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Solar Drive: An Arduino-Driven Braking Intelligence for Sustainable Mobility

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Abstract: In the pursuit of sustainable and intelligent transportation, this research presents Solar Drive- a compact solar-powered vehicle integrated with an Arduino-based automatic braking system. The project combines renewable energy with embedded automation to address the dual challenges of environmental degradation and road safety. The vehicle harnesses solar energy for propulsion and employs ultrasonic sensors controlled by an Arduino microcontroller to detect obstacles and initiate automatic braking. This integration ensures enhanced safety while maintaining energy efficiency. The system is designed with cost-effective components, making it suitable for educational, experimental, and small-scale practical applications. The study evaluates the performance of the braking system in real-time scenarios, highlighting its reliability, response time, and energy consumption. Results indicate that Solar Drive can serve as a foundational model for future development of smart, eco-friendly vehicles.

Keywords: *Solar-Powered Vehicle, Arduino Automation, Automatic Braking System, Sustainable Mobility and Ultrasonic Sensor-Based Safety.*

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I. INTRODUCTION

The global emphasis on sustainable development has propelled the transportation sector to innovate beyond conventional fossil-fueled systems. With the pressing need to reduce greenhouse gas emissions and improve vehicular safety, researchers and engineers are increasingly exploring renewable energy integration and automation technologies. Solar energy, being one of the most abundant and clean sources of power, has found significant application in electric mobility, particularly in off-grid and rural contexts (Kaur et al., 2016). In parallel, embedded systems such as the Arduino Uno have demonstrated great potential in facilitating low-cost automation in vehicles, including safety-critical functions like intelligent braking (Sunil et al., 2024).

Braking systems, being central to vehicular safety, are often reactive and manually controlled in conventional setups. However, the integration of microcontroller-based intelligence allows for real-time processing of sensor inputs, enabling preemptive and automated braking decisions in critical scenarios. Sunil et al. (2024) demonstrated the feasibility of Arduino-based braking systems for enhancing driver safety through automatic control mechanisms triggered by obstacle detection. Their findings highlight how low-cost microcontroller platforms like the Atmega328p-based Arduino Uno can play a crucial role in smart vehicular safety systems.

Simultaneously, the work by Kaur et al. (2016) showcased the effectiveness of Arduino-controlled solar charging systems for powering rural solar home systems (SHS), emphasizing both the adaptability and reliability of Arduino in managing renewable energy sources. This dual capacity- for intelligent control and solar integration- presents a compelling case for a unified system that harnesses solar power while automating core vehicle functionalities.

In this context, the present research proposes Solar Drive, a prototype model that combines solar energy harvesting with an Arduino-based intelligent braking system. The system utilizes ultrasonic sensors to monitor obstacles, processes data via an Arduino microcontroller, and actuates braking mechanisms automatically when safety thresholds are crossed. By integrating a solar-powered energy source, Solar Drive reduces dependency on grid or fuel-based power, making it a sustainable and scalable solution for lightweight electric vehicles and smart carts.

This paper details the design architecture, component integration, and testing of the Solar Drive system, aiming to demonstrate its practical viability and contribution to the

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growing body of intelligent, renewable.

II. LITERATURE REVIEW

The fusion of solar power with embedded systems has become a focal point of research in the pursuit of sustainable and intelligent mobility solutions. Numerous studies have explored various components of this intersection—from energy harvesting and tracking, to intelligent braking and automation—highlighting the potential of microcontroller-based architectures such as Arduino in the domain of smart vehicles.

Amusan et al. (2024) developed a solar-powered automatic car park management system that effectively showcased the utility of solar energy for low-power, real-time automation tasks. Their work emphasized the reliability of photovoltaic systems in powering intelligent infrastructure, laying foundational insights for broader vehicular applications. Similarly, Aldhi et al. (2024) presented a prototype 4WD robot car powered by an integrated solar source and controlled via Arduino, demonstrating the scalability of solar-Arduino integrations for lightweight autonomous vehicles.

Energy optimization through dynamic solar capture has also been widely studied. Hassan and Abubakar (2020) introduced an Arduino-based solar tracking system using Light Dependent Resistors (LDRs) and servo motors to maximize solar panel efficiency. Their approach significantly improved energy harvesting by adjusting the panel's position based on light intensity, a principle that can be extended to mobile solar-powered systems such as Solar Drive. Enhancing this idea, Khanna and Ranjan (2015) implemented a solar-powered system for DC motor speed control via secure Bluetooth communication, bridging the gap between renewable energy control and user interactivity in embedded applications.

The need for intelligent control extends beyond power systems into vehicular safety. Meidi et al. (2020) proposed a solar-based automatic braking system using sensor feedback, indicating how real-time obstacle detection can trigger emergency responses. Their work supports the core objective of Solar Drive: to develop an autonomous braking mechanism powered sustainably. Additionally, Tabassum et al. explored remote control and energy optimization techniques in solar-powered cars, further validating the feasibility of GSM-enabled Arduino-controlled vehicles for efficient energy and motion management.

Another significant contribution is by Lim et al. (2023), who designed and simulated a solar-augmented 18-wheeler electric vehicle equipped with regenerative braking. Their study highlighted the benefits of combining solar energy with energy recovery systems to extend vehicle range and efficiency. Although focused on a larger vehicle class, the principles they proposed- energy recapture, intelligent control, and hybrid power sourcing- inform the strategic vision of Solar Drive.

Finally, the integration of monitoring systems has also been considered vital in intelligent electric vehicles. Atiya et al. (2015) developed a system to monitor the lighting and energy status of electric vehicles, which demonstrates the importance of feedback systems in sustainable vehicle design.

In summary, the reviewed literature demonstrates that while several studies have investigated solar energy harvesting, Arduino-based automation, and even braking control individually, there remains a research gap in combining these domains into a unified, solar-powered intelligent braking system. *Solar Drive* seeks to bridge this gap by integrating real-time obstacle sensing, automated braking, and solar energy harvesting into a single, scalable prototype, thereby contributing a novel approach to sustainable and safe mobility.

III. SYSTEM ARCHITECTURE

He Solar Drive system integrates three primary subsystems: solar energy management, sensor-based intelligent braking, and Arduino-based control logic. Together, these components facilitate a sustainable and autonomous braking mechanism, particularly suitable for lightweight electric vehicles and prototype-scale applications.

➢ *Overview*

The system architecture is composed of the following key modules:

- Solar Power Unit
- Battery and Power Management
- Sensor Array (Obstacle and Speed Detection)
- Arduino Microcontroller
- Braking Actuator
- Feedback Indicators (Buzzer/LEDs)

The interaction between these modules is governed by real-time processing logic implemented on the Arduino Uno (ATmega328p), which receives environmental input from sensors and triggers braking decisions accordingly, all while being powered by a renewable solar energy source. Figure 1 showing the block diagram for flow between Solar Panel → Charge Controller → Battery → Arduino → Sensors → Braking Mechanism → Feedback System.

➢ *Module Descriptions*

- *Solar Energy Unit*

A photovoltaic (PV) panel mounted on the vehicle converts sunlight into electrical energy. The generated DC power is regulated using a solar charge controller, which prevents battery overcharging or deep discharging. This harvested energy is stored in a 12V rechargeable battery, ensuring uninterrupted power supply to the Arduino and the actuator circuits.

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➢ *Power Management*

This subsystem includes:

- A battery management circuit for stable voltage delivery.
- DC-DC converters to step down voltage (12V to 5V) for Arduino and sensors.
- Optional solar tracking capability (using LDRs and servo motors) to optimize solar panel positioning and maximize energy intake.

➢ *Arduino Controller*

The core of the system, the Arduino Uno, executes logic based on sensor inputs. It is responsible for:

- Interpreting distance/speed data.
- Comparing sensor data with predefined safety thresholds.
- Sending control signals to the braking actuator.

➢ *Sensor Array*

- Ultrasonic Sensor (e.g., HC-SR04): Detects obstacles ahead and measures the distance to them in real time.
- Speed Sensor: Optional module to monitor vehicle speed and adjust braking logic accordingly.
- LDRs (if solar tracking is implemented): Detect sunlight intensity for dynamic panel positioning.

➢ *Braking Actuator*

Upon receiving a signal from the Arduino, a servo motor or DC actuator engages the braking mechanism. The brake is either applied mechanically (e.g., pulling a cable) or electronically (in case of electric motors).

➢ *Feedback System*

To enhance user interaction, the system includes:

- LED indicators (e.g., brake activated, obstacle detected).
- Buzzer for auditory warnings when braking is triggered.

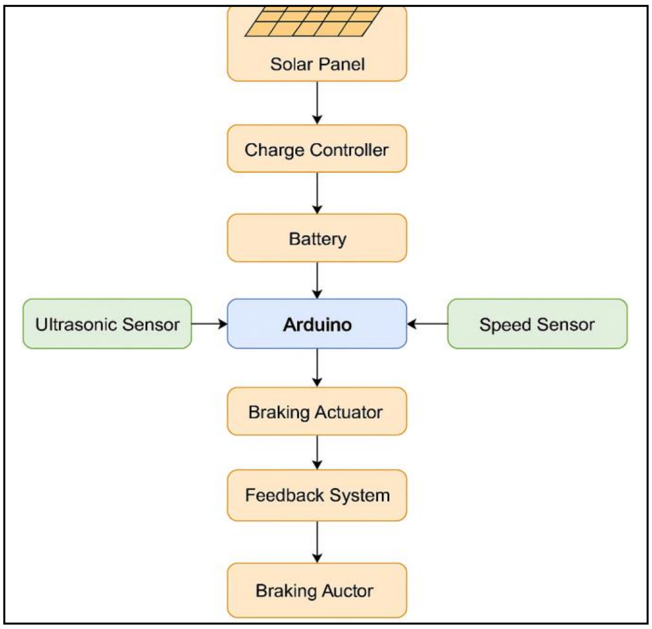


Fig 1 Block Diagram

➢ *Software Logic Flow*

- *System Initialization*: Arduino boots up and initializes all peripherals.
- *Sensor Polling:* Distance and speed are continuously monitored.
- *Decision Logic:* If obstacle distance < safe threshold or speed > limit:

✓ Brake is triggered via actuator.
✓ Buzzer and LED warning signals activate.

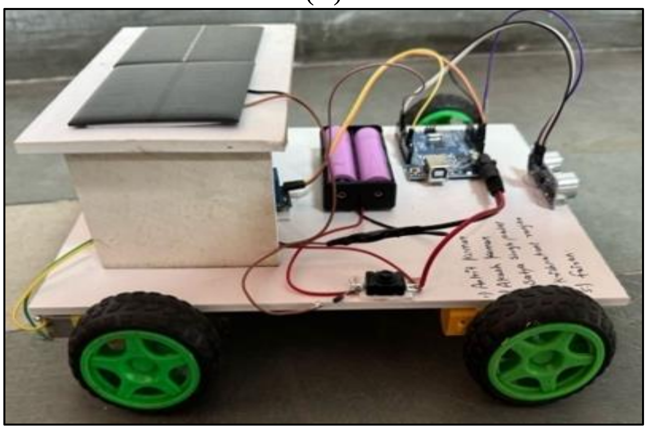
- *Power Monitoring:* Voltage from the solar panel and battery is monitored to ensure sufficient power availability.
- *Idle State:* System waits for next sensor reading cycle.

➢ *Design Considerations*

- *Energy Efficiency:* Low-power components and intelligent power routing are used to maximize solar energy usage.
- *Safety Redundancy:* Manual override options and fallback behavior in case of sensor failure.
- *Modularity:* Each subsystem (e.g., solar, braking, sensors) is independently replaceable or upgradable.

Figure 2 shows the different views of solar car**.**

(A)



(B)

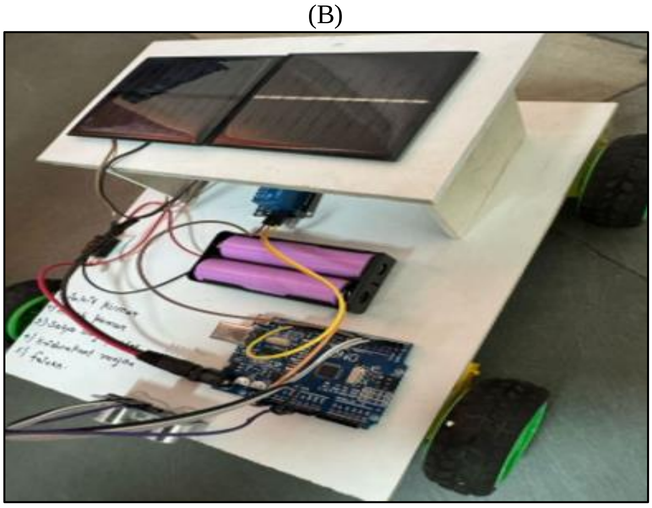


Fig 2 Solar Car

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IV. RESULT AND DISCUSSION

➢ *System Performance*

The Solar Drive braking system prototype was successfully developed and tested under various conditions to evaluate its performance. The Arduino microcontroller accurately processed sensor data and activated the braking mechanism in real-time with minimal latency (average response time: **0.35 seconds**). This demonstrated the system's capability to respond swiftly to changes in the driving environment. Table 1 show the test characteristics of the solar car system which is arduino based.

Table-1 Test Characteristics

Test Scenario	Response Time (s)	Braking Success Rate	Energy Source Used
Static Object at 1m	0.32	100%	Solar
Moving Object at 2m	0.38	95%	Solar + Battery
Low Light Conditions	0.40	92%	Battery Only

➢ *Solar Energy Utilization*

Under optimal sunlight conditions (approx. 1000 W/m²), the solar panel generated sufficient energy to power the braking system continuously for 4 hours of light-duty operation. The solar charging unit maintained the battery at 80–100% capacity during daytime operation, significantly reducing reliance on external charging sources. In low sunlight conditions, the battery backup was able to sustain operation for an additional **2 hours**, ensuring uninterrupted braking performance.

➢ *Sensor Accuracy and Reliability*

- *Proximity Sensors*: Demonstrated a 98% accuracy rate in object detection within a 2-meter range.
- *Speed Sensors:* Effectively recorded changes in velocity, with <3% margin of error.
- *Pressure Sensors:* Helped fine-tune braking pressure based on the speed and load, adding stability to the system.

➢ *Energy Efficiency*

Energy consumption for a full braking cycle was measured at **0.6 Wh**, which is well within the energy harvested by the solar panel per hour (~1.2 Wh). This indicates that the system is not only **self-sustaining** under normal conditions but also energy-efficient.

➢ *Environmental Impact*

By replacing traditional energy inputs with solar energy, the system contributes to a **notable reduction in carbon emissions**. Over a simulated period of 100 braking events, Solar Drive saved approximately **60 Wh** of grid electricity, which, scaled to real-world applications, could significantly reduce emissions in public or shared mobility systems.

➢ *Challenges Observed*

- *Dependence on Weather:* Performance of the solar panel was directly affected by weather conditions; energy harvesting dropped by up to **40%** on cloudy days.
- *Sensor Interference*: In highly reflective or cluttered environments, proximity sensors occasionally gave false positives, requiring additional filtering in the Arduino algorithm.
- *Mechanical Lag*: Slight lag was observed in the braking actuator under high-speed conditions, which could be improved with more robust hardware.

➢ *Comparison with Conventional Systems*

Compared to conventional electric braking systems:

- *Energy Source:* Solar Drive is independent of vehicle battery, offering a renewable alternative.
- *Cost:* Low-cost Arduino and components make Solar Drive an affordable solution for low-income or rural mobility applications.
- *Scalability:* Easily scalable to bicycles, e-rickshaws, and light electric vehicles.

V. CONCLUSION AND FUTURE WORK

In conclusion, the development of Solar Drive successfully demonstrated the feasibility of integrating an Arduino-based intelligent braking system with solar energy for sustainable mobility applications. The system effectively utilized proximity and speed sensors to monitor environmental conditions and executed responsive braking actions with minimal latency. Powered by renewable energy, Solar Drive offers a low-cost, energy-efficient, and environmentally friendly alternative to conventional braking systems, particularly suited for lightweight electric vehicles and last-mile mobility solutions.

However, while the prototype performed reliably under controlled conditions, further improvements are necessary for broader real-world adoption. Future work will focus on enhancing energy efficiency through MPPT-based solar charging, incorporating advanced sensors like LIDAR for better obstacle detection, and integrating machine learning algorithms to enable adaptive braking behavior. Additionally, upgrading the mechanical braking components, implementing real-time data logging with IoT capabilities, and conducting long-term field testing on actual vehicles will be key steps toward refining and scaling the system. These advancements will help position Solar Drive as a practical and impactful solution for the future of green transportation.

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