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INSPECTING MEGA SOLAR PLANTS THROUGH COMPUTER VISION AND DRONE TECHNOLOGIES

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Abstract

This research introduces an innovative method for monitoring large-scale grid-connected photovoltaic modules in solar power plants using the advanced YOLO v5 object detection algorithm alongside traditional image processing techniques. We emphasize a crucial component of an automated system where a drone autonomously surveys the solar park and captures video footage. Our trained YOLOv5 identifies clean and dirty panels effectively. This process is tailored for a specific site and will be implemented using a Raspberry Pi. The system processes drone-captured images, generates reports, and automatically emails them to the relevant department daily, ensuring timely maintenance for the longevity and safe operation of solar arrays. While the project is straightforward, it stands out due to its use of cutting-edge technologies for inspecting large solar power plants. The inspection time has been reduced from approximately one hundred and twenty hours to just five minutes, resulting in a time savings of 99.93% through advanced vision and robust automation techniques.

Keywords—Solar panels, YOLO v5, Computer Vision, Internet of Things, Raspberry Pi, Inspection, Monitoring, contours.

I. Introduction

Pakistan, situated between 24° to 27°N latitude and 61° to 76°E longitude, is located in the sunbelt, providing it with ample sunshine throughout the year. This creates significant potential for harnessing solar energy, which could help address the country's energy crisis, particularly in remote villages. Currently, around 40,000 villages in Pakistan lack access to electricity.

The Alternative Energy Development Board indicates that 95% of the country receives sufficient sunlight, with solar radiation levels ranging from 900 to 1000 W/m² at sea level. Research on solar mapping shows that Pakistan has the potential to generate 2.9 million megawatts (MW) of solar energy. Additionally, solar energy is increasingly recognized as a clean source of electricity generation globally, he focus of this study is to compare the conventional visual inspection technique, herein termed as the Conventional Technique (CT) with the VR inspection technique – newly developed by the authors. A Leica P40 3D laser scanner is used to automate the data collection process and a Samsung Gear VR headset is used for visualisation. A section of the Mancunian Way flyover, Manchester United Kingdom, is selected as the test subject. Principle inspection is performed by

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two approaches; the CT method and the proposed VR method. The paper describes the hardware, software used; explains field observations, post-processing stages involved in both approaches and provides a critical comparison to highlight the most effective bridge inspection technique. To the authors' knowledge, this research is the first reported work on the inspection of concrete bridges which combines 3D scanning and virtual reality.

Presently, Pakistan's electricity generation relies heavily on fossil fuels, which are environmentally damaging and impose a significant economic burden due to imports. Consequently, the adoption of renewable energy sources is on the rise, with solar power technology seen as a key solution to the electrical energy shortfall. The increasing demand for solar energy is driven by its cleanliness, abundant sunshine, and suitability for remote applications. Furthermore, there is growing social acceptance of solar technology, with both households and businesses installing photovoltaic (PV) panels on rooftops and available land, thereby boosting the solar industry and benefiting both the country and individual users.

Pakistan's first on-grid solar project of 178.08 kW was launched in 2010 at the Planning Commission and Pakistan Engineering Council Building. A larger 2 MW system was later installed in the National Assembly, contributing surplus energy to the grid. Notably, the Pakistani parliament became the first in the world to transition to PV cells. In 2015-16, the Quaid-e-Azam Solar Park was commissioned, with a capacity of 1000 MW. To encourage the growth of solar technology, the government is issuing letters of support and intent to various Independent Power Producers and companies.

However, solar panels require regular maintenance and cleaning to maintain efficiency, as dust accumulation can significantly reduce their performance. While small installations can be easily monitored and cleaned, larger sites present more challenges. Despite advancements in water-free cleaning methods, this study focuses on inspecting PV panels at a pharmaceutical facility in Karachi using drone-based aerial imaging. The research is divided into two main parts: first, identifying and counting clean panels using computer vision algorithms with a Raspberry Pi for on-site image processing; second, developing an IoT-based system that utilizes pandas and email protocols to automatically generate reports from the visual data and send them to the relevant department.

This article is structured as follows: Section II reviews the literature on techniques for inspecting solar modules, Section III details the implementation of the inspection method using the YOLOv5 algorithm, Section IV presents the simulation results for the proposed approach, and the final section concludes with recommendations for future work.

II. Literature Survey

Typically, manual inspections suffice for small solar sites, but larger companies with extensive projects often hire third-party services for fault detection, cleaning, and inspection. Technological inspection methods are essential for optimizing renewable energy systems. Various researchers have suggested different techniques for inspecting solar panels. One common method involves monitoring electricity generation to detect malfunctions in photovoltaic

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(PV) cells, with continuous analysis of data to identify any abnormalities. While effective, this approach can be exhausting and impractical for larger installations. Some researchers utilize string measurement devices to detect faults and efficiency drops, which also require data processing and analysis.

Hicham Tribak and Omar El Kadmiri proposed a method where a robot captures images of PV panels using a high-definition camera. They employed a convolutional encoding technique, enhanced with a spread spectrum method, and applied discrete cosine transform (DCT) for image watermarking. The images undergo brightness adjustment and stitching, followed by the extraction of points of interest using the SURF algorithm. Finally, the RANSAC and homography techniques help retain accurate matching points. Their system also incorporates Raspberry Pi microcomputers for implementation.

Infrared thermography is a widely used non-destructive testing method and a key area of research. This technique captures heat variations in PV panels, allowing for the easy identification of broken or faulty cells. Thermal imaging can reveal various defects, but this process is often performed manually by third-party vendors using portable thermal guns, requiring workers to individually inspect each panel. Recently, unmanned aerial vehicles (UAVs) have been adopted to automate this process, enabling thermal imaging from above and identifying issues such as abnormal heat generation.

Álvaro Huerta Herraiz and colleagues applied an R-CNN-based deep learning technique to identify solar panels and hotspot regions using images from solar power plants. When hotspots are detected, telemetry data from IR-UAV systems—such as altitude, orientation, GPS position, camera angle, and vision angle—are combined with the identified areas to locate defective modules.

H.S. Nalamwar and others discussed using IoT for panel inspections, employing data acquisition modules and sensors to monitor electrical parameters. Their IoT-integrated software platform triggers alerts for anomalous power generation patterns. Additionally, some researchers have explored using Bluetooth technology connected to Android devices for monitoring smaller solar sites. Harley Denio proposed aerial monitoring to identify issues across large panel arrays, helping to prevent fire hazards and cell damage.

Pia Addabbo and Antonio Angrisano adopted a similar approach with thermal imaging and UAVs, adding innovation through the use of the Global Navigation Satellite System for precise panel localization. Their drone utilizes a U-Blox NEOM8N for this purpose.

This research presents a system design for inspecting large solar plants using UAVs. The drone captures images from various heights, which are then processed with the YOLOv5 algorithm to detect solar modules. Results are emailed using a Raspberry Pi, demonstrating accurate real-time processing capabilities.

III.System Analysis

Existing System: To effectively monitor mega solar plants, the current approach involves manual inspections, which can be time-consuming and labor-intensive. Companies often rely on third-party services for tasks such as fault detection, cleaning, and inspection. Recognizing issues early and

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maintaining solar panel efficiency are crucial for maximizing energy output and reducing operational costs. The existing system aims to utilize traditional inspection methods combined with basic image analysis techniques to assess the condition of solar panels. Disadvantages of Existing System

- Manual inspections can lead to inconsistent results and oversight of critical issues.
- The reliance on human intervention increases the time and cost of inspections.
- Algorithm Used: Basic Image Analysis Techniques.

Proposed System: The proposed system leverages advanced computer vision and drone technology to enhance the inspection of mega solar plants. By employing machine learning algorithms, specifically using YOLO (You Only Look Once), the system can efficiently analyze aerial images captured by drones. This method facilitates real-time identification of clean and dirty panels, ensuring timely maintenance and optimal performance. The use of drones allows for comprehensive site coverage, reducing inspection times significantly and increasing accuracy in fault detection. Advantages of Proposed System are:

- Utilizing drone technology and computer vision can drastically reduce inspection time and costs.
- The YOLO algorithm enhances accuracy in detecting panel conditions, supporting proactive maintenance.
- Algorithm Used: YOLO (You Only Look Once).

IV. System Study

Feasibility Study: The feasibility of the project is analyzed in this phase and business proposal is put forth with a very general plan for the project and some cost estimates. During system analysis the feasibility study of the proposed system is to be carried out. This is to ensure that the proposed system is not a burden to the company. For feasibility analysis, some understanding of the major requirements for the system is essential. Three key considerations involved in the feasibility analysis are,

Economical Feasibility: This study is carried out to check the economic impact that the system will have on the organization. The amount of fund that the company can pour into the research and development of the system is limited. The expenditures must be justified. Thus the developed system as well within the budget and this was achieved because most of the technologies used are freely available. Only the customized products had to be purchased.

Technical Feasibility: This study is carried out to check the technical feasibility, that is, the technical requirements of the system. Any system developed must not have a high demand on the available technical resources. This will lead to high demands on the available technical resources. This will lead to high demands being placed on the client. The developed system must have a modest requirement, as only minimal or null changes are required for implementing this system.

Social Feasibility: The aspect of study is to check the level of acceptance of the system by the user. This includes the process of training the user to use the system efficiently. The user must not feel threatened by the system, instead must accept it as a necessity. The level of acceptance by the users solely depends

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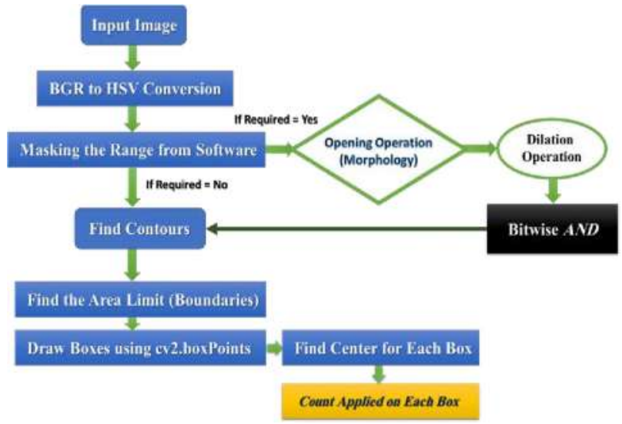
on the methods that are employed to educate the user about the system and to make him familiar with it. His level of confidence must be raised so that he is also able to make some constructive criticism, which is welcomed, as he is the final user of the system.

The power & utilities market includes electricity and water management companies operating in production, transmission and distribution segments. Although all segments are driven by similar trends, there are still significant differences in how these trends affect the market situation, the competitiveness level of the industry and companies' operations. The global power & utilities market has been driven by growing demand for energy supply as a result of urbanisation and growth in population and technology use. Other major trends include the transition from fossil fuels to clean energy, regulatory pressure to bring energy prices down and technological innovations disrupting existing business models. In the water industry, it is becoming increasingly important to develop pollution prevention strategies and manage wastewater, as well as prevent leakages in pipelines and drainage channels not to waste water, especially in areas where it is scarce.

V. System Design

Reliability of supply is an important consideration, especially in countries where energy prices are regulated. If power utilities are able to reduce the frequency and duration of outages they can receive better pricing outcomes from regulatory authorities, and avoid penalties from failing to meet reliability standards. While globally energy prices are expected to decrease, players in the power & utilities industry must especially work towards minimising outages of transmission and distribution infrastructure.

Architecture:



The data flow diagram is also called as bubble chart. It is a simple graphical formalism that can be used to represent a system in terms of input data to the system, various processing carried out on this data, and the output data is generated by this system.

It one of the most important modelling tools. It is used to model the system components. These components are the system process, the data used by the process, an external entity that interacts with the system and the information flows in the system.

It shows how the information moves through the system and how it is modified by a series of transformations. It is a graphical technique that depicts information flow and the transformations that are applied as data moves from input to output.

It may be used to represent a system at any level of abstraction. It may be partitioned into levels that represent increasing information flow and functional detail.

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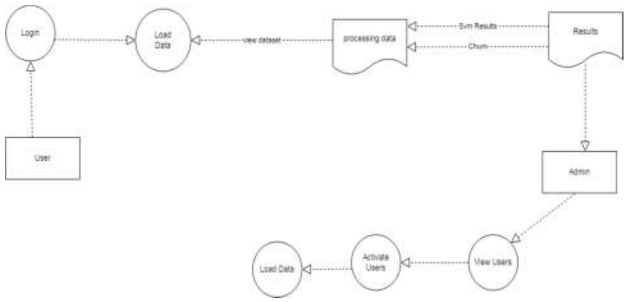


UML is a standardized general-purpose modelling language in the field of object-oriented software engineering. The standard is managed, and was created by, the Object Management Group.

The goal is for UML to become a common language for creating models of object oriented computer software.

In its current form UML is comprised of two major components: a Meta-model and a notation. In the future, some form of method or process may also be added to; or associated with, UML.

The Unified Modelling Language is a standard language for specifying, Visualization, Constructing and documenting the artefacts of software system, as well as for business modelling and other non-software systems.

The UML represents a collection of best engineering practices that have proven successful in the modelling of large and complex systems.

The UML is a very important part of developing objects oriented software and the software development process. The UML uses mostly graphical notations to express the design of software projects. The Primary goals in the design of the UML are as follows:

Provide users a ready-to-use, expressive visual modelling Language so that they can develop and exchange meaningful models.

Provide extendibility and specialization mechanisms to extend the core concepts.

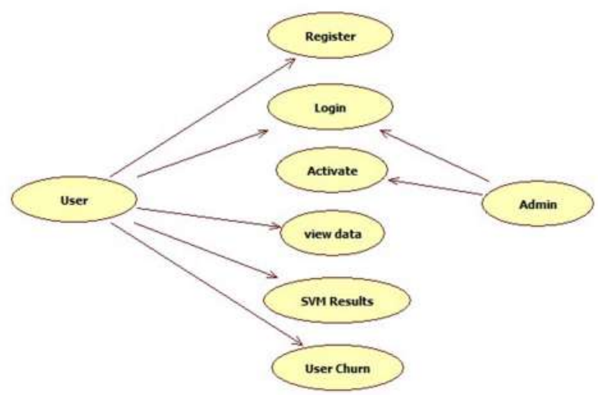
Be independent of particular programming languages and development process.

Provide a formal basis for understanding the modelling language.

Encourage the growth of OO tools market.

Support higher level development concepts such as collaborations, frameworks, patterns and components.

Integrate best practices.



A use case diagram in the Unified Modelling Language (UML) is a type of behavioural diagram defined by and created from a Use-case analysis. Its purpose is to present a graphical overview of the functionality provided by a system in terms of actors, their goals (represented as use cases), and any dependencies between those use cases. The main purpose of a use case diagram is to show what system functions are performed for which actor. Roles of the actors in the system can be depicted.

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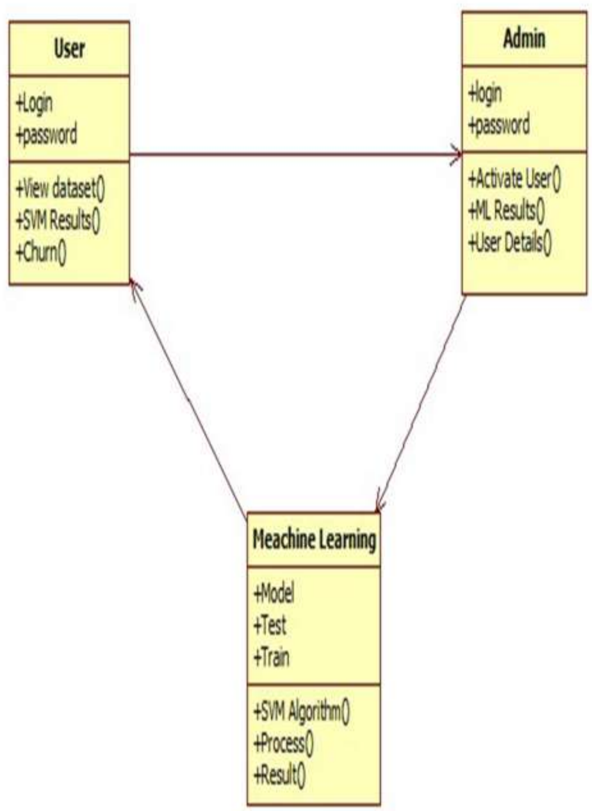
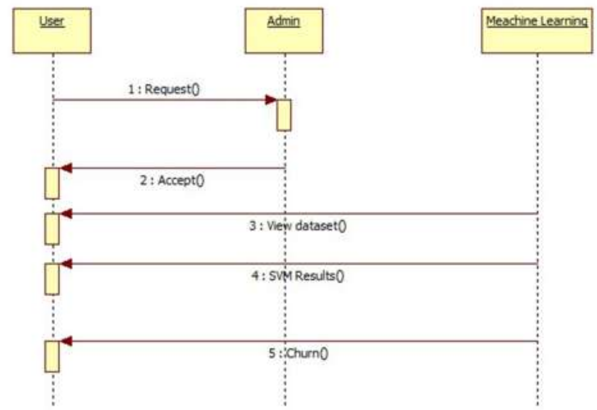
In software engineering, a class diagram in the Unified Modeling Language (UML) is a type of static structure diagram that describes the structure of a system by showing the system's classes, their attributes, operations (or methods), and the relationships among the classes. It explains which class contains information.

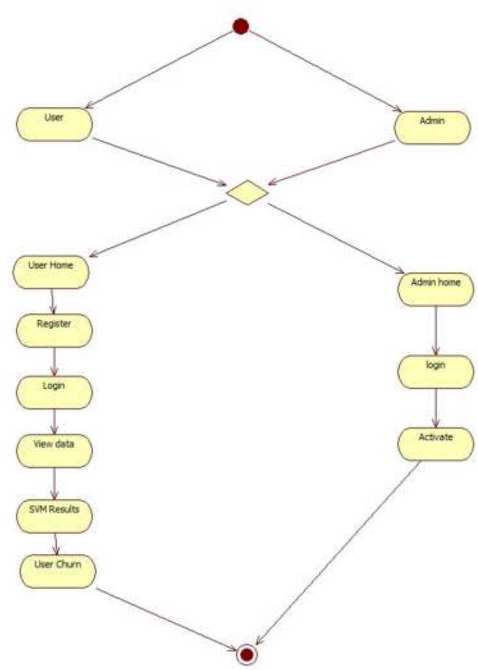


A sequence diagram in Unified Modelling Language (UML) is a kind of interaction diagram that shows how processes operate with one another and in what order.

It is a construct of a Message Sequence Chart. Sequence diagrams are sometimes called event diagrams, event scenarios, and timing diagrams



Activity diagrams are graphical representations of workflows of stepwise activities and actions with support for choice, iteration and concurrency. In the Unified Modeling Language, activity diagrams can be used to describe the business and operational step-by-step workflows of components in a system. An activity diagram shows the overall flow of control.



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VI.Modules Classification

User:The User can register by providing a valid email and mobile number for communication. After registration, the admin must activate the user account. Once activated, the user can log in to the system. The user can upload aerial images of solar panels that match the required dataset format. For analysis, the images must be in a compatible format.

Users can also add new images to the existing dataset through the web application. By clicking on the "Classification" option, the user can view results such as accuracy, F1-Score, recall, and precision based on the algorithms used. Users can also make predictions about panel conditions and receive feedback categorized as clean, dirty, or faulty.

Admin:The Admin can log in with specific credentials and has the authority to activate registered users. Only after activation can users log into the system. The admin has the ability to view overall data in the browser and can click on the "Results" section to see metrics such as accuracy, F1-Score, precision, and recall for various algorithms.

After all algorithms have been executed, the admin can review the overall accuracy displayed on the web page.

Data Preprocessing: Data preprocessing involves preparing the dataset for analysis, which includes a collection of image objects representing solar panels. Each image is characterized by features that capture essential attributes, such as brightness levels and panel conditions. The preprocessing stage applies techniques such as noise reduction, handling missing data, adjusting default values, and organizing image attributes for prediction at various levels.

Machine Learning: The cleaned dataset is divided into 60% for training and 40% for testing. The images are then analyzed using machine learning classifiers, such as YOLO (You Only Look Once). The system calculates metrics like accuracy, precision, recall, and F1-Score for each classifier. The classifier with the highest accuracy is identified as the best performer for panel condition prediction.

VII. Conclusion

Therefore, from the above discussion, it can be concluded that every organization involved in solar energy must prioritize the inspection and maintenance of solar plants. Efficient monitoring is essential for ensuring optimal performance and longevity of solar panels. Implementing advanced technologies, such as computer vision and drone technology, significantly enhances the inspection process. Utilizing algorithms like YOLO for image analysis provides accurate and timely assessments of panel conditions. This report emphasizes the importance of regular inspections and the role of machine learning in improving maintenance strategies for mega solar plants. Overall, adopting these technologies is crucial for maximizing energy output and reducing operational costs.

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