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Solar Tracking System for Efficient Power Generation using Image Processing

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Abstract: The emerging era is energy demanding and there is a drastic need to shift to more eco-friendly methods for power generation. The non-renewable resources generate 86% of the world's power. Around the world, coal and gas power plants are shutting down due to lack of fuel. With more and more industries and governments joining the Green Movement, the demand for cost effective renewable energy has surged. Solar power can be easily harnessed as compared to other eco-friendly methods, using solar panels and the conventional process of converting solar energy to electrical energy. Even though solar power is used in domestic as well as industrial applications, it is still a long way from making an impact on environmental change. Since solar panels can only be utilized up to their full potential in clear sky and sunny conditions, its usage is affected by geographic location. However, even in conditions of optimal usage, it's not used up to its full potential. As all solar panels are fixed due sunny side, they receive direct sunlight only for half a day. During the other half, the sun is behind the panels and hence, the power generation drops steadily.

To rectify this, we introduce the principle used by sunflowers. Sunflowers intake energy by following the sun from sunrise till sunset. Using the same concept, we make the panels follow the sun resulting in significant increase in energy production. We take images of the sun throughout the day, using image processing make sure that the sun is directly incident to the panels, follow this procedure till sunset. This method makes sure that even in conditions of slight to moderate overcast weather, the sun will be directly incident on panels, such is the power of image processing. The status of the device as well as energy generated can be easily visualized using the mobile application provided. The system can further be made cost effective by modifying the existing panels.

The concept is simple yet very efficient, robust and scalable. This method can be used for domestic as well as industrial applications. In optimal conditions, this method can generate up to 40% more energy than a conventional solar panel system of the same size. In conclusion, just by learning from nature, using only a gearbox and controller in addition to panels, we can generate significantly more electricity. In addition to this method, using most efficient solar panels that give maximum power output even in overcast conditions can further increase power output.

Keywords: Border Tracing, Sun Detection, Sun Tracking, Offset Correction, Solar Panel Efficiency.

I. INTRODUCTION

Renewable energy resources pass almost 15% of the total world energy demand. It includes biomass, hydropower, geothermal, solar, wind and tidal energy. In all of this, our concentration is solar energy which is reachable in both forms, direct as well as indirect. The sun sends out energy at a rate of 3.8x10^23 KW of which approximately 1.8x10^14 kW is interrupted by Earth. Solar energy can be converted into electricity with the help of photovoltaic panels. Therefore, converting this abundant amount of solar energy into electrical energy would do much good because conventional energy sources are finite & fast depleting. Solar power is used reciprocally with solar energy but refers more accurately to the conversion of sunlight into electricity by photovoltaic.

A. Overview

The 2021–2022 global energy shortage is the most recent in a series of cyclical energy shortages experienced over the last fifty years. In 2019, the global energy consumption was 170,000 TWh out of which 135,807 TWh was generated by Non-Renewable Resources while 25,468 TWh was generated by Renewable Resources. Global energy consumption continues to grow averaging around 1% to 2% per year. India experienced power outages in Uttar Pradesh, Rajasthan, Punjab, Jharkhand, Maharashtra, and Kerala as the country's coal stockpiles at power plants were dangerously low. In order to mitigate the outage, coal supplies were re-routed from industries to power plants. In October 2021, the crisis reached its peak, with 1/3 of coal power plants having less than three days of supply.

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Solar Power is a form of renewable energy that can be easily harnessed as compared to others. Solar panels have taken home on millions of people's rooftops. Solar Farms are generating tremendous amounts of energy. But Conventional solar panels still need a clear sky to output optimal amounts of energy. Some scientists have developed panels that can produce electricity even in overcast weather, however, this is not enough to power a community. In 2020, there was a plea made to Hon. Supreme Court of India to shutdown coal power plants in 11 states. Further-more, the Vehicle industry which is one of the largest consumers of energy is slowly shifting to Electric vehicles encouraging energy demand. With the governments worldwide looking for efficient power generation with minimal cost, that's where we come in.

B. Project Objective

The concept of our solution is to apply the principle used by sunflowers to solar panels, thereby making the panels follow the sun throughout the day. Conventional panels are fixed in place in the direction of clear sky. This configuration allows them to intake maximum energy only for half cycle of operation. When the sun shifts behind the panels, the energy production is reduced significantly. By adding sun tracking to conventional solar panels, we can produce approx. 40% more energy.

C. Application

The concept can be used in any location with a clear sky and directly incident sunrays. By using existing panels, we can reduce setup costs to make it more affordable for domestic usage. Using this same solution in solar power plants will significantly increase the power output. This setup can also be used in narrow spaces where only 1-2 panel space is available.

II. DESIGN AND PROPOSED WORK

A. Problem Definition

In the Era of Industry 4.0, power generation is a key problem. Eco – friendly power generation methods struggle to keep up with the growing energy demands. Solar Panels have helped in industrial and home power generation. But the traditional stationary design drawbacks have finally caught up, leading to ~40% wastage of energy. The stationary panels also have space restrictions. Being the most affordable and easily implementable eco power generation method these drawbacks must be nullified. The previously mentioned drawbacks can be nullified by improving the performance output of a conventional solar panel system. This can be achieved by covering the ~40% lost energy. The following sections discuss about the same in detail.

B. Problem Specification

1) *Energy Capturing:* Our device will consist of a set of 4 solar panels connected parallelly in a circuit, forming a pattern similar to a sunflower when opened. At dawn, it will open up and follow the sun by continuously capturing images and calculating the location of the sun, to produce as much energy as possible, whilst maintaining efficiency and safety. It'll stay open and keep on tracking the sun, until sunset, after which it will coil up and return back to its starting position.
2) *Energy Conversion:* The solar panels will generate a DC current which will be regulated by the charge controller. This charge controller will then give the regulated output to the battery for storage. From there, it can either be accessed directly in the form of DC current or it can be passed through an inverter to be used in AC appliances.

C. Block Diagrams

1) *Sun Tracking*

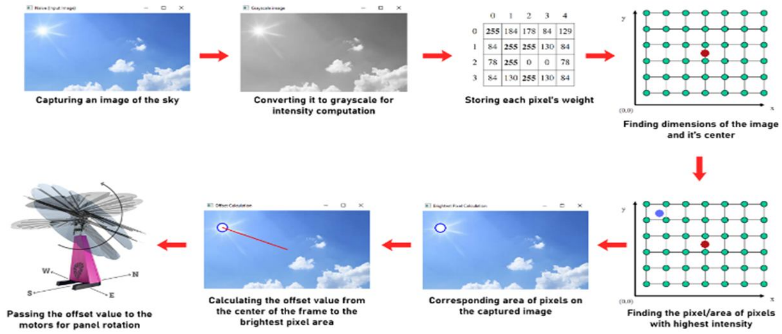

Fig. 1 Sun Tracking Block Diagram

Fig. 1 showcases the basic flow of information of the Sun-Tracking prototype. A more detailed workflow will be discussed in the later sections. The algorithm starts off during sunrise, where it captures a stream of images of the sky, to accurately locate the sun. Now, since the images captured are in the RGB (Red, Green, Blue) (8 bits each) color space, they will result in overheads during computations. Hence, they are to be converted to the grayscale color space which is just an individual color channel, the intensity (8 bits).

The grayscale intensity values are recorded in a matrix format, stored in an object variable. Now, since the images are captured through the camera sensor, the dimensions are extracted from the camera itself. The width and height are halved and the center of the frame/image is fetched. These pixel coordinates are stored in the memory, which will be used in further computations.

Using the previously captured image of the sun, the pixel value with the highest intensity is recorded. This pixel value (coordinates) will be the seed for the border tracing and object detection algorithm. After the algorithm is successfully executed, an erosion (discussed in detail later) operation is carried out which will eliminate the noise detected, causing only a region of pixels of the sun to persist. The centroid of this region will be calculated (average of all the points).

Finally, the Euclidean distances along the vertical and horizontal axes, between the centroid and the center of the image frame will be calculated and will be denoted by (offsetX, offsetY). These set of coordinates will then be passed onto the rotation mechanism as distances in global space, which will then result in the actual movement of the panels, and hence all the panels will be perfectly aligned with the sun to produce maximum power. The said process will run until dawn, that is, when the sun sets or, until a pre-determined time is achieved. This will result in more production of solar energy as compared to conventional static solar panel systems.

2) Solar Energy Conversion

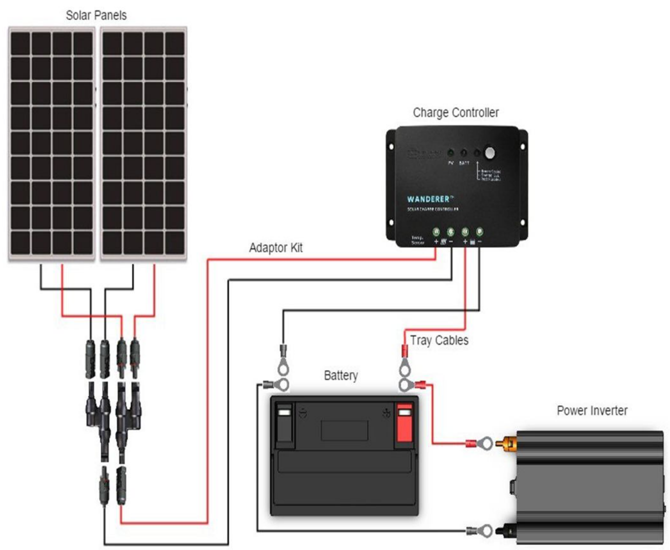

Fig. 2 Energy Conversion Block Diagram

As can be seen in Fig. 2, our structure will follow the conventional process of solar energy conversion into electrical energy. Multiple solar panels (amount: 4), a solar charge controller, a Battery, an Inverter, and other connecting wires will be used to achieve this.

Solar radiation is converted directly into electricity by solar cells (photovoltaic cells). In such cells, a small electric voltage is generated when light strikes the junction between a metal and a semiconductor (such as silicon) or the junction between two different semiconductors. The power generated by a single photovoltaic cell is typically only about two watts. By connecting large numbers of individual cells together, however, as in solar-panel arrays, kilowatts of electric power can be generated in a given span of time.

The solar panels will be connected in parallel to the solar charge controller, which in turn will be connected to the Battery for energy storage and an inverter. The charge controller will directly regulate the flow of current to the DC appliances, and indirectly the AC appliances, through the Inverter. The battery will be in charge of storing the generated power during the day and for also supplying the minimal power required to operate the other electrical components of the prototype.

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3) Controller Module

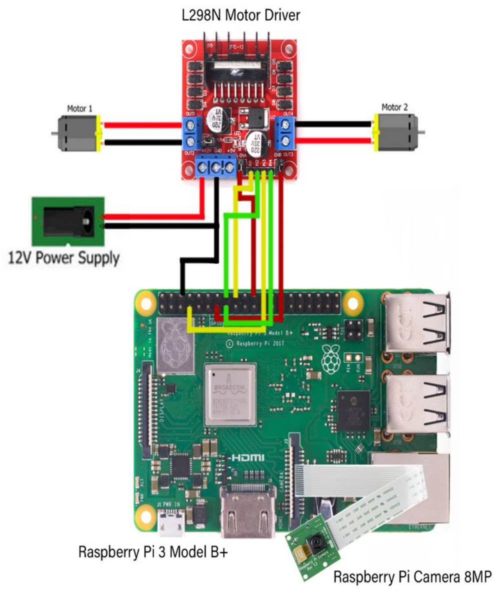

Fig. 3 Controller Module Circuit Diagram

Motor 1		Motor 2	
L298N Pins	Raspberry Pi Pins	L298N Pins	Raspberry Pi Pins
EN1	GPIO 25	EN2	GPIO 27
IN1	GPIO 24	IN3	GPIO 4
IN2	GPIO 23	IN4	GPIO 22

Fig. 4 Pin Connections

The Controller Module consists of the Raspberry Pi 3 Model B+, the L298N Motor Driver, the Raspberry Pi Camera 8MP, 2 High-Torque motors and a 12V Battery (Power Storage and Supply)

The Raspberry Pi 3 Model B+ is the heart of the system, tasked with commanding the Raspberry Pi Camera to capture the images of the sun, passing offset values to the L298N motor driver to carry out dual motor rotations, along with monitoring the health of the system as a whole, fetching weather forecast data, sending power statistics to the firebase database, among other things.

The GPIO Pins on the Raspberry Pi board are used as communication links, to communicate with the L298N Motor Driver. GPIO stands for General-Purpose Input/Output. These pins are a physical interface between the Raspberry Pi and the outside world. At the simplest level, you can think of them as switches that you can turn on or off (input) or that the Pi can turn on or off (output). The GPIO pins allow the Raspberry Pi to control and monitor the outside world by being connected to electronic circuits. The Pi is able to control LEDs, turning them on or off, run motors, and many other things. It's also able to detect whether a switch has been pressed, the temperature, and light. We refer to this as physical computing.

As can be seen in Fig. 3, various GPIO pins are used to transmit signals to the L298N Motor Driver.

Following are the Pin connections (referring to Fig. 4):

EN1 Pin of the Motor Driver – GPIO 25 Pin of the RPI
IN1 Pin of the Motor Driver – GPIO 24 Pin of the RPI
IN2 Pin of the Motor Driver – GPIO 23 Pin of the RPI
EN2 Pin of the Motor Driver – GPIO 27 Pin of the RPI
IN3 Pin of the Motor Driver – GPIO 4 Pin of the RPI
IN4 Pin of the Motor Driver – GPIO 22 Pin of the RPI
GND Pin of Motor Driver – GND (Physical Pin 3) Pin of the RPI (Shorted)

The Raspberry Pi Camera 8MP is connected to the CSI (Camera Serial Interface) of the Raspberry Pi board. This port allows the Raspberry Pi to access the features of the Camera and enable it to capture images and videos and save it is the board's storage card.

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The 2 motors are connected to the input lines of the L298N Motor Driver. Following are the connections made:
OUT1 of Motor Driver – Live end of the first motor
OUT2 of Motor Driver – Neutral end of the first motor
OUT3 of Motor Driver – Live end of the second motor
OUT4 of Motor Driver – Neutral end of the second motor
Lastly, the Power Supply, or the 12V Battery is connected to the L298N Motor Driver in the following way:
Positive end of Battery – 12V port of Motor Driver
Negative end of Battery – GND port of Motor Driver

4) Schematic Diagrams

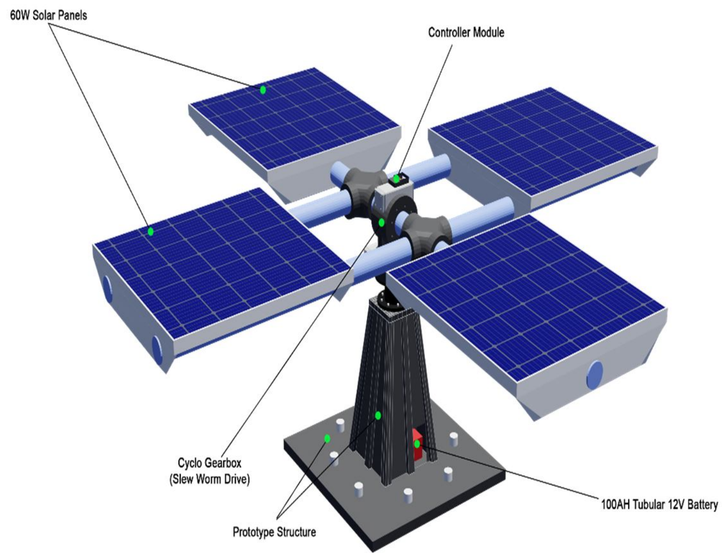

Fig. 5 Prototype Schematic

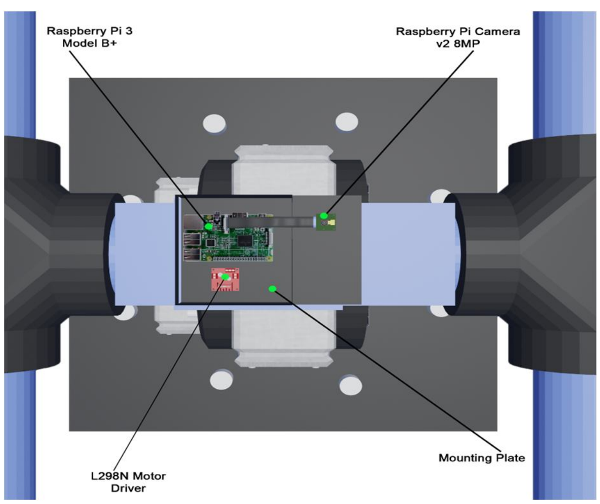

Fig. 6 Controller Module Schematic

Fig. 5 consists of the 4x 60W Solar Panels arranged in a Sunflower type pattern, the controller module mounted at the center, the Cyclo-Gearbox (Slew Worm Drive) which handles the dual axis rotation of the entire structure, the 100AH 12V Tubular Battery for power storage and supply and the prototype structure consisting of various materials.
Fig. 6 is an enhanced version of the controller module, which consists of the Raspberry Pi 3 Model B+, the Raspberry Pi Camera V2 8MP, the L298N Motor Driver and the mounting plate.

III. IMPLEMENTATION

Border Tracing Algorithm

1) *Overview:* The border tracing algorithm is used to extract the contours of the objects (regions) from a given image. When applying this algorithm, it is assumed that the image with regions is either in a binary format or those regions have been previously labelled. Extracting the borders of an object in a given image helps us to identify it's exact shape which can further be used in object detection algorithms, pathfinding applications, medical analysis, traffic control, among other things.
2) *The Concept:* The border tracing algorithm usually takes a binary image or an image who regions of importance are already labelled. It executes in either a 4-neighborhood fashion or in an 8-neighborhood fashion. A linear search for binary 1 is carried out from the first pixel of the image (0,0) and this is considered to be the seed pixel value for the algorithm. The coordinates are noted down as well.

3		2		1
	(x-1, y+1)	(x, y+1)	(x+1, y+1)	
4	(x-1, y)	(x, y)	(x+1, y)	0
	(x-1, y-1)	(x, y-1)	(x-1, y-1)	
5		6		7

Fig. 7 8-Neighborhood of a Pixel

Fig. 7 depicts the 8 possible neighbors with their directions. The binary image is considered to be a table of m rows and n columns. In order to describe the process, the variable *dir* is used to record the search direction. The initial search direction is 7, that is, *dir* = 7. The next border point is selected from the 3 × 3 – neighborhood (one of 8 neighbors). Integers from 0 to 7 are used to record the different directions of the neighborhood of the pixel.

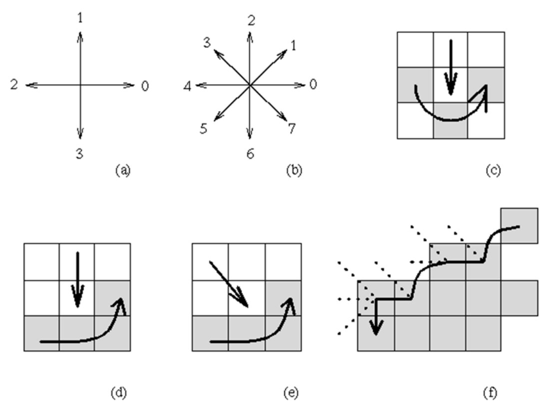

Fig. 8 Border Tracing Intermediate Steps

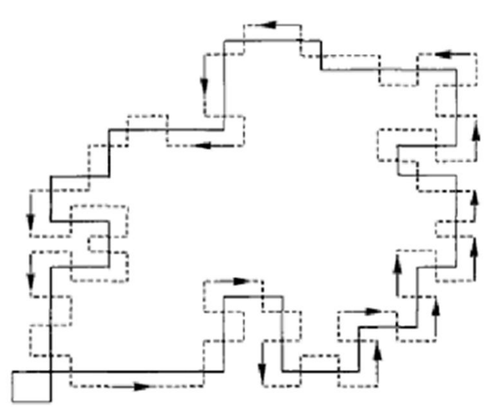

Fig. 9 Border Completely Traced

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The search direction begins with an odd number less than the previous direction 7. Hence, the search starts from direction 5 in an anticlockwise direction. The first object point p1 found is selected as the new border point, followed by the update dir = 5. The next search is in the neighborhood of p1. The search begins from direction 3 in an anticlockwise direction to direction 6 where another border point p2 is obtained. This search process may be repeated until the closed border p0 p1 p2 … p9 p10 p0 is constructed, that is, the procedure is repeated till the first two pixel locations match the current and previous pixel location. Fig. 8 depicts an example of the updates done to the directions during the algorithm execution. Fig. 9 depicts the final imaginary border detected, and the object's shape and size being correctly identified.

IV. PROS AND CONS OF THE SOLUTION

A. Pros

1) The proposed system comes with a humidity, temperature, dust sensor.
2) By using image processing, we get an accurate position of the sun through the
3) usage of state-of-the-art object detection algorithms.
4) Based on the sensor data fed to it, if it detects distress in the operating
5) environment, it will generate a report and notify the user.

B. Cons

1) The proposed system is weather resistant, not weather-proof.
2) Initial investment is high
3) Requires a clear field of view for optimal performance.

V. CONCLUSIONS

By following the sun movement throughout the day, the prototype can generate up to ~40% more energy than a conventional (fixed) solar setup of the same configuration. The prototype configuration can be modified as per user requirement and budget. Alternatively, an existing setup can be upgraded to solar tracker setup which reduces the overall cost. The prototype comes with a user-friendly Android and iOS app, which can be used to monitor health and statistics of the prototype in real time. The initial investment in the prototype is recovered in 5 years of continuous operation.

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