

INTEGRATED SYSTEM OF SOLAR TRACKING, LIFI TECHNOLOGY AND INDUSTRIAL ENERGY AUTOMATION FOR SMART SUSTAINABLE SOLUTIONS

A PROJECT REPORT

Submitted by

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*in partial fulfilment for the award of the degree
of*

BACHELOR OF ENGINEERING

in

COMPUTER SCIENCE AND ENGINEERING



ADHIPARASAKTHI ENGINEERING COLLEGE

MELMARUVATHUR 603 319

ANNA UNIVERSITY::CHENNAI 600 025

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BONAFIDE CERTIFICATE

Certified that this project report titled “ **INTEGRATED SYSTEM OF SOLAR TRACKING, LIFI TECHNOLOGY AND INDUSTRIAL ENERGY AUTOMATION FOR SMART SUSTAINABLE SOLUTIONS** ” is the bonafide work of **JAYANTHI M (420421104030), SWATHI E (420421104078), SWETHA N (420421104081)** who carried out the work under my supervision.

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With the divine blessings of **Goddess Adhiparasakthi**, I express my deep gratitude for the spiritual blessings of His holiness **PADMA SHRI ARULTHIRU AMMA** and the divine guidance of **THIRUMATHI AMMA** that has undoubtedly taken us to path of victory in completing this project.

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ABSTRACT

The Integrated System of Solar Tracking, Li-Fi Technology, and Industrial Energy Automation for Smart Sustainable Solutions combines renewable energy management, secure wireless communication, and intelligent industrial automation into one efficient system. This project aims to improve energy use and safety in industrial environments by integrating solar tracking, Li-Fi communication, and real-time monitoring technologies. The solar tracking system increases energy output by automatically adjusting the position of solar panels to follow the sun throughout the day. This helps in maximizing the use of available sunlight. Li-Fi technology is used for fast, reliable data communication through light signals, making it suitable for areas where traditional wireless networks may face interference or limitations. The system also includes industrial automation features such as gas, temperature, and flame sensors, which monitor environmental conditions and trigger alerts or actions when needed. A camera module with AI-based fire detection (using YOLO) adds an extra layer of safety by identifying fire risks in real time. Overall, this integrated solution offers a smart, sustainable, and cost-effective way to manage energy and improve safety in modern industrial and remote environments.

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LIST OF ABBREVIATIONS

SYMBOLS	ABBREVIATION
IOT	Internet of Things
AI	Artificial Intelligence
LDR	Light Dependent Resistor
Li-Fi	Light Fidelity (Visible Light Communication)
YOLO	You Only Look Once
LED	Light Emitting Diode
RF	Radio Frequency
IoT	Internet of Things
API	Application Programming Interface
PWM	Pulse Width Modulation
DC	Direct Current
IDE	Integrated Development Environment
CNN	Convolutional Neural Network
OCR	Optical Character Recognition
FTDI	Future Technology Devices International (USB-to-Serial)
mAh	Milliampere Hour (Battery Capacity)
°	Degree (Angular measurement for solar panel rotation)
Ω	Ohm (Resistance)
V	Volt (Voltage unit)

CHAPTER 1

INTRODUCTION

1.1 DOMAIN OVERVIEW

The integration of renewable energy systems with intelligent communication and safety technologies has gained significant traction in recent years. One such innovation is the Automated Solar Tracker with Li-Fi Technology and Fire Detection, which lies at the intersection of sustainable energy management, wireless data communication, and AI-based hazard monitoring. This domain is particularly vital in the context of smart energy infrastructure, where efficient energy harvesting, seamless data exchange, and real-time safety measures are paramount.

Solar tracking systems are designed to maximize the efficiency of photovoltaic panels by dynamically adjusting their orientation based on the sun's position. This approach significantly enhances power generation compared to static systems. However, traditional solar trackers often operate in isolation without integrated communication or safety features. To address these limitations, the incorporation of Li-Fi (Light Fidelity) a high-speed, light-based data communication technology has emerged as a promising solution for wireless, interference-free information transmission, especially in electromagnetically sensitive or remote environments.

Simultaneously, ensuring the safety of solar installations, particularly in high-temperature or fire-prone zones, has become a critical concern. The application of YOLO (You Only Look Once), a real-time object detection algorithm, enables the system to identify and respond to fire incidents swiftly. The deep learning model continuously monitors the environment through video input and issues alerts upon detecting signs of fire, thereby preventing potential hazards.

This integrated approach not only improves energy efficiency but also adds a layer of smart automation and security, marking a significant advancement in the domain of green energy solutions.

1.1 OVERVIEW OF THE PROJECT

Our project is focused on the development of an Automated Solar Tracker integrated with Li-Fi technology and AI-based fire detection. The primary objective is to enhance the efficiency of solar energy harvesting while ensuring real-time monitoring and safety through advanced communication and detection systems. The system is designed to automatically adjust the orientation of solar panels to track the sun's movement throughout the day, thereby maximizing the energy output.

To facilitate seamless data transmission, Li-Fi (Light Fidelity) is employed as an alternative to traditional wireless communication. Li-Fi offers high-speed, interference-free data exchange using light waves, making it ideal for environments where radio frequency communication is either unstable or restricted.

In parallel, the system incorporates a YOLO (You Only Look Once) based fire detection module using deep learning. This module continuously processes video feeds to detect fire hazards in real time. Once a fire is identified, alerts are immediately triggered to enable timely preventive action.

The project leverages multiple modules including sensor input processing, solar tracking mechanics, Li-Fi data transmission, and AI-powered image recognition. Performance evaluation of the system is carried out using metrics such as detection accuracy, response time, energy efficiency improvement, and reliability of communication. This multi-functional approach aims to deliver a sustainable, smart, and safe solar energy solution suitable for modern energy infrastructure.

1.2 OBJECTIVE OF THE PROJECT

This project focuses on the development of an Automated Solar Tracker integrated with Li-Fi technology and AI-based fire detection, aimed at enhancing solar energy utilization while ensuring real-time monitoring and safety. The core objective is to increase the efficiency of energy capture by dynamically adjusting the solar panel's orientation based on the sun's position throughout the day.

To enable reliable and high-speed communication, the system uses Li-Fi (Light Fidelity) a visible light communication technology that offers interference-free data

transmission. Li-Fi is particularly advantageous in locations where radio frequency-based communication is restricted or unreliable, providing a robust and secure channel for data exchange.

Simultaneously, the system features an AI-driven fire detection module based on the YOLO (You Only Look Once) deep learning algorithm. This module processes real-time video streams to detect the presence of fire with high accuracy. Upon detection, immediate alerts are generated, allowing for timely intervention and enhancing overall system safety.

The project integrates several modules, including:

- Sensor input processing (for solar positioning),
- Servo-controlled solar panel movement,
- Li-Fi communication setup,
- YOLO-based image recognition for fire detection.

System performance is evaluated based on key metrics such as detection accuracy, response time, energy efficiency gains, and communication reliability. The result is a comprehensive, smart, and sustainable solution designed to contribute to modern green energy infrastructure with built-in safety and automation.

1.3 MOTIVATION

The motivation behind this project stems from the growing need for efficient, sustainable, and intelligent energy systems in today's technology-driven world. With increasing global emphasis on renewable energy sources, solar power has emerged as a viable and eco-friendly alternative. However, the effectiveness of solar energy generation is often limited by the static nature of traditional solar panels, which do not adjust according to the sun's position throughout the day. This results in suboptimal energy capture and reduced efficiency.

To address this challenge, the project introduces an automated solar tracking system that dynamically aligns the solar panel with the sun's movement, significantly enhancing energy output. Furthermore, the use of Li-Fi technology offers a modern solution to communication issues in areas where radio frequency (RF) communication is unreliable or restricted, such as industrial sites, remote locations, or sensitive zones.

Additionally, fire hazards remain a critical concern in solar installations, particularly in large-scale or remote environments. To mitigate this risk, the project integrates a YOLO-based AI fire detection system that enables real-time monitoring and rapid alert generation, thereby increasing safety and reducing the risk of damage or failure.

This multi-functional system is motivated by the vision of creating a smart, autonomous, and safe solar energy solution that not only boosts power efficiency but also ensures reliable communication and proactive hazard detection meeting the evolving demands of modern energy infrastructure.

CHAPTER 2

LITERATURE SURVEY

PAPER 1

Title : “Design and Implementation of an Automatic Solar Tracking System”
Author : Vikas Singh et al.
Year 2024

Description:

This paper presents a dual-axis solar tracking system designed using Arduino and LDR sensors. The system automatically adjusts the position of solar panels to face the sun, improving energy efficiency by up to 40%. The research emphasizes hardware design simplicity and cost-effectiveness. However, it lacks remote communication and intelligent hazard detection capabilities, which are addressed in our proposed system.

PAPER 2

Title : “A Survey on Li-Fi Technology: Applications, Challenges and FutureScope”
Author : R. Nandhini, S. Ramesh
Year 2024

Description:

This paper provides a comprehensive overview of Li-Fi technology, highlighting its potential as a high-speed, secure, and energy-efficient alternative to traditional wireless communication systems. It explores applications in healthcare, transportation, and smart buildings. While the paper outlines the theoretical benefits of Li-Fi, it does not focus on its practical integration with energy or safety systems, a gap filled by our project.

PAPER 3

Title : “Real-Time Fire Detection Using YOLOv5 in Surveillance Systems”
Author : Meena Kumari and Ankit Sharma
Year 2023

Description:

The paper introduces a fire detection system using the YOLOv5 deep learning model on real-time surveillance video feeds. The system demonstrates high accuracy and low false detection rates compared to traditional methods. Although effective, it is presented as a standalone safety mechanism. Our project incorporates this AI-based fire detection as an integral part of a broader solar tracking and communication system, enhancing both safety and automation.

PAPER 4

Title : “IoT-Based Smart Solar Tracking System”

Author : Priya M. and Rohit Jain

Year 2022

Description :

This paper proposes an IoT-enabled solar tracker using sensor inputs and a microcontroller for sun tracking. The system allows real-time data monitoring but lacks advanced communication like Li-Fi and integrated safety modules like industrial energy automation for smart sustainable solutions.

PAPER 5

Title : “A Review on industrial energy automation for smart sustainable solutions Techniques Using Image Processing”

Author : K. Shalini and P. Rajesh

Year 2020

Description :

The paper reviews various image processing-based industrial energy automation for smart sustainable solutions methods, such as flame color recognition and motion analysis. It notes that these methods struggle with false positives and recommends AI-based solutions for better accuracy, which aligns with our use of YOLO.

PAPER 6

Title : “Visible Light Communication: Emerging Trends and Research Directions”

Author : Deepak Sharma and A. Bhattacharya

Year 2023

Description :

This study explores the current state of Li-Fi technology and its applicability in IoT and smart infrastructure. It outlines benefits such as high-speed, low-latency communication but lacks practical implementations in energy systems like solar trackers.

CHAPTER 3

PROJECT DESCRIPTION

3.1 PROBLEM STATEMENT

In the face of rising energy demands, climate concerns, and the need for efficient industrial operations, existing systems often fall short due to their reliance on conventional energy sources, inefficient communication technologies, and manual control mechanisms. Solar tracking systems, although more efficient than static panels, are often underutilized due to high costs and complex setups. Meanwhile, traditional wireless communication methods such as RF and Wi-Fi face challenges in highly sensitive or interference-prone industrial environments, affecting reliability and data security.

Additionally, many industrial processes still depend on manual monitoring and operation, which can lead to inefficiencies, delays, and safety risks. These disjointed systems fail to meet the modern requirements for sustainability, real-time control, and smart automation.

To address these challenges, there is a growing need for a unified system that integrates renewable energy, secure and fast data communication, and intelligent automation. Such a system should be cost-effective, energy-efficient, and capable of operating with minimal human intervention while supporting environmentally sustainable practices. This project proposes a smart and sustainable solution by integrating an automated solar tracking system for optimized energy harvesting, Li-Fi (Light Fidelity) for secure high-speed wireless data communication, and industrial automation using sensors and microcontrollers. This combination ensures energy efficiency, enhances communication reliability, and enables real-time industrial monitoring and control, making it ideal for deployment in factories, remote industrial sites, and smart infrastructure environments.

3.2 METHODOLOGY

The proposed system combines three major technological components solar tracking, Li-Fi communication, and industrial automation into a single unified framework. The methodology is structured as follows:

Automated Solar Tracker: A dual-axis solar tracking mechanism is developed using a microcontroller (such as Arduino UNO), LDR (Light Dependent Resistors), and a stepper motor. The system dynamically adjusts the solar panel's orientation throughout the day to maximize solar energy absorption. Energy generated is stored in a lead-acid battery for consistent power supply to the entire system.

Li-Fi Data Transmission: Light Fidelity (Li-Fi) technology is implemented using high-intensity white LEDs as the transmitter and photodiodes or solar panels as receivers. Information is encoded in the modulation of light intensity, which is invisible to the human eye but can be detected and decoded by the receiving module. Li-Fi enables fast, secure, and interference-free communication between sensors and control units.

Industrial Automation: Various sensors (e.g., temperature, gas, flame detectors) are integrated with the microcontroller to continuously monitor environmental and operational parameters. When specific thresholds are exceeded, the system triggers actions such as activating alarms, switching off equipment, or sending alerts. The system can also be connected to an IoT platform or web interface for real-time monitoring and data visualization.

Fire Detection using YOLO (You Only Look Once): A computer vision model (YOLO) is used to detect the presence of fire or smoke using live camera feed. The ESP32-CAM module captures real-time images, which are processed using the YOLO algorithm for immediate fire detection and response.

The system is programmed using embedded C/C++, Python (for ML tasks), and integrated with a local server or cloud platform for visualization and logging. The Li-Fi module replaces conventional wireless systems in scenarios requiring secure communication without RF interference.

3.3 ARCHITECTURE DIAGRAM

The architecture of the proposed project is designed to create a smart and sustainable system by integrating three core components solar tracking, Li-Fi communication, and industrial automation into a unified, energy-efficient framework. At the heart of the system is a microcontroller (such as Arduino or ESP32), which coordinates the operations of all

integrated modules to enable real-time monitoring, communication, and control. The solar tracking module is responsible for optimizing the energy harvested from sunlight. It consists of a solar panel mounted on a movable platform, controlled by stepper motors. Four Light Dependent Resistors (LDRs) are strategically positioned to detect sunlight intensity from different directions. Based on the data from these LDRs, the microcontroller dynamically adjusts the panel's orientation to follow the sun throughout the day, thereby maximizing energy generation. The energy collected is stored in a rechargeable battery, which powers other components of the system, promoting energy sustainability.

To facilitate high-speed and secure communication, the system employs Li-Fi (Light Fidelity) technology. A powerful LED acts as a transmitter by modulating light to encode data, while a photodiode or solar panel serves as the receiver. The transmitted light-based signals are decoded by the receiving module and forwarded to the controller for further processing. This Li-Fi communication ensures interference-free and efficient data transmission in industrial environments where traditional RF communication may be unreliable or restricted. The industrial automation segment of the system integrates various sensors such as gas, temperature, and flame sensors to monitor the working environment. These sensors continuously send data to the microcontroller, which evaluates the readings and performs specific automated actions if abnormal conditions are detected such as activating alarms, turning off machinery, or sending notifications to operators. This enhances safety, reduces the need for manual intervention, and supports smarter industrial operations.

CHAPTER 4

SYSTEM ANALYSIS

4.1 EXISTING SYSTEM

Existing solar tracking systems primarily rely on manual or basic automatic mechanisms using Light Dependent Resistors (LDRs) and microcontrollers to align solar panels with the sun. These systems improve energy generation by tracking sunlight throughout the day. However, they are often limited to single-axis or dual-axis mechanical movement without intelligent optimization. In terms of communication, most existing models use conventional wireless methods such as Wi-Fi or Bluetooth, which can be prone to interference and are unsuitable for use in RF-sensitive environments. Additionally, safety monitoring, especially for fire detection, is generally not integrated into these systems, leaving infrastructure vulnerable to potential hazards.

Current systems in the domains of solar tracking, fire detection, and Li-Fi communication face several limitations that hinder their effectiveness and usability. In many conventional solar tracking systems, the tracking mechanism is either manual or based on simple fixed algorithms that do not adapt well to dynamic light conditions. This often leads to suboptimal performance in maximizing energy capture, especially under varying weather conditions or during the day-night cycle. Many of these systems are also prone to mechanical failures due to the complexity of motors and sensors, requiring frequent maintenance. Existing Li-Fi communication systems are also limited in terms of practical implementation. Additionally, the data transfer rates are often lower than those achievable through traditional RF-based communication methods. This impacts the effectiveness of the technology for real-time applications, such as transmitting fire detection alerts or solar energy data.

For fire detection, traditional methods often rely on simple smoke or heat-based sensors, which can generate false positives or miss smaller, slower-developing fires. These methods are not equipped to detect fires early enough, especially in areas with limited visibility or where fires are not immediately visible to heat sensors. Moreover, the lack of integration with advanced technologies like image recognition makes the fire detection process slower and less reliable. Fire detection in standalone systems often uses smoke or heat sensors, which can be slow to respond or inaccurate in outdoor conditions. Image-based AI detection methods are rarely implemented in existing solar systems, missing opportunities for real-time, accurate

hazard detection. Thus, while current systems enhance energy capture, they lack intelligent automation, advanced communication, and safety features—gaps that our proposed system addresses.

4.1.1 DISADVANTAGES

Limited Communication Range: Most existing solar tracking systems use traditional RF-based communication like Wi-Fi or Bluetooth, which can suffer from interference, limited range, and are unsuitable in RF-restricted zones.

Lack of Real-Time Safety Features: Fire detection is often absent or implemented with basic heat or smoke sensors, which may not provide timely or accurate alerts.

Low Energy Optimization: Many current systems are restricted to fixed-angle panels or basic tracking, which limits their ability to fully maximize solar energy harvesting throughout the day.

No Intelligent Automation: There is minimal integration of AI or smart decision-making systems, reducing efficiency and adaptability in dynamic environmental conditions.

Scalability Issues: These systems are typically designed for small-scale applications and are difficult to adapt for large-scale solar infrastructures with integrated safety and communication needs.

4.2 PROPOSED SYSTEM

The proposed system addresses the shortcomings of existing systems by integrating advanced technologies like solar tracking, Li-Fi communication, and fire detection using YOLO (You Only Look Once) to create a smarter, more reliable solution. The system uses a dynamic solar tracking mechanism that continuously adjusts the solar panel's position based on light intensity readings, ensuring optimal energy collection throughout the day. This approach significantly increases efficiency compared to fixed or rudimentary tracking systems and minimizes energy loss.

Incorporating YOLO-based fire detection offers a considerable advantage over traditional smoke or heat detectors. YOLO allows for real-time image processing and detection

of fire through visual recognition, making it faster and more accurate. The system can detect small or hidden fires that might be missed by conventional sensors, and it minimizes false alarms. This advanced detection also allows the system to identify fire-related risks more quickly, which is critical in preventing larger disasters.

The Li-Fi communication system in the proposed design overcomes many of the limitations found in current wireless communication systems. By using light to transmit data, it offers high-speed, secure, and interference-free communication, even in environments where RF-based communication would typically face issues (e.g., near sensitive equipment). It also provides a reliable method for transmitting data over moderate distances, ensuring that the system remains responsive and efficient in delivering fire alerts and solar energy data.

4.2.1 ADVANTAGES

- **Reduced Manual Intervention** as the system operates autonomously with minimal human input.
- **Low Maintenance Cost** due to robust components and intelligent system design.
- **Eco-Friendly Operation** leveraging renewable solar energy and light-based communication.
- **Improved System Integration** ensuring seamless coordination between solar tracking, Li-Fi, and fire detection.
- **Faster Response Time** enabling quick detection and communication of fire hazards.
- **Enhanced Safety and Monitoring** through continuous surveillance and smart detection algorithms.
- **Adaptable Technology** that can be customized for industrial, agricultural, or remote settings.

CHAPTER 5

SYSTEM REQUIREMENTS

The system is designed to integrate solar tracking, Li-Fi-based communication, and AI-driven fire detection into a cohesive and intelligent energy solution. The following specifications outline the hardware and software components required to implement the proposed system:

5.1 FUNCTIONAL REQUIREMENTS

The functional requirements of the "Integrated System of Solar Tracking, Li-Fi, and Fire Detection" focus on the core functionalities that the system must perform to meet its objectives. These include the accurate tracking of the solar panel's position in response to light intensity changes, ensuring maximum energy capture through the solar tracking system. The system must also detect fires using a camera and YOLO-based image recognition algorithm, providing timely alerts when a fire is detected. Additionally, the Li-Fi communication module must efficiently transmit data between the light transmitter and the receiver, enabling data exchange through modulated light. Furthermore, the system should include an interface that integrates these modules seamlessly, allowing for easy monitoring and control.

5.2 NON-FUNCTIONAL REQUIREMENTS

The non-functional requirements define the performance standards and constraints that the system must meet to ensure it operates effectively in real-world conditions. These include system reliability, where the system must consistently function without errors over long periods of operation, ensuring accuracy in solar tracking and fire detection. The system must also meet performance expectations such as quick response times, where fire detection should occur within a set time frame, and the Li-Fi communication should function effectively over varying distances and lighting conditions. Additionally, scalability is a non-functional requirement, as the system should be adaptable to various environments or applications with minimal adjustments. Lastly, the system must ensure user-friendliness, with an intuitive interface that facilitates easy setup and operation without requiring complex configurations.

5.3 HARDWARE REQUIREMENTS

The hardware components used in this project are essential for performing solar tracking, Li-Fi communication, and fire detection. A solar panel is used to convert sunlight into electrical energy, which powers the system. An Arduino UNO microcontroller controls the entire setup. LDR sensors detect the sunlight direction, helping the stepper motor move the solar panel to face the sun. This movement is controlled by a motor driver module (L298N). A battery is used to store the generated power for later use. For Li-Fi communication, an LED is used to send data through light, and a photodiode or light sensor receives this data. A fire sensor helps detect any fire or flame nearby. A camera module captures video for detecting fire using the YOLO algorithm. A Wi-Fi module (ESP8266) is included to send alerts or data wirelessly. Other supporting tools like a breadboard, jumper wires, and a power supply unit are used to build and test the circuit.

Solar panel

The solar panel converts sunlight into electrical energy and powers the entire system. It acts as the primary renewable energy source, reducing dependency on external power supplies. The energy generated is either directly used or stored in a battery. This supports the project's sustainability goal. Solar panels are eco-friendly, cost-effective, and easy to maintain. They are crucial for off-grid energy supply, especially in remote or industrial areas.



Figure 5.1 Solar panel

Arduino UNO / Mega

Arduino UNO or Mega is the main microcontroller used to control all components. It takes sensor inputs and processes them to control outputs like motors, LEDs, and alarms. Its compatibility with a wide range of sensors and modules makes it ideal for embedded applications. Arduino is easy to program using its IDE, even for beginners. It operates at 5V

and can be powered via USB or battery. Its open-source nature encourages flexible and customizable development.



Figure 5.2 Arduino UNO Mega

LDR (Light Dependent Resistor)

LDR is a light sensor whose resistance varies with light intensity. It is used to detect the brightest direction of sunlight. This helps the solar tracker align the panel correctly to get maximum sunlight. LDRs are low-cost, energy-efficient, and simple to integrate with Arduino. They are highly responsive to natural light and help improve the energy efficiency of solar panels. The accuracy of the solar tracking system depends largely on proper LDR placement.



Figure 5.3 Light Dependent Resistor

Servo Motor

Motors are used to move the solar panel in the direction of the sun. Stepper motors offer precise, controlled movement in steps, while servo motors are ideal for fixed-angle rotations. These motors adjust the panel automatically based on LDR feedback. The motor's torque and angle can be set programmatically. They enhance automation and eliminate the need for

manual repositioning. The choice between stepper and servo depends on the desired movement range and load.



Figure 5.4 Servo motor

Motor Driver Module (L298N)

The motor driver acts as an interface between the Arduino and motor. It provides sufficient voltage and current to the motor that the Arduino alone can't deliver. It allows control of motor direction and speed using PWM signals. The L298N module supports two motors simultaneously and has built-in heat sinks for protection. It simplifies motor integration in embedded systems. It is a critical component for safe and reliable motor operation.



Figure 5.5 L298N Motor Driver

Battery

The battery stores excess energy generated by the solar panel for later use. It ensures the system remains functional even when sunlight is unavailable. Lead-acid batteries are affordable and widely used, while lithium-ion offers longer life and faster charging. The stored power is used to operate the system during cloudy weather or nighttime. It provides reliability

and independence from the grid. A proper charging circuit is needed to avoid overcharging or damage.



Figure 5.6 Lithium ion battery

LED Light (for Li-Fi)

The LED acts as a data transmitter in the Li-Fi system. It emits light that changes rapidly to represent binary data, which is picked up by a receiver. LEDs are fast-switching, energy-efficient, and can carry data at high speed. They also serve as a light source, combining illumination and communication.



Figure 5.7 Light Emitting Diode

Photodiode

The photodiode detects light signals emitted by the LED and converts them into electrical signals. It serves as the Li-Fi receiver and plays a key role in decoding transmitted data. These sensors are highly sensitive to changes in light intensity. Their fast response time ensures real-time data reception. Photodiodes are compact, cost-effective, and easily integrated with microcontrollers. Proper alignment with the LED ensures accurate data transfer.



Figure 5.8 Photodiode

4.4 SOFTWARE REQUIREMENTS

Arduino

Arduino IDE is the official software used to write and upload code to Arduino boards. It supports C/C++ language and includes built-in libraries for sensors and modules. It has a serial monitor for real-time debugging and data monitoring. The interface is beginner-friendly and widely used in embedded development. Sketches (programs) are easy to write and test. It plays a key role in integrating hardware with logic.

Python

Python is used in this project for implementing the YOLO algorithm. It is simple to read, write, and debug, making it suitable for students and developers. Python supports a wide range of libraries for AI, image processing, and networking. It runs on different platforms like Windows, Linux, and Mac. Its flexibility allows fast prototyping and testing of models. It acts as the brain for the fire detection module.

OpenCV

OpenCV is a powerful library used for image and video processing in Python. It enables the system to detect fire by analyzing the camera input. OpenCV offers functions for color detection, motion tracking, and shape recognition. It is open-source and supported by a large community. It plays a critical role in real-time computer vision tasks. It helps extract visual information needed by YOLO for fire detection.

YOLO

YOLO is a deep learning model that detects objects in real time. In this project, it is trained to detect fire in images or videos captured by the camera. YOLO is fast and accurate, capable of detecting multiple objects at once. It uses convolutional neural networks (CNNs) for detection. YOLO is suitable for real-time applications like surveillance. It enhances the safety feature of the system with smart detection.

Anaconda

Anaconda is a Python distribution that simplifies managing packages and environments. Jupyter Notebook, included in Anaconda, is an interactive tool for writing and running Python code. It helps in testing and visualizing the fire detection model. It supports inline images and graphs, making it useful for debugging. It's widely used in data science, machine learning, and academic research. It enables step-by-step execution of the YOLO model.

CHAPTER 6

SOFTWARE TESTING

6.1 TESTING OBJECTIVE

Test case design is a critical part of software testing, involving the creation of conditions and scenarios to assess whether the system operates as expected. The primary objective of testing is to identify and validate functional and non-functional requirements of the system. For this project, test cases are designed for individual modules, such as the solar tracking system, Li-Fi communication, fire detection via YOLO, and system integration. Each test case includes inputs, expected outputs, and actual results. For example, a test case for the fire detection module would provide an image containing fire and verify if the YOLO model correctly detects it. Similarly, test cases will validate the responsiveness of the Li-Fi communication and solar tracking alignment. Well-structured test cases ensure the system's robustness and help in detecting errors efficiently.

6.2 TEST CASE DESIGN

Test case design follows a systematic approach, ensuring the quality, reliability, and correctness of the integrated system. The design process includes testing at various levels to cover the entire software structure, from individual modules to full system integration.

UNIT TESTING

Unit testing involves testing individual components of the system in isolation. The goal is to verify that each component works as expected. In this project, unit testing includes verifying that the solar tracking system responds correctly to light intensity variations by adjusting the position of the solar panel, ensuring the fire detection module accurately identifies fire in images, and confirming that the Li-Fi communication transmits and receives data correctly. Each of these modules is tested independently with various inputs to ensure their functionality before integration.

INTEGRATION TESTING

Integration testing checks how different modules interact with each other when combined. It verifies that data flows correctly between integrated units. In this project,

integration testing includes verifying that the solar tracking system correctly interacts with the light sensors and stepper motors. It also checks that the fire detection system using YOLO works seamlessly with the camera input, and the Li-Fi communication system transmits data between the transmitter and receiver. This ensures that all modules function together as a cohesive system.

VALIDATION TESTING

Validation testing ensures that the system works as expected in real-world scenarios. In this project, it tests if the fire detection system can accurately detect fire in various lighting conditions, from simulated flames to real fires. Additionally, it validates if the solar tracking system performs effectively across different times of the day, tracking the sun accurately to maximize energy capture. The Li-Fi communication is validated to check its reliability and data integrity under different distances and light conditions.

INTERFACE TESTING

Interface testing focuses on ensuring the correct communication between software modules and hardware components. In this project, it checks the interface between the sensors (LDR, fire sensor), the camera, the motor control system, and the Li-Fi communication module. It ensures that inputs (sensor readings, camera images) are correctly processed by the software, and the outputs (motor control, Li-Fi transmission) are accurate and responsive.

MODULE TESTING

Module testing focuses on validating the functionality of individual system components. Each module—such as the solar tracking algorithm, fire detection algorithm (YOLO), and Li-Fi communication—is tested independently for its specific functionality. This includes testing the response of the motor to sensor input, the accuracy of fire detection with various scenarios, and the data transfer capabilities of the Li-Fi system. Edge cases, such as low light conditions or sensor malfunctions, are also tested to ensure the system's robustness.

CHAPTER 7

MODULES

7.1 MODULES DESCRIPTION

The integration of solar tracking, Li-Fi communication, and fire detection systems creates a comprehensive, autonomous, and intelligent platform that optimizes renewable energy use and ensures safety through real-time monitoring. Each module plays a distinct role but is designed to work in harmony with others for seamless operation. The Solar Tracking Module is the backbone of the system, ensuring that the solar panel is always oriented toward the sun, maximizing energy generation, and minimizing energy loss due to inefficient panel positioning. The energy generated is directly used to power the Li-Fi Communication Module, which facilitates secure, high-speed data transmission without interference, even in environments with high electromagnetic noise. This unique feature of Li-Fi makes it ideal for scenarios where traditional wireless communication methods might face disruptions. The Fire Detection Module, powered by artificial intelligence and advanced image processing algorithms like YOLO, ensures accurate, fast identification of fire hazards. The real-time video feed processed by the YOLO algorithm detects even small fires or smoke, triggering immediate alerts to prevent larger disasters. The Power Management Module ensures that the system operates autonomously and efficiently by regulating energy flow, making sure that all modules, from the solar panel to the fire detection system, are powered and optimized for performance.

Furthermore, the Dashboard Interface module provides users with a clear, real-time visualization of the system's status. This includes the solar panel's orientation, the battery charge level, the operational status of the fire detection system, and live data transmission logs. The dashboard helps users monitor the system's efficiency, performance, and any urgent alerts from the fire detection system. With this centralized monitoring, users can respond to potential issues instantly. By combining energy efficiency, real-time communication, and fire safety, this system stands out as a highly integrated solution for smart, sustainable living. The collaborative functioning of the modules ensures that the system not only supports continuous solar power generation but also contributes to enhanced safety and proactive risk management. Overall, this modular approach allows for smooth operation, effective monitoring, and immediate action, making the system both a forward-thinking renewable energy solution and a critical fire safety device.

7.1.1 SOLAR TRACKING MODULE

This module uses LDR sensors placed in four directions to track sunlight intensity. Based on the input, the Arduino or microcontroller controls a stepper motor to rotate the solar panel toward the direction of maximum light. This improves energy efficiency by keeping the panel aligned with the sun throughout the day. The system resets itself during low light or at night using a position reset logic.

7.1.2 POWER MANAGEMENT MODULE

The solar energy generated is stored in a 12V lead-acid battery. This module handles charging, voltage regulation, and power distribution. A charge controller is used to protect the battery from overcharging or deep discharge. The stored power is supplied to the Li-Fi transmitter, fire detection camera, dashboard system, and other connected devices, ensuring off-grid and continuous operation.

7.1.3 FIRE DETECTION MODULE

This module uses a camera module (e.g., ESP32-CAM or USB camera) to capture live video feeds, which are processed using the YOLO (You Only Look Once) algorithm on a processing unit. YOLO detects fire in real-time based on its shape, color, and motion. When fire is detected, an alert message is generated immediately and passed to the communication module for transmission.

7.1.4 Li-Fi COMMUNICATION MODULE

The Li-Fi module transmits data using visible light. When a fire is detected, this module uses an LED to send the encoded alert signal to a photodiode receiver. The photodiode decodes the signal and passes it to a microcontroller for display or further processing. This allows wireless and interference-free communication without radio signals.

7.1.5 DASHBOARD INTERFACE MODULE

This module is a web-based or local dashboard that displays system status. It shows real-time information such as fire alerts, solar panel angle, battery charge level, and Li-Fi transmission logs. The interface allows users to monitor and review previous alerts, making it useful for security or industrial automation applications.

7.1.6 HARDWARE INTEGRATION MODULE

All the hardware components like the solar panel, battery, stepper motor, camera, LEDs, and sensors are integrated on a common board or setup. Proper wiring, connectors, and casing are used to ensure safety and durability. The microcontroller or Arduino board acts as the central controller for handling signals and logic.

7.1.7 PROGRAMMING & CONFIGURATION MODULE

This module handles coding and logic configuration. The microcontroller is programmed using Arduino IDE or Python scripts for fire detection and motor control. YOLO model integration and Li-Fi encoding/decoding are also configured here. Network and hardware initialization are included in this setup to make the system functional at startup.

7.1.8 COMPONENT PROCUREMENT MODULE

This module involves selecting and acquiring components like solar panels, LDRs, stepper motors, ESP32-CAM, LEDs, photodiodes, batteries, regulators, and microcontrollers. All items are tested for compatibility and performance before integration. Timely procurement and inventory tracking ensure smooth development and assembly of the project.

CHAPTER 8

CODING

8.1 Solar Panel Tracking Code

```
#include "global.h"

#include "ss.h"

#include "set_up.h"

#include "read_data.h"

void setup() {

    SET_UP_FUNCTION();

}

void loop() {

    READING_DATA();

    if (ldr_2 == 0 && ldr_1 == 1 && solar_left == false) {

        if (servo_flag2 == true) {

            for (pos = 170; pos >= 130; pos--) {

                servo_flag1 = false;

                servo_flag2 = false;

                Myservo1.write(pos);

                Myservo2.write(pos1);

                delay(50);

            }

        }

        for (pos = 130; pos >= 90; pos--) {

            solar_left = true;

            solar_right = false;
```

```

servo_flag1 = true;

Myservo1.write(pos);

Myservo2.write(pos1);

delay(50);

}

}

if (ldr_1 == 0 && ldr_2 == 1 && solar_right == false) {

  if (servo_flag1 == true) {

    for (pos = 90; pos <= 130; pos++) {

      servo_flag1 = false;

      servo_flag2 = false;

      Myservo1.write(pos);

      Myservo2.write(pos1);

      delay(50);

    }

  }

  for (pos = 130; pos >= 90; pos--) {

    solar_left = false;

    solar_right = true;

    servo_flag2 = true;

    Myservo1.write(pos1);

    Myservo2.write(pos);

    delay(50);

  }

}

```

```

if (ldr_1 == 0 && ldr_2 == 0) {

    if (servo_flag2 == true) {

        for (pos = 170; pos >= 130; pos--) {

            Myservo1.write(pos);

            Myservo2.write(pos1);

            delay(50);

        }

        servo_flag2 = false;

    }

    if (servo_flag1 == true) {

        for (pos = 90; pos <= 130; pos++) {

            Myservo1.write(pos);

            Myservo2.write(pos1);

            delay(50);

        }

        servo_flag1 = false;

    }

}

if (ldr_2 == 0)

{

    if (servo_flag2 == true)

    {

        for (pos = 90; pos <= 170; pos++) {

            Myservo1.write(pos);

            delay(50);

        }

    }

}

```

```

    }

    servo_flag2 = false;

    }

    else

    {

    for (pos = 130; pos <= 170; pos++) {

        Myservo1.write(pos);

        delay(50);

    }

    delay(3000);

    for (pos = 170; pos >= 130; pos--) {

        Myservo1.write(pos);

        delay(50);

    }

    servo_flag1 = true;

    }

    else

    {

    for (pos = 90; pos <= 130; pos++) {

    delay(3000);

    Myservo1.write(130);

        delay(50);

    if (ldr_1 == 0)

    {

        if (servo_flag1 == true)

```

```

{
    for (pos = 130; pos <= 170; pos++) {
        Myservo1.write(pos);
        delay(50);
    }
    servo_flag1 = false;
}
else
{
    for (pos = 130; pos >= 90; pos--) {
        Myservo1.write(pos);
        delay(50);
    }
    delay(3000);
    for (pos = 90; pos <= 130; pos++) {
        Myservo1.write(pos);
        delay(50);
    }
}
servo_flag2 == true;
}
else
{
    for (pos = 170; pos >= 130; pos--) {

```

```

    delay(1500);

    Myservo1.write(130);

    delay(50);

    }

}

if(ldr_1==1 && delay(500);

}

void serialEvent() {

    while (Serial.available() > 0) {

        PYTHON_DATA = Serial.read();

        Serial.println(PYTHON_DATA);

        switch (PYTHON_DATA)

        {

            case 'F':

                ss.write('A');

                break;

        }

    }

}

```

8.2 Fire Detection using YOLO Code

```

from ultralytics import YOLO

import cvzone

import cv2

import math

```

```

import serial

import time

# Running real-time from webcam

cap = cv2.VideoCapture(0)

model = YOLO('fireModel.pt')

ser = serial.Serial('COM12',9600)

# Reading the classes

classnames = ['Fire','default','smoke']

while True:

    ret, frame = cap.read()

    frame = cv2.resize(frame, (640, 480))

    result = model(frame, stream=True)

    # Getting bbox, confidence, and class names information to work with

    for info in result:

        boxes = info.boxes

        for box in boxes:

            confidence = box.conf[0]

            confidence = math.ceil(confidence * 100)

            Class = int(box.cls[0])

            print('confidence:'+str(confidence))

            if confidence > 30:

                x1, y1, x2, y2 = box.xyxy[0]

                x1, y1, x2, y2 = int(x1), int(y1), int(x2), int(y2)

                cv2.rectangle(frame, (x1, y1), (x2, y2), (0, 0, 255), 5)

                cvzone.putTextRect(frame, f'{classnames[Class]} {confidence}%', [x1 + 8, 100],

```

```
scale=1.5, thickness=2)

print('TANKER NAME:'+str(classnames[Class]))

# # Send data to the serial port based on the detected class

if classnames[Class] == "Fire":

    print("Fire")

    ser.write(b'A') # Send '1' for half ripened

elif classnames[Class] == "smoke":

    print("smoke")

    ser.write(b'A') # Send '2' for green

cv2.imshow('frame', frame)

cv2.waitKey(1)
```

CHAPTER 9

SNAPSHOTS

9.1 Solar Tracking System Snapshot

This snapshot captures the real-time operation of the solar tracking mechanism, where four LDR sensors are strategically placed to detect variations in sunlight intensity from different directions. When an imbalance in light intensity is detected, the Arduino microcontroller commands the stepper motor to rotate the solar panel toward the direction of maximum sunlight. This intelligent alignment ensures optimal energy generation throughout the day. The dashboard interface simultaneously displays the panel's angle, sunlight intensity values from each LDR, and the real-time voltage output from the solar panel, allowing for performance analysis and efficiency monitoring.



Figure 9.1 Automatic Solar Panel Alignment using LDR-Based Solar Tracker

9.2 Fire Detection System Snapshot

This snapshot shows the object detection interface powered by the YOLOv5 algorithm, which processes a live video stream from a connected camera module. The algorithm accurately identifies fire by recognizing its visual patterns and outlines the detected flame with bounding boxes in real time. The detection confidence score is also displayed. Once fire is detected, the system generates an alert which is forwarded for transmission via Li-Fi.



Figure 9.2 Real-Time Fire Detection using YOLO Algorithm

9.3 Li-Fi Data Transmission Snapshot

In this snapshot, the working of the Li-Fi module is presented. The system utilizes a high-intensity white LED powered by the solar energy stored in a rechargeable battery. Encoded data (such as a fire alert) is modulated using light pulses that are invisible to the naked eye. On the receiver side, a photodiode detects these pulses and converts them back into electrical signals which are decoded into readable data. The dashboard concurrently displays the transmitted and received data in textual form, confirming successful delivery and showcasing the efficiency of this eco-friendly communication method.

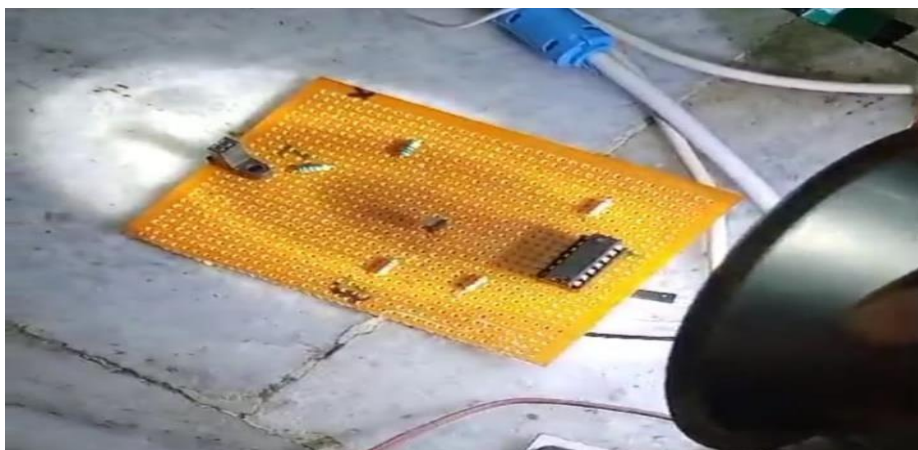


Figure 9.3 Secure Data Transmission using Solar-Powered Li-Fi System

9.4 Dashboard Snapshot: Fire Alert via Li-Fi

This snapshot captures the unified dashboard where multiple modules of the project converge. Once the YOLO algorithm detects a fire, an alert message is generated and transmitted via the Li-Fi system. The dashboard displays a real-time notification stating “FIRE DETECTED - ALERT SENT VIA Li-Fi” along with timestamps, sensor data, and confirmation of successful data reception through the Li-Fi receiver. This central interface offers users a comprehensive view of the system’s responses, including fire detection, solar power generation status, and Li-Fi communication—ensuring quick monitoring and control from a single platform.

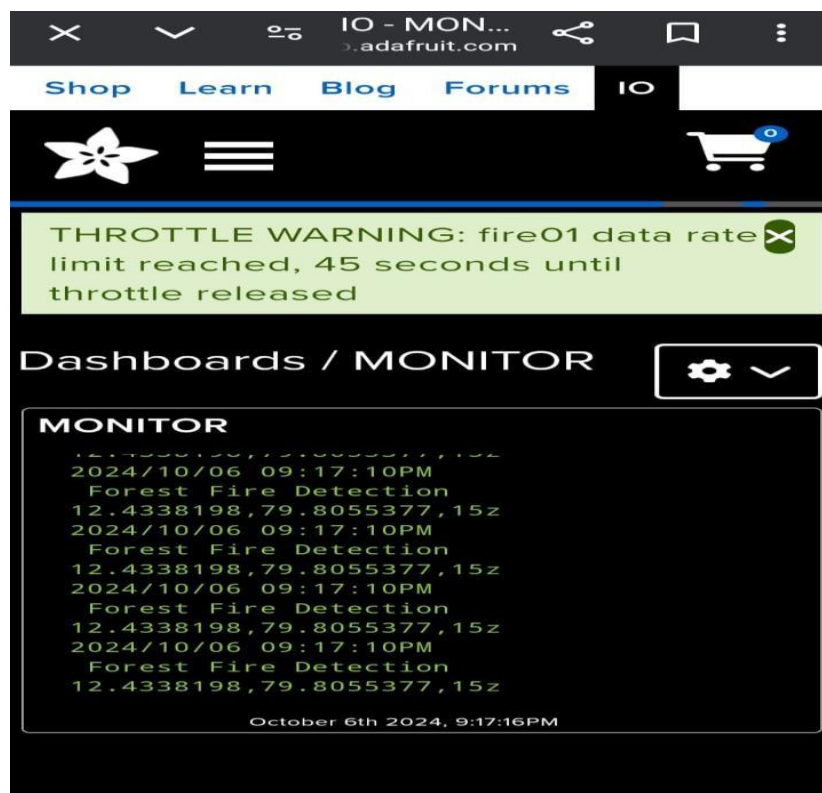


Figure 9.4 Integrated Dashboard Displaying Fire Alert Transmitted via Li-Fi

CHAPTER 10

CONCLUSION

This project, titled “Integrated System of Solar Tracking, Li-Fi Technology, and Industrial Energy Automation for Smart and Sustainable Solutions,” brings together multiple technologies to address real-world problems in a smart and eco-friendly way. The solar tracking system developed here uses LDR sensors and a stepper motor to rotate the solar panel toward the sun throughout the day. This helps in capturing maximum sunlight and improves energy generation efficiency. The power generated is stored in a battery and used to run the rest of the system, making the project energy-independent and environmentally sustainable. This module demonstrates how solar tracking can be used in practical scenarios to improve the performance of renewable energy systems.

The second major part of the project is the implementation of Li-Fi (Light Fidelity) communication, which uses LED light to transmit data. In this setup, Li-Fi is powered by the energy generated from the solar panel, showing how renewable energy can support modern communication methods. Unlike traditional Wi-Fi, Li-Fi does not cause electromagnetic interference and is ideal for use in sensitive places like hospitals, labs, and industries. In this project, it was used to send alert messages quickly and securely. This shows the potential of Li-Fi as a cost-effective, high-speed communication system in short-range applications. It not only supports the idea of wireless automation but also ensures safer data transmission in real-time environments.

The third and most critical component of the project is the fire detection system using the YOLO algorithm, which identifies fire through a live video feed. On detection, an alert message is instantly transmitted via the Li-Fi system and displayed on a dashboard. This allows users to take immediate action and prevent major damage. The dashboard also shows data from the solar tracker and Li-Fi system, providing a complete view of the system’s performance. The use of AI in fire detection makes the process faster and more accurate compared to traditional sensors. Overall, this integrated system demonstrates how solar energy, Li-Fi communication, and AI-based safety can work together to build a smarter, greener, and safer solution. It can be further developed and implemented in industries, remote areas, and smart cities to promote automation, energy efficiency, and safety.

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