Masters Project Final Report

(MCS)

2019

Project Title	Identify dusts on solar panels using drone still images
Student Name	Balage Don Ishan Uditha
Registration No. & Index No.	**Registration No** : 2015/MCS/076 **Index No** : 15440764
Supervisor's Name	Prof. N. D. Kodikara

For Office Use ONLY

Identify dusts on solar panels using drone still images

A dissertation submitted for the Degree of Master of Computer Science

B D I Uditha

University of Colombo School of Computing

2019

Declaration

The thesis is my original work and has not been submitted previously for a degree at this or any other university/institute.

To the best of my knowledge it does not contain any material published or written by another person, except as acknowledged in the text.

Student Name : B. D. Ishan Uditha
Registration Number : 2015/MCS/076
Index Number : 15440764

____

Signature: Date: 11/11/2020

This is to certify that this thesis is based on the work of **Mr. Balage Don Ishan Uditha (2015/MCS/076)** under my supervision. The thesis has been prepared according to the format stipulated and is of acceptable standard.

Certified by:
Supervisor Name: Prof. N. D. Kodikara

____

Signature: Date:

Abstract

These days electricity power is one among the basic needs of man. As the demand of electricity power is expanding, there is have to exploit renewable sources of energy. In the current period of power shortage in world, the utilization of solar energy could be helpful to great extent. Hence, the number and size of the Photovoltaic (PV) systems are developing and subsequently the amount of the investments and the related opportunities and risks are expanding

To make solar energy progressively helpful, the effectiveness of solar power systems must be expanded. For the efficiency assessment of solar panels, that has been talked about with specific thoughtfulness regarding the presence of dust and maximum intensity of light on the solar panel surface. Essentially, the impacts of dusts and intensity of light on the efficiencies of solar panels have been highlighted.

This paper gives the concise portrayal of the design and construction of dust identification of solar panels utilizing drone still images. It depends on the definition of an feature vector that characterizes portions of images that can be gained with a drone camera. The proposal has been applied to a lot of images taken in a operating solar panel power stations and the outcomes got exhibit its validity and robustness. Solar power station staff can without much of a stretch distinguish dusty solar panels utilizing this system. It will improve the output of power generation of solar power station and minimize manual work which doing by solar power station staff.

Acknowledgement

The achievement and ultimate result of this project required a lot of guidance and assistance from numerous individuals and extremely privileged to have this all along the completion of my project. All that has done is just because of such supervision and assistance. I would not forget to thank them.

I respect and thank Mr. W. K. H. Wagapitiya who is the Chairman - Laugfs Holdings Ltd and Mr. Indika Gunawardana who is the CIO - Laugfs Holdings Ltd and his team for giving me an opportunity to do the project and giving us all support and direction, which made me complete the project appropriately.

I owe my profound appreciation to my project supervisor Prof. N. D. Kodikara, who took distinct interest on the project work and guided from the start, till the end of the project work by giving all the important information to building up a good system. I am extremely grateful to him for giving such a pleasant support and guidance, although he had busy schedule.

I generously thank project coordinator, Dr. Randil Pushpananda for his guidance and suggestions during this project work.

I am appreciative to and fortunate enough to get consistent encouragement, support and guidance from academic staffs of UCSC which helped us in effectively completing the project work. Additionally, I would like to extend our genuine regards to all staff in research center and laboratory for their timely support.

Table of Content

List of Figures

List of Abbreviations

AC	: Alternative Current
AI	: Artificial intelligence
CMS	: Content Management System
CPV	: Concentrator Photovoltaic
DC	: Direct Current
GW	: Giga Walt
MPP	: Maximum Power Point
MW	: Mega Walt
OCR	: Optical Character Recognition
PS	: Partial Shading
PV	: Photovoltaic

List of Tables

Chapter 1: Introduction

1.1 Background and Problem

Solar power generation is the transition of energy from sunlight to electricity, either indirectly using concentrated solar power energy, or directly victimization photovoltaic (PV). Focused alternative energy systems use lenses or mirrors and pursuit systems to focus an outsized space of daylight into small beam. Photovoltaic cells transit light into an electrical current using the photovoltaic effect.

Sri Lanka is a tropical country with great daylight nearly consistently. Along these lines, solar power is a one of the most reasonable power generation method for Sri Lanka. It recognise as a cost-effective as well as environment friendly power generation method.

As an eco-friendly electric power generation methodology not harm nature. Global warming straightforwardly influence the survival of nature and human culture, likewise because the survival of innumerable species. Solar power produces electricity power without contributing to global warming pollution.

Society's existence is currently threatened by global warming and it has been projected that among the approaching decades, the issue of global warming itself to cost society trillions of moneys if left unattended. Solar Power would be the one of best source for energy production which will help humans/societies in fighting with global warming.

As a tropical country, all know precisely once the sun can rise and set on a daily basis of the year. Whereas clouds could also be a small amount less predictable, tend to additionally do have fairly sensible seasonal and daily projections for the number of sunlight that that may receive in numerous locations. All in all, this makes solar power a particularly reliable offer of energy. On top of the above reliability benefit, nobody or a group might extremely control the reception of sunlight and it's freely available without any cost. Associated with the simplicity of solar power and therefore the benefit of energy security, solar power as a source of energy creation is being widely looked at by many developed nations and furthermore the ones who try to gain competitive advantage with the prices of other energy generating sources keep rising for social & political reasons.

Like the energy security boost, solar energy gives the better advantage of energy independence. Once more, the "fuel" for photovoltaic (PV) panels cannot be bought or monopolized. It’s free for all to use. When an individual has solar panels mounted on roof, that person can get an essentially independent source of electricity which belongs to that person. This is necessary for people, however additionally for cities, countries, and even firms. As a source of energy, solar power stations are a job generating powerhouse. Money invested in solar power creates double or triple times more jobs compared to money invested in coal or natural gas.

Considering benefits of solar power generation, LAUGFS Holdings LTD decided to generate power using solar. LAUGFS Holdings LTD has a large Solar Power Station located in Hambantota. This is a gigantic power plant and it contains hundreds of solar panels spread over several acres.

The company has faced with a practical problem while generating power. When solar panels are covered with dusts or rubbishes, to a greater extent affects the potential to generation of power. Therefore, the management of LAUGFS has decided to place staff to clean the panels on regular intervals and during and after adverse weather conditions. Though this is the current practice and the procedure put in place to ensure maximum potential power generation efficiency the process is difficult to say the least as it entails human effort and does not guarantee process effectiveness. Solar panels are dispersed over several acres; therefore, the staff designated cannot check and clean panel by panel every day. Further, it also takes a lot of time and cost to perform these tasks.

On top of the issues stated above, the operational process itself is error prone due to human involvement, perception differences and lack of availability of a validation method and as a result certain PVs could be left with dust particles unclean hindering the panels true power generation potential.

1.2 Motivation

The technology revolution throughout the most recent two decades and modern technology and computer systems can make people's life easier. Among huge numbers of the modern technological techniques and theories, AI gets interest as can utilize and derive AI techniques into numerous forms & innovate new life changing systems. Image processing with AI techniques is such an application of technology that will solve significant number of the problems of this sort in time to come.

With all these motivations, this was a brilliant opportunity to study profoundly about image processing algorithms, techniques and related theories.

Solar based power generation is one of new power generation trends in the world as there are multiple advantages for solar users and for the environment. Some of these advantages are in the likes of lower operational cost, environment friendliness, and users will be able to make additional income from these panels. In any case, likewise with every single other systems, there are few drawbacks too in this technology. Most significant one is that the users should keep their solar panels clean with minimum dust levels on them in-order to get expected power output. When a user mounts the solar panel on top of their roofs, they would not know or see the dust particles or any other types of fungus that get deposited on them which will eventually lower the output by as many as 25 – 40% on average.

Through this project, a solution to overcome this unique problem using Image processing, AI and condition-based maintenance techniques. All that learned in MCS greatly helped to successfully arrive at the solution while broad image processing algorithms and theories helps to operationalize the concept and to make this unique project a success.

1.3 Research Contribution

Image processing and condition-based systems are consistently a fascinating subject for innovators. When looking into related historical projects, there are scarcely any individual and corporate programs and approaches which have recognized the requirement for such solutions and utilization of drone-based images to take decisions for condition-based maintenance.

The organization Paul Kitawa is situated in Calau, Germany and is spent significant time in film creations. Mario Hambsch who is owner of Paul Kitawa , got the in contact with the subject of thermography in 2011 and made a thermal imaging drone camera based dust identification system[1]. As per to Mario Hambsch’s research thermography is return better results for inspecting electrical photovoltaic systems. An infrared camera recognizes temperature variations on an electrical photovoltaic module and highlights in captured thermal images. Thermal images of an appropriately functioning photovoltaic module can show homogeneous temperature dispersion inside the module all through the typical operation. On the off chance that a solar panel module isn't acceptable, significant temperature varieties might be found in individual cells or the entirety of the PV modules. In this manner detection of errors with high definition thermal imaging cameras mounted on photovoltaic drones is an efficient and economical approach to guarantee sustained profitability of a PV system.

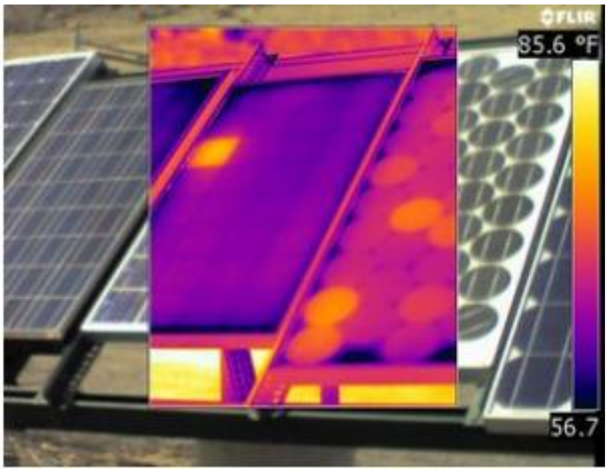

Figure 1.1 Thermal image of solar panel

A new company called Skycatch has built a UAV with support from investors such as Google and that’s utilized for remote monitoring and inspecting construction sites, mining operations, and farms [2].

Figure 1.2 Quad copter created by Skycatch

Clean Solar Solutions offer a complete infrared thermography service utilizing drones and handheld thermal imaging cameras as keep on hoping to add advantage to solar maintenance service to solar panel builders, investors and solar panel owners [3]. Two students study at the Faculty of Mechanical Engineerings, K. N. Toosi University of Technology, Iran developed an Image Processing based high-precision sun tracking system as their university research [4]. Amine Mansouri arranged research paper by describing defect discovery in solar panels using electroluminescence imaging [5].

Even though there were there were many related projects and approaches, no individual or organization has shared their system development methodology, algorithms, AI libraries or patterns to lead R&D procedure to instruct and involvement with deep image processing algorithms and utilization of related AI libraries. MCS Image Processing course materials and Research Supervisor's advices (same person who conduct lectures) has given huge contribution to build suitable algorithm for the research solution.

1.4 Scope of the Solution

The research will help to minimize manual work which done by company staff. This research cover dust identification on solar panel, notify if there is any dusty panels to relevant staff members, track cleaned solar panels as well as analytical reports which help to top management to take strategic decisions.

Main areas of research scope of the provided solution are as listed below:

- Master data feed to the system :
  System administrator should feed master data such as Solar Panel sections, subsections, panel label names…etc. to the system.

- Daily drone service to capture all panel images :
  Staff capture drone images in daily basis by following given guidelines and upload to the system.

- Segregate panel sections and subsections in drone captured image set :
  Split solar panel sections and subsections by system using advance algorithms to simplify process.

- Identify solar panels, its modules and segment them as smallest object :
  Identify and read labels printed on solar panels by using Optical Character Recognition (OCR) algorithm.

- Identifying any dust or debris on solar panel, module by module :
  Dust identification is done by analysing each panel images. Calculate dust or debris covered percentage per module using histogram of them.

- Mark dusty solar panels :
  If the system identifies any dust or debris percentage on a panel exceeding the benchmark, mark that particular PV module as a dusty module that needs cleaning.

- Send notifications :
  Notify relevant staff members to clean marked dusty solar panel modules.

- Mark as clean panel :
  Once cleaning is done, mark solar panels as cleaned.

- View analytical reports :
  Managers and supervisors have facility to view clean panel modules as a report and its historical analytical statistical reports to take strategic decisions.

1.5 List of Deliverables

Following items will be discuss and describe more on chapters of the thesis.

- Literature regarding solar power generation, potential for growth and demand for it as pollution free power generation source.
- Define why solar power generation is ideal for countries like Sri Lanka as source of electricity generation.
- Find challenges currently faced by stakeholders in the solar power generation industry.
- Segmenting of areas, sections, panels and modules of drone still images of solar panel power station by using image processing algorithms.
- Find how drones could be used to navigate and transmit solar panel images for processing.
- Build an algorithm to identify dusts and calculate dusts covered percentage.
- Structural and UI design of proposed computer solution for identify dusts on solar panels.
- Develop and implement proposed system.
- Evaluation analysis by using questioners and user interview.
- Cost benefits analysis of the proposed solution.

1.6 Work Breakdown Structure

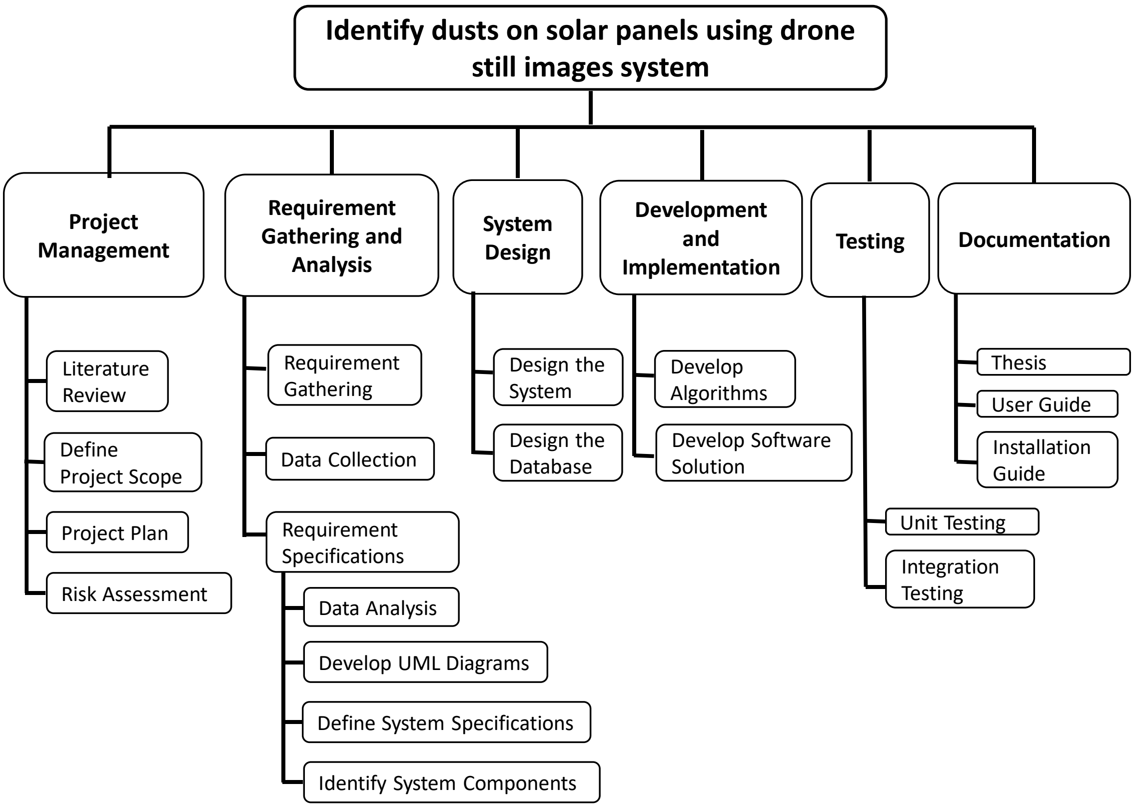

Figure 1.3 Work Breakdown Structure

1.7 Project Plan and Timeline

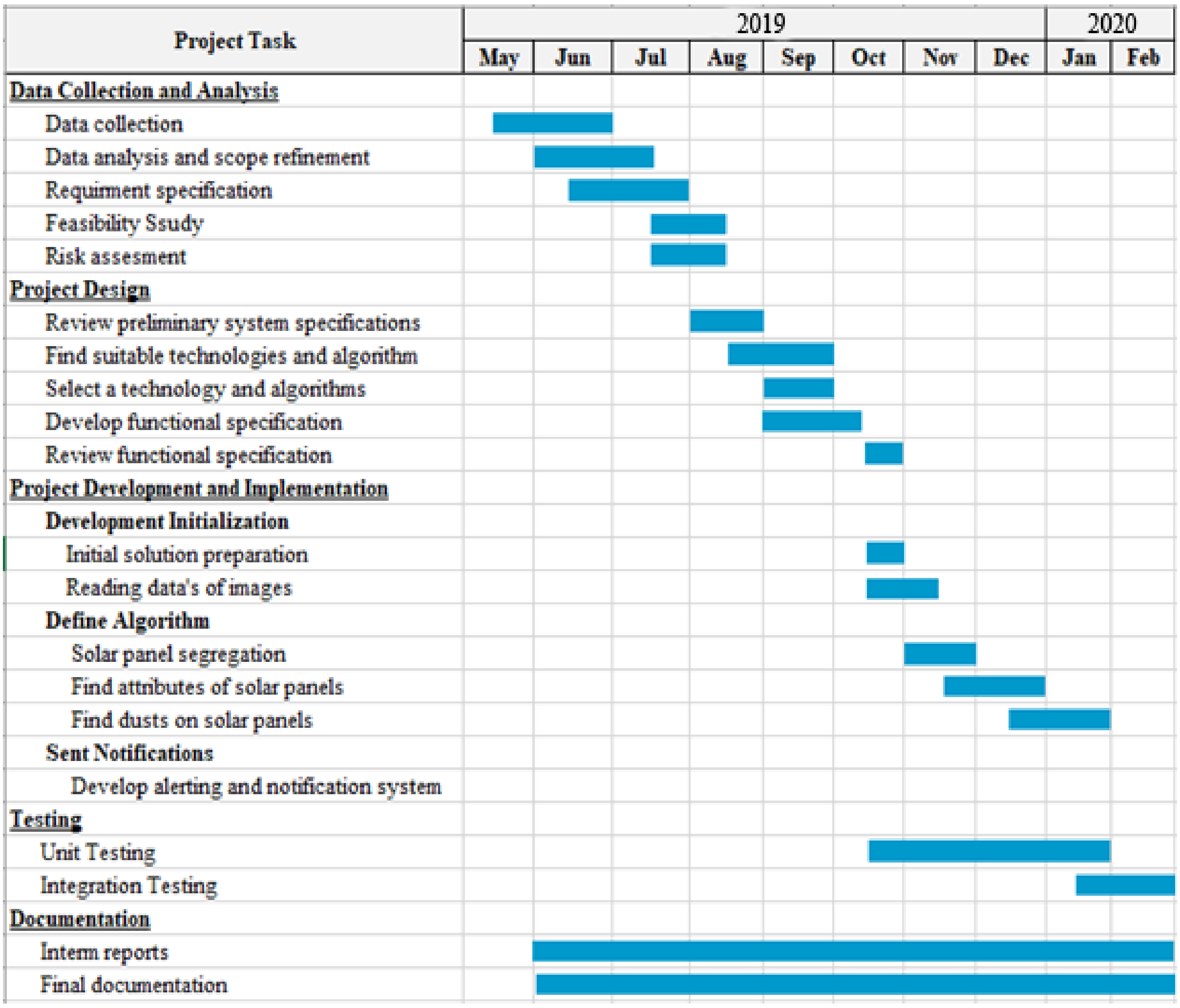

Figure 1.4 Project time line

Chapter 2: Background and Literature Review

2.1 Solar Panel Introduction

The electricity power generated by a solar panel module relies powerfully on the irradiance that the solar panel cells reach. Numerous factors determine verify the best performance or optimum output in a solar panel.

However, the environment is one of the favourable parameters that directly influence solar panel performance. Periodical reviews and evaluation assists to understand the most significant contributors to the power impacts and the mitigation of the power loss caused by pollution on a solar panel surface. Electrical properties of solar panels known as voltage and current are referenced with as to shading due to contamination. The shading due to soiling is recognized as two classifications, namely a soft shading such as air pollution and hard shading that happens once a solid like accumulated dirt blocks the sunlight.

The outcomes show that soft shading affects the current given by the solar panel module, anyway the voltage stays identical. Within the case of hard shading, the power of the solar panel module relies on whether few cells are shaded or all cells of the solar panels are covered. If some cells are covered, as long as not covered cells receive solar radiation, there will be some power, though there will be a decrease within the voltage output of the solar array. This study conjointly provides a few cleaning methods to avoid dust accumulations on the surface of solar arrays.

2.2 Solar Panel Technology and Power Techniques

Solar energy returning from the sun within the variety of solar radiation may be regenerate directly into electricity using photovoltaic (PV) technology. PV technology uses solar cells made from semiconductors to soak up radiation from the sun and convert it into voltage. At present, solar power has attracted worldwide attention and plays a necessary role within the delivery of clean and sustainable energy [6]. However, analysis on the character of semiconductors used in solar cells has restricted the efficiency of PV plants to 15-20%. As to extend to increase the efficiency of the PV system, some enhancements have conjointly been created to boost the PV system, like the utilization of sun tracker and maximum power point tracking controllers.

Solar modules are commonly expected to supply the best result or optimum yield. The factors that influence the determination of the best result or the ideal yield can be separated into two classifications, namely variable variables and invariable variables. The variables which will be changed provide design flexibility to reply to totally different installation requirements, whereas the variables that are unchangeable should be adjusted as standard. The varied variable and unchanging variables influence the configuration and design of a PV, the installation and operation of a solar array and play a vital role within the production of solar cells. However, as an increasing range of solar panel power stations are being built in the higher MW and GW power areas, a lot of attention is required on this problem area that directly affects the potency of electricity generation.

The characteristics of solar panel modules are often demonstrated by electricity power or current-voltage curves. Figure 2.1 illustrate the solar panel power voltage curve for different conditions of solar radiation and cell temperature. Because the figure shows, the solar panel output power is depends on the solar radiation and the cell temperature. Low irradiation leads to low power and high temperature results in a reduction in output power. Furthermore, for every curve of the solar array, there is some extent on the curve at that the solar array provides maximum power for the load. This point is used as the maximum power point (MPP).

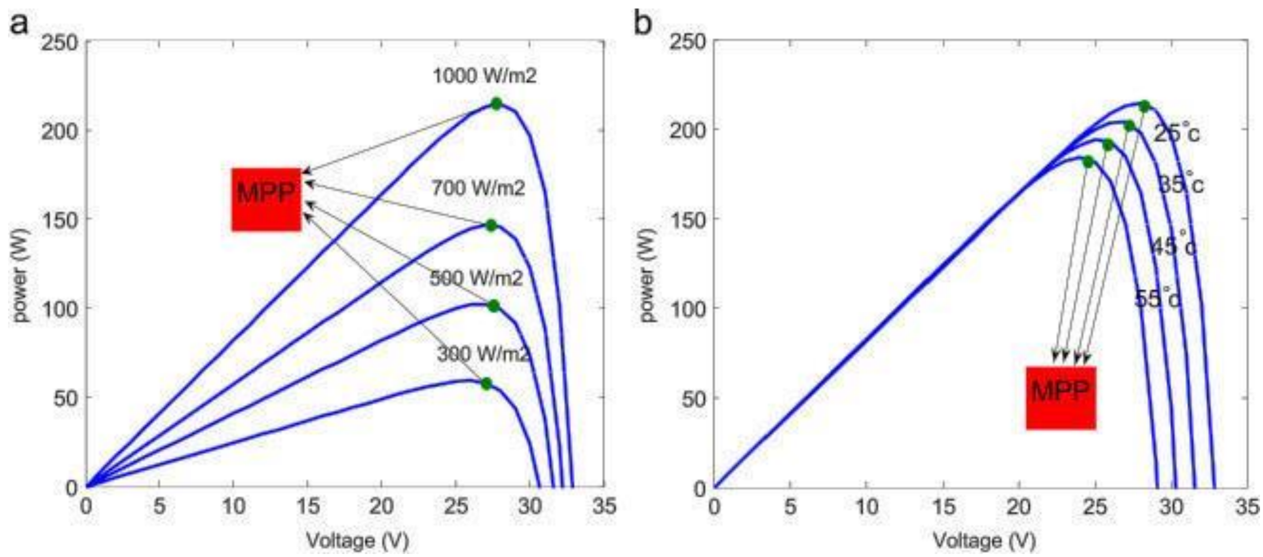

Figure 2.1 PV and location Characteristics of the MPP for various irradiances

There are two factors that influence the performance of a PV module. Those factors are solar irradiation and cell temperature. In addition to these factors, the amount of energy delivered by a solar panel array relies upon other factors, like the reliability of other components of the overall system and other environmental conditions. This section provides an outline of those factors [8,9].

- **Nameplate DC Rating**: Known as the Direct Current (DC) rated power is that the greatest power under standard test conditions that solar panel manufacturer's display on their modules. In any case, there can be an error between the particular field performance and name tag rating, which can output from two queries. Measuring accuracy is one among the possible sources of error which will be experienced by manufacturers throughout testing. Additionally, the initial exposure of sunlight could cause some modules to suffer from photo induced degradation as they become stable during the starting hours of their operation [8]. Photo induced degradation could be an essential hindrance for the actual application of novel semiconductors for photovoltaic (PV) applications.

- **Diode and Connection loss:** The preliminary application of bypass diodes is that the PV system, as to protect solar panel modules in partial shading conditions. Such a protection element might end in a type of loss of connection referred to as loss power within the system. The other type connection loss occurs in the PV system where solar panel arrays and other electrical components are interconnected to form PV arrays, known as resist losses [8]. A survey of hotspots in solar cells related to bypass diode which is conduct by Herrmann et al. inn 1997. Since the series circuit of the PV generator forces all cells to operate with the same current (string current), the shaded cell within a module is biased in the reverse direction, resulting in a dissipation energy in the form of heat [9].

- **Mismatch losses:** At the point when solar array having different properties are interconnected, they supply a total output energy that is less than the power achieved by summing the output power provided by every of the modules. Solar panel modules with the identical nominal values that come from a production line in a factory have no same voltage characteristics for several reasons. This difference causes solar panel modules to compromise common voltage and current when connected in series or parallel in an array. This compromise results in a sort of loss of performance called mismatch losses recognized by several researches. Mismatch loss minimization was tested in PV arrays and proposed a solution based on the arrangement of solar panel modules in arrays by genetic algorithms. The output of this study illustrates that a genetic algorithm-based array of modules reduces error-matching losses a lot of effectively than classical module sorting methods [10].

- **DC and AC Wiring:** Direct Current (DC) and Alternative Current (AC) wiring loss consists of the resistance losses of the cables and wires utilized over through the PV system from the PV, together with the complete distance from the PV module to the main power grid.

- **Sun-Tracking loss:** Sun is moving east to west across the sky throughout the day. In the case of solid solar collectors, the projection of the collector region on the plane perpendicular to the radiation direction is given by the function cosine of the angle of incidence. Sun tracking loss happens when the single or dual axes of the tracking solar module are not set to the optimum orientation or misaligned due to a mechanical error. Examined the principles of Sun tracking methods to maximize PV production in a research done by Hossein Mousazadeh. They looked at different kinds of Sun tracking systems. The foremost efficient and popular solar tracking device has been found in the form of polar axis and azimuth/elevation types [11]. Azimuth and Elevation are measures wont to determine the position of a flying overhead. According to Azimuth, what direction to face and Elevation implies how high up in the sky to look. Both are measured in degrees.

- **Shading losses:** Shading loss happens when solar panels are shaded by trees, buildings or other objects near solar panel power station. Since the power generation output of the solar panel module is a function of the solar radiation, a reduction of the solar radiation by partial or complete shading will influence the efficiency of the solar panel module [3]. The PV system is damaged with a weakness of non-linearity among current and voltage under partial shading. As per to statistical, the power dissipation can vary from 10% to 70% due to partial shading [12].

- **Soiling losses:** Pollution loss refers to loss of power due to dust, dirt and other particles that cover the surface of the solar panel module. Thin layer covering the surface of the solar array called as Dust. Dust particles diameter is depends on the location and its environment. The typical dust particles are less than 10μm in diameter. Dust is generated from several sources like pedestrian volcanic eruptions, vehicle movement, wind pollution…etc. The accumulated dust over time aggravates the soilure output. In fact, the number of accumulated dust on the solar panel surface affects the full energy delivered by the solar panel on a periodically basis. Sanaz Ghazi examine the pattern of dust distribution in varied elements of the planet is assessed and it absolutely was found that the North Africa and Middle East have the worst dust collection areas in the planet[13]. Figure 2.2 shows dust intensity in various colours all over the planet. The darker areas show the higher dust environment. Research done by Travis in 2012, led important contributions to performance, effects, understanding and mitigating these problems [14]. These contributions spanned a technical history of virtually seven decades. The main target is on transmissive surfaces (use for flat panel PV or CPV) and reflective surfaces.

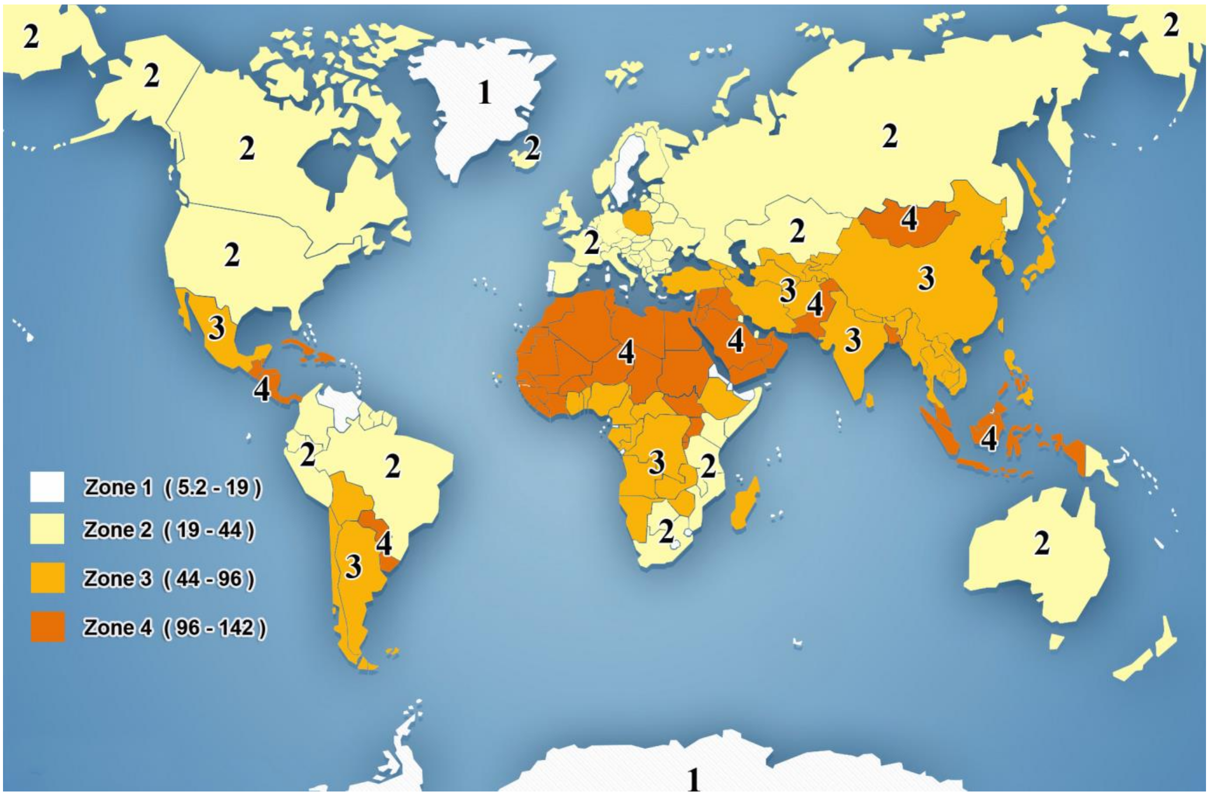

Figure 2.2 Dust intensity of world

2.3 Critical Studying in Dust

There are various experiments on solar panel performance. In spite of the fact that the effectiveness of the solar panels plant has expanded because of numerous enhancements, there are environmental and natural factors, for example, the deposition of soil, snow, fowl dropping, salt, etc. on the solar panel surfaces, which can prompt wasteful aspects in performance. So as to ensure optimal efficiency and extreme energy output, an top to bottom examination is required to analyse the effect of dust on solar cells.

A three-month test was led by Hotel and Woertz [15] in an industrial area almost a four-track railway 90meters from Boston, Massachusetts to research the impact of dust accumulation on solar collectors. As indicated by their discoveries, a dust of 1% emerged, which showed up on the solar panel surface with an angle of inclination of 30°. During the period, most elevated decrease was found at 4.7%. This outcomes in the researchers characterizing a adjustment factor which is the permeability ratio from an exposed glass plate or impure to a clean, of 0.99, with a 45° angle of inclination. Shockingly, this value was perceived during the development of conventional flat collectors until 1970.

Kimber et al. examined the impacts of pollution on huge grid associated solar panels in California, USA. The investigation was principally expected to provide a better model for predicting pollution losses more correctly throughout the year. Beforehand, a constant yearly value was the conventional assumption of pollutant losses by numerous researchers. Furthermore, this investigation ought to supplant the characterization strategy of describing the impact of soil on solar panels, which could be utilized distinctly for a particular area rather than for the entire region.

A direct relapse model was utilized to characterize contamination misfortunes over the dry time. From 250 locales that were explored, 46 were excluded as a result of the non-linearity that had happened in their information because of pollution and significant rainfall. A simulation was performed to contrast the energy generation prediction with a model, utilizing just a constant yearly pollution rate and a variable pollution rate model. The end was that this investigation indicated an average daily efficiency reduction of 0.2% in days without rainfall in dry climate. Yearly losses brought about by this tendency because of pollution go from 1.5% to 6.2% contingent upon the area of the solar power system.

In addition, it was discovered that the month to month yield simulation with the pollution information could give a more precise yield prediction than the simulation model with an accepted constant yearly pollution loss. The information from this examination indicated some interesting facts about the impact of rain on solar power modules. After a light rain, the efficiency of some solar panels decreased significantly, while the performance of other PV was improved. At any rate 20 mm of precipitation is expected to clean the surface of the solar panel system, in any case the system will continue to experience power loss because of dust and ground disposition.

Ali Kazem et al examined the impact of residue on solar panel use in the Iraq. Their examination was not restricted to Iraqi geographical and meteoric characteristics, yet they likewise researched the human exercises that prompted desertification in Iraqi territories, reflecting the increasing sand and dust storms in the nation. They likewise centered around dust-accumulated causes, types and specifications that were foremost to analyse their effect on solar panel power station. The point of their investigation is to show that Iraq has a very good potential for solar power because of the long daily duration of solar hours and high solar radiation. As of late, the Iraqi researchers have seen the high effect of dust storms that have accumulated on the solar panel surface. Examination was to think about reasons for dust storms and how to forestall it. The Iraqi dust in the urban territory could be a source of overwhelming metal pollution from three main sources that is weathered material, industrial, and automotive activity the concentration of Pb, Ni,Cd, Zn and Cr in road and house dust.

Zaki Ahmad et al. In 2014 [16] examined impact of residue pollutant type on solar panels. She has featured a couple of focuses related with the properties of residue on solar array and discovered 15 kinds of cleans that were referenced in different examinations, including red soil, concrete, debris, carbon, limestone, silica, calcium carbonate, soil, mud, sand, sand earth and coarser method of air conceived residue, and Harmattan dust. Every one of these materials, six of them have increasingly noteworthy consequences for solar panels. Additionally found that the impact of these martials is restricted to solar panel properties, as it were, a large portion of the examination as counterfeit residue as opposed to common residue collection. At last, they proposed to research distinctive pollutant types and diverse solar force advances in future investigations.

Further examination in 2013, the impact of fog pollution on two sorts of solar arrays, specifically flat photovoltaic and tracking of shallow photovoltaic under a tropical atmosphere, was explored.

Different elements that may prompt loss of execution of solar panel grids. One of the key factors in this 2013 examination was haze pollution in Southeast Asia, since Indonesian forests were burned to destroy rural land and the subsequent smoke passed up the breeze to cover the neighboring nations. Energy loss because of pollution was considered previously, during and during haze pollution in 2013. The information were gathered for 8 months from solar panels and condition. The information was looked at between the both arrays and the outcome shows that the following of level photovoltaic is progressively appropriate as a strong level [17].

Another examination by E. Asl Soleimani and et al in Iran, Teheran in 1999, the examination depended on the impact of air pollution from vehicles and local industries on the effectiveness of the solar panel systems. In this examination, did on the top of the University of Tehran, a few solar panel systems with various inclination angles as indicated by Figure 2.3.

The examination shows that the performance of the system shifts with the season and the purpose behind this is the measure of the Pollution that exist noticeable all around in various seasons. In winter, because of the high air density, the pollution is most noteworthy noticeable all around and influences the radiation, and thus the efficiency decreases. In the autumn, as the climate is windy, the pollution normally vanishes and the creation is higher than the winter. In spring, the system has the most elevated effectiveness when the angle of inclination increments as the rain storms the dirt. At long last, in summer, the yield is among autumn and spring when the tilt angle increments. It can likewise be seen that the 0-tilt angle and 23, in summer the productivity of the system is the most noteworthy. And furthermore, they saw that the performance of a PV system is secured by over 60% because of air pollution, which blocks the outside of the PV panel, which impedes the daylight [18].

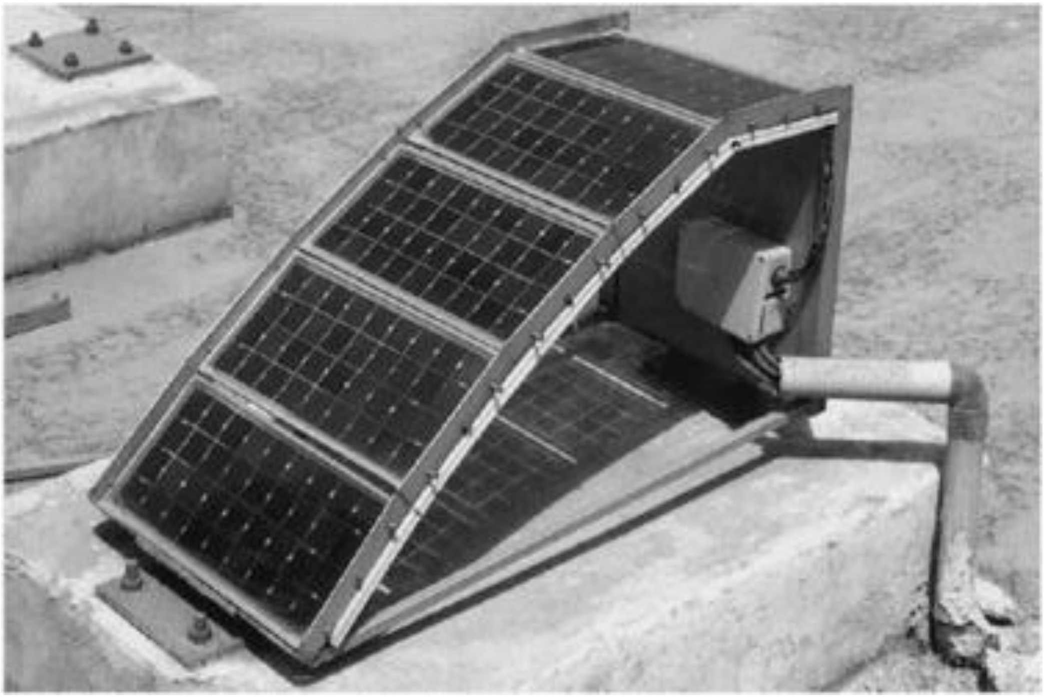

Figure 2.3 PV system with various angles in Tehran

2.4 Cause of Dust Accumulation

There are two independent boundaries that influence the portrayal of pollutant gatherings on solar authorities, the property of dust, and the neighbourhood condition. Dust property comprises of size, parts, shape and weight [19]. For instance, in Malaysia, the dust in corrosive and can cause disintegration on the outside of the solar panel. The nearby condition refers to the condition that human action has made straightforwardly or by implication as fabricated condition, vegetation types and climate conditions.

The surface is likewise a significant factor for the ruining procedure. On the off chance that the surface isn't smooth, and rather is unpleasant, outrage, clingy… and so on., it permits more ground to gather. The situation of the panel, which relies upon the heading of the sun and the wind, is additionally significant on account of the dirtying activity. The more even the surface, the more dust can be collected.

Likewise, a moderate breeze can likewise prompt dust aggregation, while solid breeze can eradicate the plate surface. In any case, the wind current through wind might be fit for causing dust gathering or dissemination at specific areas of the solar panel [20]. The velocity is and the weight isn't consistent over the solar cell surface.

Nearness of a breeze, where the flights speed is higher; there is a lower pressure which can prompt less ground gathering and the other way around. Dust qualities such as type, size, weight and shape additionally assume a significant job in dust scattering.

Figure 2.4 depicted different issues which lead to ground gathering on solar panels. It additionally shows which components have a connection that happens through blunders that must be inspected by a future report. [19]

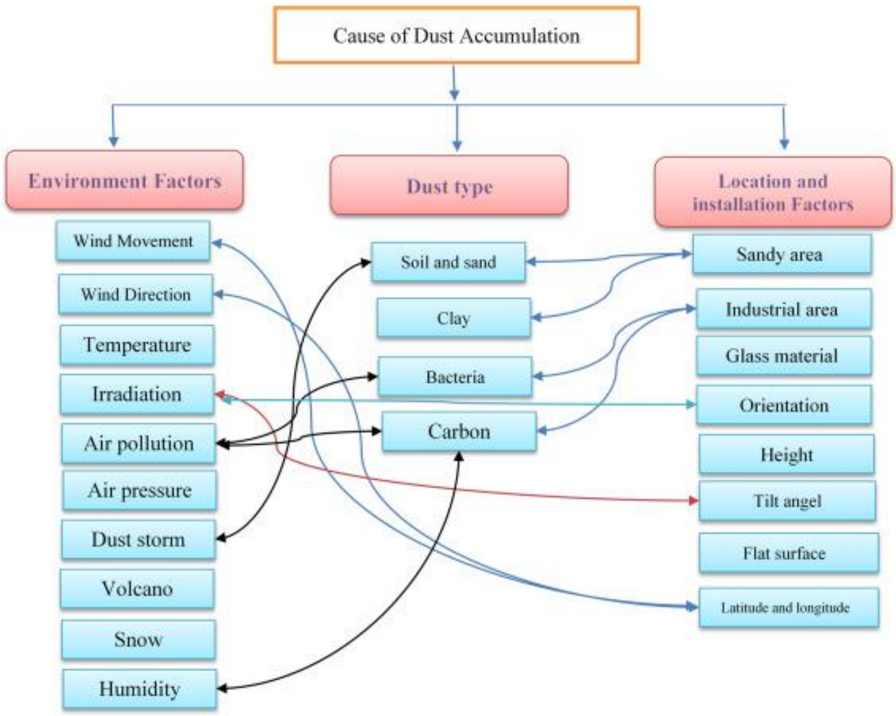

Figure 2.4 Dust accumulating on the surface of solar panel grid

Table 2.1 represent soil impacts look at changed locales around the globe. It is found in the table that most of studies are directed in the US and Asian nations. Actually, dust diminishes the yield solar panel power between 2% to half in various extents. In Asiatic standard, the vast majority of the dusts are sand and soil, and furthermore in African nations dust originates from the deserts that collect on a surface.

Table 2.1 Dust accumulation on the surface of solar panels as per the area

Authors	Time	Key point	Conditions
Region : **USA**			
Hottel and Woertz [10]	3 months	Misfortunes during this examination around 4.7%	The angle of PV panel is 45°
Dietz et al. [16]	3 months	Illumination misfortune because of dust 5% revealed	The angles design for this examination between 0° and 50°
Anagnostou and Forrestieri [17]	1 year		Nearby condition is generally harming
Hoffman et al. [18]	Lab	Test strategy for two field-related issues:	

		Surface ruining and embody delaminating	
Pettit et al. [19]	1 month	The convenient directional reflect meter used to gauge the specular reflector misfortune because of dust collection can be restricted to a solitary frequency	Strategy to decide solar-found the middle value of reflectance misfortune from a solitary estimation at 500 nm
Blackmon and Curcija [20]	6 months	Washing heliostat by splash is achievable, and downpour and snow could adequately clean it	
Berg et al. [21]	5–6 weeks	Splashing the outside of PV can recuperate 95% of the reflectance misfortunes	Utilizing the portable system for cleaning
Freese et al. [22]	7 months	Reflecting can be decline by numerous elements like breeze. Downpour and dissolving snow are powerful in expelling dust from PV	Valuable connections with wind, downpour; cleaning cycle tests
Murphy and Forman [23]	18 months	Assess of dust gathering on the outside of PV	
Hoffman et al. [24]	17 weeks	Examining the earth variable that expansion dust collection	Open air presentation testing for long terms is the best methods for assessing dirtying
Roth et al. [25]		Reflectance as capacity of molecule size/dissipating impacts. Little particles are most critical dispersing source (<1 µm)	Announced viability of surface coatings and electrostatic biasing for moderation. Air stream examines
Cuddihy [26]	Theory	Portray known and proposed instrument of soil maintenance on surfaces	Dust morphology/size information
Pettit et al [27]	10 months	Dust collection are significantly more compelling in reflecting particles than retaining it	
Michalsky et al. [28]	2 months	1% decrease for the uncovered, not-cleaned pyranometer	
Ryan et al. [29]	6 year	Messy solar array has 1.4%	

		decrease every year.	
Hammond et al. [30]	16 months to 5 years	Dust impact on solar panel increment as the tilt edge of occurrence increments. Force misfortune ascend from 23% in ordinary episode to 4.7% 24° and 8% at 58° for radiometer,	Winged animal dropping one of the issues in this investigation
Mekhilef et al. [31]Malaysia	2 months	Examined impact of dust on PV performance as capacity of tilt. Study show that normal conclusion in power yield in various rule, for instance power yield lessen in Saudi 40% in Kuwait round 65%, Egypt 33–65% and in USA 1–4.7%	Particles are including dusts, parasites, microscopic organisms, vehicular and volcanic action
Jiang et al. [32] China		Soil collection layer 0 to 22 g/cm2	Efficiency of PV diminish by 26%
Sulaiman et al. [33] Malaysia	Lab	Dust accumulation reduce peak power around 18% e.	power misfortune contrast among mud and deodorant powder statement
Ju and Fu [34] China	1 year	Reduction during rainy season and dry season is 0.98 & 0.95 respectively.	So as to examine dust impact the examination partitioned into 3 stage the first arranging the subsequent one is improvement and last is activity.
Yerli et al. [35] Turkey		Dust and soil and temperature are the elements that affected on PV performance	
Mani et al. [14] India	Review paper	Research on writing after 1960, distinguishing cleaning, condition factors	Proposed the most ideal route for cleaning
Kobayashi et al. [36]Tokyo Japan	Lab	The establishing shows that corruption yield of 80% or less with 3% of spot earth on the PV module	
Mastec bayeva et al. [37] India	1 month	During one month power yield diminish from 87 to 75%.	

Region : **Middle East**			
Nimmo et al. [38] Saudi Arabia	6 months	Efficiency decrease 26% and 40% from solar authorities and PV module, separately	
Ibrahim et al. [39]Kuwait	10 days	Voltage misfortune around 0.86% on other hand current decreases 13%.	Impact of concealing explored on solar cells.
Alhamdan et al. [40]Saudi Arabia	13 months	Illumination was diminish around 9% inside one month later after downpour wash the surface lessen to 5% measure of misfortune.	Dust is soil and sand, dry condition
Hassan et al. [41,42]Saudi Arabia	6 months	Efficiency decreases following 1 and half year by 33.5% and 65.8% separately.	Dry region
El-Nashar et al. [43] UAE	1 year	Decrease in transmittance from 0.98 to 0.7,	Application is seawater refining
El-Nashar et al. [44] UAE	1 year	Force decreases reason for dusty surface between 14%–18%.	Dry zone, soil and sand
Asl-Soleimani et al. [13], Iran	10 months	Vitality yields lessen around 60% by pollution in Tehran.	PV modules are structure in various point under air pollution
El-Nashar [45] UAE	1 year	Intermittent Glass transmittance is decline 6.5 in winter and 10.5 in summer. Full scale hardship without washing the PV chasing after 1 year 70%.	Data assembled from PV hourly and month to month from solar panel.
Alamoud et al [46]Saudi Arabia	1 year	Efficiency of PV lessen from 5.7% to 19%	Explored on PV, module details to manufacturers cases (contrasts). Hot, bone-dry condition.
Region : **Europe**			
Zorrilla-Casanova et al. [14] Spain	1 year	Force yield lessens during multi month in dry season 20% and yearly normal conclusion in PV was 4.4%.	
Pravan et al. [47] Italy		Think about kind of dust, cleaning strategies, how to control misfortune in PV. Force yield decrease around 6.9% with	Examined two 1MW PV under STC. Relapse model utilized for think about various variable.

		sandy soil and 1.1% with more compact soil	
Vivar et al. [48] Spain;	4 months	Dust diminishes 26% force yield in CPV and more influenced than Flat PV.	CPV more affected than flat PV system in dusty conditions.
Becker et al. [49]Germany	Lab	Air pollution lessen PV yield around 4%	Air pollution reason for shadow in PV and diminishing force yield.
Region : **Africa**			
Elminir et al. [50] Egypt	7 months	Yield power lessen around 17.4%	Examine on tilt edge and dust substance properties.
Hegazy et al. [51]Egypt	1 year	Solar transmittance as capacity of tilt edges. Vertical panel had particles with measurements 1 µm. Force misfortune in transmittance ordinarily 75–80% longer than a month's presentation	Look at the force yield among Kuwait and India
Adanuet et al. [52]Ghana	4 years	Dust materials noticeable all around reason for decline light which is lead to decrease power yield.	Proposed to cleaning the outside of PV

2.5 Shading by Soiling on Solar Panels Performance

The expression "Ruining" is utilized to depict the aggregation of dirt, dust, leaves and bloom dust and winged animal droppings on solar panels. The performance of a solar panel module diminishes because of surface tainting and the solar panel power loss increments with an expansion in the ground level on the solar panel module. Subsequently, the gathering of the dirt on the solar panel module can prompt a huge abatement in the vitality produced by the solar panel module. The condition turns out to be far more atrocious in certain circumstances, for example, snowfall on solar panel modules where the snow totally covers the outside of the solar panel module and no force is produced at all [58].

2.6 Partial Shading of Solar Panel Module by a Soil Patch

Expansion to the vitality decrease, some soil stains, for example, leaves, fledgling droppings and dirt stains, which obstruct a few cells of a solar panel module, yet not the entire, affect solar panel modules.

Figure 2.5 shows a solar panel module comprising of 10 cells and concealed with a cell and can't create power. As the figure appears, the concealed cell in this state goes about as a protection from the current produced by different cells. This warms the concealed cell and prompts a hotspot that may harm the module [59, 60].

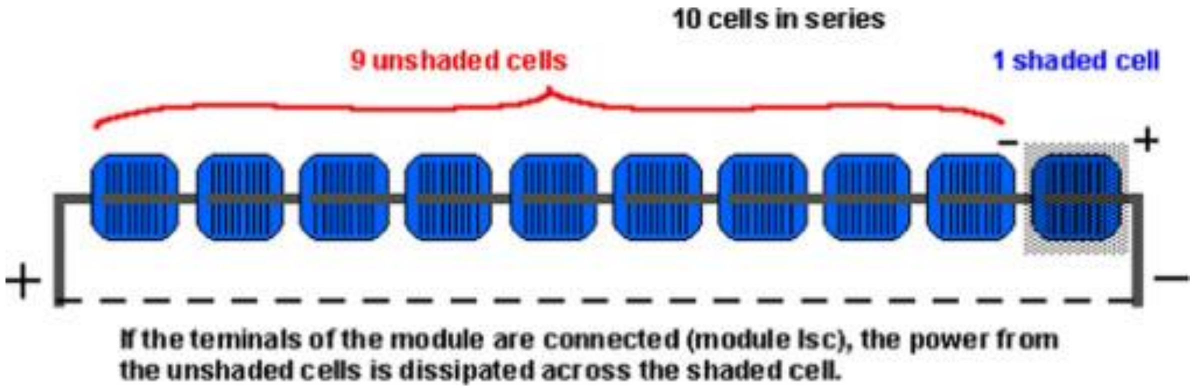

Figure 2.5 Current flows through concealed cells

Bypass diodes are utilized in crystalline silicon modules to take care of the issue of halfway shading. As appeared in Figure 2.6, when fractional shading happens, the current produced by not shaded cells goes through the detour diode rather than the concealed cell. Accordingly, the detour diode keeps the concealed cells from warming and framing problem areas [58].

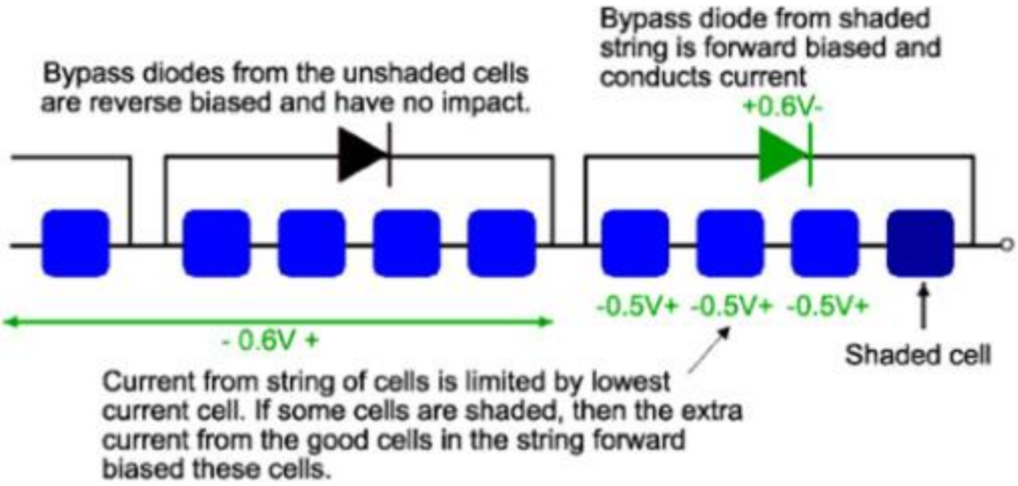

Figure 2.6 Bypass diode in solar panel for hot spot avoidance

2.7 Impact of Soft Shading and Hard Shading on Module Performance

There are two kinds of floor shading on solar panel modules, in particular hard shading and soft shading. Hard shading happens when a strong, for example, amassed dust obstructs the daylight in an unmistakable and perceptible structure. Soft shading happens when a few particles like exhaust cloud in the air or some dust on the outside of the solar panel modules lessens the general force of the solar radiation consumed by solar cells.

Every one of these shades impacts the solar panel modules. Soft shading influences the current of the solar panel module, however the voltage continues as before. For hard shading, the intensity of the solar panel module relies upon whether a few cells are shaded or all cells of the solar panel module are shaded. In the event that a few cells are shaded, at that point, as long as the not shaded cells get some solar radiation, there will be a current stream.

A partial shadowing hotspot condition may happen in this state; however the issue can be tackled by utilizing bypass diodes. On account of hard shading, all cells of a solar panel module are shaded and no force gracefully is provided by the solar panel module. Figure 2.7 shows how each kind of shading influences the voltage and current of a solar panel module, and Figure 2.8 shows the voltage-power normal for the solar panel module for each shading condition.

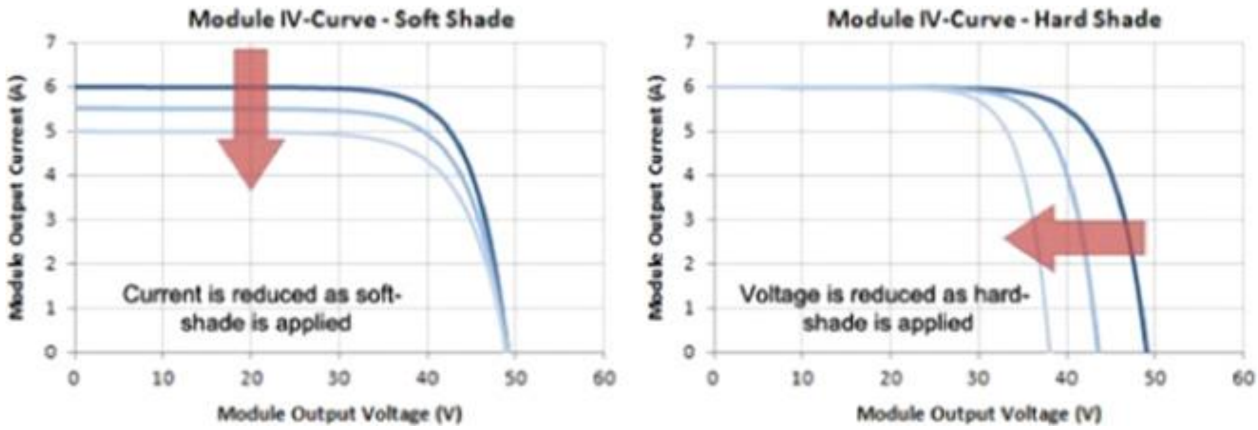

Figure 2.7 Voltage-current qualities of a PV module for soft and hard shading

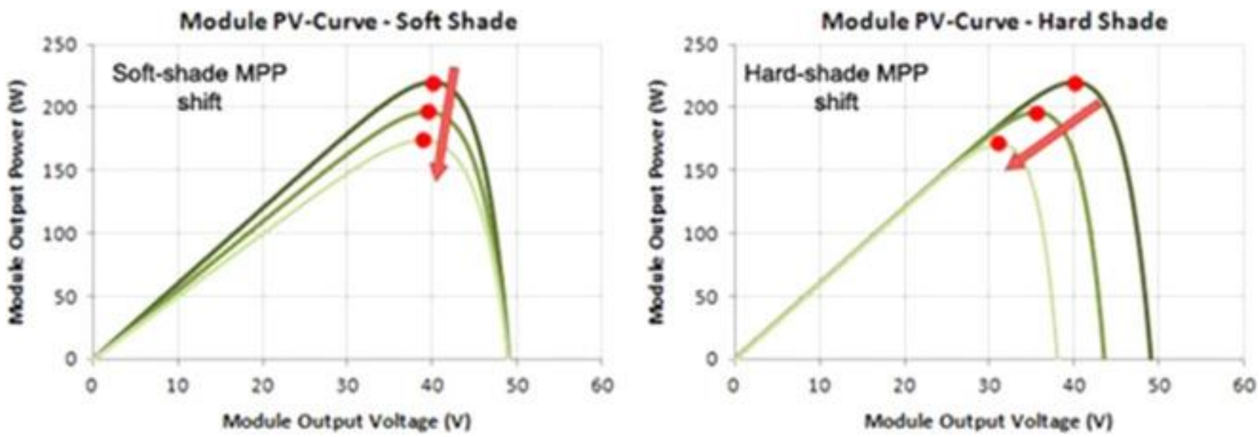

Figure 2.8 Voltage-power qualities of a PV module for soft and hard shading

As the figures appear, on account of soft shading, the voltage of the solar panel module stays consistent and just the lower radiation consumed by the solar cells prompts a lessening in the current from the solar panel module. Then again, hard shading on certain cells of a solar panel module will cause a decline in the voltage of the solar panel module, yet since the not shaded cells despite everything get solar radiation, the current stays consistent.

2.8 Impact of Soft Shading and Hard Shading on Array Performance

The impact of the soft shading of the ground on a solitary strand array is equivalent to the solar panel module portrayed previously. Nonetheless, on account of more than one string in a solar panel array, the current unbalance in a string that is the consequence of the shading influences different strings in equal by the basic common inverter associated with the equal strings.

Hard dust on a surface of a solar panel array with single string decreases the pressure of the string, yet the inverter distinguishes this decrease and controls it right away. Notwithstanding, when uneven hard dust is corresponding to various strings, a voltage crisscross happens. In this state, alluded to as incomplete shading, distinctive equal strings, which are associated with a typical inverter, gracefully various voltages to the inverter. This makes it hard for the inverter to look for the ideal voltage point where the most extreme power is conveyed. Figure 2.9 shows the voltage-current and voltage-power bends of a solar panel array under this condition.

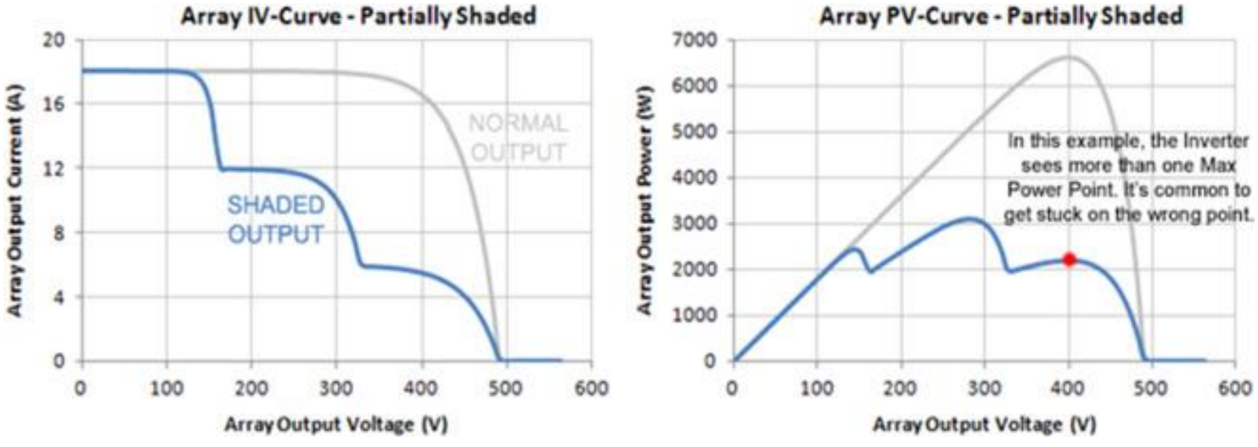

Figure 2.9 Attributes of the solar panel array under partial shading condition

Chapter 3: Analysis and Design

This chapter has given a detailed in general enlightening breakdown. Conceptual diagram for overall system is also represented in this chapter. And furthermore the entire system process described step-by-step utilizing some genuine information caught.

The proposed solution for distinguishing proof of dust is based on nearby methodology however with learned feature representations using bag of features. Since this means to section and solar panel identification method, separation of module in the panel and dust identification is done. Then the bag of feature framework has been utilized with both SURF feature extractors and projection profile based custom feature for the identification. The solution focuses on the Identify dusts on solar panels utilizing drone images as shown in Figure 3.1. descriptive overview of the solution proposed to solve the problem under consideration and to outcome the defined objectives as well as technologies and algorithms that are used in the solution are portray in the coming sub areas of this chapter.

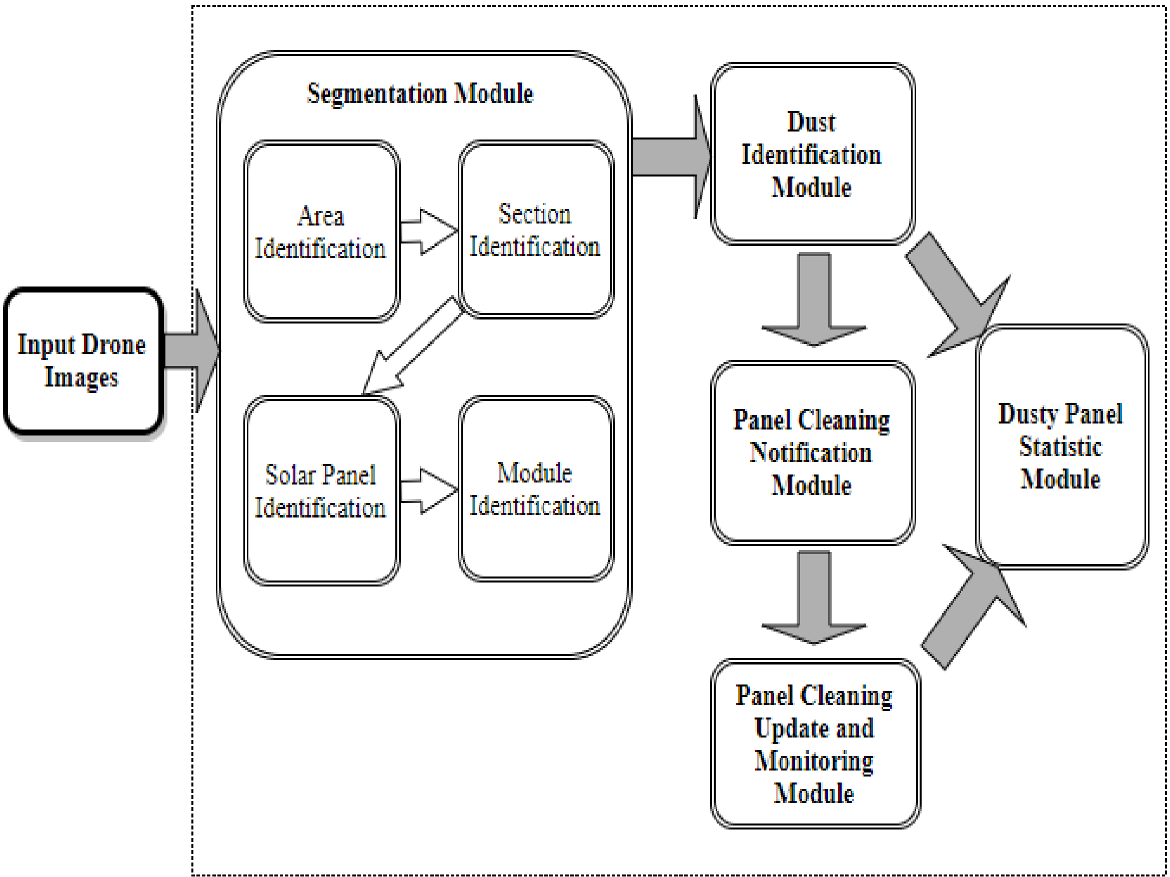

Figure 3.1 Conceptual diagram of Identify dusts on solar panels utilizing drone images

3.1 Solar Panel Segmentation

Solar panels are spread in an immense zone as appeared in Figure 3.2. Larges segmentation of solar power station is section. Under that there is solar panel, modules and cells as appeared in Figure 3.3. Proposed system segment panel sections, solar panels and module and identify panel numbering. That panel numbering (Solar panel identification labels) is physical numbering system as showing in Figure 3.4 which given by proposed system. Use of good algorithm will gain massive effective to identify panel numbers.

Figure 3.2 Solar power station

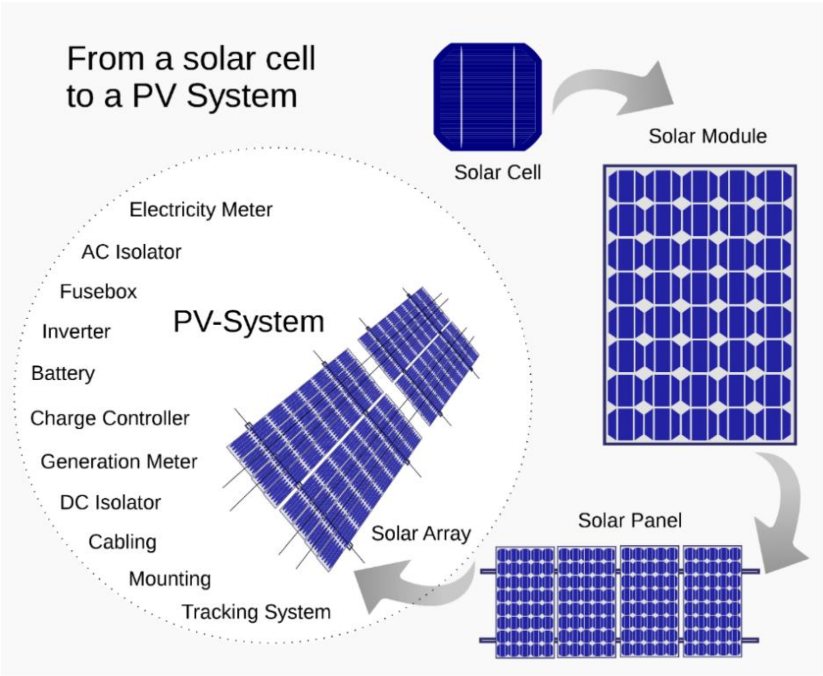

Figure 3.3 Parts identification of solar panel

Figure 3.4 Solar panel identification labels

Power station has grouped solar panels to section as A, B, C…etc. and subsections as A01, A02, B01…etc. Each subsection has many numbers of solar panels which is on same line. Proposed system has identified sections, subsections and solar panels utilizing uploaded drone still images.

3.1.1 Choice of Bag of Feature Based Classification

Solar panel segmentation is a difficult errand. So as to scope with this, most researchers essentially depend on statistical models that figure out how to catch these highly profoundly veering visual appearances of semantically equivalent instances, similar to section shapes, sun shines…etc. portrayal conversely, is resolved heuristically. This implies, it isn't a piece of a learning procedure where its properties are adjusted to the characteristic of dusts. In this thesis, a methodology has been proposed towards consequently learning feature representations. In this way, the considered technique is called Bag of features and is already widely utilized in image retrieval and categorization.

3.1.2 Feature Detector and Descriptors

Benefit of the BoF algorithm is for the most part depending on the choice of feature detector and descriptor. Contingent upon the pros and cons, SURF is selected to direct the examination and profile based custom feature extractor.

First system needs to distinguish subsection and afterward segregate solar panels individually. Optical Character Recognition (OCR) algorithm has to use for read segregated solar panel labels.

3.1.3 Dust Identification on Solar Panel

Variability is very high in various dust shapes spread in the solar panel module. In this way, dust identification is troublesome assignment.

Dust can be with in numerous structures. Sometimes it might have completely covered the panel. In some cases it might mostly have covered panel with a shape. If there are rubbishes, it may cover least one solar panel with many wide ranges of shapes.

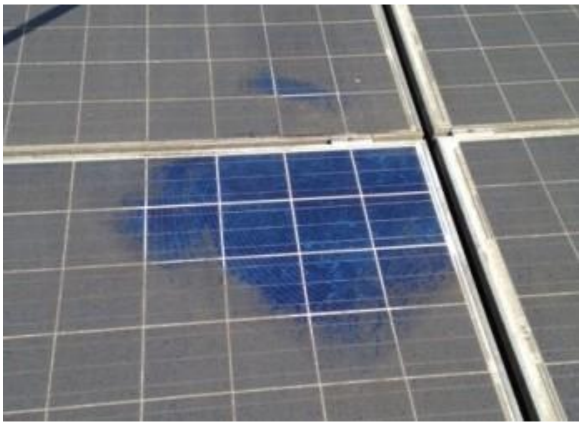

Figure 3.5 Solar panel cover with dust

Figure 3.6 Perfect and clear solar panel

3.1.4 Dust Finding Using Threshold and Contrast

Drone image may comprise of noise and lack of quality. Proposed system should reduce noise utilizing image sharping techniques and improve features of image using image enhancement techniques.

Perfect and clear solar panel has shine and high intensity value. System will keep threshold estimations of RGB and Contrast level of clean and clear solar panel. It ought to keep up by system and it can be change by system users. Since, lighting intensity of each day may be deferent.

If system utilize one sample threshold value for process images each day, it is not effective. As an example, when sample image taken on shiny day and image processing day is darker day then system will distinguish dusts on perfect and clear solar panels. It is an error with the conclusive outcome.

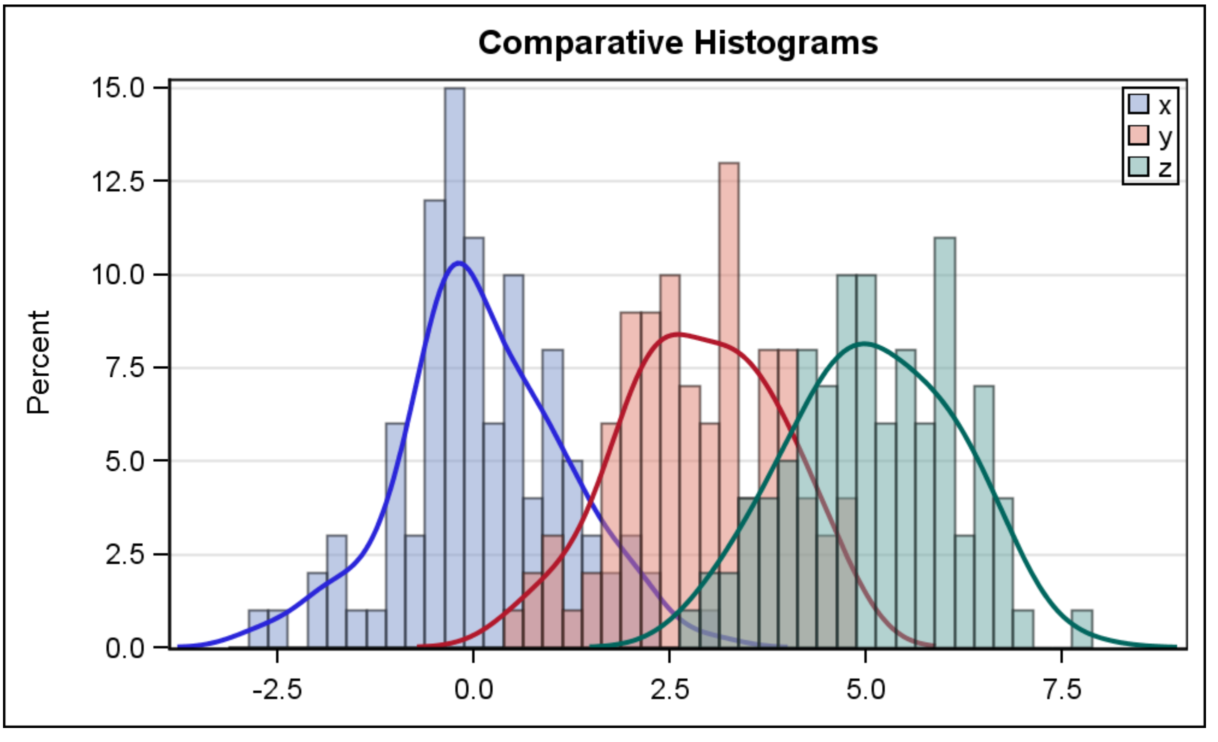

Figure 3.7 Comparative intensity histograms

Proposed system contrasts recently captured drone image with existing image which captured on perfect and clear solar panel. Algorithm discovers variance deference of intensity value and analyst histogram with sample. On the off chance that intensity value of comparison is excessively high, it will distinguish as dusty solar panel and figure dust cover rate.

3.2 Solar Panel Cleaning Notification

After processing the drone image, system finishes which solar panels need to clean by staff. At that point it will inform to power station staff. After staff member clean solar panels by physically, they have to update solar panels as cleaned.

3.3 Dust Panel Statistics

Dust panel statics module utilizes for decision making by top management. Analytical report executives to management for take strategic decisions.

As an example, if one solar panel or section frequently covers with dust, there may be some sort of physical or environment reason and it can be fix at one time without cleaning solar panels in daily basis.

This module contains different sorts of dashboards, charts and analytical information which backing to take decisions. User can recognize dusty solar panels and perfect solar panels by using user dashboard. Analytical reports have provided as a statistic to take quantitative and qualitative analytics of solar panel and its status.

Chapter 4: Implementation

4.1 Chapter Overview

In this chapter, author has introduced and described the implementation process of the proposed system, where it has described few implementation approaches. The system functionalities and the steps that have followed to achieve the objective of the project have defined in details during this chapter. Author has used sample images and snippets of source code to represent the functionalities and process flow of the proposed system. The difficulties which overcome during the implementation are also briefly explained in the chapter.

4.2 Selection of Suitable Programming Language

The system needed an OOP conceptual programming language, for example C++, C#, Java…etc. But the author has selected C# as the programming language, Main reason for selection is C# compiles the code into an intermediate form before converting it to a native language and it has been specially developed for MS windows platform. C# has capability to do memory management automatically, which unnecessary memory flush by a garbage collector without involvement of the developer. The garbage collector has object usage information, and utilizes to take memory management decisions, choices, like wherever in memory to locate a newly created object, when to relocate an existing object, and when an existing object is no longer in use inaccessible.

The developer of the system is familiar and comfortable with C# language rather than working with other programming languages. Final output of system is web based ASP.NET MVC application, which is supported to easily access through internet in anywhere without installing to a computer.

In the project, Open CV image processing class library has used to develop the solution and it can be easily integrate with C# using Emgu CV wrapper connector.

4.3 Selection of Tools and Technologies

This section describes the tools, technologies and libraries that are utilized to do the total working solution easier.

4.3.1 Open CV

Open CV is third party open source class library which is using for process images. Open CV class library associated with of numerous inbuilt functions which is highly focused on real time image processing. It includes several of image processing and computer vision algorithms which help to enhance images identify features associated with on images and develop advanced computer vision applications simple and productive.

Following are hardly any motivations to choose Open CV as the image processing library of this project.

- **Speed:** Open CV is essentially a library which is based on C programming language. It is nearer to legitimately give machine language code to the PC to get executed. In this way more image processing accomplished for computers processing cycles, and not more deciphering. Accordingly if this, programs developed by using Open CV library runs a lot quicker than similar other programs developed by using alternative image processing libraries such as MatLab.

- **Resources Needed:** Hardware resources utilized by both programming environments should be thought of. Nature of Image and video processing can be resource substantial because of the measure of pixel information in each image; However, there is a wide gulf on the resource scale between MatLab kind of other image processing libraries, source codes that has required over a gigabytes of RAM to go through video. In correlation, Open CV programs just require considerably less RAM as ~70mb to run real-time. Along these lines the resource required for Open CV is less when contrasted with other image processing libraries.

- **Portability:** Because of a light weight programing language use as core (C programing language), and which it can run on any device, can run Open CV.

4.3.2 Emgu CV

Emgu CV is a cross platform wrapper the Open CV image processing library which is written using Microsoft.NET technologies. Permitting Open CV functions to called form Microsoft.NET compatible languages such as VB, C++, C#, IronPython…etc. The wrapper can be compiled by Microsoft Visual Studio Code, Microsoft Visual Studio, Xamarin Studio and Unit, which can run on Windows, Linux, and Mac OS for PC and iOS, Android for mobile device.

4.3.3 Microsoft Visual Studio

There more integrated development environment (IDE) available in nowadays. Microsoft native associate integrated development environment (IDE) is known as Microsoft Visual Studio. Microsoft Visual Studio is used to develop computer programs for Microsoft Windows as well as web applications, web services and websites. Microsoft Visual Studio has capability to utilize Microsoft software development platforms such as Windows Forms applications, Windows Presentation Foundation (WPF) applications, ASP.Net web forms applications, ASP.Net MVC applications, Windows Store applications, Microsoft Silverlight applications and Microsoft Windows AI framework,. Microsoft Visual Studio capable to work with both native code and managed code.

Microsoft Visual Studio can work with totally different programming languages such as C, C++, C#, Python…etc. and permits the code editor and debugger to support (to differing degrees) closely any programming language which gave a language-specific service exists.

4.3.4 Microsoft SQL Server with Entity Framework

There are so many SQL Database engines such as Microsoft SQL Server, Oracle database engine, MySQL database engine…etc. Native database of Microsoft is Microsoft SQL Server and it is a one of the market leading database engine technology. Microsoft SQL Server is a relational database management system (RDBMS) which heavily supports with a wide variety of transaction processing, business intelligence and analytics applications in software development.

Comparing other RDBMS software, Microsoft SQL Server is built on prime of SQL, a standardized programming language that database administrators (DBAs) and distinctive IT experts use to oversee databases and query the information they contain. Microsoft SQL Server is attached to Transact-SQL (T-SQL), an associate implementation of SQL from Microsoft that include a set of proprietary programming extensions to the standard programming language.

Microsoft Entity Framework is an open source, Object relational mapping framework by Microsoft and it has used to develop Microsoft .NET applications. Microsoft Entity Framework allows program developers to figure with data using objects of domain specific classes without focusing on the underlying database schemas, tables and field and field types where this data is stored. The Entity Framework facilitate to developers which they can work at a good level of abstraction when they work with row data, and might generate and maintain data-oriented applications with less source code and database awareness compared with traditional application development.

Microsoft Entity Framework has three approaches; those are known as Code First, Model First and Database First. Author has selected Microsoft Entity Framework code first approach for develop the solution. The Code First Approach provides to the entity data model by using source code and creates a database using source code without interaction with database.

4.3.5 AForge.NET

AFrog.NET is a wrapper framework which based on Microsoft C#. AFrog.NET has developed for image processing developers in the fields of computer vision and Artificial Intelligence image processing, neural networks, machine learning, genetic algorithms, robotics…etc.

4.4 Environment Specification

Implementation of the system is build and tested under following specifications.

- Windows 10 Pro with IIS server 8 or above
- Intel ® Core™ i5-7200U CPU @ 2.5GHz (4 CPUs), ~2.71GHz
- 4GB RAM

4.5 System Implementation

The implementation process can be divided into several processes. System has reduced image capacities to process images with low time consumption. If image capacity is high, it will consume more resources and time to process it. But image capacity reduction process is not effect to existing features.

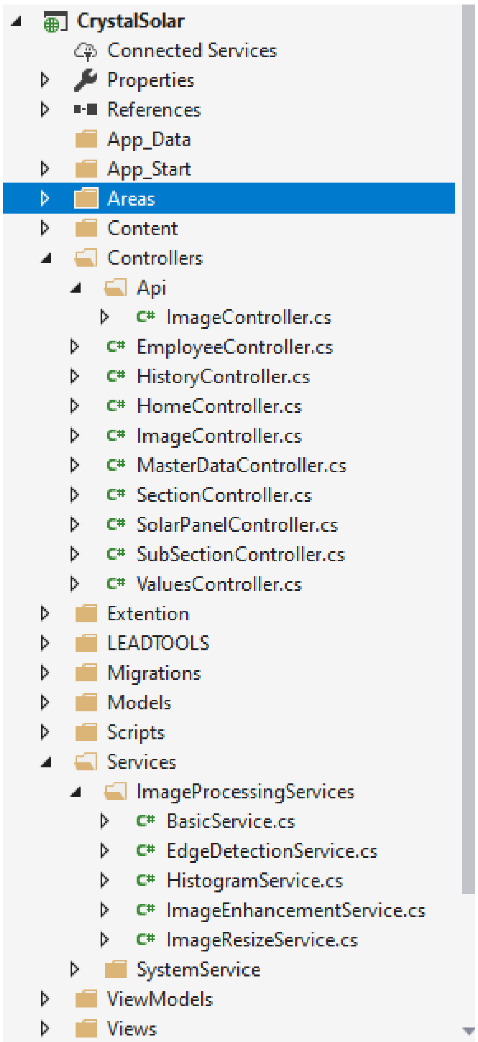

Figure 4.1 Aarchitecture overview of the system

4.5.1 Solar Panel Identification

System need to identify individual solar panels separately. At first categorized solar panel section, subsections with identification names and decided solar panel labelling sequence and labelling format. Then marked solar panel label physically as shown in Figure 4.2.

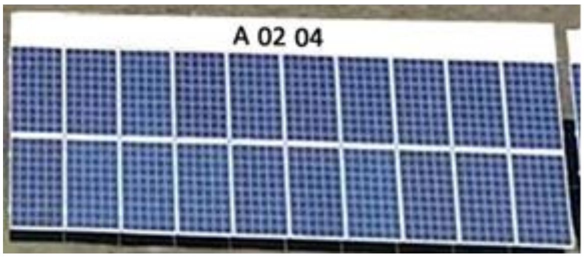

Figure 4.2 Solar panel with label

Staff member has responsibility to capture still drone images with good quality according to given guidelines and uploaded it to Crystal Solar System by login with particular user credentials.

System has store uploaded drone image and take copy of it and process the copy. First system removed some unnecessary parts of the image by using dilation image processing technique. Then apply Laplacian 3x3 filter to enhance solar panel edges and apply dark colours to outside of solar panels.

Figure 4.3 System screen - Solar panel identification

Split whole image into small parts by using identified solar panel edges. Those split images are considered as identified solar panel images. Split solar panel images temporally stored in Database. Apply OCR algorithm to read label of each identified solar panels by labelled names.

Solar panel edge detection was most critical part of the project. Following source code in Figure 4.4 and Figure 4.5 are showed some available edge detection techniques.

```
#region Laplacian Operations
1 reference
public Bitmap Laplacian3x3Filter(Bitmap sourceBitmap, bool grayscale = true)
{
    Bitmap resultBitmap = ConvolutionFilter(sourceBitmap, laplacian3x3, 1.0, 0, grayscale);
    return resultBitmap;
}

0 references
public Bitmap Laplacian5x5Filter(Bitmap sourceBitmap, bool grayscale = true)
{
    Bitmap resultBitmap = ConvolutionFilter(sourceBitmap, laplacian5x5, 1.0, 0, grayscale);
    return resultBitmap;
}

#endregion
```

Figure 4.4 Source code - Edge enhancement technique (1)

```
#region Laplacian Of Gaussian Operations
0 references
public Bitmap LaplacianOfGaussian(Bitmap sourceBitmap)
{
    Bitmap resultBitmap = ConvolutionFilter(sourceBitmap, laplacianOfGaussian, 1.0, 0, true);
    return resultBitmap;
}

0 references
public Bitmap Laplacian3x3OfGaussian3x3Filter(Bitmap sourceBitmap)
{
    Bitmap resultBitmap = ConvolutionFilter(sourceBitmap, gaussian3x3, 1.0 / 16.0, 0, true);
    resultBitmap = ConvolutionFilter(resultBitmap, laplacian3x3, 1.0, 0, false);
    return resultBitmap;
}

0 references
public Bitmap Laplacian3x3OfGaussian5x5Filter1(Bitmap sourceBitmap)
{
    Bitmap resultBitmap = ConvolutionFilter(sourceBitmap, gaussian5x5Type1, 1.0 / 159.0, 0, true);
    resultBitmap = ConvolutionFilter(resultBitmap, laplacian3x3, 1.0, 0, false);
    return resultBitmap;
}

0 references
public Bitmap Laplacian3x3OfGaussian5x5Filter2(Bitmap sourceBitmap)
{
    Bitmap resultBitmap = ConvolutionFilter(sourceBitmap, gaussian5x5Type2, 1.0 / 256.0, 0, true);
    resultBitmap = ConvolutionFilter(resultBitmap, laplacian3x3, 1.0, 0, false);
    return resultBitmap;
}

0 references
public Bitmap Laplacian5x5OfGaussian3x3Filter(Bitmap sourceBitmap)
{
    Bitmap resultBitmap = ConvolutionFilter(sourceBitmap, gaussian3x3, 1.0 / 16.0, 0, true);
    resultBitmap = ConvolutionFilter(resultBitmap, laplacian5x5, 1.0, 0, false);
    return resultBitmap;
}

0 references
public Bitmap Laplacian5x5OfGaussian5x5Filter1(Bitmap sourceBitmap)
{
    Bitmap resultBitmap = ConvolutionFilter(sourceBitmap, gaussian5x5Type1, 1.0 / 159.0, 0, true);
    resultBitmap = ConvolutionFilter(resultBitmap, laplacian5x5, 1.0, 0, false);
    return resultBitmap;
}
```

Figure 4.5 Source code - Edge enhancement technique (2)

While processing the images convolution filter algorithm (Figure 4.6) was most suitable algorithm to identify solar panel edges. But manually written algorithm which in Figure 4.7 is most effective to enhance raw image and identify solar panels and its features.

```
private Bitmap ConvolutionFilter(Bitmap sourceBitmap, double[,] filterMatrix,
double factor = 1, int bias = 0, bool grayscale = false)
{
    BitmapData sourceData = sourceBitmap.LockBits(new Rectangle(0, 0, sourceBitmap.Width, sourceBitmap.Height),
        ImageLockMode.ReadOnly, PixelFormat.Format32bppArgb);


    byte[] pixelBuffer = new byte[sourceData.Stride * sourceData.Height];
    byte[] resultBuffer = new byte[sourceData.Stride * sourceData.Height];
    Marshal.Copy(sourceData.Scan0, pixelBuffer, 0, pixelBuffer.Length);
    sourceBitmap.UnlockBits(sourceData);

    if (grayscale == true)
    {
        float rgb = 0;
        for (int k = 0; k < pixelBuffer.Length; k += 4)
        {
            rgb = pixelBuffer[k] * 0.11f;
            rgb += pixelBuffer[k + 1] * 0.59f;
            rgb += pixelBuffer[k + 2] * 0.3f;

            pixelBuffer[k] = (byte)rgb;
            pixelBuffer[k + 1] = pixelBuffer[k];
            pixelBuffer[k + 2] = pixelBuffer[k];
            pixelBuffer[k + 3] = 255;
        }
    }

    double blue = 0.0, green = 0.0, red = 0.0;

    int filterWidth = filterMatrix.GetLength(1);
    int filterHeight = filterMatrix.GetLength(0);
    int filterOffset = (filterWidth - 1) / 2;
    int calcOffset = 0, byteOffset = 0;

for (int offsetY = filterOffset; offsetY < sourceBitmap.Height - filterOffset; offsetY++)
{
    for (int offsetX = filterOffset; offsetX < sourceBitmap.Width - filterOffset; offsetX++)
    {
        blue = 0;
        green = 0;
        red = 0;

        byteOffset = offsetY * sourceData.Stride + offsetX * 4;

        for (int filterY = -filterOffset; filterY <= filterOffset; filterY++)
        {
            for (int filterX = -filterOffset; filterX <= filterOffset; filterX++)
            {
                calcOffset = byteOffset + (filterX * 4) + (filterY * sourceData.Stride);

                blue += (double)(pixelBuffer[calcOffset]) * filterMatrix[filterY + filterOffset, filterX + filterOffset];
                green += (double)(pixelBuffer[calcOffset + 1]) * filterMatrix[filterY + filterOffset, filterX + filterOffset];
                red += (double)(pixelBuffer[calcOffset + 2]) * filterMatrix[filterY + filterOffset, filterX + filterOffset];
            }
        }

        blue = factor * blue + bias;
        green = factor * green + bias;
        red = factor * red + bias;

        if (blue > 255) { blue = 255; }
        else if (blue < 0) { blue = 0; }

        if (green > 255) { green = 255; }
        else if (green < 0) { green = 0; }

        if (red > 255) { red = 255; }
        else if (red < 0) { red = 0; }

        resultBuffer[byteOffset] = (byte)(blue);
        resultBuffer[byteOffset + 1] = (byte)(green);
        resultBuffer[byteOffset + 2] = (byte)(red);
        resultBuffer[byteOffset + 3] = 255;
    }
}
Bitmap resultBitmap = new Bitmap(sourceBitmap.Width, sourceBitmap.Height);

BitmapData resultData = resultBitmap.LockBits(new Rectangle(0, 0, resultBitmap.Width, resultBitmap.Height),
                        ImageLockMode.WriteOnly, PixelFormat.Format32bppArgb);
Marshal.Copy(resultBuffer, 0, resultData.Scan0, resultBuffer.Length);
resultBitmap.UnlockBits(resultData);
return resultBitmap;
}
```

Figure 4.6 Source code - Edge enhancement technique (Convolution Filter)

```
public Bitmap MarkEdge(Bitmap bitmap, Bitmap originalBitmap, Bitmap cleanBitmap, long sectionId)
{
    var sectionItem = sectionService.GetSection(sectionId);
    imagePartService.DeleteAll();
    bitmapData = bitmap.LockBits(new Rectangle(0, 0, bitmap.Width, bitmap.Height), ImageLockMode.ReadWrite, bitmap.PixelFormat);

    // Turn background to black
    var colorFilter = colorFilterMask;
    colorFilter.ApplyInPlace(bitmapData);

    // Locating objects
    var blobCounter = blobCounterMask;
    blobCounter.ProcessImage(bitmapData);
    blobs = blobCounter.GetObjectsInformation();
    bitmap.UnlockBits(bitmapData);

    // Check objects' type and highlight

    MarkPointOfEdges(bitmap, originalBitmap, cleanBitmap, sectionItem, blobCounter, blobs, shapeChecker);

    #region Dispose Pen/ Graphic Obj
    redPen.Dispose();
    brownPen.Dispose();
    graphic.Dispose();
    graphicColor.Dispose();
    #endregion

    return originalBitmap;

}


private void MarkPointOfEdges(Bitmap bitmap, Bitmap originalBitmap, Bitmap cleanBitmap, Models.Section sectionItem,
    BlobCounter blobCounter, Blob[] blobs, SimpleShapeChecker shapeChecker)
{
    graphic = Graphics.FromImage(bitmap);
    graphicColor = Graphics.FromImage(originalBitmap);
    AForge.Point center;
    float radius;

    for (int i = 0, n = blobs.Length; i < n; i++)
    {
        List<IntPoint> edgePoints = blobCounter.GetBlobsEdgePoints(blobs[i]);
        if (!shapeChecker.IsCircle(edgePoints, out center, out radius))
        {
            List<IntPoint> corners;
            if (shapeChecker.IsConvexPolygon(edgePoints, out corners)) // is triangle or quadrilateral
            {
                PolygonSubType subType = shapeChecker.CheckPolygonSubType(corners); // get sub-type
                if (subType == PolygonSubType.Unknown)
                    continue;
                else if ((subType == PolygonSubType.Parallelogram || subType == PolygonSubType.Rectangle) && corners.Count == 4)
                    pen = redPen;
                else
                    continue;

                int minX = -100, minY = -100, maxX = 0, maxY = 0;
                foreach (var corner in corners)
                {
                    if (minX == -100 || corner.X < minX) { minX = corner.X; }
                    if (minY == -100 || corner.Y < minY) { minY = corner.Y; }
                    if (corner.X > maxX) { maxX = corner.X; }
                    if (corner.Y > maxY) { maxY = corner.Y; }
                }
                var width = maxX - minX;
                var height = maxY - minY;
                if (width > 200 && height > 60)
                {
                    graphic.DrawPolygon(pen, ToPointsArray(corners));
                    graphicColor.DrawPolygon(pen, ToPointsArray(corners));
                    try
                    {
                        AnalizePanelStatus(originalBitmap, cleanBitmap, minX, minY, width, height, sectionItem);
                    }
                    catch (Exception ex) { }
                }
            }
        }
    }
    ReadPanelNames(sectionItem);
}
```

Figure 4.7 Source code - Edge detection

4.5.2 Dust Identification

Find Solar panel status (regardless of panel is clear, not good or need to clean) by utilizing own algorithm dependent on image histogram and comparing predefine RGB and intensity threshold values with panel average RGB and intensity, at that point store Solar Panel status on database according to the identified label. Dust identification algorithm is shown on Figure 4.8 and Figure 4.9.

```
private void AnalizePanelStatus(Bitmap originalBitmap, Bitmap cleanBitmap, int minX, int minY, int width, int height, Models.Section section)
{
    Rectangle cloneRect = new Rectangle(minX, minY, width, height);
    System.Drawing.Imaging.PixelFormat format = cleanBitmap.PixelFormat;
    Bitmap imagePart = cleanBitmap.Clone(cloneRect, format);
    var labelPanel = new PanelLabel();

    var imagePartHistrogram = histogramService.ApplyHistogram(imagePart);

    Byte[] binaryImagePartHistrogram = (Byte[])new ImageConverter().ConvertTo(imagePartHistrogram, typeof(Byte[]));
    int red = 0, green = 0, blue = 0, total = 0;
    CrystalSolar.Models.PanelStatus PanelStatus = Models.PanelStatus.NotProcessed;
    var filePath = folderPath + DateTime.Now.ToString("ddMMyyhhmmss") + ".jpg";

    try
    {
        #region RGB %
        for (int x = 0; x < imagePart.Width; x++)
        {
            for (int y = 0; y < imagePart.Height; y++)
            {
                Color clr = imagePart.GetPixel(x, y);
                // Exlude unnessesory pixels
                if (!(clr.R > 130 && clr.G > 180 && clr.B > 150))
                {
                    if (!(clr.R < 50 && clr.G < 50 && clr.B < 50))
                    {
                        red += clr.R;
                        green += clr.G;
                        blue += clr.B;
                        total++;
                    }
                }
            }
        }


        //Calculate RGB average
        red /= total;
        green /= total;
        blue /= total;

        #region Find Image Status
        if (red < 97 && green <= 120 && blue >= 130)
            PanelStatus = Models.PanelStatus.Good;
        else if (red < 150 && green <= 150 && blue >= 100)
            PanelStatus = Models.PanelStatus.NotGood;
        else
            PanelStatus = Models.PanelStatus.NeedToClean;
        #endregion
        #endregion

        try
        {
            var imagePartForName = imageEnhancementService.Crop(imagePart, imagePart.Width, imagePart.Height / 4, 0, 0);
            imagePartForName = imageResizeService.ResizePanel(imagePartForName);
            imagePartForName.Save(filePath, System.Drawing.Imaging.ImageFormat.Jpeg);
            labelPanel = MarkEdgeForProcessed(imagePartForName, section, true, filePath);
        }
        catch (Exception ex) { }
        if (labelPanel == null)
            return;
    }
    catch { }

    Byte[] binaryImage = (Byte[])new ImageConverter().ConvertTo(imagePart, typeof(Byte[]));
    imagePartService.InsertImage(binaryImage, binaryImagePartHistrogram, red, green, blue, PanelStatus, labelPanel);
    imagePartService.InsertTempImage(binaryImage, binaryImagePartHistrogram, red, green, blue, PanelStatus, imagePart.Height, filePath);
}
```

Figure 4.8 Source code - Find dust on solar panels

After solar panel segregation, again process image to remove unnecessary features. Solar panel label identify by using OCR algorithm which is shown on Figure 4.10.

```
public PanelLabel MarkEdgeForProcessed(Bitmap bitmap, Models.Section section)
{
    var text = "";
    BitmapData bitmapData = bitmap.LockBits(new Rectangle(0, 0, bitmap.Width, bitmap.Height), ImageLockMode.ReadWrite, bitmap.PixelFormat);
    ColorFiltering colorFilter = new ColorFiltering();

    colorFilter.Red = new IntRange(0, 64);
    colorFilter.Green = new IntRange(0, 64);
    colorFilter.Blue = new IntRange(0, 64);
    colorFilter.FillOutsideRange = false;

    colorFilter.ApplyInPlace(bitmapData);

    BlobCounter blobCounter = new BlobCounter();

    blobCounter.FilterBlobs = true;
    blobCounter.MinHeight = 5;
    blobCounter.MinWidth = 5;

    blobCounter.ProcessImage(bitmapData);
    Blob[] blobs = blobCounter.GetObjectsInformation();
    bitmap.UnlockBits(bitmapData);

    SimpleShapeChecker shapeChecker = new SimpleShapeChecker();

    Graphics g = Graphics.FromImage(bitmap);
    Graphics gColor = Graphics.FromImage(bitmap);


    for (int i = 0, n = blobs.Length; i < n; i++)
    {
        List<IntPoint> edgePoints = blobCounter.GetBlobsEdgePoints(blobs[i]);

        AForge.Point center;
        float radius;

        if (!shapeChecker.IsCircle(edgePoints, out center, out radius))

        {
            List<IntPoint> corners;
            if (shapeChecker.IsConvexPolygon(edgePoints, out corners))
            {
                PolygonSubType subType = shapeChecker.CheckPolygonSubType(corners);

                bool panelNotFound = true;

                text = ReadPanelName(bitmap, section.SectionName).Replace(" ", "");
                if (text.Length > 0)
                {
                    var panelName = FindPanelLabel(text, section);
                    if (panelName != null)
                    {
                        g.Dispose();
                        gColor.Dispose();
                        return panelName;
                    }
                    break;
                }
                Comment
            }
        }
    }
    g.Dispose();
    gColor.Dispose();
    return null;
}
```

Figure 4.9 Source code - Post process algorithm

```
1 reference
private string ReadPanelName(Bitmap img, string section)
{
    var ocrResult1 = Ocr.ReadMultiFrameTiff(img);
    var text = ocrResult1.Text.Trim();
    if (text.Contains(section))
    {
        text = text.ToUpper().Replace("()", "0").Replace("O", "0").Replace("\"", "").Replace(",", "").Replace(";", "")
            .Replace(";", "").Replace("[", "").Replace("]", "").Replace(".", "").Replace(":", "")
            .Replace(" ", "").Replace("'", "").Replace("}", "").Replace("t", "").Replace("?", "")
            .Replace("TT", "").Replace("II", "").Replace("LL", "").Replace("TL", "").Replace("LT", "")
            .Replace("!", "").Replace("-", "").Replace("SS", "").Replace("IS", "").Replace("SI", "")
            .Replace("IF", "").Replace("FI", "").Replace("IL", "").Replace("LI", "").Replace("\r", "").Replace("\n", "")
            .Replace("LF", "").Replace("\\", "").Replace("/", "").Replace("00", "0").Replace("‘", "").Replace("“", "");
    }
    return text;
}
```

Figure 4.10 Source code - OCR algorithm

IronOCR class library is most suitable OCR engine for reading text on the solar panel. But solar panel has so many vertical and horizontal line grids. Those vertical and horizontal line grids has detected as text by OCR engine. Therefore system has removed those unnecessary characters.

Before identify solar panel label, crop the whole solar panel image and get only image part which contain panel label. Image enlargement will increase accuracy of the output of OCR.

```
public PanelLabel FindPanelLabel(string text, Models.Section section)
{
    if (text.Length > 0)
    {
        if (text.Contains(section.SectionName))
        {
            try
            {
                char[] characters = text.ToCharArray();
                for (int c = 0; c <= characters.Length; c++)
                {
                    if (section.SectionName == characters[c].ToString())
                    {
                        var panelName = text.Substring(c, 5);
                        var subSection = section.SubSections.FirstOrDefault(t => t.SubSectionName == panelName.Substring(0, 3));
                        if (subSection == null)
                            continue;

                        var panelNameProcessed = subSection.SubSectionName + "-" + panelName.Substring(3, 2);
                        var panel = subSection.SolarPanels.FirstOrDefault(t => t.PanelName == panelNameProcessed);
                        if (panel != null)
                        {
                            return new PanelLabel()
                            {
                                SectionId = section.SectionId,
                                SubSectionId = subSection.SubSectionId,
                                SolarPanelId = panel.SolarPanelId,
                                SolarPanelName = panelNameProcessed
                            };
                        }
                    }
                }
            }
            catch { }
        }
    }
    return null;
```

Figure 4.11 Source code - Algorithm to find panel label using OCR output

```
1 reference
public Bitmap Crop(Bitmap bmpImage, int width, int height)
{
    Bitmap bmpCrop = bmpImage.Clone(new Rectangle(0, 0, width, height), bmpImage.PixelFormat);

    return bmpCrop;
}
```

Figure 4.12 Source code - Crop image

```
internal Bitmap ResizePanel(Bitmap image)
{
        double scaleFactor = (double)30 / (double)image.Height;
        var newWidth = (int)(image.Width * scaleFactor);
        var newHeight = (int)(image.Height * scaleFactor);
        var thumbnailBitmap = new Bitmap(newWidth, newHeight);

        var thumbnailGraph = Graphics.FromImage(thumbnailBitmap);
        thumbnailGraph.CompositingQuality = CompositingQuality.HighQuality;
        thumbnailGraph.SmoothingMode = SmoothingMode.HighQuality;
        thumbnailGraph.InterpolationMode = InterpolationMode.HighQualityBicubic;

        var imageRectangle = new Rectangle(0, 0, newWidth, newHeight);
        thumbnailGraph.DrawImage(image, imageRectangle);
        thumbnailGraph.Dispose();
        return thumbnailBitmap;
}
```

Figure 4.13 Source code - Image enlargement

Chapter 5: Evaluation and Testing

5.1 Chapter Overview

This chapter describes how well the implemented system performs and their algorithms. The evaluation can be done by dividing the whole process into Solar Panel Segregation, Dust Identification and Clean Solar Panels.

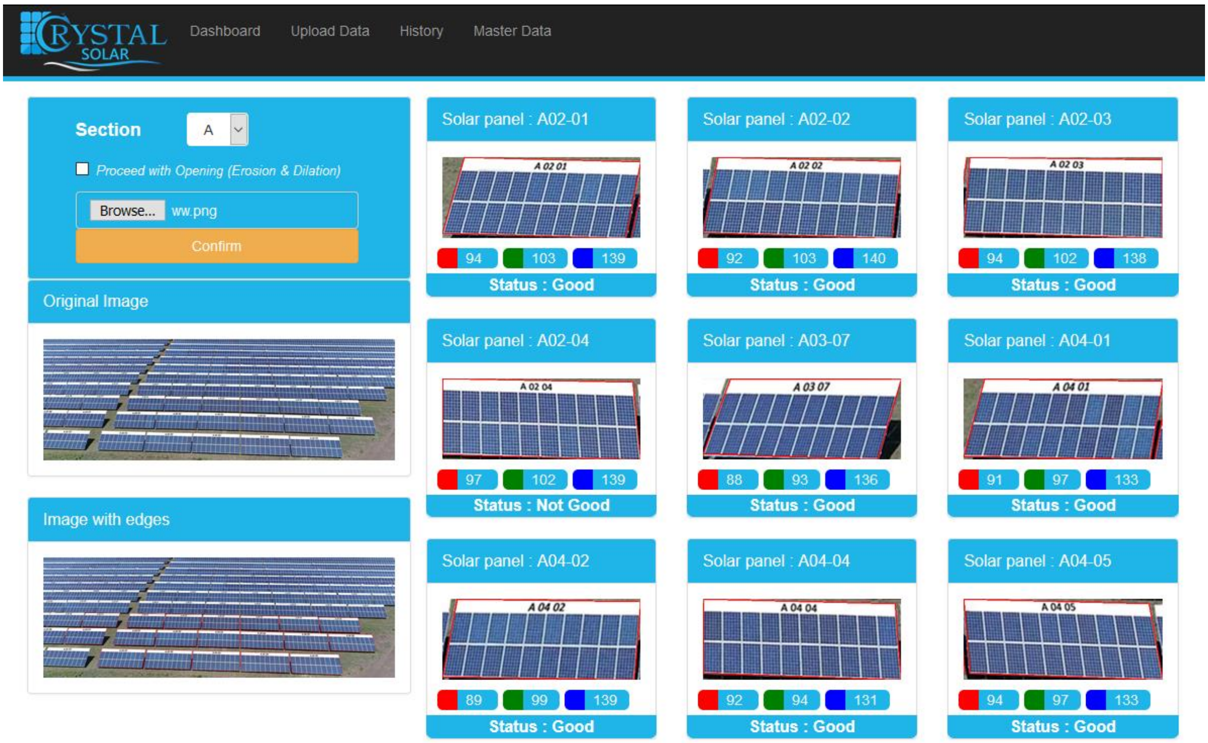

Figure 5.1 System screen - Solar panel segmentation and panel status

5.2 Solar Panel Segregation and Panel Identification

5.2.1 Solar Panel Segregation

Solar panel segmentation is more difficult task as well as time consuming task. Enlarging the uploaded image will increase number of segmentation images. But it will effect to processing time. Therefore system has enlarged uploaded image by 2X for segment image. If system enlarges more output will increase, but it badly effect to performance of the system. Solar panels in so far are difficult to identify. Therefore author has recommended capturing solar panel image by straight top of the solar panel grid.

Figure 5.2 System screen - Solar panel segmentation

Use of opening morphology is increasing output of the panel segregation. That means it increase number of panel identification as well as it mostly identifies panel edges.

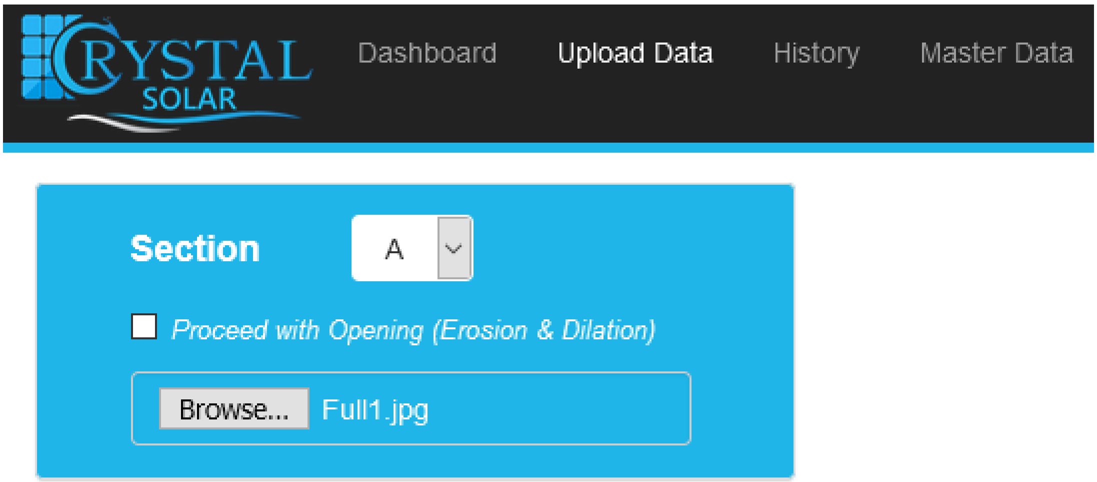

Figure 5.3 System screen - Application of filters

Opening morphology is one of two significant operators from morphology in image processing. Opening operators is ordinarily applied to binary images, in spite of the fact that it is likewise grey level versions and it is gotten from the fundamental tasks of erosion and dilation.

The basic effect of an opening morphology is to some degree like erosion in that it will in general evacuate a portion of the bright foreground pixels from the edges of foreground pixels regions. Anyway it is less dangerous than erosion all in all. Similarly as with various morphological operators, the exact activity is dictated by a structuring element. The consequence of the operator is to protect foreground region that have an equivalent structure to this organizing element, or that can totally contain the structuring element, while eliminating of every single other foreground pixels regions.

But due to lengthy process of opening morphology, opening morphology consumes considerably more processing time and resources.

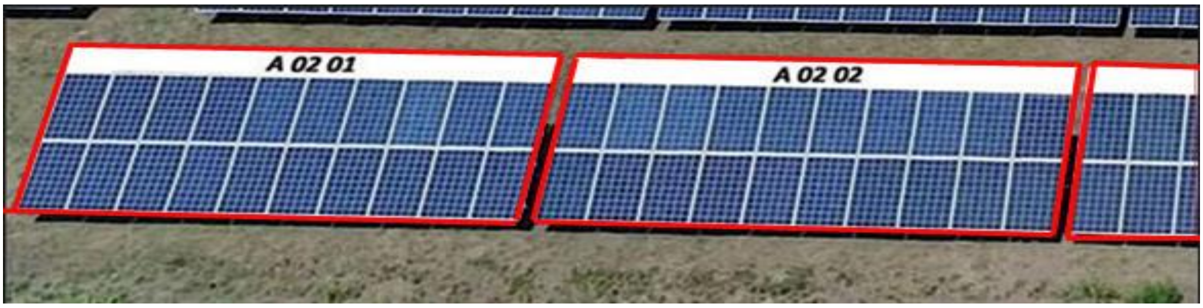

Figure 5.4 System screen - Solar panel segmentation with opening morphology

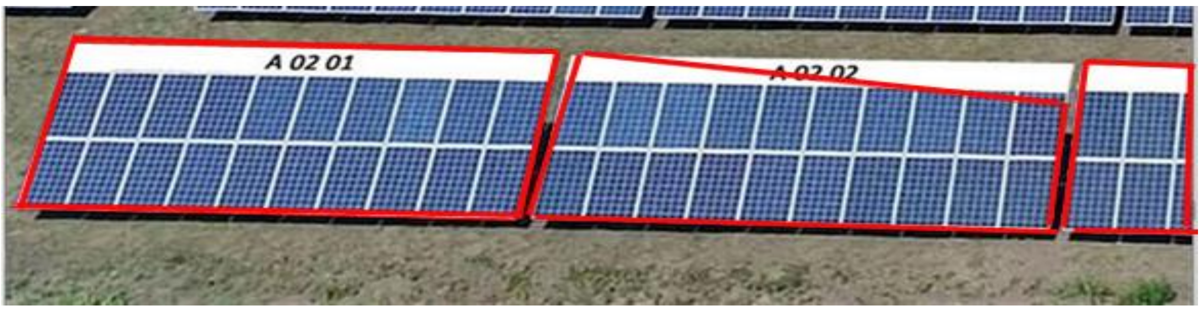

Figure 5.5 System screen - Solar panel segmentation without opening morphology

Figure 5.6 System screen - Solar panel segmentation without opening morphology

Author has consumed more experiments and time to discover appropriate algorithm to segregate solar panels. Even smaller grid lines in solar panels (Solar panel modules) were identified as a solar panel in early.

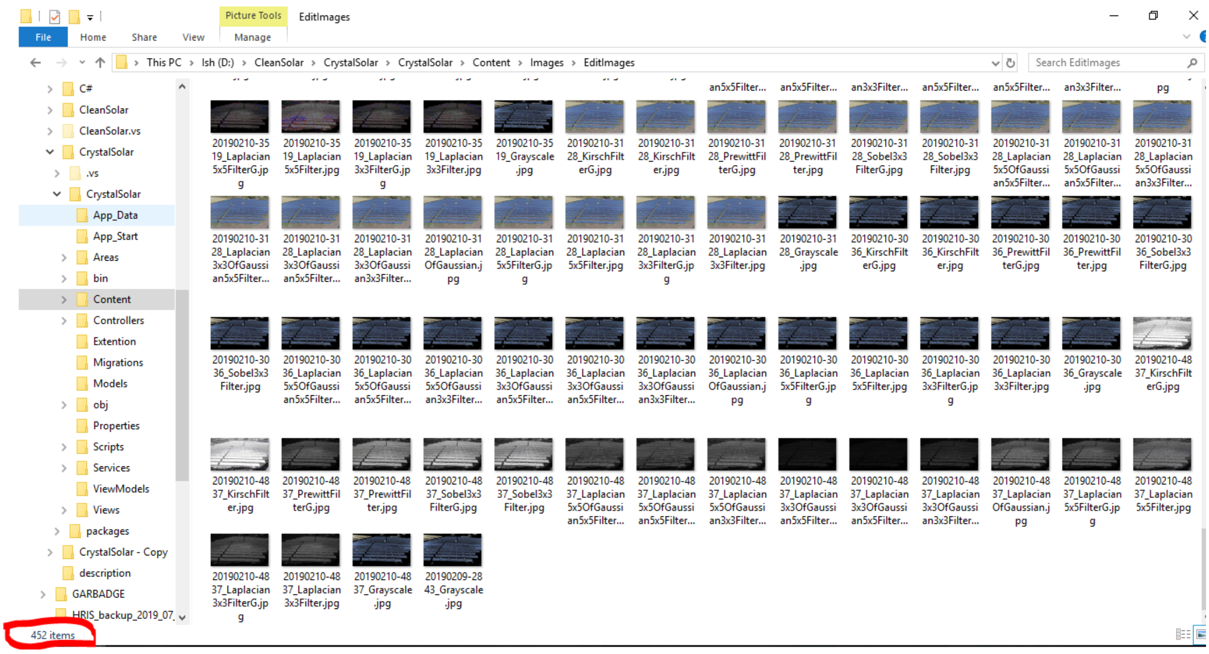

Figure 5.7 System screen - Solar panel segmentation

In some cases edges detection of solar panels has not effectively marked. Wrongly marked solar panel edges have shown in green color in Figure 5.8, Figure 5.9.

Figure 5.8 System screen - Wrongly marked solar panels edges

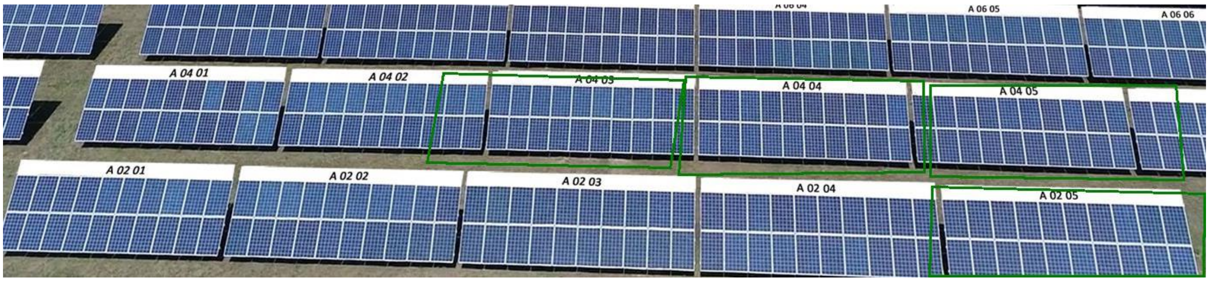

Figure 5.9 System screen - Wrongly marked solar panels edges

5.2.2 Panel Identification

Panel identification is done by using OCR technology. OCR is a technology that perceives text among a digital image. There are so many OCR class libraries available. But characters identification in top of the solar panel is more difficult task rather than identify characters on images.

System has identified solar panel labels correctly. But solar panel has so many vertical and horizontal lines as grid. Therefore available OCR libraries read those lines as characters.

Figure 5.10 System screen - Incorrectly identified solar panel name

But system has outcome that limitation by crop only the solar panel label first and then read characters on it. But before that system will increase or decrease each solar panel height to 30px to get better answer. Author has selected panel height as 30px by doing more R&Ds.

Figure 5.11 System screen - Solar panel label identification

Solar Panel identification algorithm has become troublesome procedure. System has identified five solar panels in Figure 5.12. In any case, system has only capable for recognized four panels as which show in right half of Figure 5.13.

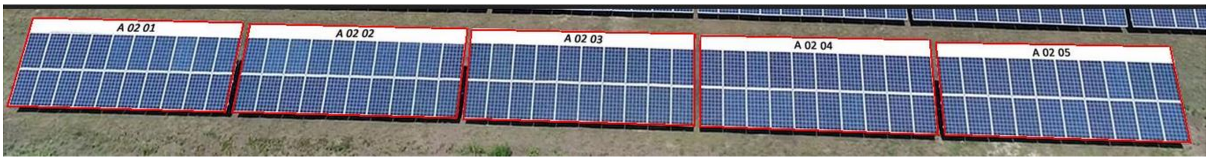

Figure 5.12 System screen - Solar panel identification

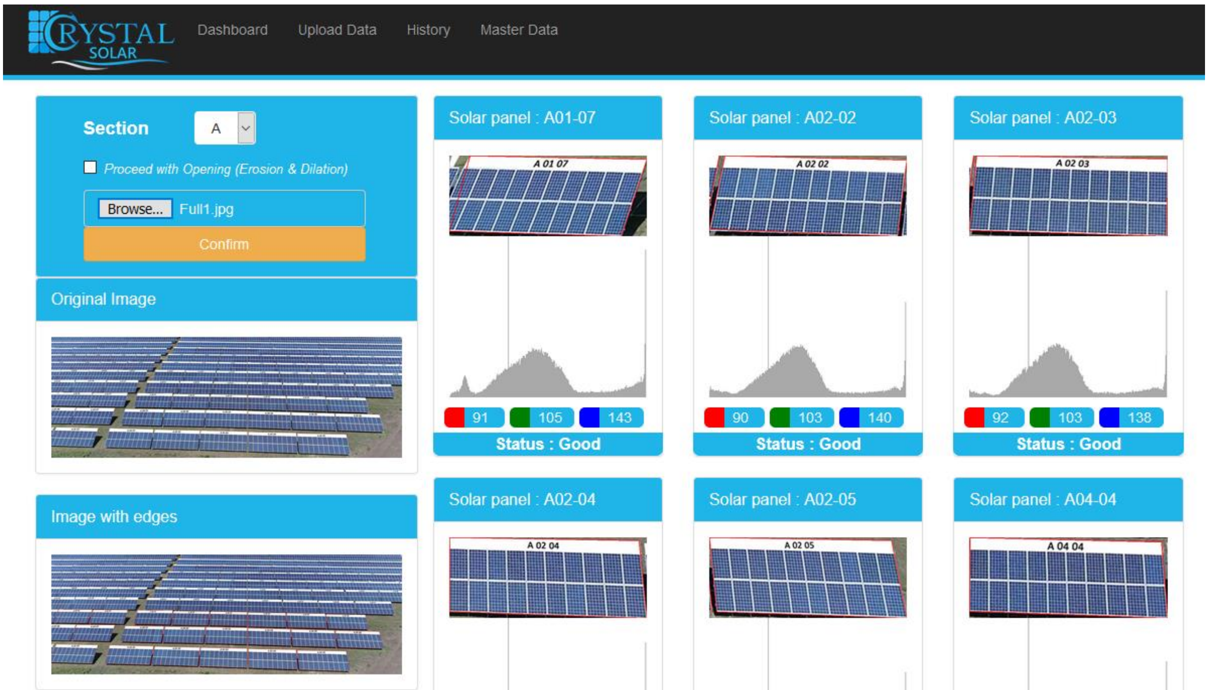

Figure 5.13 System screen - Solar panel identification on the system

5.3 Dust Identification

System has recognized dust by investigating solar panel histograms and analysing its average RGB values. An image histogram is a sort of histogram that goes about as a graphical delineation of the tonal distribution in an exceedingly digitized image. It plots the pixels amount for each tonal value. By analysing the histogram for a solar panel may have the option to pass judgment on the whole tonal distribution at a glance.

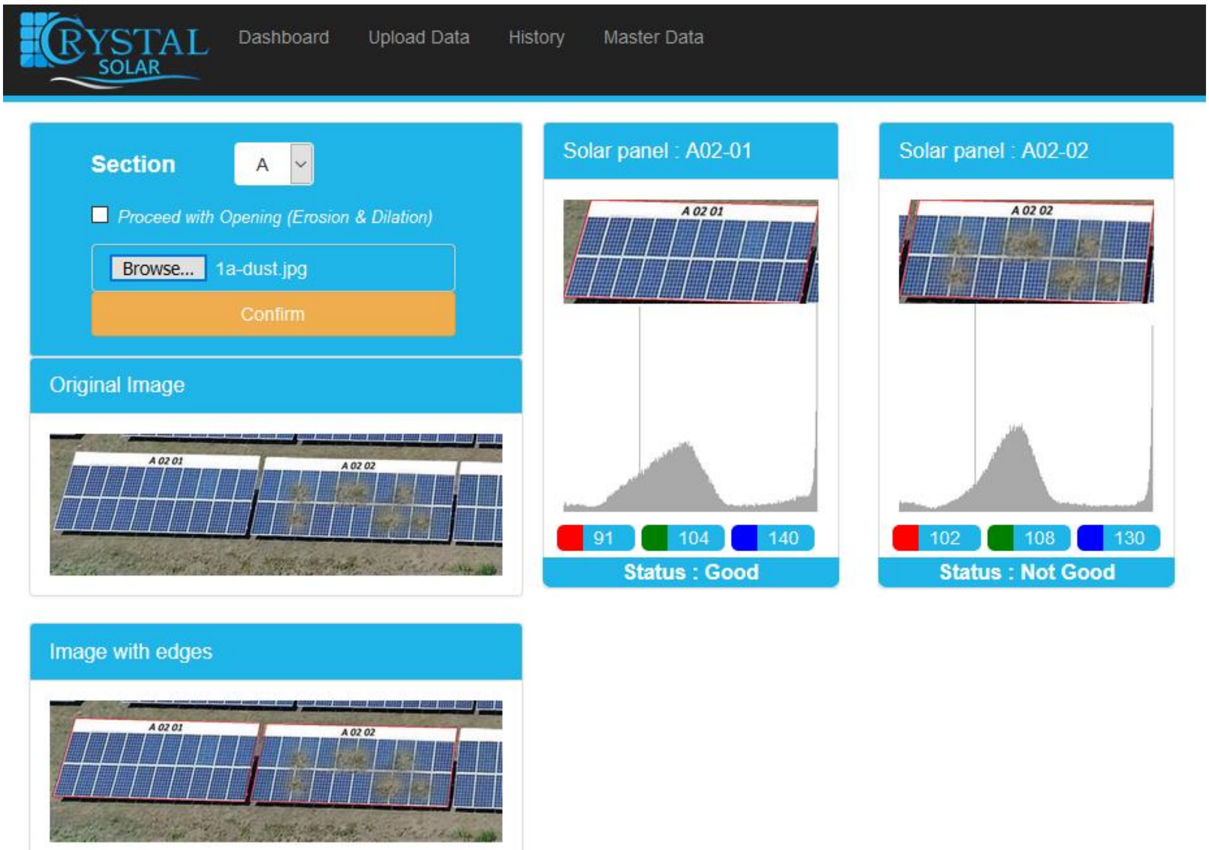

Figure 5.14 System screen - Dust identification of solar panels

System will categorize by using solar panel status and mark solar panel as "Good", "Need to Clean" and "Not Good" by analysing solar panel histogram.

5.4 Solar Panels Dashboard and Mark as Clean

Staff member can graphically view solar panel status by using dashboard. All solar panels has categorised as followings.

- **Not Processed** - Solar Panels not processed
- **Good** - Healthy solar panel
- **Need to Clean** - Solar panels which staff must clean.
- **Not Good** - Better to clean solar panels
- **Not Found** - Solar panels not found while processing. Those solar panels consider as "Need to Clean" solar panels. Staff must check and clean those solar panels
- **Manually Cleaned** – Solar panels cleaned by staff

Each solar panel status has displayed in different colour code to easily identify by staff members.

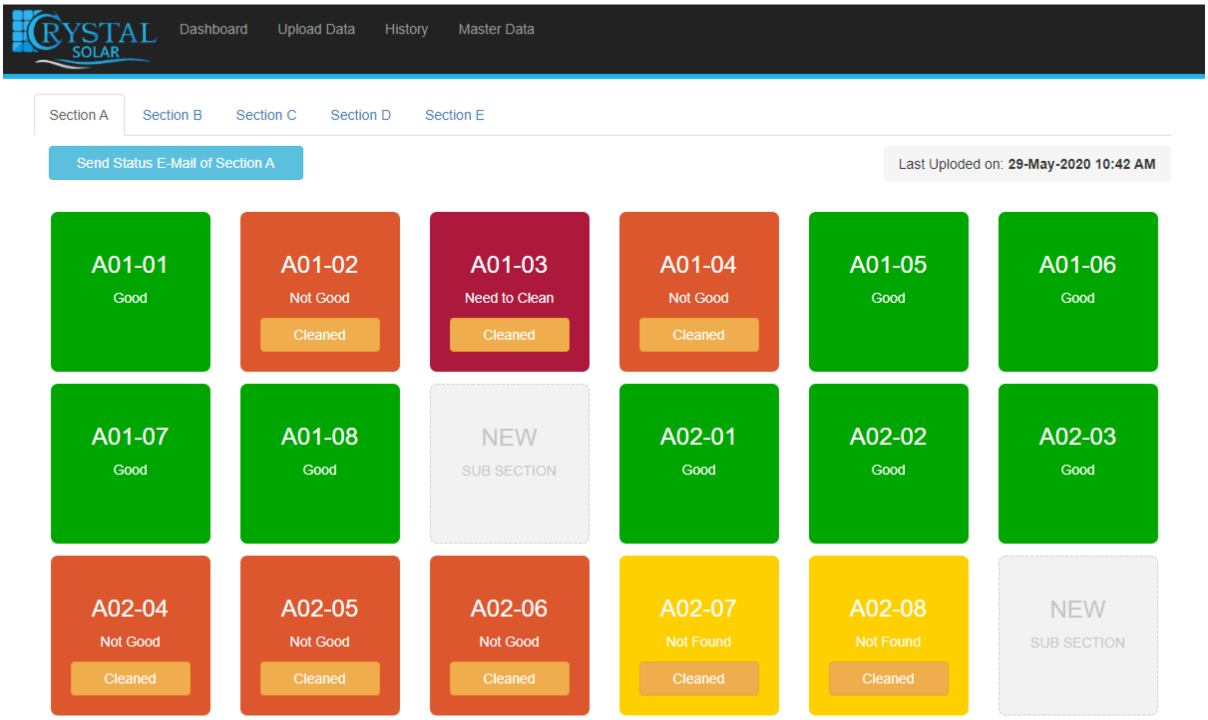

Figure 5.15 System screen - Dashboard

Designated person of each solar panel sections has taken their solar panel status email in daily basis after complete the process of image analysis. The responsible person should check it and must clean solar panel which has status as "Not Good", "Need to Clean" and "Not Found". Then responsible person must update system as cleaned against particular solar panel.

Solar Panel status for A on 13-May-2020 Inbox ×

CrystalSolar@gmail.com
to pasanc, me

Dear Pasan Chaminda,
Following Solar Panels need to clean. Please take necessary action and update the system.

Panel Name	Status
A01-02	Not Good
A01-03	Need to Clean
A01-04	Not Good
A02-04	Manually Cleaned
A02-05	Manually Cleaned
A02-06	Not Good
A02-07	Not Found
A06-03	Not Good
A06-04	Not Found
A06-05	Not Good
A06-07	Not Found
A06-08	Not Found
A07-01	Not Found
A07-02	Not Found
A07-03	Not Found

Following Solar Panels are in good condition.

Panel Name	Status
A01-01	Good
A01-05	Good
A01-06	Good
A01-07	Good
A01-08	Good
A02-01	Good

Figure 5.16 System screen - Solar panel status email

5.5 Evaluation of the Crystal Solar System

- **Integrate Image Cropping/Re-scaling tool**

  This system has applied image cropping and re-scaling algorithms. But integrating advance tool will helped to enhance output.

- **Reduce Processing Time and Resources**

  Current algorithms have mostly optimised, but it consumes considerable time as well as system resources. Existing algorithms needed to optimize to enhance performance by programmatically.

- **Develop AI based analytical reports**

  Database has historical data of solar panels status. System can evaluate by developing AI based decision making system by utilizing historical data.

- **Parameterize configurable benchmarks**

  System has hard coded some benchmark esteems, for example, ideal image intensity, RGB values…etc. But if system has functionality to CMS those values will be add value to the system.

- **Get stakeholders feedbacks and address them**

  Stakeholders are who use the system and they have new ideas to improve current system. Their ideas will support to enhance system to solid system.

Chapter 6: Conclusion

As part of the research, developed an algorithm which has capability to identify defective Solar panels automatically, based on its intensity statistics. However, given that the proposed algorithm was implemented only on drone still images in this study, additional image analysis will have to be performed to prove the reliability of the algorithm in terms of completeness and accuracy and further improve its performance. Use of Opening morphology is enhancing the identification of solar panel, but it is badly effect to system performance.

Additionally, the sample images were of comparable panel sizes and intensity characteristics; it is thus necessary to conduct an extra sample analysis study, thereby varied conditions such as the years of service of panels, observation hours, and scale of photogrammetric measure. Despite the small sample size analysed, this study is significant in that it ascertained the feasibility of using intensity statistics of drone images as parameters for automatic fault diagnosis of Solar panels.

In future research, it is desirable to explore how to use orientation parameters of a sensor and ground control point (GCP) based photogrammetric survey to precisely determine the locations of defective panels to establish an efficient maintenance and repair regimen for large-scale Solar Panel Power Stations.

References

[1] M. Hambsch, "Photovoltaic systems thermography from the air using drones". 2011.

[2] T. Lombardo, "UAVs to Inspect Solar Farms". 2014.

[3] S. Beattie, "Solar Panel Drone & Handheld Thermal Imaging". 2013.

[4] K. Azizi and A. Ghaffari, "Design and Manufacturing of a High-Precision Sun Tracking System Based on Image Processing". 2013.

[5] A. Mansouri, "Defect detection in photovoltaic modules using electroluminescence imaging". 2012.

[6] M. Jacobson and M. Delucchi, "Providing all global energy with wind, water, and solar power". 2009.

[7] W. Xiao and W. Dunford, "A modified adaptive hill climbing MPPT method for photovoltaic power systems". 2004.

[8] S. Wenham, Applied Photovoltaics. Earthscan, 2007.

[9] W. Herrmann, W. Wiesner, and W. Vaassen, "Hot spot investigations on PV modules-new concepts for a test standard and consequences for module design with respect to bypass diodes". 1997.

[10] S. Shirzadi, H. Hizam, and N. Wahab, "Mismatch losses minimization in photovoltaic arrays by arranging modules applying a genetic algorithm". 2014.

[11] H. Mousazadeh, A. Keyhani, A. Javadi, H. Mobli, K. Abrinia, and A. Sharifi, "A review of principle and sun-tracking methods for maximizing solar systems output". 2009.

[12] S. Hajighorbani, M. Radzi, M. Ab Kadir, S. Shafie, R. Khanaki, and M. Maghami, “Evaluation of fuzzy logic subsets effects on maximum power point tracking for photovoltaic system”. 2014.

[13] S. Ghazi and A. Sayigh, “Dust effect on flat surfaces”. 2014.

[14] T. Sarver, A. Al-Qaraghuli, and L. Kazmerski, “A comprehensive review of the impact of dust on the use of solar energy”. 2013.

[15] H. Hottel and B. Woertz, “Performance of flat-plate solar-heat collectors”. 1942.

[16] Z. Darwish, H. Kazem, K. Sopian, M. Al-Goul, and H. Alawadhi, “Effect of dust pollutant type on photovoltaic performance”. 2015.

[17] M. Maghami, H. Hizam, C. Gomes, S. Hajighorbani, and N. Rezaei, “Evaluation of the 2013 Southeast Asian Haze on Solar Generation Performance”. 2015.

[18] E. Asl-Soleimani, S. Farhangi, and M. Zabihi, “The effect of tilt angle, air pollution on performance of photovoltaic systems in Tehran”. 2001.

[19] M. Mani and R. Pillai, “Impact of dust on solar photovoltaic (PV) performance”. 2010.

[20] M. El-Shobokshy and F. Hussein, “Degradation of photovoltaic cell performance due to dust deposition on to its surface”. 1993.

[21] A. Dietz, “Diathermanous materials and properties of surfaces”. 1963.

[22] E. Anagnostou and A. Forestieri, “Endurance testing of first generation (Block I) commercial solar cell modules”. 1978.

[23] A. Hoffman and R. Ross, “Environmental qualification testing of terrestrial solar cell modules”. 1978.

[24] R. Pettit, J. Freese, and D. Arvizu, “Specular reflectance loss of solar mirrors due to dust accumulation”. 1978.

[25] J. Blackmon and M. Curcija, “Heliostat reflectivity variations due to dust buildup under desert conditions”. 1978.

[26] R. Berg, “Heliostat dust buildup and cleaning studies”. 1978.

[27] J. Freese, “Effects of outdoor exposure on the solar reflectance properties of silvered glass mirrors”. 1978.

[28] S. Forman, “Photovoltaic module performance and degradation at various MIT/LL test sites”. 1979.

[29] A. Hoffman and C. Maag, “Airborne particulate soiling of terrestrial photovoltaic modules and cover materials”. 1980.

[30] E. Roth and R. Pettit, “The effect of soiling on solar mirrors and techniques used to maintain high reflectivity”. 1980.

[31] F. Cuddihy, “Theoretical considerations of soil retention”. 1980.

[32] R. Pettit and J. Freese, “Wave length dependent scattering caused by dust accumulation on solar mirrors”. 1980.

[33] J. Michalsky, R. Perez, R. Stewart, B. LeBaron, and L. Harrison, “Design and development of a rotating shadowband radiometer solar radiation/daylight network”. 1988.

[34] C. Ryan, F. Vignola, and D. McDaniels, “Solar cell arrays degradation due to dirt”. 1989.

[35] R. Hammond, D. Srinivasan, A. Harris, K. Whitfield, and J. Wohlgemuth, “Effects of soiling on PV module and radiometer performance”. 1997.

[36] S. Mekhilef, R. Saidur, and M. Kamalisarvestani, “Effect of dust, humidity and air velocity on efficiency of photovoltaic cells”. 2012.

[37] H. Jiang, L. Lu, and K. Sun, “Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules”. 2011.

[38] P. Pande, “Effect of dust on the performance of PV panels”. 1992.

[39] F. Ju and X. Fu, “Research on impact of dust on solar photovoltaic (PV) performance”. 2011.

[40] B. Yerli, M. Kaymak, E. İzgi, A. Öztopal, and D. Şahin, “Effect of derating factors on photovoltaics under climatic conditions of Istanbul”. 2010.

[41] S. Kobayashi, T. Iino, H. Kobayashi, K. Yamada, and T. Yachi, “Degradation of output characteristics of a small photovoltaic module due to dirt spots”. 2005.

[42] S. Biryukov, “Degradation of reflectivity of parabolic mirror caused by dust on its surface”. 2000.

[43] B. Nimmo and S. Said, “ Effects of dust on the performance of thermal and photovoltaic flat, plate collectors in Saudi Arabia-Preliminary results”. 1981.

[44] A. Ibrahim, “Effect of shadow and dust on the performance of silicon solar cell”. 2011.

[45] I. Al-Helal and M. Alhamdan, “Effect of arid environment on radiative properties of greenhouse polyethylene cover”. 2009.

[46] H. Badran, “Mirror cleaning and reflectivity degradation at 1300 and 2300 m above sea level”. 2004.

[47] A. Al-Hasan and A. Ghoneim, “A new correlation between photovoltaic panel’s efficiency and amount of sand dust accumulated on their surface”. 2005.

[48] A. El-Nashar, “Effect of dust deposition on the performance of a solar desalination plant operating in an arid desert area”. 2003.

[49] A. El-Nashar, “Seasonal effect of dust deposition on a field of evacuated tube collectors on the performance of a solar desalination plant”. 2009.

[50] A. El-Nashar, “The effect of dust accumulation on the performance of evacuated tube collectors”. 1994.

[51] A. Alamoud, “Performance evaluation of various photovoltaic modules in hot and arid environment”. 1993.

[52] M. Pavan, A. Mellit, and D. De Pieri, “The effect of soiling on energy production for large-scale photovoltaic plants”. 2011.

[53] M. Vivar, R. Herrero, I. Antón, F. Martínez, R. Moretón, and G. Sala, “Effect of soiling in CPV systems”. 2010.

[54] H. Becker, W. Vaassen, and W. Herrmann, “Reduced output of solar generators due to pollution”. 1997.

[55] H. Elminir, A. Ghitas, R. Hamid, F. El-Hussainy, M. Beheary, and K. Abdel, “Effect of dust on the transparent cover of solar collectors”. 2006.

[56] A. Hegazy, “Effect of dust accumulation on solar transmittance through glass covers of plate-type collectors”. 2001.

[57] K. Adanu, Photovoltaic Energy Conversion. 1994.

[58] D. Gesellschaft, Planning and Installing Photovoltaic Systems. Earthscan, 2008.

[59] M. Ngan and C. Tan, “A study of maximum power point tracking algorithms for stand-alone photovoltaic systems”. 2011.

[60] M. Sheraz and A. Abido, “An efficient MPPT controller using differential evolution and neural network”. 2012.