Cloud Images Capturing System for Solar Power Level Prediction

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***Abstract*—Solar energy has received increasing attention as one of the potential renewable energy sources for power generation in recent past. Introduction of Net Metering and the increment in provision for renewables encouraged the usage of Solar PV systems in Sri Lanka. However, the intermittent nature of solar energy has become one of the barriers for solar energy based power to be integrated to the national power grids. Due to unpredictability solar energy based power plants are non-dispatchable and can cause network instability. With an efficient and reasonably accurate predictable model, a better system balance can be achieved. Shadowing on solar PV modules results in reduction of power produced. Cloud coverage blocking the sun can be identified as the major contributor in shadowing. Identifying and tracking the clouds can be used to finally predict the solar PV output. This paper presents a methodology to obtain cloud image data and an algorithm to process the images which can be used to predict the relationship between the cloud movements and the solar PV output.**

Keywords—solar tracking; camera protection system; cloud detection; image processing; OpenCV

I. Introduction

With the rapid growth of electricity demand in Sri Lanka, it is evident that Sri Lanka needs to enhance capacity for more power generation methodologies. According to the national energy policy, it is expected to integrate 20% renewable energy by 2020 [1]. As Sri Lanka is a tropical country with bright sunny weather throughout the year, solar energy is identified as one of the highest potential energy sources for power generation. Unlike steam turbines or hydro turbines, solar PV systems produce power in an intermittent nature. Due to this reason grid connected solar PV plants often increases interferences with the network stability [2]. At small quantities this may go unnoticed or even ignored as it can be balanced off by the system inertia and the reserved margin. But if the chunk of power that is either added or reduced from the system could lead to system instability.

When considering the current trend of installing grid connected solar PV systems at present, it shows an exponential growth. And it is forecasted to even increase more by 2020. With the introduction of net metering in early 2008, many domestic users have initiated to produce power using roof mounted solar PV systems. Though the intermittent nature of single units can be ignored, the accumulated numbers cannot be ignored. In Colombo and suburbs the households that have already installed solar PV systems have increased rapidly. Also those who are willing to install them are on the rise. This can cause system instability and problems in the power plant dispatching.

Therefore, solar prediction methods can be used for power plant dispatch scheduling and thus to avoid system instability due to solar intermittency [3]. An efficient forecasting method will help the grid operators to better manage the power balance between the demand and the power generation.

It was found that the power output of a solar PV module is directly proportional to the amount of solar irradiation incident upon the surface of the solar panel [4]. The power output decreases when the solar panel is shaded. Clouds can be considered as the major component that stops the direct sun light from reaching the solar panel. If it can be predicted when and how much cloud cover is there blocking the direct sun light, then it is possible to predict how much power output will be given from the solar panel [5].

Therefore, the major objectives of the research are to predict the cloud movements in the sky and develop a relationship between the cloud movement and the power output of the solar panel. This paper proposes a method of developing a cloud movement capturing system to develop a short term prediction model for the electrical power output of a solar PV system.

A. Methodology

To achieve the objective, following methodology has been implemented.

The first and foremost task is to have a method to detect the clouds, their position and the movements. For this sky imaging from the ground level is done. To achieve this, a camera fitted with a fish eye lens is used. By using a fish eye lens an angle of 170^{o} can be clearly captured. This gives a full image of the sky.

As the camera is kept directly under the sun during image capturing, it is necessary to construct a protection method for the camera lens. This is to prevent direct sun light incident on the lens. The glare on the lens also leads to unclear images that cannot be effectively processed. The camera protection therefore has a shadowing object above the lens directed at the sun position. The shadowing object moves with the position of the sun to cover the lens and thus delivers a clear image of the full sky.

The sky could be recorded with consecutive images at a predefined sample time. These images then are analyzed to detect clouds, their position and direction of movement. This is primarily done by computer vision analysis. OpenCV libraries are used along with Visual C++ programming. Once a stream of images is processed the next position of the clouds after a certain time interval can be predicted. The cloud imagery data and solar PV module output data are recorded simultaneously.

II. HARDWARE IMPLEMENTATION

Since the vast majority of this work depends on the cloud images, obtaining a sky image plays a vital role in this project. An acceptable imaging has to be a high resolution image, wide-angled and taken for real-time processing. In selecting suitable components to capture and fetch a sky image these main requirements were taken into consideration. In addition to that the protection of the system also matters.

A. *Sky Imaging*

Among the available technologies for such sky imaging, Total Sky Imager is one of the most commonly used equipment which is an automatic, full-color sky imager system that provides real-time processing and display of daytime sky conditions [6]. But comparatively this provides a less resolution and also due to its expensiveness and bulkier nature, managing several such systems at distinct locations would be difficult.

The requirement of the high resolution can be accomplished by using a Digital Single Lens Reflex camera through which a wide angle can be covered by fixing a fish-eye lens. But this altogether increases the expense of the work and at the same time a separate mechanism has to be used for fetching the image.

Therefore as the most convenient method, a commercially available webcam (Logitech c270) was used. In order to enhance the angle of coverage of the sky, a 170 degree fish-eye lens was attached to the webcam. A series of images are captured by this system and transferred to a processing unit by which the images are taken for real-time analyzing.

B. *Camera Protection System*

If a high lux level of light fall on a camera lens then, there is a glare occurring on the image and the sensor of the camera is damaged by the excess energy of light waves. When the camera turns towards the sky, inevitably the lens of the camera is exposed to the direct sun light and it is at the risk of getting damaged. Therefore the direct sunlight must be avoided while allowing the system to capture sharp images of the sky.

In order to block the direct sunlight, a shadowing object which is made out of a light-weighted and opaque material has been placed in between the sun and camera. A Styrofoam sphere which is large enough just to cover up the sun is held by an arm which is capable of moving freely with respect to the solar position. Usage of a thin steel wire as the arm prevents covering up considerable area of the image by the arm. Fig. 1 shows an image taken with the camera protection system.

Fig. 1. Sky Image Taken by the Sky Imaging System

The control of the arm of the camera protection system is done by the servo motors which are much accurate and easier to manage compared to a mechanism of motor controllers with a feedback system. Control signals for the servo motors are sent by the microcontroller system shown in Fig. 2.

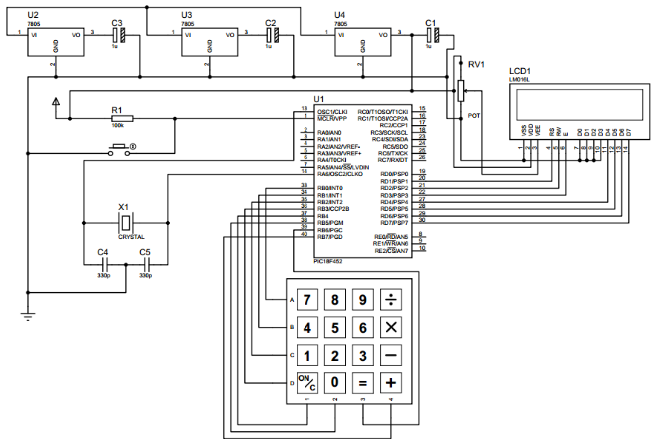

Fig. 2. Circuit Diagram of the motor controller

a) Solar Position Algorithm

The shadowing object follows the solar path so that it is in line with the sun at any given time blocking the direct sun light. Several methodologies exist for accurate solar tracking out of which Solar Position Algorithm (SPA) is a well-established method in finding solar path in two coordinates on celestial sphere. Solar Position Algorithm was developed by NREL (National Renewable Energy Laboratory) in America [7]. Date, time, location in longitude and latitude, time zone, elevation, pressure, temperature, slope, azimuth rotation, atmospheric refraction are taken as the inputs, thus the solar position is given in zenith angle, the angle which is from the zenith (θ in Fig. 3) and in azimuth angle, the angle which is from the North in clockwise direction (φ in Fig. 3). These values are calculated through a processing unit by considering the system time which is as same as the Coordinated Universal Time.

b) Internal Communication

The zenith and azimuth values calculated by the Solar Position Algorithm are fed into the microcontroller through Serial Port Communication.

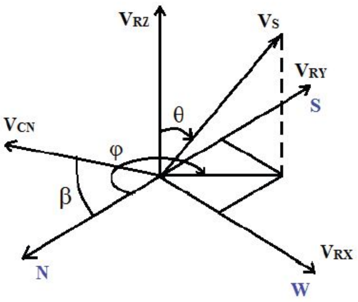

Fig. 3. Coordinate System for Solar Position Algorithm

c) Two Servo Motor Mechanism

In order to position the shadowing object, two servo motors are used with an arm connected to each motor to rotate in 3-Dimentional space. Zenith and azimuth values are taken in such a way that they are directly proportional to the servo angles of each arm respectively. Since the servo motors cover only a range of 180 degrees, algorithm has been modified so that at a certain time the calculated zenith values are reversed and fed into the microcontroller. With this mechanism all the positions of the top hemisphere can be accurately obtained by the shadowing object.

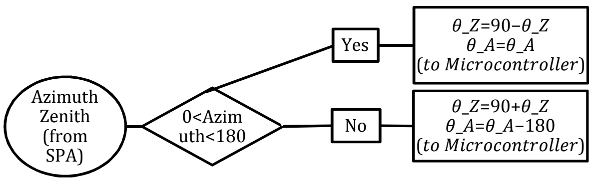

Fig. 4. Arm Positioning Algorithm

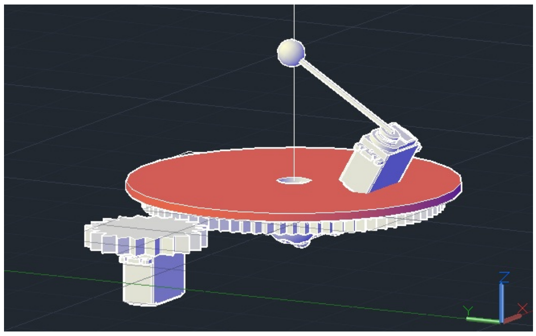

Fig. 5. Solar Tracker

III. IMAGE PROCESSING

A. Programming with OpenCV

Once an image of the sky is obtained the image should be processed to extract the necessary information. A computer vision technique is used to process the image. For the computer vision implementation two image processing tools were identified, Matlab® and OpenCV (Open source computer vision). OpenCV is a set of libraries which can be used in any platform while Matlab® requires specific resources. In both techniques, the image is stored as a three dimension matrix with the RGB distribution of each pixel. With the intention of developing a standalone system, OpenCV is used as the image processing tool.

B. Cloud identification

The requirement of the image processing is to identify and segment clouds and to determine the speed vector of the clouds. First step is the segmentation of clouds.

To achieve that, color based segmentation is used. Input image for the program is an RGB image. For a given color, RGB variation shows a non-liner pattern. To avoid that input image can be converted to another format such as HSV and then segmentation is implemented. The segmentation base for clouds and sky must be identified based on a statistical process. An example of cloud segmentation is shown in Fig. 6. Once the clouds and the sky are segmented a mathematical approach is required to determine the geometry of clouds.

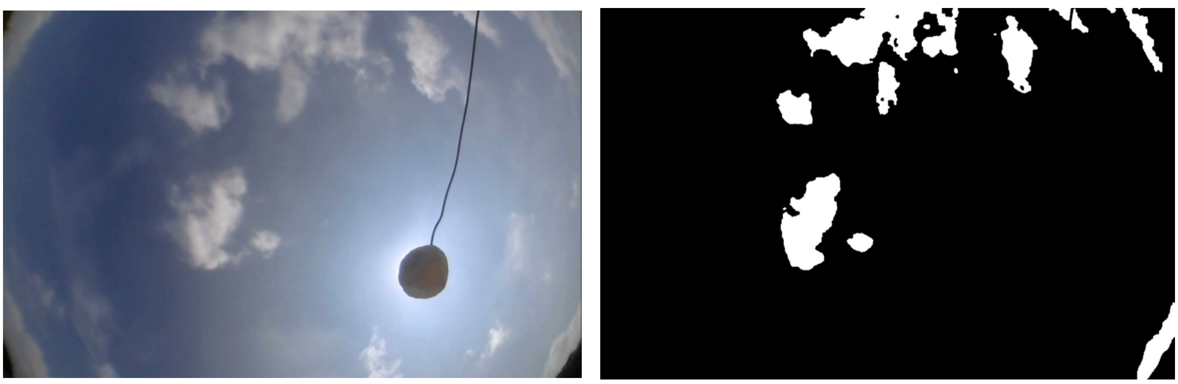

Image captured by camera

Binary image

Fig. 6. Identifying clouds using segmentation

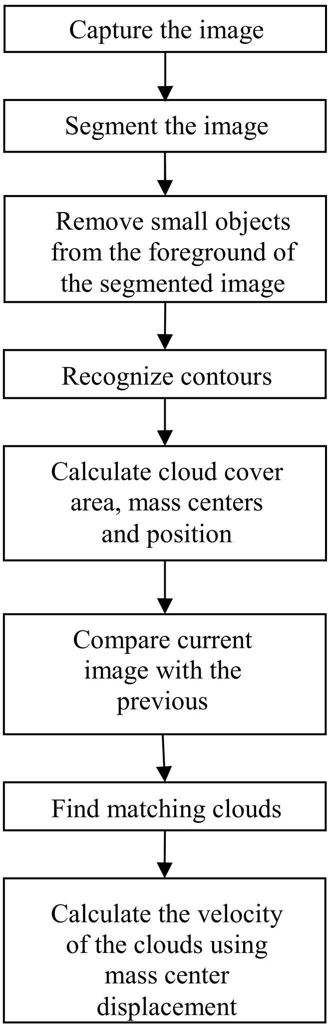

Fig. 7. Computer Vision Algorithm

The contour approach is used to achieve this task. The output of the segmentation function is a binary image and the contours of the segmented binary image can be identified. The contours of the image are stored as a set of 2-D points. Number of geometrical features such as area, arc length and mass center can be calculated based on the points.

There are two restrictions at this stage. One is the small contours on the image and the other is overlapping contours. A threshold value is introduced for the cloud area to identify small contours which can be neglected in the process. Contours that fall below the threshold value of area are deleted. These small contours do not affect the shade of the solar panel and the threshold value is obtained heuristically. To distinguish overlapping contours a method called watershed algorithm is used. The resultant contours are stored in a vector with an index to recognize each cloud. One of the identified contours is highlighted in Fig. 8s.

Then the next image is loaded to the system and with the same process the contours of the second image is also obtained.

C. Matching of clouds and detection of speed vectors

The two consecutive images are compared to identify the same clouds which might be at a different location. To match the clouds moment, following algorithm is used.

Match value of contour A and B is given by;

$$I(A,B) = \sum_{i=1}^{7} \left| m_i^A - m_i^B \right| \tag{1}$$

Where $m_i^A = sign(h_i^A).\log h_i^A$

$h_i^A = Hu\ moment\ of\ A$

Once the clouds are matched clouds on the second image is arranged according to the matching clouds of the second image. Some clouds may be out of the picture and those cloud indices will be left as empty. The time between two successive images can be found through the programme. The speed of the cloud is calculated from the variation in the mass center. Mass centers of same cloud in two instants are shown in Fig. 9.

$$\bar{v} = \frac{d\bar{r}}{dt} \tag{2}$$

Where $\bar{r} = (x, y)$

Segmented binary image

Contour drawn around a detected cloud

Fig. 8. Finding Contours

Position of cloud at time t1 Position of cloud at time t2

Fig. 9.Mass Centers in two instants

The vector $\bar{r}$ is the coordinates of the mass center of a cloud of which the speed is needed to be determined. Since the sampling time is in milliseconds region, velocity can be approximated as,

$$\bar{v} = \frac{\bar{r}_2 - \bar{r}_1}{\Delta t} \quad (3)$$

where Δt is the sampling time.

The speed vectors of the clouds are stored in a vector with corresponding index of the cloud. Current speed vector is compared with the cumulative average speed and if the speed has changed with a reasonable percentage, current speed is set as the new speed and otherwise the average speed is set as the speed of the cloud. Based on the speed vector of the cloud the position of the cloud after a certain period of time can be predicted with high confidence margin.

The position of the sun is taken from the SPA algorithm and whether a cloud reaches the solar position at a given time can be estimated with this method. Since the cloud is stored as a set of points, the amount of coverage can be predicted by projecting the current set of points with the speed vector. Extracted data and a sample calculation of speed are shown in table 1.

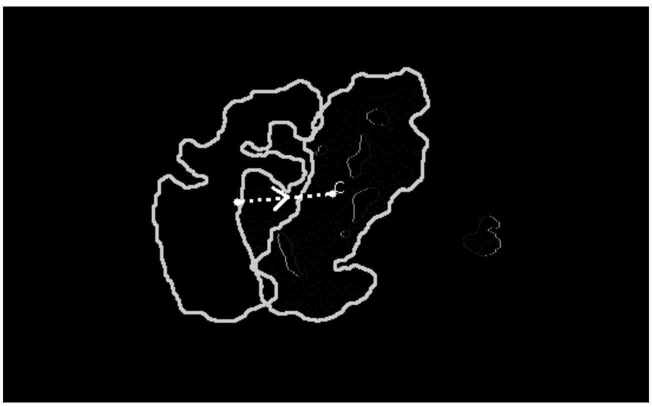

Fig. 10. Path of the cloud determined using the displacement of mass center

TABLE 1.ACQUIRED DATA

Image index	Area	Mass center	Match value	Time (s)	Velocity
0	8052.5	300.47,449.59	-	0	0,0
1	8328.5	304.185,449.333	0.109	1	3.718,0.737
2	8532.0	308.428,449.023	0.117	2	4.243,0.690

Note: All the values are in pixels except time.

IV. SUMMARY AND CONCLUSION

A hardware system has been developed to obtain cloud data and an algorithm to process the images was successfully developed. The system is capable of capturing real time images of the full sky. Software implementation is done to identify clouds, find the speed vectors and to track the path of the clouds. Speed vectors of the clouds are detectable with high accuracy.

This system can be used to obtain data to develop a statistical relationship between cloud movements and solar power output. A regression model to predict the solar power output can be statistically obtained by analyzing above data.

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