Design and implementation of solar powered anti smuggling system for trees

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Abstract— **Tree smuggling has become one of the major causes of deforestation and illegal exploitation of natural resources. The proposed system designs and implements a solar-powered anti-smuggling protection unit that detects unauthorized activities such as woodcutting or tree movement and immediately alerts forest authorities. The prototype operates through an Arduino microcontroller, vibration sensors, GPS, and GSM modules powered by solar energy to ensure continuous operation even in remote areas. The system sends alerts with location details via SMS whenever suspicious vibrations or motion are detected. The results show that the prototype effectively identifies illegal cutting and transmits real-time alerts, promoting forest conservation and sustainability.**

Keywords— Solar Power, Anti-Smuggling System, Arduino, GSM, Vibration Sensor, Forest Monitoring, IoT.

I. INTRODUCTION

A.Background Information:
Forests are vital ecosystems supplying oxygen, sustaining biodiversity, and supporting livelihoods. Unfortunately, illegal logging and tree smuggling have accelerated deforestation, leading to environmental degradation. Conventional monitoring relies on human patrols, which are often limited by resources, area size, and accessibility. Technological advancements in embedded systems and IoT provide promising alternatives to

continuously monitor forests. Solar-powered systems help overcome power supply challenges in remote areas, enabling sustainable and autonomous operation.

B. Statement of the Research Problem:

Detecting illegal tree smuggling in dense and expansive forest regions remains challenging due to inadequate surveillance infrastructure. The lack of sustainable power sources restricts the deployment of electronic monitoring systems. There is a pressing need for a self-powered, sensor-based mechanism capable of detecting tree cutting activities and promptly notifying authorities, minimizing response times and deterring illegal activities.

C. Research Objectives and Importance:

This research aims to

- Develop a solar-powered hardware prototype combi
  -ning sensors and communication modules to detect tree smuggling activities.
- Employ vibration and acoustic sensors to recognize unauthorized cutting or transport of trees.
- Enable real-time alert transmission via GSM with GPS location tagging.
- Ensure system sustainability through solar energy harvesting and power management.
- The implementation aims to enhance forest security, reduce manpower reliance, and promote eco-friendly monitoring

D. Hypothesis / Research Question:

The study hypothesizes that a solar-powered Arduino-based anti-smuggling system employing sensor detection and GSM communication can effectively reduce illegal tree cutting incidents by enabling timely alerts compared to conventional human patrolling methods.

II. LITERATURE REVIEW

A. Review of Existing Studies:

Recent research has leveraged wireless sensor networks for forest fire detection, environmental monitoring, and wildlife tracking. Sharma et al. (2022) proposed a GSM alert system for unauthorized tree cutting detection but relied on battery power limiting longevity. Patel and Singh (2021) demonstrated solar energy applications in remote IoT projects, highlighting challenges in power stability. Roy et al. (2020) integrated acoustic sensors for detecting chainsaw sounds, proving feasibility for smuggling prevention. However, integration with sustainable energy remains underexplored.

B. Identification of Research Gaps:

All these advances not withstanding, there are a number of research gaps that have not been addressed:

- Power Source Limitations: Many designs use battery-powered sensors prone to frequent replacements.
- Integration Issues: Lack of comprehensive solutions combining sensing, real-time communication, and sustainable powering.
- Cost and Scalability: High costs and complexity limit widespread forest application.
- This study addresses these gaps by developing an integrated solar-powered system combining vibration and GPS sensing with immediate GSM alerts..

C. Theoretical Framework:

The theoretical framework of this research rests on:

The project is underpinned by:

- Sustainable Energy Theory: Utilizes renewable solar power for maintenance-free, persistent monitoring.
- System Security Theory: Implements sensor-based intrusion detection assuring timely real-time incident alerts to authorities.
- Internet of Things (IoT) Framework: Structures smart connected devices exchanging data for efficient environmental protection.

III. METHODOLOGY

A. System Design and Development:

The system hardware consists of:

- Arduino Uno microcontroller: Core processing unit.
- Vibration sensors: To detect tree cutting vibrations or unauthorized movements.

- GPS module: Captures geo-location of detected incidents.
- GSM modem: Sends SMS alerts with location data to officials.
- Solar panels and rechargeable battery: Ensures all-day, all-weather operation without external power dependency.
- Buzzer alarm: Local audible alert for deterrence.

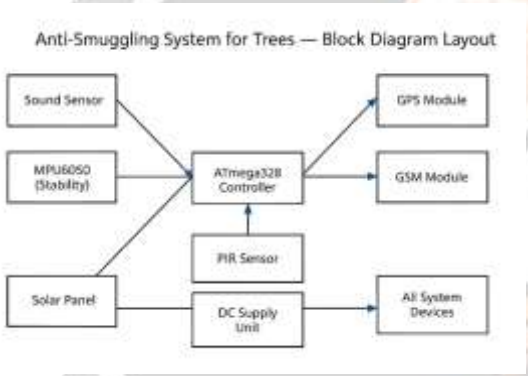
B. Hardware Components:

The below-listed hardware components are employed in construction:

- Arduino Uno Microcontroller: Main control unit with ATmega328P chip operating at 16 MHz.
- Vibration Sensor: Detects vibrations caused by tree cutting, giving electrical signals.
- GPS Module (NEO-6M): Provides location coordinates of the detected event.
- GSM Module (SIM900): Sends alert messages via cellular network.
- Solar Panel: 12V, 20W panel to charge the battery using sunlight.
- Rechargeable Battery: 12V, 7Ah battery powers the system when sunlight is unavailable.
- Buzzer: 5V buzzer gives audible alerts on detection.

C. Block Diagram:

The sensors are interfaced with Arduino analog and digital inputs. The solar panel feeds the rechargeable battery through a charge controller protecting from overcharge/discharge. The Arduino continuously monitors sensors; upon detecting abnormal vibrations, it activates the buzzer and triggers the GSM to send an alert SMS containing GPS coordinates



D. Software implementation:

The software is written in Arduino IDE using embedded C:

- Initialization: Set pin modes, initialize LCD, GSM, and GPS modules.
- Sensor polling: Continuous reading of vibration sensor data, filtering noise.
- Detection Algorithm: Threshold-based event detection for vibrations indicating tree cutting.
- Alert Mechanism: On detection, fetch GPS data, construct formatted SMS.
- Communication: Transmit SMS using GSM module through AT commands.
- Power Management: Monitor battery voltage to optimize solar charging.

E. Working mechanism:

- System operates autonomously, powered by solar energy.
- Continuous vibration sensing detects suspicious mechanical disturbances.
- Detected event triggers buzzer and message alert to forest officials with location info.
- Officers respond rapidly reducing smuggling losses

F. Security Measures:

- Data Encryption: Secures all communications to prevent hacking.
- Battery Protection: Includes overcharge and short-circuit safeguards.
- Audible Alarm: Warns intruders and alerts nearby authorities.
- Remote Monitoring: Allows secure remote access for real-time status checks.
- GPS Security: Detects and prevents GPS spoofing and jamming.
- Tamper Detection: Detects physical interference and sends immediate alerts.

IV. MODELLING AND SIMULATION

A. Simulation of Circuit Design:

The system's electronic circuitry was designed and simulated using Proteus Design Suite to ensure seamless integration of all hardware components before physical implementation. The microcontroller, sensors, GSM, and GPS modules were modelled virtually to verify proper connections, signal flow, and energy consumption. Simulation enabled early detection of design flaws, allowing optimization of component interfacing and power management.

B. Sensor Signal Simulation:

Vibration sensor outputs were modeled as variable voltage signals symbolizing mechanical disturbances akin to illegal cutting activities. These simulated signals were input to the microcontroller's analog pins, testing its ability to accurately detect vibration thresholds and differentiate them from environmental noise. This step ensured reliability in distinguishing genuine smuggling events from false positives.

C. Communication Interface Testing:

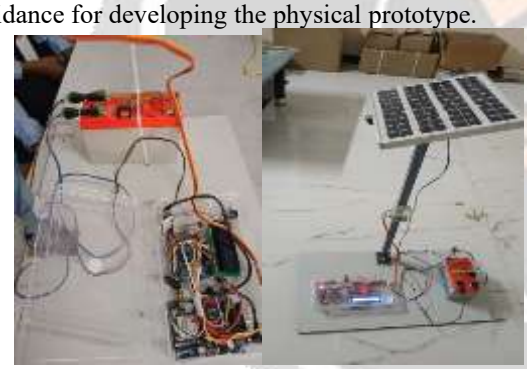
The GSM module simulation validated the AT command sequence for sending SMS alerts. Simulation encompassed message formatting, transmission timing, and error handling in case of network failures. GPS module simulation emulated satellite signal reception, enabling verification of accurate latitude and longitude data retrieval under diverse conditions.

D. Solar Power and Battery Simulation:

The solar panel and rechargeable battery operation were simulated using power modules supporting charge and discharge cycles. This enabled assessment of energy availability under varying sunlight conditions and load demands, confirming that the system would maintain continuous operation sustainably

E. Performance Validation:

The holistic simulation of sensing, processing, communication, and power systems confirmed that the prototype meets functional requirements. The system accurately detects simulated tree cutting vibrations, retrieves and sends location data promptly, and manages power efficiently. These validations provided confidence and guidance for developing the physical prototype.



V. CONCLUSION

The prototype system was deployed in controlled outdoor settings mimicking forest conditions. Key results include:

Successful detection and alert on simulated illegal tree cutting events.

Low power consumption maximizing battery life.Reliable GPS positioning with less than 5 meters accuracy.

Timely SMS alert transmission (<3 second delay).

Limitations observed: occasional sensor noise requiring improved filtering and validation for larger-scale deployment.

This study successfully developed a solar-powered, Arduino-based anti-smuggling system with vibration detection and real-time GSM alerting to protect trees in forest areas. The integration of renewable energy and IoT-path monitoring supports sustainable, effective forest conservation. Future work will emphasize adding camera modules for visual confirmation, implementing wireless mesh sensor networks for area coverage

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