Inspecting Mega Solar Plants through Computer Vision and Drone Technologies

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Abstract—**This research presents a unique approach for monitoring the large-scale grid-connected photovoltaic modules in solar power plants using state-of-art object detection YOLOv5 algorithm and classical image processing techniques. We have highlighted an integral part of the fully automated system in which a drone takes flight over the solar park and shoot the videos. Videos are preprocessed and used for trained YOLOv5 model to recognize the clean and dirty panels. The process is defined for a selected site and can be implemented using a Raspberry Pi. This system processes the images taken by drones, generates a report, and sends it to the concerned department automatically via email every day so that timely maintenance can be done for the long-life and safe operation of solar arrays. The inspection timeline for the same process was about one hundred and twenty hours, reduced to five minutes. It means that 99.93% of the time is saved through vision and robust automation techniques.**

Keywords— Solar panels, Yolo V5, Computer Vision, Internet of Things, Raspberry Pi, Inspection, Monitoring, contours.

I. Introduction

Pakistan, with 24° to 27°N latitude and 61° to 76°E longitude, lies in the sunbelt [1]. It means that the country has long sunshine throughout the year. In other words, the country has a massive potential to harness solar energy for practical purposes. Specifically, the country's energy crisis could be overcome with the help of solar energy resources, especially in remote villages [2]. The current estimates indicate that there are 40,000 villages in Pakistan without the basic necessity of electricity [3].

According to the Alternative Energy Development Board (AEDB), 95% of the country's area receives the requisite insulation [4]. At sea level, country approximate solar radiation of 900-1000 w/m². The research in collaboration with USAID linked to solar mapping proves that the country has a potential of 2.9 million Mega Watt (MW) of energy[5]. More importantly, solar energy is widely recognized as a clean source of electricity generation worldwide.

Currently, Pakistan's electricity generation primarily depends on fossil fuel-based power plants. These fossil-fuel-based solutions are harmful to the environment and an excessive import burden on the country's economy. Therefore, the trend of renewable energy is rising in Pakistan like Quaid-e-Azam Solar Park [6] and Gaddu thermal power plant [7] . One of the fastest remedy for overcoming the shortfall of electrical energy is considered to be solar power technology [8]. Specifically, electricity generation via solar energy is increasing due to its clean nature, surplus sun hours, and being remotely usable [8]. Likewise, Pakistan has exponentially increased social acceptance of solar power technology. From households to commercial entities, people are installing photovoltaic (PV) panels on their rooftops or vacant places. Subsequently, this acceptance is boosting the business of solar solution providers and local companies. It will benefit the country and the individuals shifting towards it.

The first on-grid solar project of 178.08 kW was commissioned by the Planning Commission and Pakistan Engineering Council Building in 2010. A 2 MW system was installed in the National Assembly of Pakistan that was producing surplus energy and adding it to the grid [9]. The Pakistani parliament is the world's first parliament to be shifted to PV cells [10]. In 2015-16 a 1000MW project became functional named Quaid-e-Azam Solar Park at Bahawalpur [11]. Fig. 1 below presents the idea of the

Fig. 1. Quaid-e-Azam Solar Park at Bahawalpur 1000 MW capacity

Quaid-e-Azam solar park having a capacity of 1000 MW of energy. To promote the prevalence of solar technology, the government is giving letters of support (LoS) and letters of intent (LoI) to several Independent Power Producers (IPPs) and companies [12].

The growing demand for PV power stations also gives rise to the need for their maintenance and inspection. The PV panels require proper care and dust particle cleaning to prevent overall efficiency reduction. Dust-fall significantly impacts the overall efficiency of panels [13]. Gaofa He, Chuande Zhou, et al. [14] found that the layer of dust of 4 gm/sq-meter decreases efficiency by 40%. For small sites, it is convenient to monitor the surface of solar panels and clean, but it is a hectic process for solar plants spanning larger areas. Although the research has progressed to the water-free cleaning process [15].

The focus of this work is the inspection of the PV panel sites of the pharmaceutical industry in Karachi. This is done by aerial imaging via drone technology. First, the images are preprocessed then different used both classical (Morphology) and deep learning (Yolov5) algorithms to identify the clean and dirty solar panels modules. Second, an Internet-of-Things (IoT)-based pipeline can be built. It uses pandas and a simple mail transfer protocol that automatically generates the report from the output of our vision software and email to the concerned department.
The structure of this article is as follows. In Section II, the literature review related to techniques used for the inspection of solar modules has been summarized. Section III illustrates the implementation of the inspecting method for a mega-solar system using morphology and YOLOv5 algorithm. Section IV explains simulation results for the proposed approach. In the last section, the conclusion of the article and future recommendations are drawn.

II. Literature review and survey

Typically, manual inspections are sufficient for monitoring small sites. However, bigger companies with mega-projects hire third-party companies to provide external services, such as fault detection, cleaning, and inspection. Technology inspection measures are necessary to ensure the best performance of the renewable energy setup. Several researchers have proposed different techniques for the inspection of solar panels. In the simplest form, malfunctions in the PV cells are detected by monitoring electricity generation. The monitoring data is analyzed continuously for possible abnormalities. An occurrence of an outlier usually indicates a fault and is traced to the specific panel [15]. The process is being used increasingly. However, at the same time, it is very exhausting, passive, and not feasible for large sites. Some researchers also use string measurement devices to identify the faults and the decrease in efficiency [16]. This method is also linked to data processing and analytics.

H.Tribak and O.Kadmiri et al.[17] propose an approach in which, firstly, a robot captures the image of the series of PV panels with a High Definition (HD) camera. Then, they used the convolutional encoding-based trellis technique, and out of encoding is speed-up using spread spectrum technique. The Discrete Cosine Transform DCT is used for image watermarking. The images undergo brightness balancing. All these steps are involved in image stitching. The aim of the next stage is to extract the point of interest from each captured image using the SURF algorithm. The final stage is used to retain the true matching points with the help of RANSAC and homograph. Their system also uses Raspberry Pi microcomputers for implementing the system. Infrared thermography is a common non-destructive alternative test and an active area of research [17], [18]. Radiation produces heat at different levels of PV; then the thermal infrared camera can capture the subsequent electromagnetic spectrum. Broken and faulty cells can be found easily by using this technique [19]. Different defects can be found by thermal imaging and optical cameras. Since thermal guns are portable, usually third-party vendors manually carry out this process with the help of their labor. The workers visit each panel individually with the thermal gun in hand to monitor, and steadily they cover the whole site. In the subsequent phases, Unmanned Aerial Vehicles (UAVs) are used with the same approach as a thermal gun or Infrared thermal camera [20]. The same manual operation is integrated with drone technology so that all the thermal imaging processes will be free from manual intervention. The defects can now be detected from altitudes, and abnormal heat generation from any PV cell can be analyzed to identify the problem. Due to the speed of the Infrared thermal camera and the advancing UAVs, this technique is capturing engineers' and researchers' interest. UAVs are posing an adequate solution for inspecting rapidly growing PV technology.

This article[21] used the Hough transformation technique on the images taken with UAV to detect the lines, these lines are further used to detect the induvial solar panels from the images that are taken from UAV. The article [22] explains the method to diagnosis the detailed clear information of PV cells using the thermography method. Then further used the IR analysis and computer visions techniques to extract the more information. Additionally, paper proposed the software platform to generate the reports contains information about health and efficiency of each PV module. The recognition of failure or degradations in of solar panels performance is concerned issue in mega solar plants. The paper [23] has used the principal component analysis PCA with combination of k-nearest neighbor KNN algorithm to classify the features of EL images in various failure classes.

Another paper[24] implemented deep learning-based solution to recognize the defect in PV modules images obtained from unmanned aerial vehicles. It's used the CNN to classify the defects in various classes. This method has significantly increased the accuracy in comparison of existing conventional method.

Á.Herraiz et.al.[18] uses the R-CNN-based deep learning technique for identifying solar panels and the hotspot region using the dataset containing the images of solar power plants. If R-CNN detects the hotspot region, then the telemetry data gathered by IR-UAV systems containing information like altitude, orientation, Global Positioning Satellite (GPS), camera angle, and vision angle is combined with the detected part to generate the final result. The results help to locate the defective module of the power plant.

The concept of IoT for inspecting panels is discussed by [20] In the given research, the authors used data acquisition modules, sensors, and data from the electrical parameters obtained. An IoT-integrated custom software platform has been introduced for monitoring electrical parameters. With the help of said framework, anomalous patterns of power generation trigger alerts. Similarly, some researchers working on small solar sites also proposed Bluetooth technology[25] with the connection of Android phones to monitor the readings and disturbances . To pinpoint the problems in a large array of panels, H. Denio [26] presented aerial monitoring of panels. According to his research, it can also prevent fire hazards and damage to the cells.

P.Addabbo and A.Angrisano et al. [27] use a similar methodology for inspecting solar panels using thermal imaging and UAVs. The innovation, however, lies in the use of the Global Navigation Satellite System to accurately localize the concerned panels' location. The U-Blox NEO-M8N is installed on the drone for the said purpose.

This research work has proposed the design of the system to inspect the mega-solar plants with the help of a UAV. The main focused is to increase the speed and accuracy of detection using the YOLOv5 architecture. The drone takes the images from the top of the sites at different heights. These images are then processed using the YOLOv5 algorithm to detect the solar modules. The results can be sent via email using the Raspberry Pi.

III. METHODOLOGY AND FRAMEWORK

The presented methodology of PV inspection was adopted and applied at one of the leading pharmaceutical companies in Karachi. Subsequently, the given work solved the problem of reduction in efficiency of the solar power plant with minimum components to ensure cost-effectiveness. The project consists of two major parts. Detection of solar cells from the height (approx. 200-250 ft) and then tested computer vision algorithms for contour tracing and classification. First part of block diagram shown in Fig.2 is all about demonstrating the automated process.

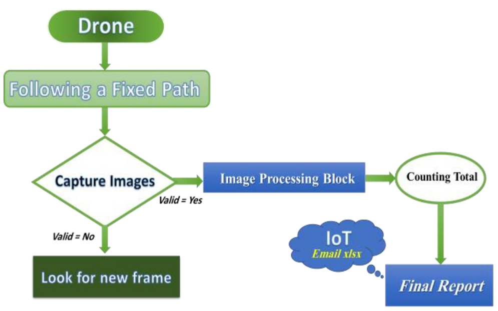

Fig. 2. Block Diagram of the automated process of Panels Inspection

The drone will fly from the pre-defined position to cover the entire site. All the path of the drone is pre-programmed to avoid manual error or external intervention. The idea is to fly over the specific building and capture pictures from the above. If the frame is captured accurately, it will be sent to the Raspberry Pi microcomputers through IoT. The image processing algorithms and our Tkinter software running on Pi will evaluate the pictures captured and add them to the excel file using the pandas' library. The total count is calculated with the clean and dirty classes. After the complete round, the report is automatically emailed to the concerned department of the company using the open Wi-Fi facility provided on-site by the company. There is also no need to deploy Raspberry Pi microcomputers on the UAVs. The Raspberry Pi works 24/7 on site with Wi-Fi connectivity for data acknowledgment, vision processing, and data transmission.

In this work we used three types of techniques in images processing block. First used the classical method for detection then extent the work using deep learning method to attain the desired result in term of accuracy and speed of detection. All methods are explained in details with pros and cons in subsections.

A. *Object Detection using Classical computer vision*

In classical computer vision, several methods are proposed to analyze and extract the features from given images. The feature extracting algorithm like, Scale Invariant Feature Transform (SIFT)[28], Histogram of Oriented Gradient (HOG)[29] and Speeded Up Robust Features (SURF)[30] are widely used in many applications, like face recognition[31], cancer detection[32] and speech resampling [33]. For this paper, first used the morphology feature extraction detect the PV modules and counting them. This method takes the input image and remove the noise, then operate for segmentation of cell to analyze the shapes, size and texture. The proposed algorithm is described in Fig. 3.

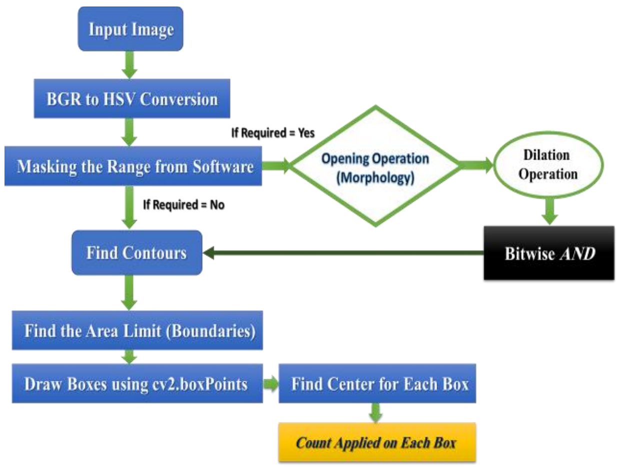

Fig. 3. Explanation of Image Processing Block of Panels Inspection

This method works fine when image is clear and without environmental noise. But the accuracy of detection is significantly decreased due to lightening effect. This deficiency led to implement the other another algorithm explained in below subsection.

B. *Combination of YOLOv5 and classical algorithm*

This module of implementation is divided into two parts. First, YOLOv5 algorithm is used divide the images into sub images. These images are actually extraction of arrays of PV from the images. The arrays of PV are detected with bounding box as shown in Fig. 4. Second, some preprocessing methods are applied to remove the noise from sub images then morphology feature algorithm is used on these sub images to detect the PV cell and then counted them. All process is shown in the fig. 4

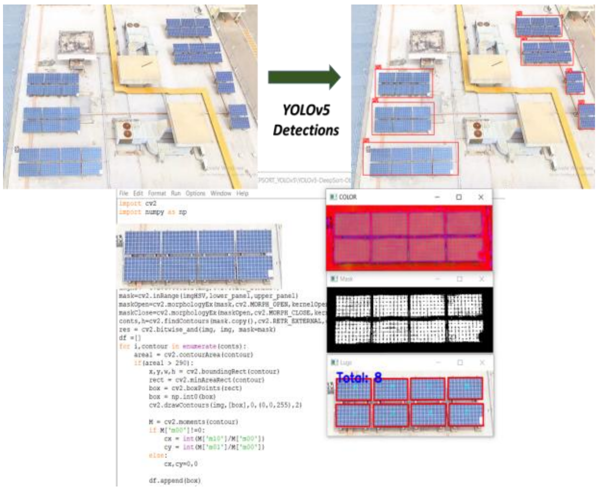

Fig.4. YOLOv5 Object Detection and Cropping with Traditional Image Processing Algorithms

This method of implementation has reduced the lightening effects in some context, but results in real-time are still lacks the accuracy and speed of detections. This problem is tackled in next sub section.

C. *Solar panel detection using YOLOv5*

The YOLOv5[34] algorithm is known for its high accuracy and expeditious detection. The YOLOv5 has the ability to process the detection with 2ms/image on NVIDIA Tesla v100. In the proposed algorithm, images are taken with drone from different heights and angles. That's the reason to select the YOLOv5 algorithm for detection, to ensure a high speed of detection with real-time performance. The architecture of YOLOv5 contains the three parts: the backbone network that is responsible for extracting the features from input images at different scales, the feature pyramid network that is responsible for fusing the features from different layers, and the detection network is responsible for predicting the object class and generating the bounding box. The YOLOv5 algorithm is improved

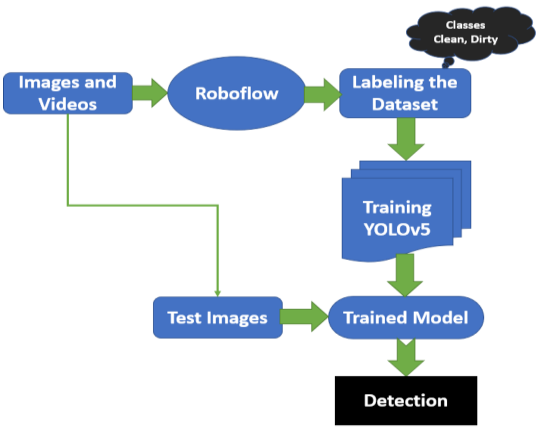

Fig.5. Complete Implementation process of YOLOv5 algorithm

and used in complex scenarios like drones images processing [35],traffic sign detections [36] and face recognition[37].

The dataset is collected from the flight of a drone over a building of an industrial site at different heights. Dataset is labelled manually using the free open resource Roboflow in two classes,. The general Implementation of YOLOv5 is shown in fig. 5.

IV. RESULTS AND DISCUSSIONS

The evaluation of Implemented methods for detection of solar panels with experimental detail is divided into two subsections.

A. *Evaluation based on Classical detection method*

We are sharing two of the aerial images captured from the drone from different height.

Fig. 6. Aerial Image one captured from the drone

These images are then processed by using classical vision algorithms defined in the methodology using Python Programming and OpenCV Library. This technique has detected the solar panels, and counted the them.

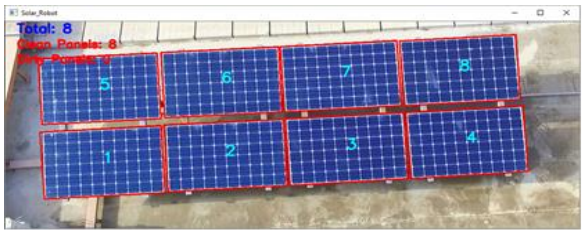

Fig. 7. Aerial Image one after Processing from Raspberry Pi

The second image that is captured from a high altitude then classical processing is used to identify the panel number to trace it easily for real-time application.

Fig. 8. Aerial Image Two captured from the drone

The processed output is also shown in Fig. 9. All the contours are formed successfully with the count on each solar panel. From the standardized height defined by the project supervisor, we can capture the picture and can find the count of 74 panels accurately.

Fig. 9. Aerial Image two after processing from the Raspberry Pi

According to the mathematical calculation, this can be done as follows.

Total count of panels = 74 panels

Time Taken for flight, capture, and processing = 5 seconds

One Batch/Frame of 74 panels = Total Time is 5 seconds

In 60 seconds = 12 batches can be covered

Total panels in 1 minute = 888 panels

These methods showed the limitation when images are noisy and accuracy of detection is decreased significantly due to light effect in real-time scenario.

B. Evaluation based on YOLOv5 algorithm

We have combined the dataset of solar panel taking from internet [38] and dataset collected from drones. First we prepared the dataset and annotate it using Roboflow tool[39]. At initial stage, we used only 2.4k images with two classes *Clean* and *Unclean* for training with 100 epochs. There are 70% images are used for training and 30% for validation. For initial testing and training Google Colab is used for generating the testing weight files for testing result. The tunning values of hyperparameter for YOLOv5 are expressed in Table. I.

TABLE I. Tuning value of hyperparameter for YOLOv5

Hyperparameter	**Value**
Learning rate	0.001
Batch Size	10
Training epoch	200
Early stop training	If loss doesn't decrease with 50 epochs

After training the model over 200 epochs evaluation matrices results are summarized in the Table. II.

TABLE II. Important results from evaluation metrics

Performance after 200 iterations	**YOLOv5**
Precision	0.90
Recall	0.86
mAP 0.5	0.86
mAP 0.5-0.95	0.80

The result has been tested on the video taken by the drone. Video results are recorded in [40]. Some detection results shown in Fig. 10.

Fig. 10. Test result from trained YOLOv5 model

V. Conclusions and Future work

In this paper, the problem of improving the performance of automatic inspection of PV plants is discussed and fast detection method is developed. The technique proposed is very simple and robust for inspection of solar plants. The implemented method using YOLOv5 has proven satisfactory results to detect and classify the solar panels into clean and unclean classes. It is a small part of our ongoing research. We are also integrating a thermal infrared camera for spots, processing for finding dirty panels, and fault detection. Also, by using counting techniques, the use of GPS as found in older systems can be eliminated. The time calculations proved that our automated process would save the vendors from previously adopted exhausting methods of inspection and monitoring. It is innovative, distinguishing, and reliable for our application.

The suggested approach can be improved further in the future by investigating other features from images, like finding the defected solar panels and their output power values of each module. There is another improved can be implemented using YOLOv5 Deep Sort or norfair models for counting and tracking each of the solar panels. Further systems can be improved by adding the new features which can generate commands to operate the other robotic system to clean the specific solar panels.

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