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Prototype of an Adaptive Wiper System for Electric Vehicles for Disabled Users Using a Servo Motor

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ABSTRACT

This study presents the design and implementation of a prototype wiper system using a servo motor, specifically developed for electric vehicles designed for persons with disabilities. The system is structured through several stages, including the creation of a wiring diagram, the development of a control system based on an Arduino Uno microcontroller, and the integration of key components such as a 12V battery, a three-position switch, a step-down LM2596 module, and an RDS3239 servo motor. The control logic enables two-speed wiping modes low and high regulated by user input via the switch. Electrical testing demonstrated that the current drawn by the system was 0.26 A at low speed and 0.37 A at high speed, with corresponding power consumption of 3.12 W and 4.44 W, respectively. These values fall within safe operating limits, indicating energy efficiency suitable for electric vehicle applications. Motion testing showed that the system achieved 30 wipes per minute at low speed and 60 wipes per minute at high speed, with the high-speed mode meeting the minimum functional criteria set by national standards. Angular deviation analysis further revealed that increased speed slightly impacted sweep precision, though still within acceptable tolerances. The results indicate that the developed system not only performs effectively in varying operational conditions but also offers energy-efficient and responsive functionality. This makes it a viable solution for adaptive and accessible mobility technologies in electric vehicles for persons with disabilities.

1. Introduction

People with disabilities are closely linked to social life in society. They are often identified by various terms such as "people with disabilities," "differently-abled," "special needs," and "individuals with limitations." The term "differently-abled" refers more to physical limitations, such as the loss of certain body parts that cause disability [1]. Each individual with a disability has their own specific limitations, which are often referred to with the prefix "tuna" in Indonesian, meaning "lack" or "absence." Examples include "tunanetra" (visual impairment), "tunagrahita" (intellectual disability), "tunalaras" (emotional or behavioral disorders), and "tunadaksa" (physical disabilities) [2].

People with disabilities are often viewed as second-class citizens, leading to discriminatory actions against them [3]. According to Law No. 19 of 2011 on the Ratification of the Rights of Persons with Disabilities, individuals with disabilities are those who have long-term physical, mental, intellectual, or sensory limitations that hinder them from participating fully and effectively in society on an equal basis with others. It is important to note that the term "differently-abled" does not imply incapacity, but rather emphasizes their unique ways of performing activities according to their limitations [4]. Therefore, it is crucial for society to understand and appreciate these differences and provide opportunities for people with disabilities to actively participate in social life and communities without discrimination [5].

Every citizen has the right to receive equal rights and opportunities, including the right to rehabilitation, education, employment, and career development. However, discriminatory attitudes still exist in society, often leading to unequal access to education and difficulty for people with disabilities in obtaining employment [6]. Employment opportunities for them are still limited and do not match their number in each region. Additionally, there is a lack of entrepreneurship training and skill development support tailored to their needs. According to Law No. 4 of 1997, Article 14, persons with disabilities are entitled to occupy at least 1% of positions in companies with more than 100 employees [7].

The government has a responsibility to ensure equal rights for people with disabilities, especially in transportation. Transportation is a basic need in everyday life, and various modes of public and private transport must be accessible to everyone. To support inclusive public services, the government regulates the accessibility rights of people with disabilities through various regulations, including the 2016 Disability Rights Law. The main challenges in this area include the adequacy of service providers, protection of rights, and public service accessibility. Inclusive transportation becomes a crucial step toward building a society that supports the participation of all individuals [8].

Transportation plays a vital role in the economy, enabling independence in daily activities such as traveling for education, work, or family needs. To enhance accessibility, special driver's licenses have been introduced for people with disabilities. One notable innovation is the modification of two-wheeled motorcycles into three-wheeled versions designed for individuals with physical disabilities, providing safer and more comfortable travel.

The term "tunadaksa" refers to individuals with physical limitations—whether congenital or acquired through accidents or disasters—that hinder their physical mobility. Although the government has issued regulations such as Law No. 4 of 1997, Article 6, to support their rights, the availability of public facilities that meet their needs is still limited. Wheelchair users often face difficulties accessing public transportation due to inadequate infrastructure, which not only restricts their mobility but also increases transportation costs. Mobility aids such as wheelchairs, crutches, and other assistive devices are essential, but their availability and suitability vary among individuals. Therefore, it is essential for the government and related parties to improve transportation accessibility to ensure equal opportunities for people with disabilities. This will enhance their independence, quality of life, and social inclusion [9].

In response to this, a team of students from Universitas Negeri Yogyakarta plans to develop a special vehicle for people with disabilities. This electric vehicle, powered by an electric motor, is designed to provide safe, comfortable, energy-efficient, and environmentally friendly mobility. The production process includes the creation of a chassis, installation of suspension, steering system, braking system, wheels, body, interior, and electrical system planning. One crucial component of this system is the wiper mechanism, which plays an essential role in maintaining visibility during rainy conditions. A well-functioning wiper is critical for driver safety, ensuring clear vision through the windshield and preventing accidents caused by limited visibility.

This study aims to enhance the safety and comfort of drivers with disabilities. The wiper system is crucial for maintaining visibility by removing rainwater and dirt from the windshield. Without this system, driving in the rain would pose significant safety risks. Therefore, before proceeding with the wiper system's construction, a detailed design must be developed, followed by testing each component to ensure optimal performance.

2. Methodology

2.1 Development Method

The development of the servo motor system for electric vehicles for disabled individuals begins with system design based on user-specific needs and the functional analysis of the servo motor in driving the wiper mechanism. This development process consists of several main stages:

1. Needs Identification
   In the initial stage, user needs are identified for disabled individuals who require a wiper system that can be easily controlled. These needs include a responsive servo motor control system and a rain sensor capable of accurately detecting rain intensity.
2. System Design
   The system design uses a microcontroller as the controller unit, with a rain sensor integrated to detect water presence on the windshield, triggering the servo motor to activate the wiper. The design prioritizes ease of operation for disabled users and energy efficiency.
3. Component Selection
   The components are selected based on quality and long-term reliability. The chosen components include a servo motor with appropriate torque and speed, a rain sensor that works well under various weather conditions, and a microcontroller with flexible programming capabilities.
4. Prototype Development and Testing
   The prototype is developed by assembling all components into a system setup, followed by testing in relevant scenarios. The prototype is tested to ensure that the servo motor functions correctly and responds to the rain sensor's signals.

2.2 Material and setup

This section describes the specifications of the materials and the experimental setup used in the study.

1. Servo Motor
   The servo motor used in the experiment is a high-torque type designed to drive the wiper on the electric vehicle. This motor is chosen for its precision and ability to be controlled by PWM (Pulse Width Modulation) signals from the microcontroller. The specifications of the servo motor used are as follows: Torque: 10 kg·cm, Speed: 60 degrees per second and Power: 5V.
2. Rain Sensor
   The rain sensor used is designed to detect the presence of water on the surface of the windshield and send a signal to the microcontroller to activate the servo motor. This sensor operates based on changes in resistance that occur when water contacts the sensor surface. The specifications of the rain sensor used are as follows: Type: Resistive-based sensor, Operating Voltage: 5V and Sensitivity: Capable of detecting rain intensity from light to heavy.
3. Microcontroller
   The microcontroller used in the system is an Arduino Uno, equipped with input/output pins to receive signals from the rain sensor and control the servo motor. The microcontroller is also programmed to adjust the servo motor's speed and movement duration based on the detected rain intensity.

4. Power Supply
   The power supply used to operate the system is a 12V Li-ion battery, commonly used in electric vehicles. This battery is chosen for its efficiency in providing stable power to the system components.

2.3 Experimental Procedure

This section describes the specifications of the materials and the experimental setup used in the study. The experimental procedure is designed to test the performance of the servo motor system controlled by the rain sensor under actual conditions. The stages of the experiment are as follows:

1. Experimental Setup Preparation
   All components, including the servo motor, rain sensor, and microcontroller, are mounted on the electric vehicle according to the design specified in the material and setup section. All connections between the devices are checked to ensure no disruptions or malfunctions in the system.
2. Rain Sensor Responsiveness Test
   In this stage, the rain sensor is tested to ensure it accurately detects the presence of water. The sensor is tested under various conditions, from light rain to heavy downpours, to observe how the system responds to different levels of rain intensity. The microcontroller connected to the sensor sends signals to the servo motor to move the wiper accordingly.
3. Servo Motor Performance Test
   Once the rain sensor is functioning correctly, the servo motor's performance in driving the wiper is tested. The motor is evaluated under various speed and movement duration conditions, as well as different levels of rain intensity detected by the sensor. The motor's reliability is measured based on its response time and the accuracy of its movement in driving the wiper.
4. Result Analysis
   The results of the experiment will be analyzed to assess the system's effectiveness in controlling the wiper motor based on the rain detection sensor. The analysis includes measuring the motor's response time, movement accuracy, and overall system performance under different rain conditions. The experimental data obtained will be used to refine the system and improve its efficiency.

3. Result and Discussion

3.1 System Design Process

The design process of the wiper system for electric vehicles intended for persons with disabilities was carried out in several stages, starting from the development of a wiring diagram, control system design, to the integration of all components into a functional system. The wiring diagram was created using the Draw.io application, which was utilized to illustrate the connectivity between key components such as the 12V battery, three-position switch, servo motor, and LM2596 step-down module. The wiring configuration is shown in Fig. 1.

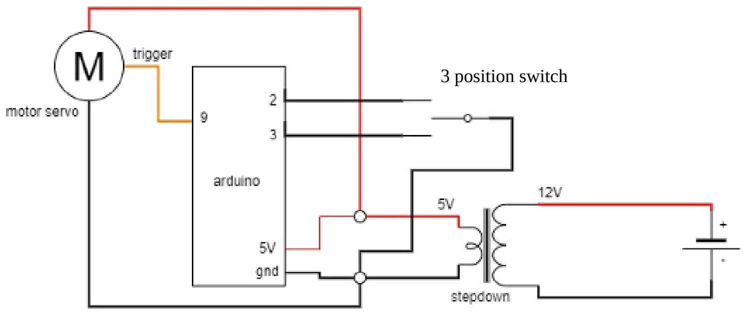

Figure 1. Wiring system diagram

The next step involved designing a control system based on the Arduino platform. The switch circuit was designed as the primary input to regulate the speed modes of the wiper sweep. Signals from the switch were received by the Arduino Uno to determine the motor servo movement instructions. The voltage from the 12V battery was stepped down using the LM2596 module to 5V, which matches the operating requirements of both the Arduino and the servo motor. The RDS3239 servo motor, acting as the actuator, was configured to produce sweeping angles based on the commands programmed into the Arduino logic [10].

Figure 2. Complete system assembly

Once each circuit was tested individually, all the subsystems were integrated into a single, unified circuit. System testing was conducted to ensure that communication among components functioned as intended. To support system performance, the Arduino program was carefully structured to enable the servo motor to operate at two distinct speed modes depending on the input from the switch [11]. The system's reliability heavily relied on the accuracy of the wiring and the correctness of the programming syntax. The complete system assembly is shown in Fig. 2.

3.2 Voltage and Current Testing

The primary objective of the current testing was to measure the electric current flowing through the wiper system under two different speed modes. The measured current serves as a key indicator to evaluate whether the electrical system can adequately support the operation of the servo motor, and to ensure that no overcurrent conditions or system failures occur due to excessive current. The test results showed that at low speed, the current drawn by the wiper system was 0.26 A, whereas at high speed, the current increased to 0.37 A. This increase in current corresponds to the higher power demand required by the motor at higher speeds [12]. In other words, the higher the operating speed, the greater the current needed to allow the motor to function optimally [13].

Table 1. Current and voltage test result

No	Data	Voltage (V)		Voltage Stepdown (V)	Current (A)	Power (W)	Resistance (Ω)
		Reference	Actual				
1	Low Speed	11–12	12	5	0.26	3.12	0.8
2	High speed	11–12	12	5	0.37	4.44	1.0

Referring to Table 1, it was found that at low speed, the wiper motor required 3.12 Watts of power, while at high speed, the power demand increased to 4.44 Watts. This difference in power consumption aligns with the typical behavior of motors, which require more energy to operate at higher speeds. It also indicates that the wiper system is capable of adjusting its energy consumption based on the required operating speed.

It is important to note that at both speed levels, the power consumption remained within safe and efficient limits. At low speed, the required power was relatively small, allowing the motor to operate efficiently without placing excessive load on the vehicle's electrical system [14]. At high speed, although the power requirement was higher, it was still within acceptable limits since the system is designed to deliver optimal performance under more demanding weather or operational conditions. This power test also demonstrates that the servo motor used in this system can operate across a fairly wide power range, providing flexibility in energy management for the vehicle. Therefore, the system not only performs effectively but also emphasizes energy efficiency, which is crucial for electric vehicles especially those designed for people with disabilities, where power optimization is a key consideration.

3.3 Wiper Movement Testing

The testing focused on evaluating the number of wiper blade sweeps or back-and-forth motions per minute. The measurement was conducted under two different speed modes low and high with the objective of assessing the performance of the servo motor-based electric wiper system. The number of sweeps is a crucial parameter as it directly reflects the system's effectiveness in clearing the windshield or wiping surface from water or debris.

The test results showed that at high speed, the system was able to produce 60 wiper sweeps per minute, while at low speed, it generated only 30 sweeps per minute. These tests were conducted using an acrylic sheet as a substitute for automotive glass, considering practicality and safety during simulation. However, the use of acrylic may introduce higher friction and load on the motor compared to standard automotive glass.

When compared to the minimum requirement set by the Indonesian National Standard (SNI), which stipulates at least 45 sweeps per minute, it can be concluded that the wiper system in high-speed mode has met the functional feasibility criteria. The servo motor used provided sufficient torque and rotational speed to produce fast, stable, and responsive movement. This indicates that the system has strong potential for direct implementation in electric vehicles for people with disabilities as a reliable windshield cleaning solution [15].

On the other hand, the low-speed mode, which achieved only 30 sweeps per minute, did not meet the minimum regulatory threshold. However, this condition is still technically acceptable, given that the low-speed mode is typically used under light rain conditions or as an energy-saving option in electric vehicles. The slower motion also tends to be smoother and does not place excessive load on the electrical system. Therefore, although it falls below the standard limit, this mode remains relevant in terms of ergonomics and energy efficiency [16].

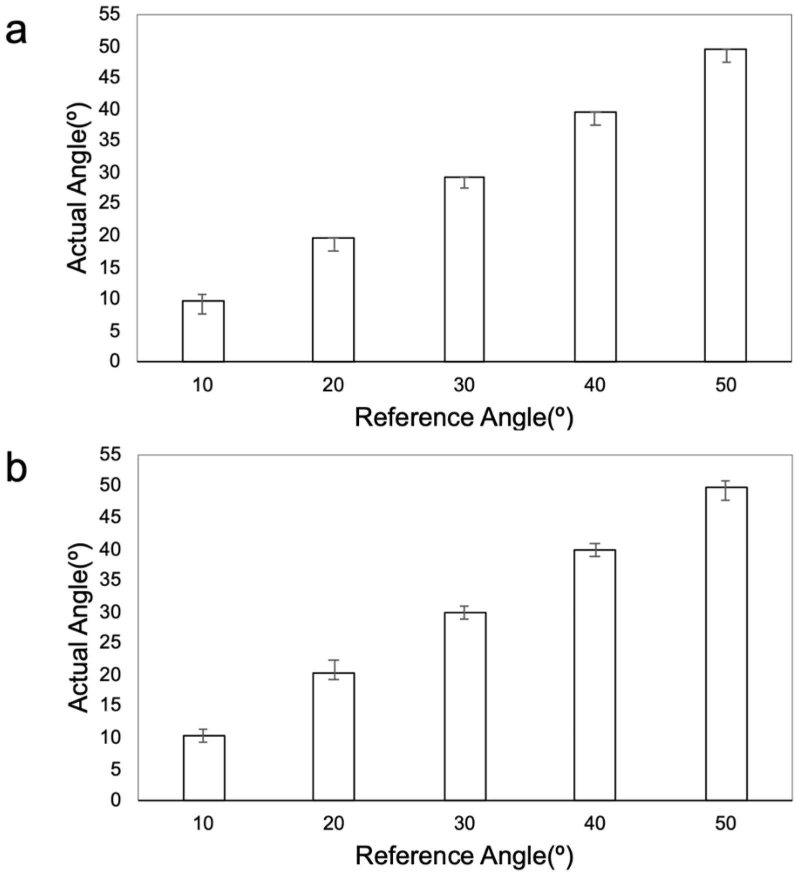

Figure 3. the measurement angel of wiper at: a) ow speed and b) High speed

Furthermore, the measurement results of the wiper sweep angles for each speed mode are illustrated in Fig. 3. For low-speed operation, the average angles observed were 10.3°, 20.4°, 29.9°, 39.9°, and 49.7°. These values show a deviation of approximately ±0.4° from the target angles of 10°, 20°, 30°, 40°, and 50°, respectively. In contrast, at high-speed operation, the measured angles were 9.7°, 19.5°, 29.4°, 39.5°, and 49.6°, with a deviation of about ±0.5°. Based on these measurements, it can be observed that higher wiper speeds tend to result in greater angular deviations. This finding indicates a trade-off between speed and motion accuracy, as the deviation values increase along with the wiper's operating speed [17].

4. Conclusion

The development of a servo motor-based wiper system for electric vehicles designed for individuals with disabilities has been carried out through a structured engineering approach, encompassing system design, control circuit development, and component integration. The system employs an Arduino Uno microcontroller to interpret inputs from a three-position switch, thereby regulating the motion of the RDS3239 servo motor. A step-down voltage module (LM2596) ensures appropriate voltage conversion from a 12V power supply to the 5V required by the control and actuator components. Current testing results indicate that the system operates within a safe and efficient electrical range. At low-speed operation, the system draws a current of 0.26 A, increasing to 0.37 A at high speed. Corresponding power consumption levels are 3.12 W and 4.44 W, respectively, which reflect the increased energy demand associated with higher mechanical output. These values remain within acceptable limits, confirming the system’s electrical efficiency and safety.

Kinematic performance was evaluated based on the number of wiper strokes per minute. At high speed, the system achieved 60 strokes per minute, thereby meeting the minimum performance threshold defined by the Indonesian National Standard (SNI). In contrast, the low-speed mode resulted in 30 strokes per minute. Although this value falls below the regulatory minimum, it remains functionally acceptable for light rainfall conditions or energy-saving applications. Additionally, angular displacement measurements revealed minimal deviation, with an average variance of ±0.4° at low speed and ±0.5° at high speed, indicating the system's capability to maintain accurate and stable actuation under varying operational conditions. In conclusion, the proposed wiper system demonstrates functional viability, electrical safety, and mechanical reliability. Its performance characteristics suggest suitability for implementation in electric vehicles for individuals with disabilities, where both energy efficiency and functional adaptability are critical. Future development may focus on system optimization, waterproofing, and extended durability testing to further enhance the reliability and practicality of the system in real-world scenarios.

Conflict of interest

The authors declare that they have no conflict of interest.

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