Detection of Soiling in Solar PV Module

Minor Project Report

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VEER SURENDRA SAI UNIVERSITY OF TECHNOLOGY, BURLA

For the partial fulfilment for the award of the degree of

Bachelor of Technology

Department of Mechanical Engineering

Under the Guidance of

Dr. Aurovinda Mohanty

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CERTIFICATE

This is to certify that the project entitled "**Detection of Soiling In Solar PV Module**" submitted to the veer Surendra Sai university of Technology (Deemed University) by **Amartya Mohanty(1602090008), Purnendu Debata (1602110032), Bibekananda Rout(1703090002), Subrat Pradhan(1703090012), Asribad Subudhi Ray (1602110012)** for the award of the Degree of **Bachelor of Technology** in **Mechanical Engineering** is a record of bonafide research work carried out by them under my supervision and guidance.

The project, in my opinion, has reached the standards fulfilling the requirement for the award of the degree **of Bachelor of Technology** in accordance with regulations of the Institute.

I considered that the thesis has reached the standards and fulfilling the requirements of the rules and regulations relating to the nature of the degree. The contents embodied in the thesis have not been submitted for the award of any other degree or diploma in thus or any other university.

Signature of supervisor(s) and

Date: **Designation**

Place: **Name- Dr. Aurovinda Mohanty**

Associate Professor

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DECLARATION

I certify that

a. The work contained in the report is original and will be done by myself under the supervision of my supervisor.

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Abstract

Being sustainable, clean, and eco-friendly, photovoltaic technology is considered as one of the most hoped solutions face to worldwide energetic challenges. India joins this context with the inauguration of numerous clean energy projects. However, one key factor in making photovoltaic installations a profitable investment are regular and effective inspections in order to detect occurred defects. For a solar powerplant company it is not an easy task to check the deposition of soil, feathers of birds and other obstacles manually and regularly. Due to the effect of soiling it leads to the decrease in efficiency, power generation of the solar PV module and results in abnormal temperature increases in module which leads to the failures of modules. Unmanned aerial vehicles (UAV) are increasingly used in various inspection fields to inspect the soiling effect. In this respect, this work focuses on the use of visual image processing taken by UAV in the inspection of photovoltaic installations. Visual image of photovoltaic modules obtained by UAV, from different installations, and with different acquisition conditions and parameters, were exploited to generate aerial image of an area for inspection purposes. Several visual defects were detected by the camera installed on the Unmanned aerial vehicles to detects cracks, soiling, feathers of birds and other obstacles. After image processing by the camera fitted on UAV the processed data will be send to the maintenance unit of that company. After getting this information the maintenance team will take the necessary action.

CONTENTS

Introduction

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy. Solar power plant has become one of the major power production means throughout the world. India ranks at 6th position in solar power generation (20GW) as on date. The Government of India has set up a target of achieving100GW power production by 2022. Solar plants are preferred to other means of power production such as thermal, nuclear, geothermal, tidal, hydroelectric power plants because solar energy is easily available. As a result, the cost of power production becomes less. However, efficiency of solar power plants is affected by accumulation of snow, dirt, dust and other particles over the period of time that cover the surface of the PV module. This process is called Soiling effect. Due to this effect the efficiency and power generation capacity of the solar PV module decreases. This soiling effect cause an abnormal temperature distribution around the solar PV module which leads to failure of the modules. This results a huge loss in generation of energy production. Our proposed idea is to detect the soiling defect using FLIR camera installed on a Unmanned aerial vehicle. The FLIR camera will provide image processing data of the surface of solar PV module. Image processing is done by segmentation and linking algorithm using python. The segmentation principle which showed that the human vision performs groupings based on the similarity and continuity of the captured images. These groupings were the motivation of segmentation studies that extended the concept computationally. Search algorithms used to find edges, textures, patterns or differences which will ensure the level of soil deposition on the solar PV module. The image processing data is sent to the maintenance unit of the solar power plant.

Cause of dust accumulation

- Because of the humidity or fog or dew, the dust particles tend to stick to the panels thereby increasing the soiling. Many times, the dry dust accumulated on the panels is carried away by the winds. Presence of dew or moisture prevents this carrying away of the particles by wind, resulting in aggravated soiling.
- Many researchers concluded from their research that bird droppings can significantly bring down panel efficiency and hence, they are also considered while calculating the soiling losses. Many times, the water or the mixture of cleaning agent and water used to clean the panels leaves behind a layer on the panels. This can also be called as a form of soiling.
- Shading can be categorized into two prime categories– soft shading and hard shading. Shading due to pollution, mist, fog affect the irradiance received by the panel and it is called as soft shading. Whereas shading due to dust particles, soil particles, bird droppings are called as hard shading.
- There are two interdependent parameters that effect on characterization of soiling accumulation on solar panels, the property of dust and the local environment. Dust property consist of size, components, shape, and weight . The dust in acidic and can cause erosion to the surface of the panel. The local environment refers to the surroundings that the human activity has directly or indirectly created such as built environment, types of vegetation, and weather condition.
- Furthermore, the surface is also a very important contributing factor in soiling process. If the surface is not smooth, and instead is rough, fury, sticky, and etc, it allows more soil to accumulate.
- The position of the panel which depends on the sunlight direction and wind is also important in soiling process. The more horizontal the surface is, the more dust can be accumulated.
- Besides, slow breeze also can result in dust accumulation whereas strong wind can clear the panel surface. However, airflow due to wind is able to effect the dust accumulation or dissipation at particular places of the solar panel .
- The air speed is and pressure are not constant over the solar panel surface. In presence of a wind, wherever the airspeed is higher, there is lower pressure which can result in less soil accumulation and vice versa.
- Dust properties such a type, size, weight, and shape also play important role in dust scattering. described different problems that result in soil accumulation on solar panel. It also shows some factors has correlation which shows by error which need to investigate by future study. compares soil effect various locations around the world.
- Technically, Dust reduces output power from PV between 2% until 50% in different area. In Asian reign most of the dust martials is sand and soil and also in African countries dust come from desert area which accumulating on the surface.

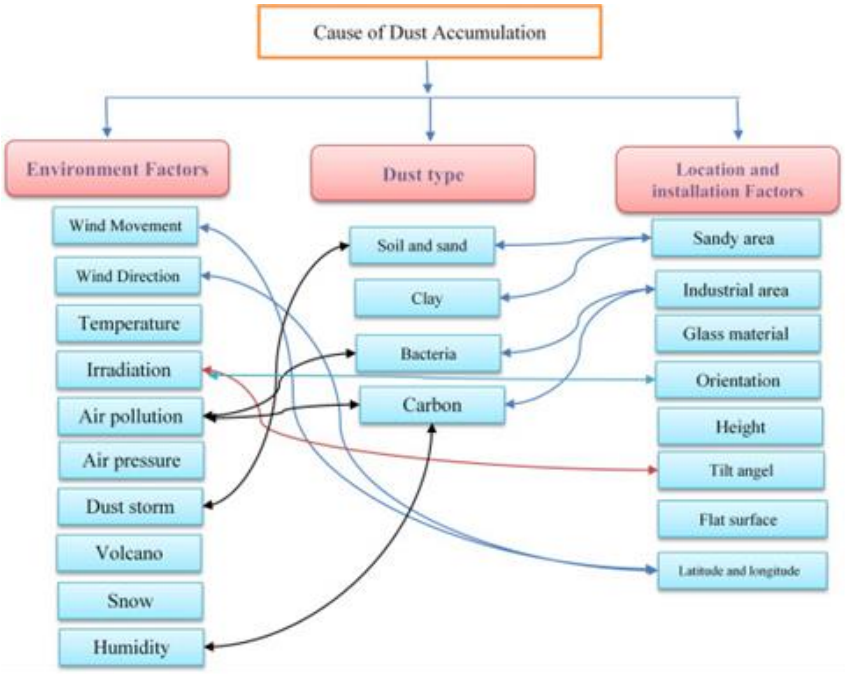


Fig1. Deposition of soil on solar PV modules

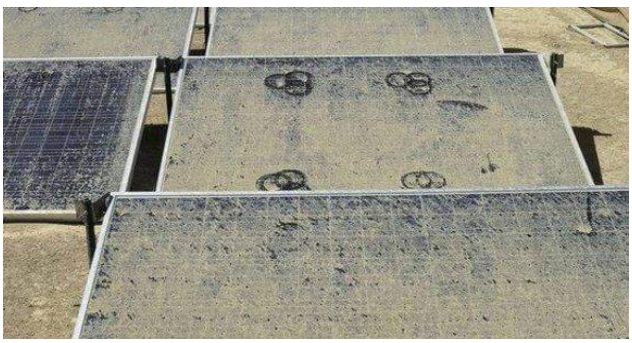


Fig 2. Soiling due to soil storm

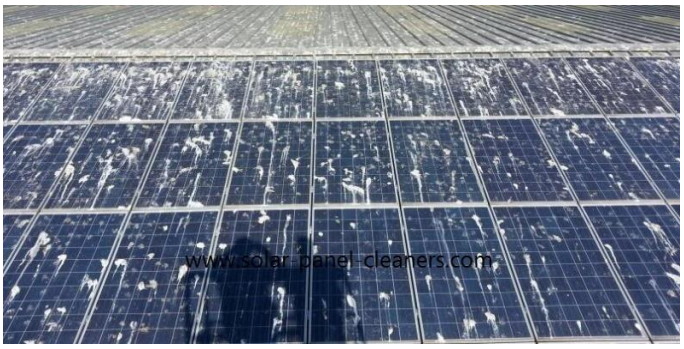


Fig 3. Deposition of bird feathers

Types of losses in solar PV module

Diode and Connection loss

The primary application of bypass diodes is PV system is to preserve PV modules in partial shading conditions. Such a protective component can cause one form of connection loss known as power loss in the system. The other type connection loss in PV system happens where PV modules and other electrical components are connected together to form PV arrays, known as resistive loss . Because the series connection of the PV generator forces all the cells to operate having the same current (string current), the shaded cell within a module becomes reverse biased which leads to power dissipation in the form of heat .

Mismatch losses

When PV modules with different characteristics (*I* & *V*) are connected together they provide a total output power less than the power achieved by summing the output power provided by each of the modules. PV modules with same ratings coming out of one production line in a factory do not possess identical current–voltage characteristics for many reasons. This inequality causes PV modules to compromise on common voltage and current when they are connected in series or parallel in an array. This compromise results in a type of power losses known as mismatch losses which is recognized by several research works. mismatch loss minimization in photovoltaic arrays can be obtain by arranging PV modules in arrays by genetic algorithm. Findings of this study show that a genetic algorithm-based arrangement of modules reduces mismatch losses more effective than classical modules sorting techniques do.

DC and AC Wiring

DC and AC wiring loss comprises of the resistive losses of the cables and wires used throughout the whole PV plant from the PV including the whole route from the PV module to the main power grid.

Sun-Tracking loss

Sun is moving across the sky during the day. In the case of fixed solar collectors, the projection of the collector area on the plane, which is perpendicular to the radiation direction, is given by function cosine of the angle of incidence. Sun tracking loss occurs when the single or dual axes of tracking solar panels are not set at the optimum orientation, or are misaligned due to a mechanical failure. The most efficient and popular sun-tracking device was found to be in the form of polar-axis and azimuth/elevation types.

Shading losses

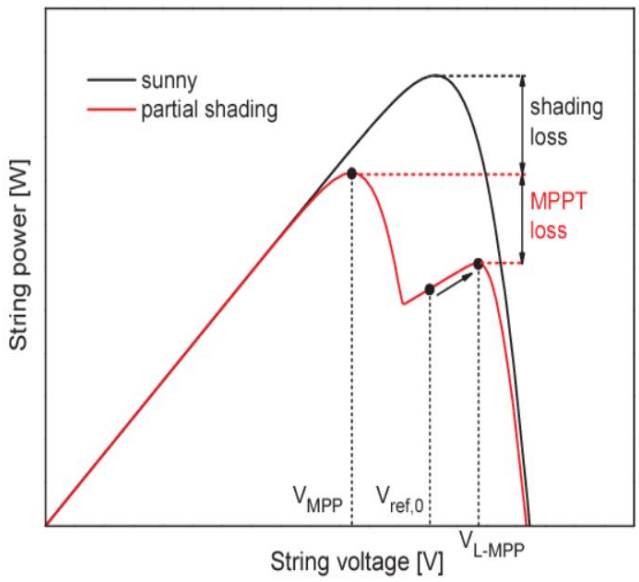
Shading loss occurs when PV modules are shaded by buildings, trees or other objects in proximity to PV modules. Since the output current of the PV module is a function of solar irradiance, a reduction in solar irradiance as a result of partial or complete shading will affect the performance of the PV module. The PV system is troubled with a weakness of nonlinearity between current and voltage under partially shaded condition. According to statistic studies the power loss can vary from 10% to 70% due to PS .

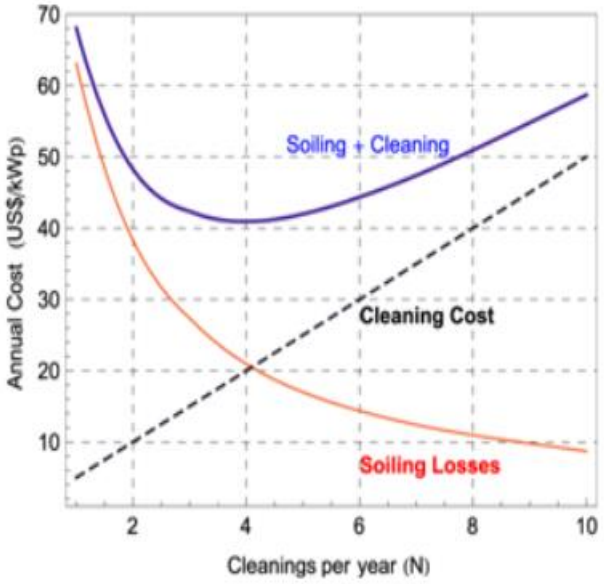
Soiling losses

Soiling losses refer to loss in power resulting from snow, dirt, dust and other particles that cover the surface of the PV module. Dust is a thin layer that covers the surface of the solar array, and the typical dust particles are less than 10 µm in diameter but this depends on the location and its environment. Dust is generated from many sources such as pollution by wind, pedestrian volcanic eruptions, and vehicular movements among many others. The accumulated dust over time aggravates the soiling effect. In fact, the amount of accumulated dust on the surface of the PV module affects the overall energy delivered from the PV module on a daily, monthly, seasonal and annual basis.

Effect on solar panel due to soiling

- **Degraded Panel Output:** Dust and soil accumulated on the panel will cover the **PV cells** under it. This will bring down both the voltage and current output of the panels. On the other hand, soft soiling will not have any observed effect on the voltage but will affect the current output of the panels. The combined result of this decrease in the current and voltage will be reduced power output of the panel.
- **Damage to The Panels: Hard soiling** due to deposition of dust particles and soil will also result in hard depositions on the panel near its frame, often called as cementing. As a result of this, the panel might get damaged permanently.
- **Economic Consequences:** The reduced power output of the panel will lead to reduced power generation from the plant. If remains neglected for longer periods, soiling can significantly bring down the quantum of every generated from the solar plant. This decrement will also lead to payment of deviation charges causing further financial losses.





Problem analysis

There is no doubt that the solar energy is an indispensable source of energy for many reasons, including development of material science, cost increase of the bio-fuel, global warming and more. The establishment of a productive PV solar farm needs a vast open land area to install. This area could be on mountain slopes, floated on the lakes, or any odd land, but even with a flat land, it needs a hard work for monitoring and controlling the performance of all these very large numbers of individual panels. Checking of each PV panel in the farm will be a major problem, especially in areas that are hardly affected by soiling. Soiling could affect all the panels in the solar farm or could affect some individual once, but in both cases the power production capability will certainly be decreased even if the PV panels are connected in series or in parallel.

The global formula to estimate the electricity generated in output of a photovoltaic system is

E = A * r * H * PR

E = Energy (kWh)
A = Total solar panel Area (m2)
r = solar panel yield or efficiency(%)
H = Annual average solar radiation on tilted panels (shadings not included)
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value =0.75)

r is the yield of the solar panel given by the ratio : electrical power (in kW) of one solar panel divided by the area of one panel.

H is the annual average solar radiation on tilted panels

PR: PR (Performance Ratio) is a very important value to evaluate the quality of a photovoltaic installation because it gives the performance of the installation independently of the orientation, inclination of the panel. It includes all losses.

Detailed losses that gives the PR value (depends on the site, the technology, and sizing of the system):

- Inverter losses (4% to 10 %)
- Temperature losses (5% to 20%)
- DC cables losses (1 to 3 %)
- AC cables losses (1 to 3 %)
- Shadings (0 % to 80%)
- Losses at weak radiation (3% to 7%)
- Losses due to dust, snow (2%)

Due to soiling effect the available area for energy conversion reduced, this leads to decrease in energy production. Our proposed ideas is to detect the soiling effect with the help of image processing by an IR camera attached on a unmanned aerial vehicles and the processed data will be send to the maintenance unit of that company.

Different Solutions for Detection of Dust Accumulation on Solar PV Module

The designed automatic cleaning system produces an effective, non-abrasive cleaning and avoids irregularities in the generation of power due to the deposition of dust on the solar panel. From the study it is proved that average efficiency of solar panel increases about 1.6% to 2.2% by regular cleaning.

1.Camera System for Detecting Dust and Other Deposits on Solar Panels

Smart cameras with R, G, B, and infrared for night vision, that take the picture of each panel continuously. The picture becomes input to the classification algorithm that decides real time if the panel needs cleaning or not. The classification algorithm consists of: the classification vector, the metric used, the training of the classifier, the testing of the classifier, and the classifier put into play for everyday use. At the present time use of commercial camera transmitting JPEG frames wireless to our server where the classification and storage takes place.

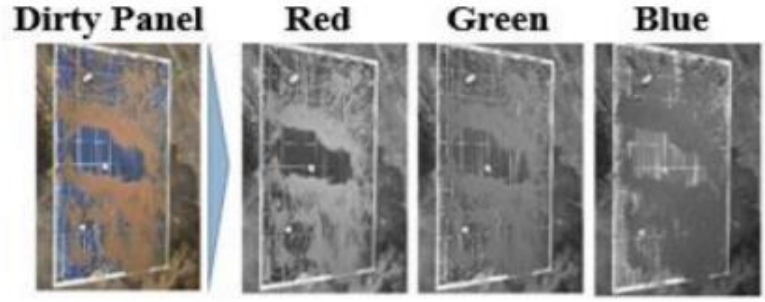


Figure 4. RGB separation layers, non-uniform dirtiness

2.Infrared sensor

First IR sensor detects the dust on panel. If the sensor gives 1 signal to microcontroller means no dust accumulated or its density does not affect solar panel performance. When it gives 0 to controller means need to remove dust by cleaning mechanism. Microcontroller take action as per programmed in uploaded in it.

3. LDR sensor

The LDR sensor is used to detect whether it is a day or night and detect dust. Depending on the solar output the presence of dust on the surface of solar is detected. If the dust is detected the wiper starts to work on the surface along with the water sprayer.

4.Image processing FLIR camera

It refers to the process in which we can modify the look and feel of an image. It basically manipulates the images and achieves the desired output. It includes conversion, sharpening, blurring, detecting surfaces, retrieval, and recognition of images.

Mathematical analysis

Mathematical equivalent circuit for photovoltaic array

The equivalent circuit of a PV cell is shown in Fig. 5. The current source I_{ph} represents the cell photocurrent. R_{sh} and R_s are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis. Practically, PV cells are grouped in larger units called PV modules and these modules are connected in series or parallel to create PV arrays which are used to generate electricity in PV generation systems.

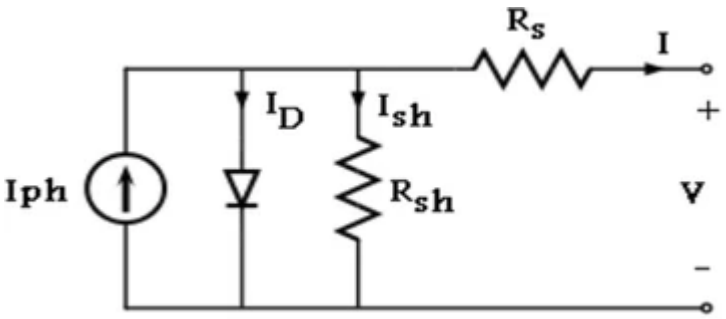


Fig 5. Circuit Diagram

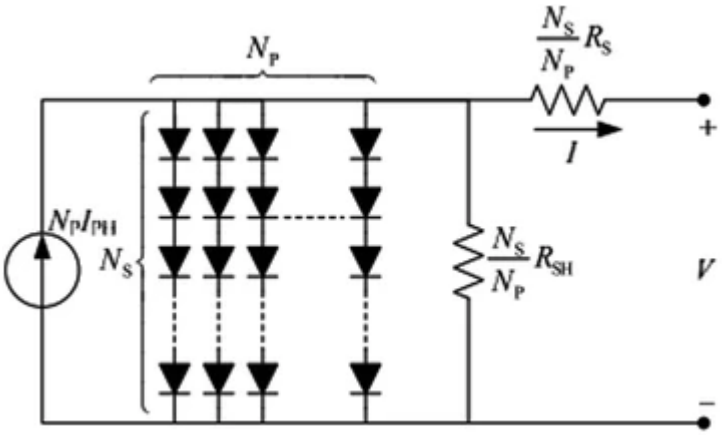


Fig 6. PV module in series and parallel combination

The voltage–current characteristic equation of a solar cell is provided as : Module photo-current I_{ph}:

$$Iph=[Isc+Ki(T-298)] \times Ir/1000 \quad (1)$$

Here, I_{ph}: photo-current (A); I_{sc}: short circuit current (A) ; K_i: short-circuit current of cell at 25 °C and 1000 W/m^2; T: operating temperature (K); Ir: solar irradiation (W/m^2).

Module reverse saturation current I_{rs}:

$$Irs=Isc/[exp(qVOC/NSknT) -1] \quad (2)$$

Here, q: electron charge, = 1.6×10^{-19}C; V_{oc}: open circuit voltage (V); N_s: number of cells connected in series; n: the ideality factor of the diode; k: Boltzmann's constant, = 1.3805×10^{-23} J/K.

The module saturation current I_0 varies with the cell temperature, which is given by:

$$I0=Irs[TTr]3exp[q\times Eg0nk(1T-1Tr)] \quad (3)$$

Here, T_r: nominal temperature = 298.15 K; E_{g0}: band gap energy of the semiconductor, = 1.1 eV; The current output of PV module is:

$$I=NP\times Iph-NP\times I0\times[exp(V/NS+I\times Rs/NPn\times Vt) -1] -Ish \quad (4)$$

With

$$Vt=k\times Tq \quad (5)$$

and

$$Ish=V\times NP/NS+I\times RSRsh \quad (6)$$

Here: N_p: number of PV modules connected in parallel; R_s: series resistance (Ω); R_{sh}: shunt resistance (Ω); V_t: diode thermal voltage (V).

Development of solution

- **Principle of quadcopter**

Quadcopter is a device with an intense mixture of Electronics, Mechanical and mainly working on the aerodynamic principle. According to Sir Cayley 4 principal forces are required to operating the plane in flight are schematized on the figure below. Two of these forces are generated by the relative movement of the air compared to the plane. The first one is the lift force and his force is directed upwards and is acting perpendicular to the displacement of the plane. The second is the drag force and it is exerted in the direction opposed to the displacement of the plane. It is due to the breaking action of the air on the plane and is opposed to the advance of the plane. The lift and the drag are called aerodynamic forces because they are resulting from the action of the air due to the displacement of the airplane. The force due to gravity, the weight of the plane, is opposed to the lift. The balance of the lift and the weight leads to the fact that the plane is maintained at constant altitude. To ensure that the plane continues to move forward, it is necessary to provide a force that compensates for the force called drag. This force is called the thrust. The thrust is generated by the system of propulsion of the planes, the engines. In the case of the flight at cruising speed, the role of the engine is thus to compensate for the force of drag, but not to make the plane climb. On the other hand, at the time of take-off, the engine power will be used to bring the plane to the altitude of flight. To keep the plane in flight at constant altitude, a force of lift must balance the force due to gravity (weight of the plane). FIG: Forces acting on a flying plan On the other hand, at the time of take-off, the engine power will be used to bring the plane to the altitude of flight. To keep the plane in flight at constant altitude, a force of lift must balance the force due to gravity (weight of the plane).

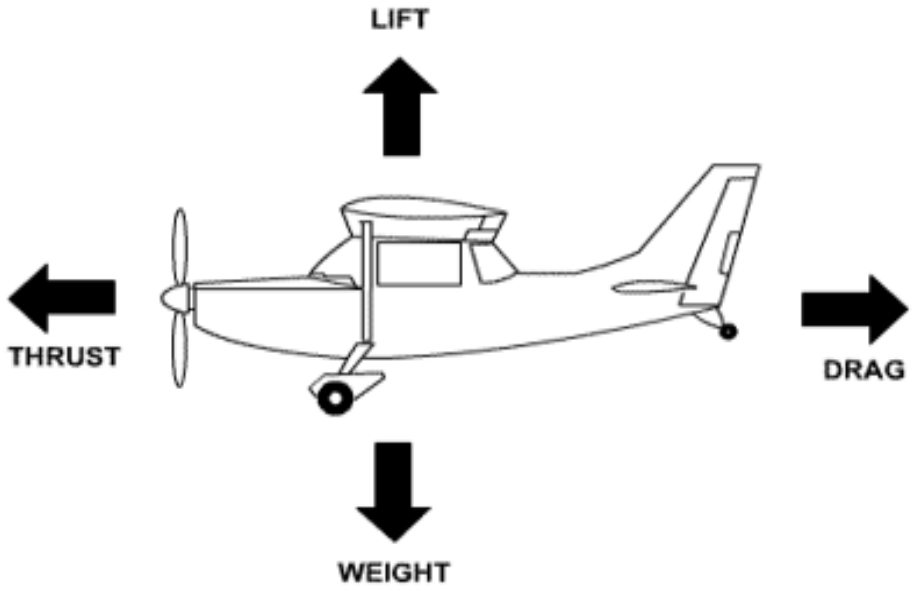
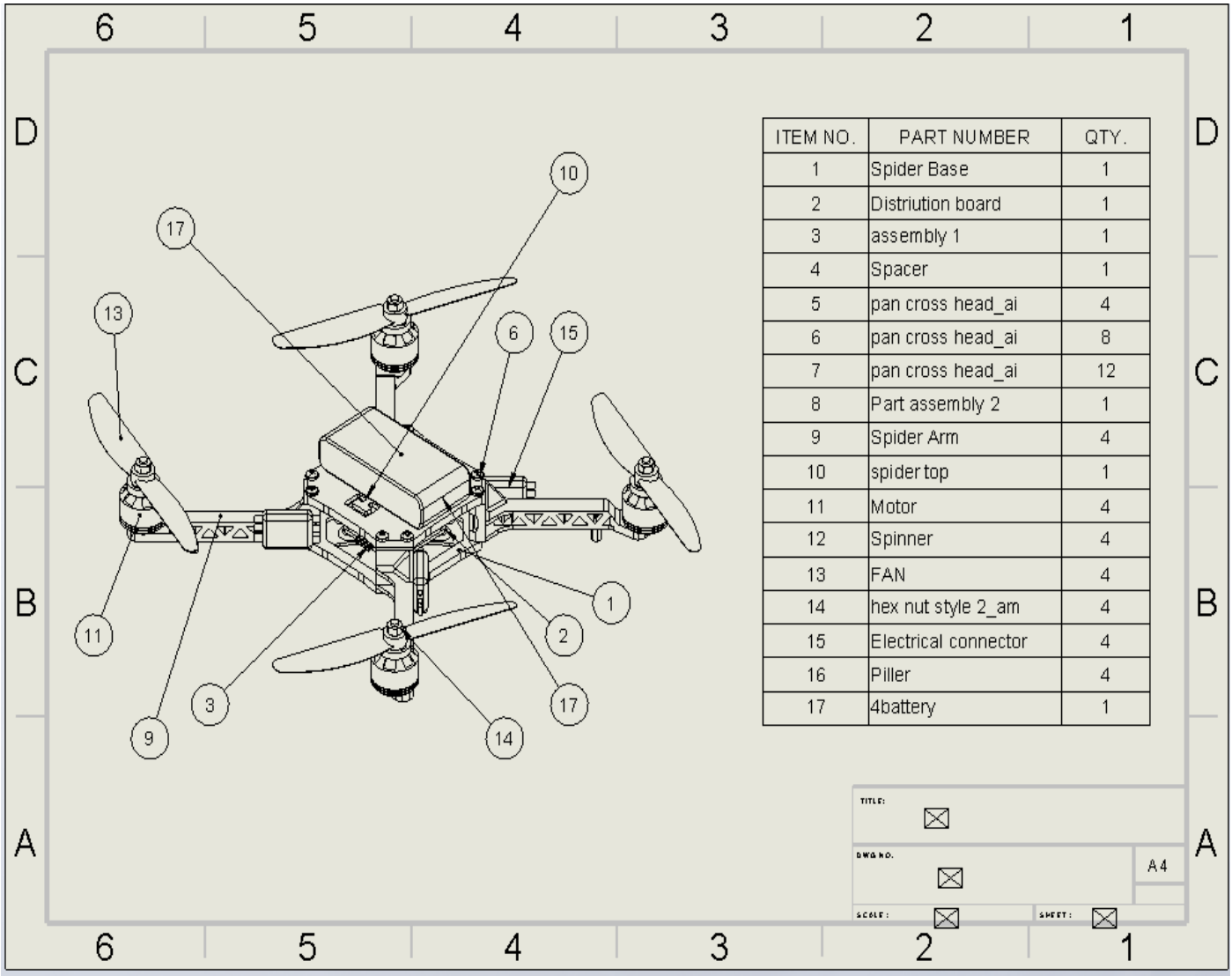


Fig 7. Forces acting on a aircraft

Construction

Quadrotor consisting of a main body having four arms centrally connected to each other and four DC brushless motor attached to each free end of arm. Quadrotor consists of four rotor/propeller attached to each motor shaft. Four rotors with fixed angles represent fixed pitch to generate equivalent force at each end to lift the body and payload. All DC brushless motors are attached to electronic speed controller to control speed of each individual motor. Four electronic speed controllers connected with each other by parallel connection in to power distribution board. A battery is used as power source. The rotation of propeller is controlled by remote controller (RC).



ITEM NO.	PART NUMBER	QTY.
1	Spider Base	1
2	Distriution board	1
3	assembly 1	1
4	Spacer	1
5	pan cross head_ai	4
6	pan cross head_ai	8
7	pan cross head_ai	12
8	Part assembly 2	1
9	Spider Arm	4
10	spider top	1
11	Motor	4
12	Spinner	4
13	FAN	4
14	hex nut style 2_am	4
15	Electrical connector	4
16	Piller	4
17	4battery	1

Fig 8. Isometric view of an unmanned Aerial vehicle

Theory

All DC brushless motor attached by parallel connection with other motors. Power distributed to power distribution board from battery. Further the power distributes equally to four electronic speed controllers and then goes in to each DC brushless motors. Accelerometers will measure the angle of Quadrotor in terms of X, Y and Z axis and accordingly adjust the RPM of each motor in order to self-stabilize by itself. The stability is provided by setting the direction of rotation clockwise of one set of opposite motors and counter-clockwise of other set of motors which nullifies the net moment and gyroscopic effects.

Quadcopter Movement Mechanism

Quadcopter can described as a small vehicle with four propellers attached to rotor located at the cross frame. This aim for fixed pitch rotors are used to control the vehicle motion. The speeds of these four rotors are independent. By independent, pitch, roll and yaw attitude of the vehicle can be control easily. Pitch, roll and yaw attitude off Quadcopter are shown in Figure.

Yaw Motion (ψ): Rotation around the vertical axis is called Yaw. The Rudder controls Yaw (Left and Right).

Pitch Motion (ɵ): Rotation around the side-to-side axis is called Pitch i.e. Moving Upside and Downside about horizontal axis. The Elevator controls the Pitch.

Roll Motion (Φ): Rotation around the front-to-back axis is called Roll i.e. Tilting about the axis. The Ailerons controls Roll axis (Left and Right).

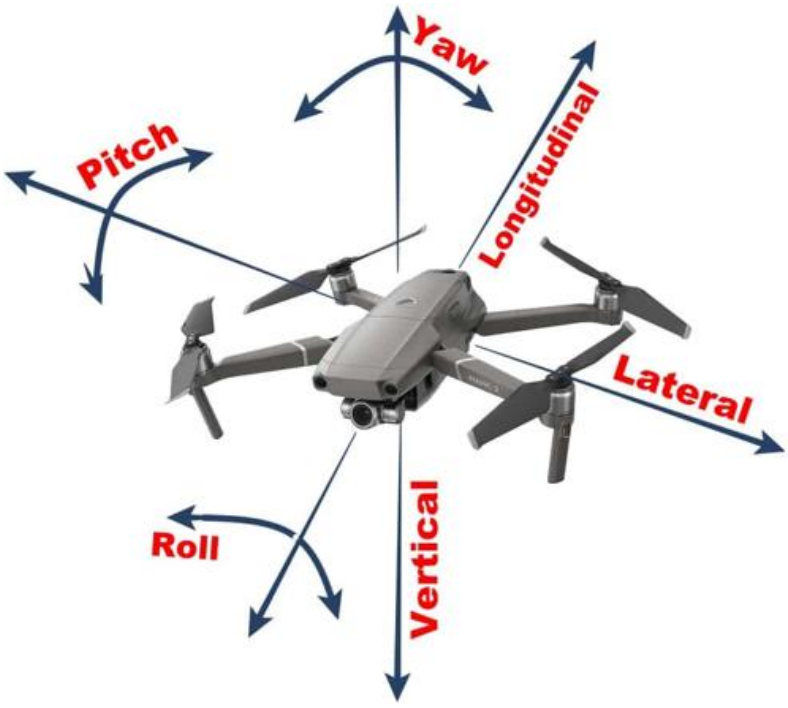


Fig 9. Different types of motion of quadcopter

Take-off and landing motion mechanism:

Take-off is movement of Quadcopter that lift up from ground to hover position and landing position is versa of take-off position. Take-off (landing) motion is control by increasing (decreasing) speed of four rotors simultaneously which means changing the vertical motion.

Forward and backward motion:

Forward (backward) motion is control by increasing (decreasing) speed of rear (front)rotor. Decreasing (increasing) rear (front) rotor speed simultaneously will affect the pitch angle of the Quadcopter.

Left and right motion :

For left and right motion, it can control by changing the yaw angle of Quadcopter. Yaw angle can control by increasing (decreasing) counter-clockwise rotors speed while decreasing (increasing) clockwise rotor speed.

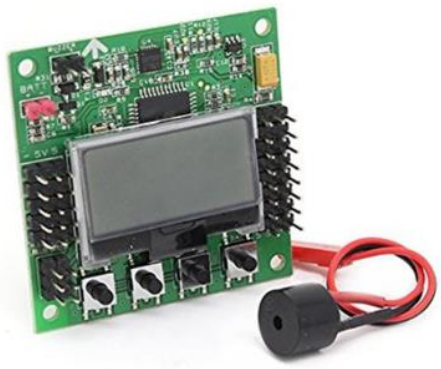
Hovering or static position :

The hovering or static position of Quadcopter is done by two pairs of rotors are rotating in clockwise and counter clockwise respectively with same speed. By two rotors rotating in clockwise and counter-clockwise position, the total sum of reaction torque is zero and this allowed Quadcopter in hovering position.

Components

Flight Controller:

The flight control board is the “brain” of the Quadcopter. It houses the sensors such as gyroscopes and accelerometers that determine how fast each of the Quadcopter’s motors spin. Flight control boards range from simple to highly complex. This Flight controller KK 2.1.5 is the latest one and program is pre-installed in it. The flight control board is regarded as the “brain” of the Quadcopter. Flight control boards range from simple to highly complex.



Battery (LiPo):

Lithium polymer batteries (LiPo) are most popular for powering Remote control aircraft due to its light weight, energy density, longer run times and ability to be recharged. We selected zippy 4000mah, 3.7 V battery.

DC Brushless Motor:

This is a high-power motor with excellent efficiency. Motors are rated by kilovolts, and the higher the kV rating, the faster the motor spins at a constant voltage. The purpose of motors is to spin the propellers. Brushless DC motors provide the necessary thrust to propel the craft. We use motor with specifications: Model:BR2630 (1050KV)

Propellers:

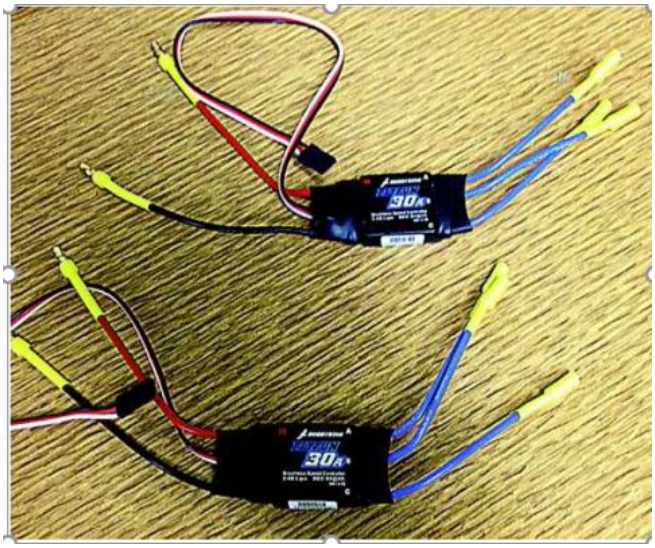
We are using two types of propeller Pushers and Pullers.

Pushers:

Pushers give thrust when they are rotated in clockwise direction. Pullers: Pullers give thrust when they are rotated in anticlockwise direction. The propellers come in different diameters and pitches (tilting effect). The larger diameter and pitch is the more thrust the propeller can generate. It also requires more power to drive it, but it will be able to lift more weight. When using high RPM (Revolutions per minute) motors, the smaller or mid-sized propellers. When using low RPM motors, the larger propellers can be used as there could be trouble with the small ones not being able to lift the Quadcopter at low speed.

Electronic Speed Controller (ESC):

The electronic speed controller controls the speed of the motor or tells the motors how fast to spin at a given time. For a quadcopter, 4 ESCs are needed, one connected to each motor. The ESCs are then connected directly to the battery through either a wiring harness or power distribution board. Electronic Speed Controller (ESC) is an electronic circuit to vary the speed, direction and possible to act as a dynamic brake, of a brushless Motor. The maximum current flowing in the ESC is in between the range 30-40 ampere.



Transmitter & Receiver:

This transmitter can be used on any of your planes and with a LCD display screen you can now program the radio at the field and no more to carry your laptop to the field to change any setting. The RCB6i has all the features and more than any high end radio but at a fraction of cost.

Image processing concepts

Segmentation

The segmentation principle which showed that the human vision performs groupings based on the similarity and continuity of the captured images. These groupings were the motivation of segmentation studies that extended the concept computationally. Search algorithms used to find edges, textures, patterns or differences. In this work we use the Gonzales taxonomy which classifies the methods in three major areas: Thresholding, edge detection and Region-based detection. It can be said mathematically that the constitution methods segmentation follows:

$$\bigcup_{i=1}^{Rn} R_i = R \quad (1)$$

Being R1, R2, R3 divisions performed in the image and R the complete image given by region summation. The same inference can be made by edges which give us the main edge as the result obtained by summation of minor edges.

Thresholding

This process consists in the object segmentation based on intensity levels, taking all pixels belonging to a level as a distinct object. In other words, the segmented region is classified if it belongs to a certain region level, it can be said mathematically as follows

$$S_{i,j} = k \quad \text{If} \quad T_{k-1} \leq f(i,j) \leq T_k \quad (2)$$

Where **S** i, j the selected is object and **T**1**, T**2**, T**3**....T**m are the thresholding values. The most intuitive method is based on manual tries and observations of results and can also be reached by making use of histograms. The histogram shows the number of pixels present in the image for each intensity light level, so that for a distinct image with homogeneous and distinct background it is presented a bimodal histogram with a valley. The regions can be separated in background and front, which have distinct intensity levels separated by the valley. In this way it is possible to perform the selections based on the histogram valleys, first coming from the valley analysis and following by spacing the valley with Otsu's method, which insure the maximum variance.

Edge Segmentation

The edge segmentation methods occur where there is an abrupt grey level variation. Once the process is done, it is necessary to fill the area between these points. The process that performs this task is called linking algorithm and uses more complex math to achieve its goal. When the intensity varies abruptly, the algorithm uses differential operators to make the detection, given that in one discontinuity the differential value skyrockets. The gradient method can be showed mathematically as:

$$\nabla f(x,y) = G[(x,y)] = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \partial f /_{\partial x} \\ \partial f /_{\partial y} \end{bmatrix} \quad (4)$$

The module and direction by:

$$|G[f(x,y)]| = \sqrt{G_x^2 + G_y^2} \quad (5)$$

$$\theta(x,y) = arctan\left(\frac{G_y}{G_x}\right) \quad (6)$$

Linking Algorithms:

The linking algorithms can produce vectorial contours by highlight the edges, that is, first an algorithm for abrupt detection is used and each abrupt detection is made and highlighted. Knowing that images can have noise, it is not common to achieve perfect edge detection, but reasonable results can be obtained. Then the linking methods are applied in order to fill the discontinuities in those edges. The most known methods are the Hough transform and the path finding graph. Local Processing: One of the simplest approaches for linking edges points is to analyse the characteristics of pixels in a small neighbourhood and select all points that are similar according to a set of predefined criteria. In a grey scale, we can say that objects can only belong to a same type if they are presented in the same range of grey level criteria. The edge is found by the difference in the values of pixels (threshold), if the mean value from the levels in this edge doesn't differ too much amongst themselves, the code finds the edge. It can be said mathematically as follows:

$$|G[f(x,y)]| - |G[f(x',y')]| \leq T \quad (7)$$

The difference between a point and its neighbour needs to be smaller than a predefined value. This calculation is made in a small neighbourhood with connectivity 3x3, 5x5 or other by the analyst choice. A good point to add is the possibility to reduce computational cost by changing the coordinate system with acquisition of a gradient angle to a vectorized system. The Hough method is used in order to achieve specific contours inside the image, as a straight, circle or ellipse, and make the coordinate system polynomial, in order to achieve the form that better adapts to the region. The path finding graph method is in general more complicated, with more processing time, but with better results in a noisy ambient. The method consists in the choice of graphs with the smaller computational cost, by testing all the viable paths as every graph is a combination of vertices and arcs.

Region Segmentation

While thresholding and edge detection find differences between pixels, the region segmentation is more focused in the similarities in the regions. The Region Growing technique is the most well-known approach and is the major tool in many publications in the state of the art. Its proposal is to joint pixels with the same characteristics, as intensity grey level, texture, colour, etc. It can be consisted as the mean calculation of every pixel in the image considering each pixel in the same neighbourhood and going forward with the actualization of this calculus. The main goal is to verify which pixels have the same mean expected, that is, the difference between the pixel intensity and the mean neighbourhood must be less than a critical value, called threshold. This is made by grouping the same tons of colour, but the process can be made with other specifications. The output mask is made by marking the points which are in the same region, which is then applied in the selected image. The mask composes the Region of Interest (ROI), the main goal from region segmentation algorithm.

Implementation

Uniform Dirtiness: The objective of this method is to expand small regions of pixels into bigger ones. The focus was in the region covered by one type of dirtiness. This approach tries to achieve a worst-case scenario in uniform deposition occurring by time in PV panels. First there are a set of seeds that search for a common characteristic, in this case scale grey level. The pixels which have the same tons are grouped together making the ROI. We created an image database varying the wet sand applicated over a photovoltaic solar panel in the horizontal position on the ground so the sand wouldn't slide. We repeated this process until obtaining a scale of dirtiness, as if it was achieved through a long period of time with real dirtiness exposure. Considering the colour of the ground having grey level intensity similar to the dirtiness over the panel, the method considered just the intensity from dirtiness. Seeds were thrown and grew over the dirtiness making a direct identifying. It was made a pre-processing using the median filter of size 3x3, which doesn't influence the edge detection, but uniformizes the inside of the regions increasing the precision of segmentation. The first analysis is performed with the application of region growing algorithm, where is obtained a "mask", the region of interest to be used in the original image. There was a need to create a double matrix for the image and the method was applied by channel, that is, Red, Green and Blue. In this way, every layer from the image could be concatenated, generating three histograms to be analysed at chapter Tests. The histogram is taken by the grown dirtiness, so with more dirtiness the mask gets amplified, letting more dirtiness in the mask and thus, increases the histograms. It can be verified that with more dirtiness, the amplitude of the channels on the histograms will be higher.

Non-Uniform: Considering the non-uniform dirtiness distribution over the photovoltaic solar panel, we applied more wet sand, threw more water and some stones, representing the worst non-uniform scenario. Once again, we use sand as the dirtiness type and we analyse the recognition of the covered area. For this method the region growing technique had difficulties, because the growing stops when another region is achieved. Just throwing a seed in the centre does not guarantee success as in the first method. Beside this, the ground is like the dirtiness, taking this information we used the data corresponding to the layers RGB.

For this new method, the red layer was used, like before. In the image we initialize some seeds, these seeds grew up and returned the regions. We sorted the regions and took the predominant two areas.

Punctual Dirtiness: In some residential areas especially, there are quite a few quantities of heavy particles in the air. It is common for solar panel to be afflicted by bird dropping, or the amount caused by time stacked with hard attraction in the particles making some types of circular draws as showed by Figure 4, a real photovoltaic solar panel dirty by the time. For localization of these punctual dirtiness we propose the Hough algorithm, which performs a calculation in neighbourhood pixels looking for a ratio that constitutes a full circle. If this ratio exists the method highlights the region, finding the circular area. If the ratio is not found, the next pixel is analysed.

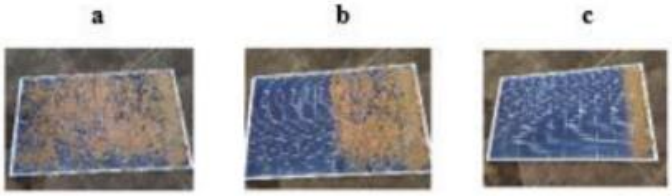


Fig 9. Level of Dirtiness

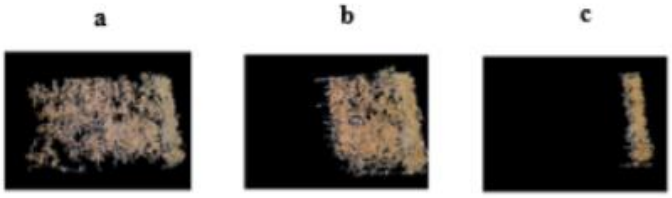


Fig 10. Image obtained by Image processing

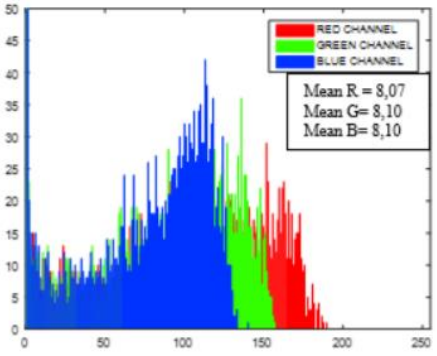
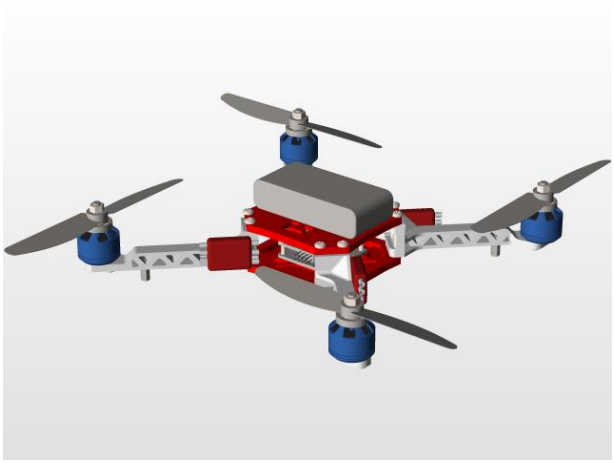
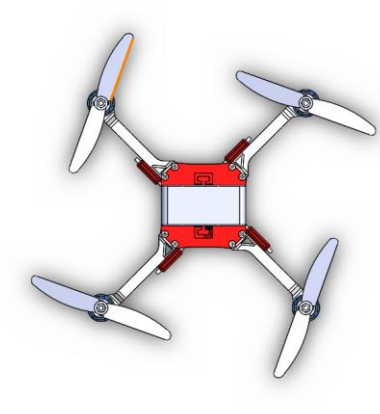


Fig 11. First panel(A) high level of dirtiness

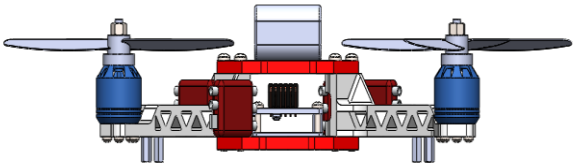
Final Product



DESIGNED PRODUCT



TOP VIEW OF UAV



FRONT VIEW OF UAV

FLIR CAMERA

WORKING MODEL

Budget Estimation

Sl no.	Component names	No of units	Price
1	DC brushless motor	4	2000/-
2	Flight controller	1	1500/-
3	Electronics speed controller	4	1000/-
4	Battery LiPo	1	2500/-
5	Transmitter and receiver	1	1500/-
6	FLIR camera	1	2500/-
7	Other parts		1000/-

GRAND TOTAL= 12000/-

Conclusion

Solar panels in the arid climates produce a great deal of energy because the sun shines either throughout the year, or close to 350 days of the year. Sandstorms, small animals, and birds, depositing their droppings are responsible for the reduction of the energy produced by the panels.

Here we introduced an algorithm that takes as input the panel picture and decides if the panel is clean or needs cleaning. By the use of FLIR camera attached with the drone the high quality pictures can be taken. So far our classification algorithm seems to be working. As the panels get dusty or subjected to bird droppings but they do not have enough deposits to pass our cut off point we see that the energy drop is within the normal fluctuation energy of clean panels. As they get dustier to the limit point that has been set for detection then we see that there is enough drop in energy that by investing some energy to clean the panel will increase the energy output enough so that we can recover the energy invested by the panel within a few hours and have an energy gain until the next cleaning is required. The mean time between cleaning could be several months or less than a day depending on the weather conditions, the day of the month, the month of the year, and even the sun spot periodicity.

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