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Solar Power Refrigerated Tricycle for Fish Transportation

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Abstract — This paper presents the design and development of a solar-powered refrigerated tricycle for safe and efficient fish transportation. Fish is a highly perishable commodity, and conventional transportation methods relying on ice boxes fail to maintain consistent low temperatures, resulting in post-harvest losses, quality degradation, and food safety concerns. The proposed system integrates a photovoltaic solar panel as the primary energy source, a rechargeable battery for uninterrupted operation, and a Peltier thermoelectric module as the cooling mechanism. An Arduino Uno microcontroller continuously monitors the internal storage temperature through a DHT11 sensor and automatically regulates the cooling operation via a relay module. A cooling fan aids heat dissipation from the Peltier module's hot side, and an LCD display provides real-time system status to the operator. The tricycle offers mobility, affordability, and eco-friendly operation, making it suitable for small-scale vendors and fishermen in rural and coastal areas. Experimental results confirm that the system effectively maintains the required low temperatures, reduces spoilage, and improves fish quality during transportation while operating independently of the electrical grid.

Keywords— Solar Energy, Refrigerated Tricycle, Fish Preservation, Peltier Module, Thermoelectric Cooling, Arduino, Renewable Energy, Cold Chain Transportation, Temperature Monitoring, Sustainable Transportation.

I. INTRODUCTION

Fish is a highly sensitive food item that requires careful handling and proper storage conditions throughout the supply chain. Even minor temperature increases can accelerate bacterial growth, leading to spoilage, unpleasant odours, and serious health hazards for consumers. In many coastal and rural regions, small-scale fishermen and vendors face significant challenges in maintaining product freshness from the point of catch to the market. Traditional ice-box transportation methods are fundamentally inadequate for reliable, continuous temperature control.

Conventional fish transportation relies heavily on manually managed ice boxes or open containers. Ice melts progressively during transit, and temperature fluctuations cannot be prevented, especially over long distances or under high ambient temperatures. These limitations contribute to higher post-harvest losses, reduced product quality, and economic losses for vendors. Furthermore, traditional methods do not include automatic temperature monitoring, leaving workers to rely on periodic manual checks that are prone to error [1].

The proposed solar-powered refrigerated tricycle addresses these limitations by integrating renewable energy technology, compact thermoelectric cooling, and automated temperature regulation into a single mobile platform. By harnessing solar energy through a photovoltaic panel and storing it in a rechargeable battery, the system provides continuous off-grid operation. A Peltier module provides environmentally safe thermoelectric cooling, while an Arduino Uno microcontroller ensures automated and precise temperature regulation [2].

This paper is organized as follows: Section II reviews relevant literature; Section III describes the proposed system and its architecture; Section IV details the hardware and software components; Section V presents the system implementation and algorithm; Section VI discusses experimental results; and Section VII concludes the paper with suggestions for future work.

II. LITERATURE REVIEW

Lubis et al. [1] investigated the effectiveness of a solar thermoelectric cooler for fish preservation using photovoltaic panels with a thermoelectric cooling module. The study reported that the system maintained temperatures suitable for fish storage even under fluctuating solar radiation, confirming the viability of solar thermoelectric cooling for off-grid applications.

Nagori et al. [2] developed a solar PV-based chilled storage system for fresh fish preservation in off-grid regions, incorporating battery backup to ensure uninterrupted cooling during nighttime or cloudy conditions. The system demonstrated low operational costs, minimal maintenance, and significant reductions in post-harvest losses.

Kumar and Singh [3] explored solar-powered Peltier refrigeration for sustainable cooling applications. Their research demonstrated that Peltier modules powered by solar energy can maintain temperatures suitable for perishable food preservation, highlighting the importance of effective heat dissipation and insulation for improved cooling efficiency.

Rahman and Ali [4] investigated an off-grid solar-powered cold storage system aimed at fish preservation in remote communities. Their system combined solar PV panels, energy storage batteries, and a cooling module. Results indicated significant reductions in fish spoilage, improved shelf life, and lower operating costs compared to diesel-based refrigeration.

Setiawan et al. [5] presented design and performance analysis of a solar-powered fish storage box. They evaluated temperature stability, energy consumption, and cooling efficiency, emphasizing that proper insulation and automated control systems are essential for reliable performance in mobile refrigeration contexts.

Shiva Murthy et al. [6] explored solar-powered cold storage using Peltier modules, confirming that compact thermoelectric systems powered by solar energy can maintain adequate storage temperatures for perishable food items. The study highlighted challenges in heat dissipation and energy storage and recommended integrating heat sinks with improved insulation.

Negara et al. [7] developed and tested a solar-powered mini cooler for fish storage, emphasizing compactness, portability, and energy efficiency. Their performance tests demonstrated effective temperature maintenance and prolonged fish shelf life, supporting the feasibility of integrating such systems into mobile tricycles.

Collectively, the reviewed literature confirms that solar-powered thermoelectric cooling systems are a viable and sustainable approach for mobile fish refrigeration. However, most existing works focus on stationary storage units rather than mobile transportation platforms. The proposed system addresses this gap by unifying solar power, battery storage, Peltier cooling, and Arduino-based automated control into a compact, mobile tricycle designed for real-world fish transport.

III. PROPOSED SYSTEM

The proposed system provides continuous, automated refrigeration for fish transportation using renewable solar energy. It eliminates the limitations of traditional ice-based methods by delivering consistent low temperatures throughout the transportation journey, regardless of weather conditions or trip duration.

1. System Architecture

The system architecture is organized into three functional modules:

The Input Module comprises the solar panel and DHT11 temperature-humidity sensor. The solar panel converts sunlight into DC electrical energy, which is stored in the rechargeable battery via a charge controller. The temperature sensor continuously measures the internal storage compartment temperature and provides real-time data to the processing unit.

The Processing Module is centred on the Arduino Uno microcontroller. It receives temperature readings from the sensor, compares them with predefined safety thresholds, and makes automated decisions to activate or deactivate the cooling system. The relay module acts as a controlled switch, enabling the Arduino to safely manage the higher-current Peltier module.

The Output Module includes the Peltier thermoelectric cooling module, the cooling fan for heat dissipation, the insulated fish storage compartment, and the LCD display. When the measured temperature exceeds the set threshold, the relay triggers the Peltier module to initiate cooling. The fan simultaneously dissipates heat from the module's hot side. The LCD displays real-time temperature and system status for the operator.

2. System Block Diagram

The block diagram (Fig. 1) illustrates the data and power flow of the proposed system. Solar energy captured by the PV panel charges the battery through a charge controller. The battery powers the Arduino Uno, Peltier module, cooling fan, and LCD display.

The DHT11 sensor feeds temperature data to the Arduino, which controls the relay to regulate cooling. The Peltier module maintains the fish storage compartment at the required low temperature, while the LCD provides real-time status feedback to the operator.

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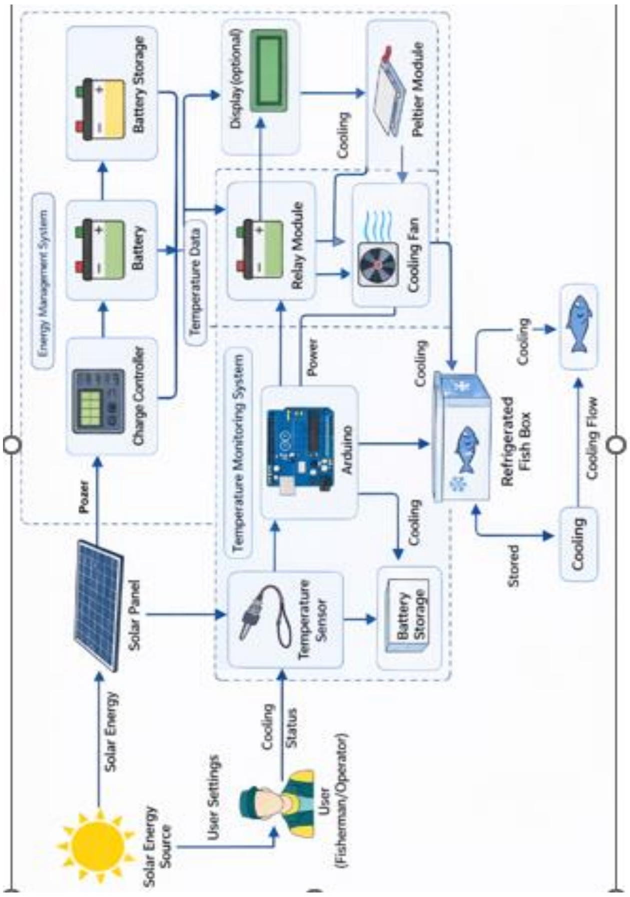

Fig. 1. System Block Diagram

3. System Advantages

- Utilizes renewable solar energy; zero fuel costs during operation.
- Provides continuous, automated refrigeration without manual intervention.
- Eco-friendly: no harmful refrigerants; low carbon footprint.
- Suitable for off-grid rural and coastal areas.
- Low operational and maintenance costs.
- Reduces post-harvest losses and improves fish quality.

IV. HARDWARE AND SOFTWARE COMPONENTS

1. Solar Panel

The solar panel serves as the primary energy source. It operates on the photovoltaic (PV) effect, converting sunlight into DC electrical energy. This powers the Peltier module, Arduino controller, relay, fan, and charges the rechargeable battery. The panel is mounted on the tricycle frame to maximize sunlight absorption. A solar charge controller regulates the voltage and current supplied to the battery, preventing overcharging and component damage. Solar energy is abundantly available in coastal and rural regions, making the system highly practical for the intended deployment environment [3].

2. Rechargeable Battery

The rechargeable battery provides energy storage for uninterrupted system operation. It stores excess solar energy generated during daylight hours and supplies power to the system during cloudy conditions or nighttime. Battery capacity is selected based on the energy consumption requirements of the Peltier module, Arduino, fan, and LCD to ensure continuous cooling throughout a typical transportation duration. This component significantly enhances system reliability and independence from grid electricity [4].

3. Temperature Sensor (DHT11)

The DHT11 temperature and humidity sensor continuously measures the internal conditions of the fish storage compartment. It interfaces directly with the Arduino Uno via a digital pin and provides real-time data for automated temperature control. When the measured temperature exceeds the preset maximum threshold (10°C), the Arduino activates the relay to enable cooling. When the temperature falls below the minimum threshold (2°C), the relay disconnects the Peltier module to conserve energy and prevent overcooling [5].

4. Arduino Uno Microcontroller

The Arduino Uno, based on the ATmega328P chip, is the central processing and control unit. It reads temperature data from the DHT11 sensor, applies the control logic, and sends commands to the relay module to regulate Peltier module operation. The Arduino is programmed in Embedded C using the Arduino IDE. Its low power consumption, multiple I/O pins, open-source ecosystem, and extensive library support make it an ideal choice for this embedded automation application [6].

5. Relay Module

The relay module serves as a controlled electrical switch between the Arduino Uno and the Peltier module. Since the Peltier module operates at higher currents than the Arduino can directly supply, the relay provides the necessary electrical isolation and safe high-current switching. When the Arduino outputs a HIGH signal, the relay closes the circuit and powers the Peltier module; when the signal goes LOW, the relay opens the circuit to conserve battery energy. This automated switching ensures consistent temperature maintenance throughout transportation.

6. Peltier Module (TEC)

The Peltier module, or thermoelectric cooler (TEC), is the primary cooling element. Based on the Peltier effect, passing electrical current through the module causes one side to absorb heat (cold side) and the other to dissipate heat (hot side). The cold side is applied to the interior of the insulated storage compartment to reduce the internal temperature. The Peltier module is compact, lightweight, and environmentally safe as it requires no chemical refrigerants. Controlled by the relay and Arduino, it operates only when necessary, optimizing energy consumption [7].

7. Cooling Fan

The cooling fan is mounted on the hot side of the Peltier module to actively dissipate heat into the surrounding environment. Effective heat removal from the hot side is critical for maintaining the required temperature gradient across the module; insufficient heat dissipation reduces cooling efficiency. The fan operates in synchronization with the Peltier module under Arduino control, ensuring that the cold side consistently maintains the desired low temperature inside the storage compartment.

8. LCD Display (16×2)

The 16×2 character LCD display provides real-time operational data to the system operator, including current internal storage temperature and system status (cooling ON/OFF). The display is interfaced with the Arduino Uno and updated continuously as sensor readings are processed. This visual feedback eliminates the need for external monitoring devices and allows operators to take immediate corrective action if the system deviates from desired operating conditions.

9. Software: Arduino IDE and Embedded C

The system software is developed using the Arduino IDE with Embedded C. The program reads temperature values from the DHT11 sensor, compares them against predefined thresholds, and controls the relay and buzzer accordingly. The Arduino IDE's built-in DHT library simplifies sensor interfacing, while the serial monitor supports debugging. The code implements a continuous monitoring loop with a 2-second sampling interval, ensuring timely response to temperature changes.

V. SYSTEM IMPLEMENTATION

1. Environmental Monitoring Algorithm

The system operates as a closed-loop feedback control algorithm:

Step 1 – Data Acquisition: The DHT11 sensor reads the internal storage temperature every 2 seconds and transmits the value to the Arduino Uno.

Step 2 – Signal Processing: The Arduino processes the raw sensor output, converts it into degrees Celsius, and applies digital noise filtering to ensure accurate readings.

Step 3 – Threshold Comparison: The processed temperature value is compared against the predefined thresholds (T_{max} = 10°C; T_{min} = 2°C).

Step 4 – Control Action: If $T > T_{max}$, the relay activates the Peltier module and the buzzer alerts the operator. If $T < T_{min}$, the relay deactivates the module. If T is within the safe range, monitoring continues without change.

Step 5 – Display Update: The LCD display is refreshed with the current temperature and system status after each control decision.

Step 6 – Continuous Loop: The process repeats indefinitely, maintaining automated temperature regulation throughout the transportation journey.

2. Hazard Condition Mapping

Table I. Hazard Condition Mapping

Condition	Temp. Range	System Action
Safe	2°C – 10°C	Monitor only; relay OFF
High Temp	> 10°C	Relay ON; Peltier & fan active; buzzer alert
Low Temp	< 2°C	Relay OFF; Peltier deactivated; normal monitoring
Sensor Fault	—	Error message on LCD; monitoring paused

VI. RESULT AND DISCUSSION

The performance of the solar-powered refrigerated tricycle was evaluated based on temperature maintenance accuracy, cooling response time, solar energy generation efficiency, and overall system reliability. Tests were conducted under varying ambient temperature conditions and different solar irradiance levels to simulate real-world transportation scenarios.

1. Temperature Control Performance

The system successfully maintained the internal storage compartment temperature within the target range of 2°C to

10°C throughout all test conditions. The Arduino-controlled relay activated the Peltier module within seconds of the temperature exceeding the 10°C threshold, demonstrating near-real-time response. The automated control loop prevented temperature overshoot and undershoot, ensuring consistent preservation conditions for the transported fish.

2. Solar Energy and Battery Performance

Under standard sunlight conditions, the solar panel generated sufficient power to operate the Peltier module and simultaneously charge the battery. The battery provided uninterrupted operation for extended periods during cloud cover and simulated nighttime testing. Energy consumption was optimized by the Arduino's on-demand control strategy, activating the cooling module only when required, which significantly extended battery runtime compared to continuous operation.

3. Communication and Display Reliability

The DHT11 sensor provided stable and accurate temperature readings throughout the test duration. The LCD display updated reliably in real time, providing operators with immediate visibility of system status. The buzzer alert triggered promptly upon detection of temperatures exceeding the safe threshold, ensuring timely warnings for corrective action during transportation.

4. System Advantages and Limitations

The system demonstrated continuous, automated operation with low latency and high reliability. Its portable and compact design makes it suitable for deployment on tricycles serving small-scale vendors in rural and coastal areas. The use of solar energy eliminates fuel costs and reduces environmental impact.

However, certain limitations were observed. The Peltier module's cooling capacity is suitable for small-scale storage but may be insufficient for large quantities of fish. Cooling efficiency is reduced during extended periods of low solar irradiance when battery reserves are low. Future improvements will focus on integrating higher-capacity batteries, improved thermal insulation, and IoT-based remote monitoring for enhanced control and scalability.

VII. CONCLUSION

This paper presented the design, implementation, and evaluation of a solar-powered refrigerated tricycle for fish transportation. By integrating a photovoltaic solar panel, rechargeable battery, Peltier thermoelectric cooling module, and an Arduino Uno-based automated control system, the proposed solution effectively overcomes the limitations of conventional ice-based fish transportation methods.

The system successfully maintained the internal storage temperature within the desired range of 2°C to 10°C under varying test conditions, demonstrating high temperature control accuracy and fast response time. Renewable solar energy ensures eco-friendly, off-grid operation with minimal operational costs, making the system highly practical for small-scale vendors and fishermen in rural and coastal areas.

The proposed tricycle reduces post-harvest fish losses, improves product quality, enhances food safety, and supports sustainable cold-chain logistics. Future work will focus on integrating IoT-based remote monitoring, increasing Peltier cooling capacity for larger storage, incorporating solar tracking systems to maximize energy generation, and adding GPS-based route optimization for improved transportation efficiency.

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