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Development of an Adaptive Headlamp Systems

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***Abstract*— The highest fatal traffic accident rate occurs on curved roads at nighttime. In most cases, the late recognition of objects in the traffic zone plays a key role. These facts point to the importance of the role of automobile forward-lighting systems. In order to provide enhanced nighttime safety measures, this work aims to design and build a prototype of steerable headlights by adapting a conventional static headlamp with a very close eye on cost and reliability. Components that are easily available in the market and suitable for developing a steerable headlight system were tested. Different kinds of tests were done on critical parts of the system in order to determine its accuracy, its response time, and the system impact. Finally, the results acquired from these various tests will be discussed. Any findings and changes that should be made are discussed and may be useful for future development.**

Keywords- Headlamp; AFS; Advanced Frontlighting System; Curved Road; Automotive; Microcontroller; Servomotor; Sensor; Actuator

I. INTRODUCTION

Because the static headlamp just provides certain illuminating fields for drivers in the nighttime and is insufficient to serve for curved roads and intersection, Advanced Front-lighting System (AFS), has been proposed by many researchers and is catching increasing interest [1-6].

Over 80 percent of all road traffic accidents occur in darkness and bad weather – a compelling reason to put efforts into developing the next generation of intelligent lighting systems with multi-functional swiveling headlamps. The aim is to improve visibility for the driver, thereby achieving a significant increase in road safety and driving comfort. Various studies on swivel-beam headlamps have shown up to a 300% increase in the illumination of the driver's gaze point as the vehicle turns into a corner [7]. The additional corner illumination results in a 58% increase in the driver's ability to recognize an obstacle [7].

Adaptive Front-lighting Systems (AFS) swivel the headlight beams in advance of the vehicle's turning. This places light into the turning radius, with the result that the driver's cornering visibility being dramatically improved. The vehicle's data network also contains real-time sensor data on steering angle and wheel speed. Based on this information, AFS equipped headlamps can match the light distribution with the vehicle's turning angle so that upcoming curves and intersections receive maximum illumination, especially at the driver's gaze point. The significant increase in light helps reduce driver stress and fatigue and improves the ability to see obstacles that fixed-beam headlamps might not illuminate [7].

The concept of swiveling headlamps is not a new one. An early innovation in lighting was to vertically tilt the beams high-beam-to-low-beam (dipped) switching dating back to 1917. It wasn't long before beam height adjustment able to compensate for rear seat occupancy or car loading became available, usually controlled through an internal, typically wheeled, adjustment. More recently, automatic self leveling has become an increasingly common requirement as the light sources have become brighter and glare has increased.

Horizontal swiveling is far rarer in the automotive industry. A first appearance in 1948 was in the the Tucker Torpedo that featured an extra steerable headlight in the center of the car. Unfortunately this steering innovation was as short lived as the Tucker Company itself. The idea cropped up again on the 67 Citroen DS19 which incorporated a pair of steerable beams. The Citroen Desirée, whilst being one of the most innovative and desirable cars at the time of its launch in 1955, reached the end of its space age design life in 1977. Unfortunately, when the model was discontinued so was the innovation of steerable headlights.

Horizontal swiveling, reemerged in the 21st century courtesy of Lexus, Porsche, Audi, and others. The reemergence of this technology was welcome as studies had shown AFS to be significant contributors to increased safety whilst driving at night, as cited previously. Given its benefits, the absence of this technique for so long is surprising. Furthermore, with its use restricted to high-end vehicles, AFS is still an inaccessible feature for the vast majority of drivers on the roads today. However, the lack of innovation in headlight systems and designs may be less to do with a lack of ambition on the part of vehicle designers and more to do with the international differences in regulations on what the designers could and couldn't do. With an eye on the export market, designers had to comply with several sets of sometimes conflicting regulations which severely limited innovation.

The objective of this work is to design and build an AFS prototype that will modify an existing fixed headlamp with a very close eye on cost and reliability. Use of existing headlamps will allow the AFS addition to maintain the vehicle’s conformity to existing vehicle aesthetics as well as government regulation. Components that are easily available in the market and suitable for developing a steerable headlight

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system were tested. Different kinds of tests were done on critical parts of the system in order to determine the accuracy of the system and its response time.

II. THE DEVELOPED SYSTEM ARCHITECTURE

The purpose here is to disassemble the conventional headlight and modify the projector light for beam rotation. In order to manage system costs and complexity, a simple framework was laid out for the developed AFS. The latter consists of three important components: input sensors, a microcontroller as the brain of the system, and a motor for positioning the headlights. The developed flow task diagram of Fig. 1 shows that the system first collects inputs, processes them, and then moves the actuator as output. In this design, there is no requirement for a feedback loop between the headlight positioning and the microcontroller.

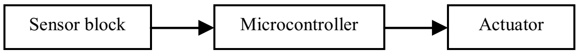

Figure 1. Basic block diagram

Again, with an eye to cost, commercially available components were sourced.

A. *Sensor Block*

The position of the headlights is dependent on the direction of the vehicle so the input to the headlight system is attached to the vehicle's steering shaft. A simple geared mechanism is attached to a low-power type potentiometer that can then feed directly into the microcontroller. As the steering shaft rotates (taking corners), it will turn the axle of the potentiometer and therefore vary the voltage input. The voltage input that varies from 0-5 volts is converted into digital input via the A/D channel of the PIC 16F877A microcontroller. For example, if the headlight is set at the center with an initial voltage of 2.5V, if the voltage increases as the potentiometer turns, the PIC reads this voltage increment and will turn the motor as programmed.

B. *Microcontroller*

A Programmable Intelligent Computer (PIC) microchip was used to control the motor. The PIC selected is the PIC16F877A which is an 8 bit microcontroller with 8KB flash program memory and USART. The PIC16F877A was selected because of its availability, low price, reliability, and its use of C language for its programming. The selected PIC also required minimal additional components in order to operate, further controlling system costs.

C. *Actuator Block*

As shown in Fig. 2, the motor is meant to turn the projector headlight mounted above it. The selection of a motor mechanism was a key step in the steerable headlights design. For this application, two types of motors were readily available: servo motors and stepping motors. Both types offer similar opportunities for precise positioning, but they differ in a number of ways. Servomotors require analog feedback control systems of some type. Typically, this involves a potentiometer to provide feedback about the rotor position, and some mix of circuitry to drive a current through the motor inversely proportional to the difference between the desired position and the current position.

In making a choice between steppers and servos, a number of issues must be considered; which of these will matter depends on the application. For example, the repeatability of positioning done with a stepping motor depends on the geometry of the motor rotor, while the repeatability of positioning done with a servomotor generally depends on the stability of the potentiometer and other analog components in the feedback circuit. Stepping motors can be used in simple open-loop control systems [8]. These are generally adequate for systems that operate at low accelerations with static loads, but closed loop control may be essential for high accelerations, particularly if they involve variable loads. If a stepper in an open-loop control system is over torqued, all knowledge of rotor position is lost and the system must be reinitialized; servomotors are not subject to this problem.

From the above, the servomotor was deemed more suitable for the AFS design since motor positioning is the most important criteria and servomotors usually come with a built-in feedback circuit that facilitates design.

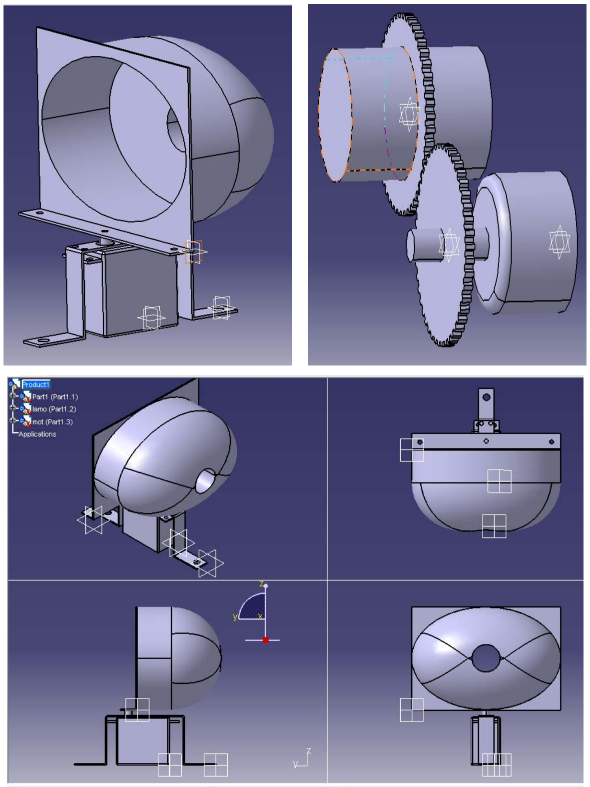

Figure 2. Multiview projection of steerable headlight mechanism design.

III. ASSEMBLY AND PROGRAMMING

A. *Modification of the Headlights*

A potentiometer was mounted on the steering shaft giving variable inputs. As the steering shaft turns, it turns the potentiometer. The potentiometer then gives an analog input into the controller unit. The controller unit processes the input and gives the exact output current to turn the servomotor as initially programmed. To move the headlight 15 degrees from left to right proportionally with car steering requires a motor and microcontroller. For example, as the car turns right, the headlight will turn right also, therefore illuminating more on right hand side of the road.

The projector light was removed and modified so that it can be attached to the servomotor. The projector light is mounted on a bended aluminum strip. Next, the mounting for the servo motor was done, by attaching it to the bended aluminum strip, so that it can be attached to the headlight casing. The aluminum strip and projector light are then mounted back in the casing. The position of the mounting is adjusted so that the projector light can rotate at least 10 degrees left to right, per the specification. Lastly, the headlight is reassembled as seen in Fig. 3.

Figure 3. Reassembled parts of the steerable headlight.

B. *Programming of the Microcontroller*

The potentiometer is used as the input; the pot will vary the voltage in the PIC which is from 0V to 5V. The potentiometer gives an analog input; therefore the PIC needs to convert it into a digital input via ADC. The digital number provided by the ADC relates to the proportion that the input voltage is of the full voltage range of the converter. For instance, applying 2V to the input of an ADC with a full-scale range of 5V will result in a digital output that is 40% of the full range of the digital output (2V / 5V = 0.4). The output digital ranges are usually expressed in terms of bits, such as 8 bits provided by the PIC16f877a. The number of bits at the output determines the range of numbers that may be read from the output of the converter. An 8-bit converter will provide outputs from 0 to 2^8 - 1 or 255. Hence, when 2V is applied to a converter with a full-scale range of 5V, an 8-bit converter would read 40% of 255, or 102. The proportion or conversion factor is summarized in the following formula:

$$\frac{V_{in}}{V_{fullscale}} = \frac{X}{2^n - 1} \qquad (1)$$

Where X is the digital output and n is the number of bits. An important issue buried in this formula is that of resolution. The resolution of measurement (or the finest increment that can be measured) is calculated as follows:

$$V_{resolution} = \frac{V_{fullscale}}{2^n - 1} \qquad (2)$$

Therefore, the finest voltage increment that can be measured, in this situation, is 20mV.

The actuator used for this system is the SANWA SX-01 servo motor. Again, the servo consists of 3 wires: red, black, and blue. The red and black are the positive and negative power supplies, whereas the blue is for signaling. The signaling is actually a varying voltage, which in this case ranges from 0V to 5V. The motor will move according to the signal voltage. This signal is called Pulse Width Modulation (PWM). PWM is a way to convert digital signals into analog signals. For the servo motor, the general pulse needed is around 50 Hz which means a pulse every 20 ms, but in the digital world, the numbers are only 0 and 1 or, in this case, 0V and 5V. An adaptation is necessary between the servomotor and processor. For example, during the 20ms interval, where the signal is “on” for 1.5ms and “off “for 18.5ms, then it is “on” for 7.5% of the interval. Doing this every 20ms or 50 Hz, will give a voltage of 7.5% * 5V = 0.375V. The pulse length will determine how much the motor will move. Table 1 displays the pulse length and motion angle for the SANWA SX-01 servomotor with a total motion angle of 210 degree.

TABLE I. PULSE LENGTH AND CORRESPONDING MOTION ANGLE OF THE SERVO MOTOR

Pulse length (µs)	**Angle (°)**
650	0
1500	105
2350	210

The PIC will receive the analog input from the potentiometer and convert it to a digital input. Then, the digital input will be manipulated so that it will produce the PWM required for the servo motor to move. Fig. 4 shows the basic software flowchart:

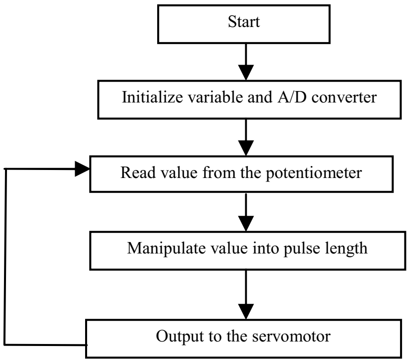

Figure 4. Basic software flowchart

The developed program aims to turn the motor continuously using the potentiometer. Since the beam on the right hand side is focused lower then the left one, the right hand side lamp need only to move 5 degrees left to right, whereas the left one can move 15 degrees left to right.

Therefore, pin 33 will be ON for 1499 microseconds and pin 34 will be ON for 1490 microseconds and both pins will be OFF for about 17500 microseconds. All of these instructions will be executed again and again forever, therefore this will produce a signal between 55Hz and 45Hz which are in the operating signal of the servo motor. The ON times of 1499us and 1490us will position the servo motor at center according to the motor specifications.

IV. TESTING RESULTS AND DISCUSSION

To put this whole system into practical use, there are several critical functions that need to be tested and analyzed. The first critical function is to determine whether the headlights or motors are moving as desired prior to the rotation of the potentiometer which represents the steering wheel. The second function is the response time of the motor i.e. the time taken for the headlight to move from one position to another. Finally, the headlight will be installed on a car to see how effective it is.

The theoretical results have been compared with the experimental results as shown in Fig. 5. In this experimental test, the input voltage variable is measured by a multimeter, whereas the frequency of the signal is measured by using an oscilloscope, and the motor position is measured using a protractor.

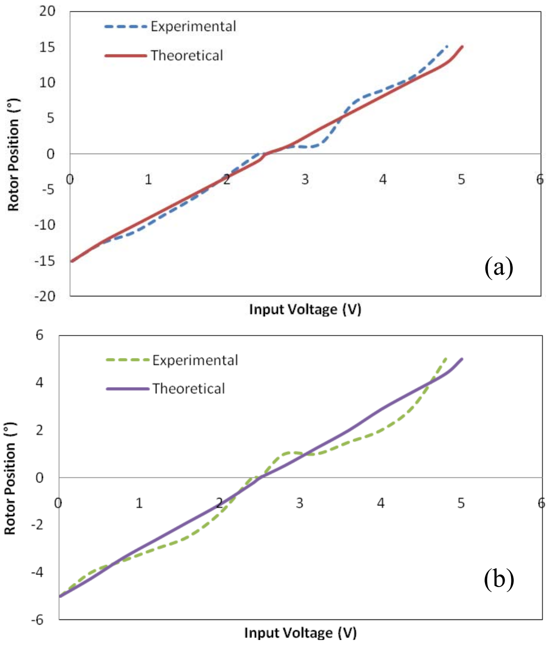

Figure 5. Comparison between theoretical and experimental results for motor 1 (a) and motor 2 (b)

As it can be seen from Fig. 5a, which is the graph of the result comparison for motor 1 that moved 15 degrees back and forth, the motor still moved from -15 to 15 degrees, but, there is a slight difference during the motion. For example, for an input voltage of 3.6V, the expected motor position is 5.88 degrees, whereas the actual position is 5.5 degrees. The voltage scale is also different; the calculation used a voltage scale from 0 to 5V whereas measured voltage scale is only from 0 to 4.8 V. This difference in voltage scale was not noticed during the tests and may have been due to a voltage drop in the PIC itself. However, the maximum and minimum degree positions are still the same and therefore this slight difference in voltage will not cause any significant effect to the functioning of the steerable headlight. Another possible cause of error of that invariant degree is the gear slop in the servo motor. Gear slop means that a gear is able to move without moving another gear because of the small space between the teeth of both gears. Another source of errors could come from the measured data, for example, the motor position is measured by a protractor which is only accurate to 1 degree. By taking all of this error into the consideration, the average percentage error of this test is about 4.6%.

The response of a motor is actually the time taken for a motor to change one position to another position. For this test, the time of the motor moving from lock to lock position, which is from 0 to 210 degrees, was recorded for various operating voltages. Fig. 6 shows the motor answer in its loaded and unloaded state where it can be seen that the ideal supply voltage for the motor is 6V and the lowest it can operate at is 4.8V. Above the ideal value, the motor will burn and below the lowest voltage it will barely move. This 6V can be maintained by a voltage regulator since the vehicle voltage is 12V. At 6V there is little difference in time with or without load as seen in Fig. 6, but the difference dramatically increases when the drop is only 0.2V. Therefore, regulating the voltage supply at 6V is crucial.

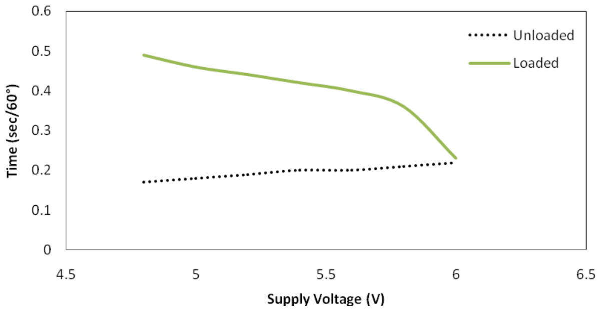

Figure 6. Time taken for the motor to move in 60 degree

Finally, the developed AFS was installed on a car and pictures were taken at different angles of swiveling. This visual test results are displayed in Fig. 7. One can notice that, when the headlight position is at the center position, the tree, representing an obstacle, can barely be seen on the right hand side of the picture (Fig. 7a). However, when the headlight is positioned at far right position, the obstacle was illuminated very clearly, as seen in Fig. 7b. Normal headlights cannot illuminate this obstacle while cornering and this is a proof of how effective this system can be.

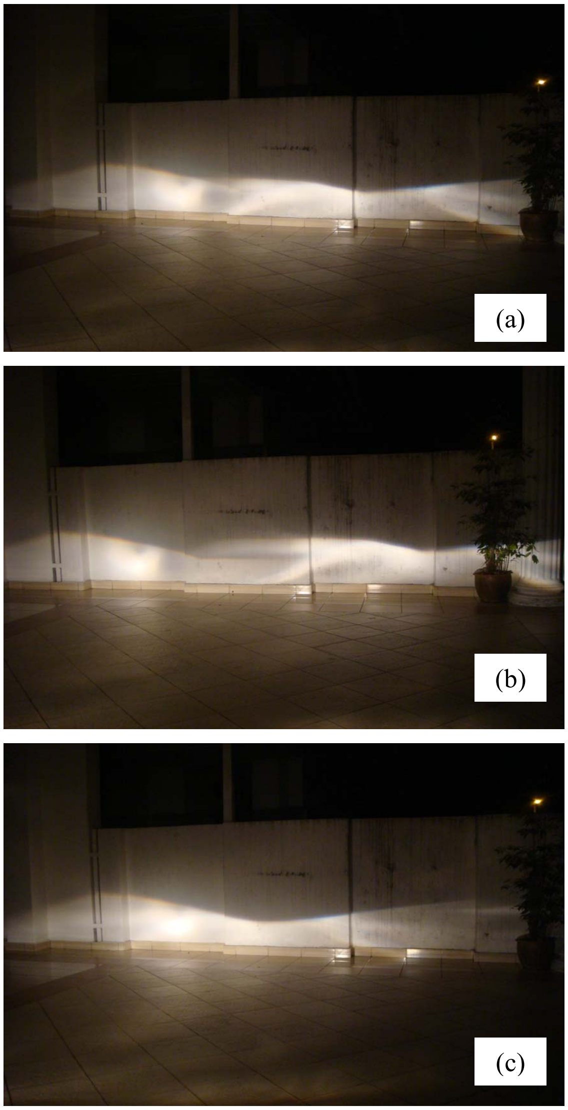

Figure 7. Headlight visual at (a) center position, (b) far right position, and (c) far left position

V. CONCLUSION

The design and build of steerable headlights from conventional static headlamps has been achieved. Moving the headlights from left to right or vice versa continuously corresponding to a sensor is achieved. An advantage of the developed headlight system is in its high adaptability as it can be easily configured to fit within space confines of a variety of vehicle designs. Indeed, the latter provides a bending lamp that allows for significant angular displacement of the light beam of a headlamp assembly without excessive light beam distortion and without the need to move the entire headlamp assembly. Furthermore, the system is of inexpensive, simple and dependable assembly.

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