_1; (c) Left_1; (d) Right_2; (e) Left_2
3.3 Digital System Implementation

There are three main entities in the digital system designed using FPGA Altera DE0, first is ADC interface, decision maker, and PWM controller or dimmer. ADC interface used as the communication interface between ADC and packing the transferred data into 12-bit parallel data and forward it to the decision maker. The decision maker determines the working area for the received data based on the threshold value designed by the fuzzy logic.

Decision maker produce information direction using three bits combination, 010, 100, 110, 001, and 011 for “Straight”, “Left_1”, “Left_2”, “Right_1”, and “Right_2” respectively. This information then forwarded into dimmer module to set the light intensity for every area. The schematic of the designed digital system can be seen in Figure 10.

![Fuzzy Logic Chart](image.png)

**Figure 9** Fuzzy logic graph.

**Figure 10** Schematic of the designed digital system

The designed system used a relatively small resource which implemented in FPGA. Figure 11 shows that there are 145 logic in the form of loop table, and 102 registers. The ADC component used in the system are 94 while dimmer and decision used 25 components. Moreover, the number of components used for LUT and registers used are 11 and 18 respectively. The power used to operate the system is 2mW which relatively small. The power measurement is done by using Quartus software, which measured when synthesizing the system, the detail can be seen in Figure 12.
RESULT AND DISCUSSION

4.1. PWM level to power consumption

It is important to find out the relation between LED intensity control using PWM to the power consumption. The detailed information of the test can be seen in our previous report in [18]. The power consumption when the system using 100% PWM duty cycle is 9.5 Watt, 0.55 Ampere with a voltage of 17.8 Volt. The PWM graph level to power consumption is shown in Figure 13.

Beam pattern analysis based on intensity composition.

Table 1. shows the beam pattern for each direction based on the LED segment intensity composition. It is showed that there are power efficiency for each condition. The reduce of light intensity in both side LED lamps made the center direction of LED lamps became brighter and there is slightly differences between the one without control, despite the power has been reduced 46% by PWM. Similar result obtained for direction “Right_1” and “Left_1” that produce power efficiency 35% while “Right_2” and “Left_2” produce 53% of power efficiency.
Table 1 Power efficiency of each beam pattern

| Beam Pattern (without control (left) and with control (right)) | Beam direction | Power consumption – with control | Power consumption – without control | Power efficiency |
|--------------------------------------------------------------|---------------|---------------------------------|-----------------------------------|-----------------|
| Straight                                                    | 6.2 Watt      | 9.5 Watt                        | 35%                               |
| Right_1                                                     | 6.2 Watt      | 9.5 Watt                        | 35%                               |
| Left_1                                                      | 6.2 Watt      | 9.5 Watt                        | 35%                               |
| Right_2                                                     | 4.44 Watt     | 9.5 Watt                        | 53%                               |
| Left_2                                                      | 4.44 Watt     | 9.5 Watt                        | 53%                               |

In order to give a better observation, Figure 14 shows the beam pattern in an adjusted contrast image. Beam direction produced by the system can follow the motorcycle direction. From Figure 14 it can be seen that the dominant intensity of the LED is in accordance with the direction of the vehicle. Although there is an intensity control system in the LED segment, visually the area of the beam is almost uniform. Thus the objectives of the proposed system are achieved, resource efficiency but still have good performance.
5. Conclusion
A light intensity control module for motorcycle based on the handle bar direction has been successfully implemented. This module is made for creating a power efficiency by considering the effective beam pattern. This system consist of direction sensors using potentiometers, main controller using FPGA, dimmer circuit, and three LED segments. The beamforming technique is build based on PWM to create a different beam direction pattern following the direction of motorcycle. In this study, the direction is divided into five areas named “Straight”, “Right_1”, “Right_2”, “Left_1”, and “Left_2” with a predefined angle. The beam direction angle is adjusted from the previous research to achieve better efficiency. The memory resources used in this system is relatively small. It used 145 logic in the form of loop up table and 102 registers. The power consumption for the hardware is 2 mW, this low power is a great advantage for the next level of prototype implementation. This system able to control the beam direction pattern based on the movement of handle bars by controlling each LED segments. The proposed method succeeded in producing power efficiency up to 53% without reducing the beam focus.

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