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DESIGN AND DEVELOPMENT OF PORTABLE MICROCONTROLLER BASED HEADLIGHT TESTER FOR MOTOR VEHICLE INSPECTION

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ABSTRACT:
Ensuring road safety for motor vehicle users is a fundamental objective of vehicle inspections, with particular emphasis on the technical condition of the vehicle's lighting system. However, traffic accidents resulting from malfunctioning headlights remain prevalent. This problem is often attributed to the poor condition of headlight testing devices (headlight testers) available in several Motor Vehicle Inspection Units, where many units are outdated, poorly maintained, or damaged. The high costs associated with the maintenance and repair of manufacturer-produced headlight testers further exacerbate this issue.This study aims to design and develop a portable, microcontroller-based headlight testing device that is both cost-effective and efficient. The proposed system utilizes a photodiode sensor to detect light intensity, with data processed by an Arduino Nano microcontroller. Measurement results are displayed on an LCD screen and can also be printed via a thermal printer.Experimental evaluations demonstrate that the device accurately and precisely measures vehicle headlight intensity in real-time, achieving accuracy levels of 99.52% for the right headlight and 99.43% for the left headlight. The portability of the system allows for convenient testing in various locations, including both indoor and outdoor environments, without requiring bulky or complex equipment. This device offers a practical solution to enhance the efficiency and accessibility of vehicle lighting inspections.

KEYWORDS: *Headlight tester, Microcontroller, Light intensity, Photodiode, Arduino Nano, Motor vehicle inspection.*

I. INTRODUCTION

Traffic safety remains a critical global concern, with the technical condition of motor vehicles playing a significant role in reducing accident risk [1].[2] One of the essential components that must meet safety standards is the primary vehicle lighting system, particularly the headlights. According to current regulations, the minimum luminous intensity of vehicle headlights must exceed 12,000 candela (cd) to ensure optimal visibility and prevent accidents, especially during nighttime driving or under adverse weather conditions [3] . Although headlight technologies have advanced in line with developments in automotive engineering, statistical data indicate that nighttime traffic accidents occur at rates three times higher than daytime incidents, despite significantly lower traffic volumes at night [4]. Additionally, the beam angle of vehicle headlights is another crucial factor in traffic accidents. Vehicles traveling uphill or carrying excessive loads tend to tilt upwards, causing the headlight beam to misalign and point away from the road surface, thereby increasing the risk of accidents [5].

Periodic motor vehicle inspections, including headlight assessments, are mandated for various vehicle categories such as public passenger cars, buses, freight vehicles, trailers, and semi-trailers [2]. The main objectives of these inspections are to ensure the technical safety of the vehicle, particularly its lighting systems, as well as to design, evaluate, and analyze the performance of testing devices [6]. [7] However, conventional headlight testing devices commonly used in vehicle inspection facilities often suffer from several limitations, such as high costs, large physical dimensions, and lack of portability [8]. These issues have posed significant challenges for many transportation agencies, making it difficult to maintain or replace defective testing equipment, as well as hindering mobile or outdoor inspection activities.

This study aims to design and develop an effective, accurate, and cost-efficient portable headlight tester based on a microcontroller platform. The proposed device utilizes a photodiode sensor to detect light intensity, which is then processed by an Arduino Nano microcontroller. The measured data are displayed on an LCD screen and can be printed using a thermal printer. The proposed solution is expected to offer an innovative approach that simplifies vehicle headlight testing procedures, enhances operational efficiency, and ultimately contributes to improving traffic safety in Indonesia.

II. METHOD

A. RESEARCH AND DEVELOPMENT (RND)

This study employed a Research and Development (R&D) approach to design and develop a portable, microcontroller-based headlight testing device. The research was conducted at the Regional Technical Implementation Unit for Motor Vehicle Testing in Bantul Regency, Special Region of Yogyakarta, from March to June 2025.

The initial stage of this research involved identifying problems associated with conventional headlight testing devices, which are typically expensive and lack portability. Subsequently, a comprehensive literature review was conducted using various sources to support the product development concept. Primary data were collected through direct observation and on-site documentation, while secondary data were obtained from relevant journals and operational standards.

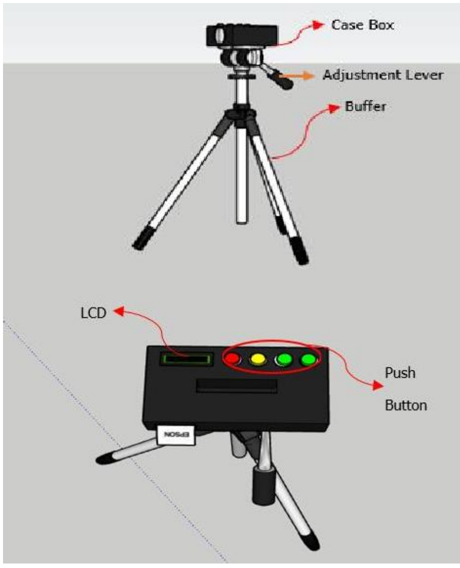

Fig 1. Prototype Design

The product design phase included system modeling using SketchUp software for 3D visualization. The main components of the device comprise an Arduino Nano microcontroller, a photodiode sensor, an LCD display, and a thermal printer. After assembly, the prototype was tested to evaluate its performance and accuracy. The testing process involved comparing the results of the prototype with those of a commercial headlight tester, both indoors and outdoors, to assess its feasibility as a portable alternative. The system's measurement calculations were based on converting sensor outputs into light intensity values expressed in candela.

B. BLOK DIAGRAM

The system block diagram was developed to illustrate the operational sequence and interconnectivity of each functional module within the microcontroller-based headlight tester in a clear and integrated format

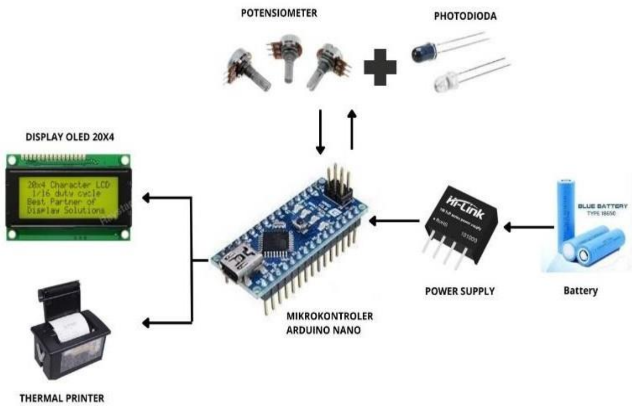

Fig 2. Blok Diagram

The portable headlight tester system integrates several key components to achieve optimal functionality. The Arduino Nano serves as the main microcontroller, responsible for processing signals from the sensors and controlling the entire system. The Arduino Nano is designed and manufactured by Gravitech [9]. The photodiode sensor is employed to measure the light intensity of vehicle headlights. The higher the amount of light absorbed by the sensor, the greater the resulting current flow [10]. Meanwhile, a potentiometer functions as a variable voltage divider. Its resistance can be adjusted according to the specific requirements of the electronic circuit or user preferences [11]. The power supply for the device is provided by an 18650 lithium-ion battery. A battery functions by converting chemical energy into electrical energy to power electronic devices [12]. Lithium-ion batteries are among the most widely used types of secondary (rechargeable) batteries due to their high energy density and rechargeability [13]. One of the most widely used types of secondary (rechargeable) batteries is the lithium-ion battery [14]. All components are interconnected using jumper wires, which are utilized to establish connections between components on a breadboard or Arduino board without soldering. Generally, jumper wires are equipped with pins on both ends for easy installation [15].

The measurement results are displayed on a Liquid Crystal Display (LCD), which serves as the interface between the user and the microcontroller. Additionally, the results can be printed physically using a thermal printer. In general, there are three common types of printers: dot matrix printers, inkjet printers, and laser printers [16]. The operating principle of the device begins when it is powered on, with the battery supplying electrical power to the Arduino Nano, the photodiode sensor, and the LCD. The photodiode sensor is then activated to detect the light emitted by the vehicle's headlights through an optical lens. Once light is detected, the sensor measures its intensity in candela (cd), and the results are subsequently displayed on the LCD and printed via the thermal printer as the final output.

III. RESULT AND DISCUSSION

A. PROTOTYPE ASSEMBLY

The circuit assembly forms the core of this system, designed to enable portable testing and analysis of vehicle headlight illumination. The assembly process begins with the integration of the main components. The Arduino Nano functions as the system controller, managing sensor operations, processing data, and displaying the measurement results. Stable power is supplied by a power supply unit, which converts external electrical sources into the appropriate voltage required by the microcontroller, sensors, and other modules, while also allowing for the use of rechargeable batteries to enhance portability. A photodiode sensor, which functions as a light intensity detector, is installed to capture the illumination from vehicle headlights, with the sensor data subsequently processed by the Arduino Nano.

The measurement results can be printed via a thermal printer, and a push button is provided as a user input interface to initiate the testing process or reset the system.

The design and development of this device are based on a microcontroller, which functions as a fully integrated computer system on a single chip [17]. The primary objective of the design process is to provide a clear and understandable framework that can be easily interpreted by both technical experts and non-experts involved in the project [18]. The design methodology consists of the following five key stages is (1) Planning,(2) Requirement Analysis,(3) System Design,(4) Circuit Implementation, and (5) System Maintenance [19].

The connections between components are systematically designed. The I2C module on the LCD reduces the number of required pins, enabling serial data communication between the LCD and the microcontroller. Once the circuit assembly is completed, the components are mounted inside an enclosure specifically designed to protect the system and enhance its visual appeal.

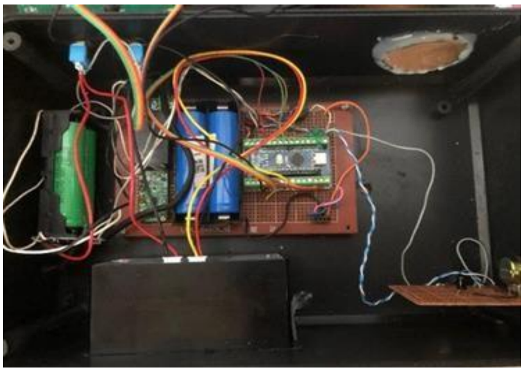

Fig 3. Prototype Assembly

Fig 4. Prototype Assembly Results

The device enclosure is mounted on a height-adjustable tripod equipped with an alignment lever, allowing precise positioning of the device relative to the vehicle's headlights. The software development process was carried out using the Arduino Integrated Development Environment (IDE). The IDE is essential for writing programs, compiling them into binary code, and uploading them to the microcontroller's memory [20]. The software processes data from the photodiode sensor and displays the results on the LCD, with an option to print the output via the thermal printer.

B. RESULT

Comprehensive testing and calibration procedures were conducted to evaluate the performance of the device. Calibration is essential to identify any deviations of the measurement device from established standards. The calibration process was carried out to compare the performance of each component during testing and to ensure that the sensor operates optimally.The initial calibration involved measuring the light intensity of a single vehicle using the developed portable microcontroller-based headlight tester. Measurements were performed 25 times for each headlight, with the device maintained in a fixed and unchanged position throughout the tests. In the calibration graph, the X-axis represents the data sequence from 1 to 25, while the Y-axis represents the measured light intensity in candela (cd).

During the data collection process, several challenges and influencing factors affected the testing results of the developed portable microcontroller-based headlight tester. One key challenge was ensuring that the light sensor was precisely aligned with the beam of the vehicle's headlights. In some cases, the sensor required a stabilization period before displaying accurate measurement values. Additionally, ambient lighting conditions in the surrounding environment significantly impacted the measurement results.

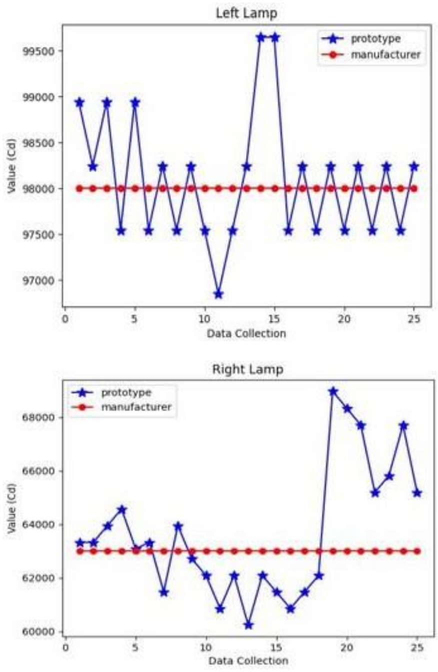

Fig 5. Prototype Calibration Chart

Testing of the device on Mandatory Vehicle Inspection Units also demonstrated good performance and high accuracy. The measurement results of the prototype showed an average accuracy of 99.52% for the right headlight and 99.43% for the left headlight. The device functioned reliably, processing data effectively, displaying sensor readings on the LCD, and printing the results via the thermal printer. The photodiode sensor was capable of detecting light intensity exceeding 200,000 candela. This high level of accuracy indicates that the developed portable headlight tester is a practical, accurate, and easily transportable alternative for vehicle headlight testing, suitable for use in both indoor and outdoor environments.

Tbl 1. Measurement Results

Measurement	LEFT LAMP CANDELA MEASUREMENT PROTOTYPE	LEFT LAMP CANDELA MEASUREMENT MANUFACTURER	DIFFERENCE	ACCURACY	RIGHT LAMP CANDELA MEASUREMENT PROTOTYPE	RIGHT LAMP CANDELA MEASUREMENT MANUFACTURER	DIFFERENCE	ACCURACY
1	49409	49300	109	99,78%	52973	52600	373	99,30%
2	46747	46500	247	99,47%	44728	44700	28	99,94%
3	34600	34483	117	99,66%	36164	35900	264	99,27%
4	36164	36100	64	99,82%	35042	35000	42	99,88%
5	28500	28409	91	99,68%	27800	27320	480	98,27%
6	38421	38100	321	99,16%	40900	40698	202	99,51%
7	17200	17189	11	99,94%	15700	15625	75	99,52%
8	16667	16400	267	98,40%	36500	36164	336	99,08%
9	35800	35602	198	99,45%	36164	36000	164	99,55%
10	34483	34300	183	99,47%	32900	32813	87	99,74%
11	30602	30300	302	99,01%	43571	43500	71	99,84%
12	38000	37855	145	99,62%	39000	38988	12	99,97%
13	37855	37600	255	99,33%	36800	36726	74	99,80%
14	22000	21939	61	99,72%	19300	19289	11	99,94%
15	17400	17189	211	98,79%	16700	16668	32	99,81%
16	44800	44728	72	99,84%	48232	48200	32	99,93%
17	28800	28409	391	98,64%	34483	34100	383	98,89%
18	55375	55000	375	99,32%	43571	43500	71	99,84%
19	17822	17800	22	99,88%	16810	16700	110	99,35%
20	60687	60600	87	99,86%	67000	66900	100	99,85%
AVERAGE	33799,1	33638,3	160,8	99,52%	35887,1	35682	205,1	99,43%

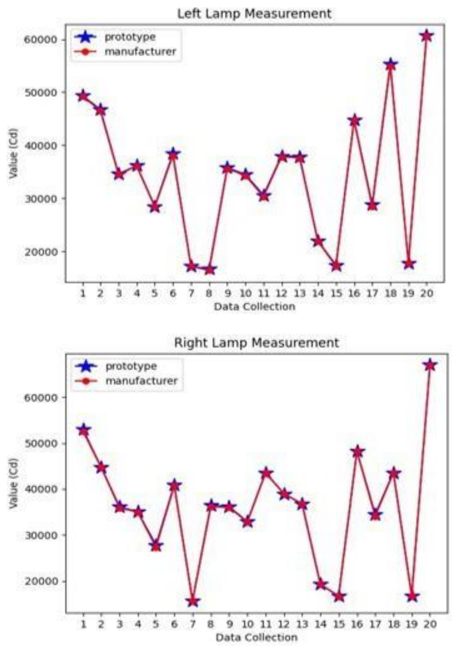

Fig 6. Prototype Testing

Variations in the graph trends may be influenced by ambient lighting conditions or by unintentional contact or adjustments made by the operator that could alter the position of the prototype device during testing.

Fig 7. Measurements Inside and Outside the Building

IV. CONCLUSION

This study successfully designed and implemented a portable microcontroller-based headlight testing device, incorporating a photodiode sensor, Arduino Nano, and LCD display. The device was specifically designed for portability and ease of use, enabling motor vehicle headlight inspections in various locations. Its operating principle involves detecting light intensity, processing the data through the microcontroller, and displaying the results in candela on the LCD. The testing results demonstrated that the device operates effectively and provides stable and accurate light intensity readings comparable to those of commercial testing equipment. The obtained measurements can be utilized to assess whether the vehicle's headlight intensity falls within the required safety limits. Therefore, the objectives of the design and analysis of this device have been successfully achieved.

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ATTACHMENT

Nomor Kendaraan	Alat Pabrikan	Alat Prototipe	Dokumentasi
AB 8642 BF	R:36800 L:37600	R:36726 L:37855	R :  L: 
AB 8755 BD	R: 27900 L: 24300	R: 27320 L: 24615	R:  L: