International Journal of Engineering &Technology, 6 (3) (2017) 105-108

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Design and implementation of tracking system based on image processing

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Abstract

A novel Variable Step Size Proportional algorithm (VSSP) has used for the sun-tracking system. The proposed algorithm does not require any feedback, and it can track the sun accurately even when there are obstacles around. Image processing techniques have been used to estimate the location of the sun, hence controlling the motors in each axis. A microcontroller board has been used to exchange data between the Matlab software, where the algorithm has written, and the peripherals. The system has offered an excellent ability to track the center of the sun in 15 iterations with 97% accuracy. The accuracy has been improved even more after 24 iterations to become 98.7%. Tracking the intensity of light is the most powerful prosperity of this algorithm that makes it able to track the sun even if it is out of the camera range. It does not require any complex processing or special sensors. The proportional controller is the base of this algorithm.

Keywords: *VSSP; Sun Tracking System; Proportional Controller; Image Processing.*

1. Introduction

Recently, renewable energy research has tended to pay more attention to solar energy, although there are other ways to generate clean energy such as tidal, wind, water, etc. Solar energy is the most important source of the renewable energy. One of the most important features of this energy source is that it's relatively simple configuration when compared to other techniques, and it is a constant source of energy that does not disappear [1]. One of the most successful ways for improving the efficiency of the solar power system is the tracking technique that reduces the angle between the sunlight and the solar cell plate [2]. There are different approaches of tracking techniques such as: Midriem Francis, 2016, suggested the sun tracking system by providing horizontal angle and vertical angle based on the calculations of time and location of the earth with tracking the sun based on image processing [3]. In the solar power tower, when the clouds were covered the sun, the efficiency of the generation is reduced. To detect this situation, Zhou Shuiliang, 2016, suggested a method based on the histogram of the colors in the picture to detect whether the sun has covered or not [4]. Kok-Keong Chong, 2010, had designed an open-loop azimuth-elevation tracking system to reduce the mismatch angle of the sunlight and added a general formula to reduce the mismatch [5]. Dongsheng Cai and, et al., 2014, predicted solar radiation to produce energy in photovoltaic power station using the camera by tracking the motion clouds near the sun through two phases: the image processing and the non-linear prediction of the trajectory [6]. Asanka S. Rodrigo and et al., 2015, provided a systematic approach to clouds tracking to predict the cloud cover that obscures the sun by obtaining visual data to be processed using an algorithm shows the relationship between clouds and the production of solar PV for better balance [7]. However, the sun is the brightest among the rest of the other objects such as clouds. In this paper, the contribution is to give a proposed algorithm based on modified PID controller to track the sun by its intensity using digital image processing to increase the accuracy of the system over time. The system is implemented using Matlab connected with a digital camera and Arduino.

2. Overview

This section will give a scientific background for the following topics: image processing, PID controller, and the complete system.

2.1. Image processing

Digital image processing is an essential field that utilized for obtaining precise information from an image [8]. There are three fundamental classes of digital images: RGB color, grayscale and black and white. Generally, in the color image, each pixel contains three cells assigned to the primary colors (red, blue and green), ranging between (0-255) [9]. Each pixel has 8-bit to give the intensity of the color. While the gray image has a pixel on each cell showing white, black and grayscale between (0 - 255) where '0' gives black and '255' gives white. The binary image contains only white and black colors so that each pixel has '0' or '1' [10]. A histogram is a tool used to describe the frequency of pixel values in an image. In the position of the sun, when the histogram is showing data for an image having the sun uncovered, the highest pixels values were assigned. In the case of covered or not visible sun, the most senior values of the pixels allocated to the illuminated spot which influenced by the sun.

2.2. PID algorithm

The PID controller is used to generate the desired system response. It has structured as a feedback loop mechanism to control the system in a variety of applications that it reduces the error

between the desired and actual response [11]. The proposed system behavior simulates the PID control mechanism with some modifications to the standard PID controller that shown in Figure (1).
Where, in Figure (1), Kp, Ki, Kd are constant parameters and e(t) is an error signal calculated from the difference between desired and actual signals that fed to the actuator (M), and the feedback signal represents the signal from the sensor.

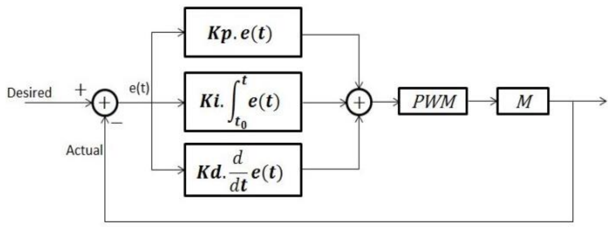

Fig. 1: Standard PID Controller.

3. Proposed system

The objective of this paper is to reduce the complexity and to improve the accuracy of the sun tracking system in the renewable energy applications. The combination of image processing and tracking systems, which was applied in the previous studies, offers the inverse relationship between complexity and accuracy. The benefit of this research is to propose a new algorithm for sun tracking where VSSP is used to achieve the optimum target without any feedback from actuators. The proposed algorithm updates the coefficients of positions in the following manner:
Step1: read an image from the camera sensor and remove the noise.
Step 2: take the normalization.
Step 3: convert the gray to a binary image with a hard threshold.
Step 4: keep the large white spot and remove the rest.
Step 5: extract the x and y position of each pixel in the spot.
Step 6: calculate the mean of x and y to find the center of the spot.
Step 7: Compute the difference between the spot center and the origin and multiply it's by the variable step size coefficient of a proportional controller.
Step 8: compute the $\Delta\Phi$ and $\Delta\theta$.
Step 9: update the angle coefficients (Φ and θ).
Step 10: limitation the angles to return the design to a safe state when the control signals exceed its limit.
From Eq. (1) and Eq. (2), the error in x and y axes will be computed respectively. Eq. (3) and Eq. (4) used to compute the variable step size for x and y axes respectively. Eq. (5) and Eq. (6) used to compute the $\Delta\Phi$ and $\Delta\theta$ respectively. The final values of Φ and θ computed by Eq. (7) and Eq. (8)

$$e_x = \bar{x} - \frac{z_x}{2} \quad (1)$$

$$e_y = \bar{y} - \frac{z_y}{2} \quad (2)$$

$$v_x = K_x + \frac{|e_x|}{\sigma_x} \quad (3)$$

$$v_y = K_y + \frac{|e_y|}{\sigma_y} \quad (4)$$

$$\Delta\Phi = e_x v_x \quad (5)$$

$$\Delta\theta = e_y v_y \quad (6)$$

$$\Phi = \Phi + \Delta\Phi \quad (7)$$

$$\theta = \theta + \Delta\theta \quad (8)$$

$$\text{Error} = \sqrt{e_x^2 + e_y^2} \quad (9)$$

Where $\bar{x}$ and $\bar{y}$ are the spot center coordinates. K_x and K_y are the coefficients of the algorithm. z_x and z_y are the original coordinates. σ_x and σ_y are very large constants. The condition that stops the operation of the algorithm is given by Eq. (9). The overall scenario of the proposed algorithm can be summarized as a flowchart in Figure (2).

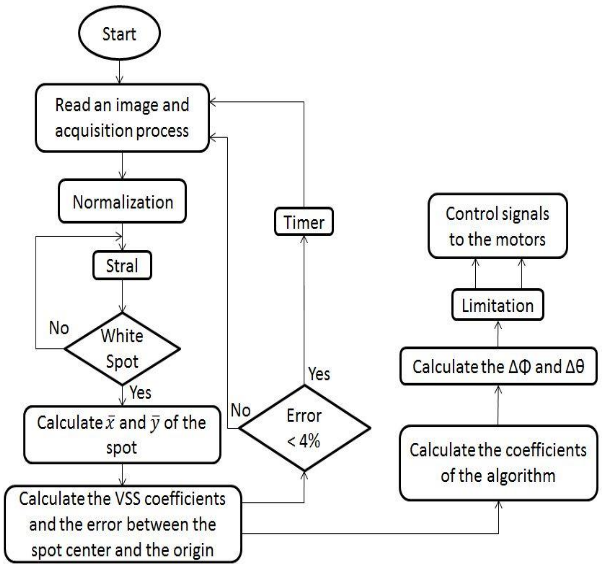

Fig. 2: The Main Steps for the Proposed System.

4. The hardware of prototype system

The hardware elements that have used in this paper are a camera web, an Arduino UNO microcontroller interfaced with Matlab, two servo motors, and Pan/Tilt Camera Platform. A block diagram of all these elements depicted in Figure (3). The camera sensor captures the image and gives it to the computer to execute the proposed VSSP algorithm using Matlab for estimating the coordinates of each axis to be used by the microcontroller to provide the PWM signal of the coordinates. This process repeats itself until the camera reaches the intended target with the desired accuracy, where it is then delayed for a specified period and then redirects the system to acceptable coordinates.

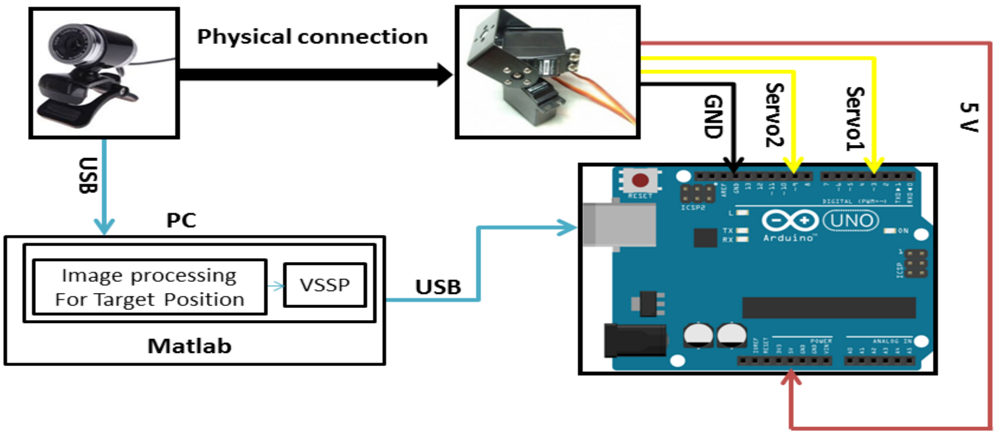

Fig. 3: The Experimental Setup and Connections for the System Components.

5. Investigational results and discussion

The VSSP algorithm has tested and verified practically. The physical system connection described as shown in Figure (4). The parameters that used in the simulation arranged in the table (1).

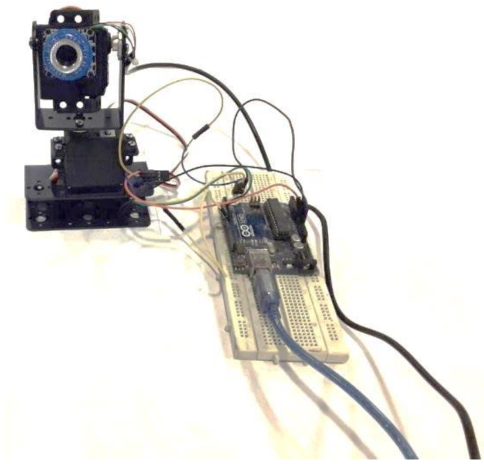

Fig. 4: Structure and Wire Connections.

The results of the VSSP algorithm computed for two types of images which are grayscale and black and white scale images. The images give the behavior of the algorithm in reducing the error by changing the location of the camera towards the target. Another parameter has evaluated that is the error ratio to demonstrate the accuracy of each iteration. Figure (5) shows the states of Sun tracking as a grayscale image captured by the camera.

Table 1: Design Parameters

Parameter	Description
Captured Image size	480×640×3
Wiener Filter size	[3×3]
Initial Position	x= 0.4652 y=0.8671
KP	0.00004
KC	0.00005
σ_x	2000000
σ_y	900000
Limitation	0≤x≤ 0.98 0.48≤y≤ 0.98
Desired accuracy	1.3%

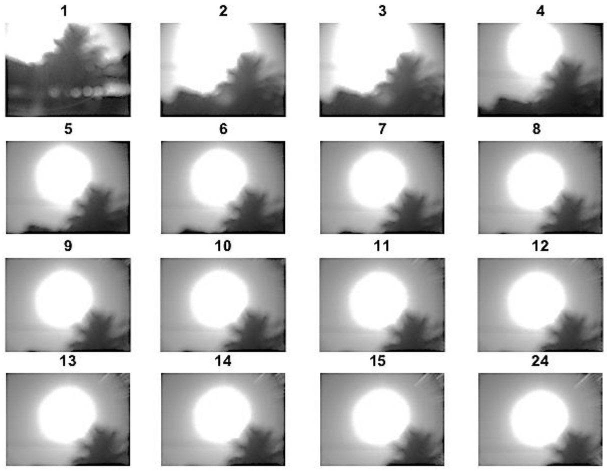

Fig. 5: The Grayscale Image of Each Iteration Behaviour.

The first 15 images from the overall iterations have been placed one by one respectively, and the last one is positioned to represent the final image that has been reached by the algorithm. For Iterations from 16 to 23, the error ratio is approximately equal to the error in iteration number 15. And they are neglected to present the necessary results. Figure (6) explains the results of the Figure (5) as a form of a black and white image. It can observe that the algorithm has successfully precisely detected the solar disk. It gives the details of the operation steps from the start to the goal points. For iterations from 1 to 15, they give the transition stages to the target until it achieved 97% accuracy. And for the iterations from 16 to 24, they tried to obtain more accuracy until it reached 98.7%. The error of each iteration will show in the Figure (7). The error fastly drops until it arrives in 8 iterations as shown in Figure (7). At this interval, the error reduced from 241.87 to 37.5 pixel. After that, in the interval from 9 to 15, the error will be reduced to 12 pixels. At the range of 16 to 24, the performance improved by decreasing the error value to 5.3 pixels.

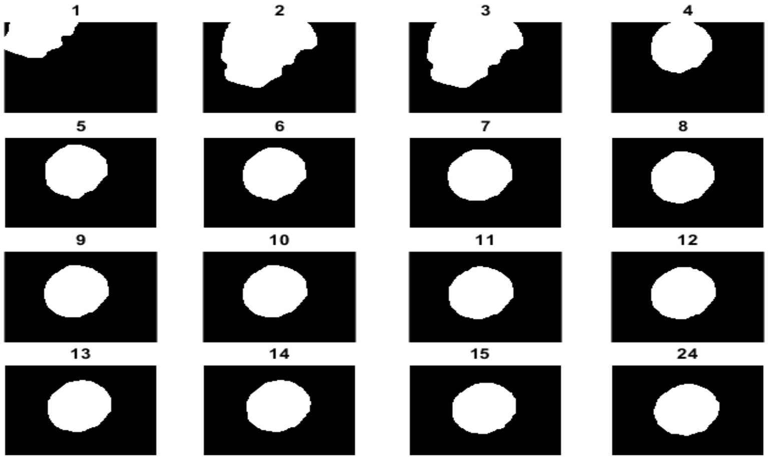

Fig. 6: The Black and White Image of Each Iteration Behaviour.

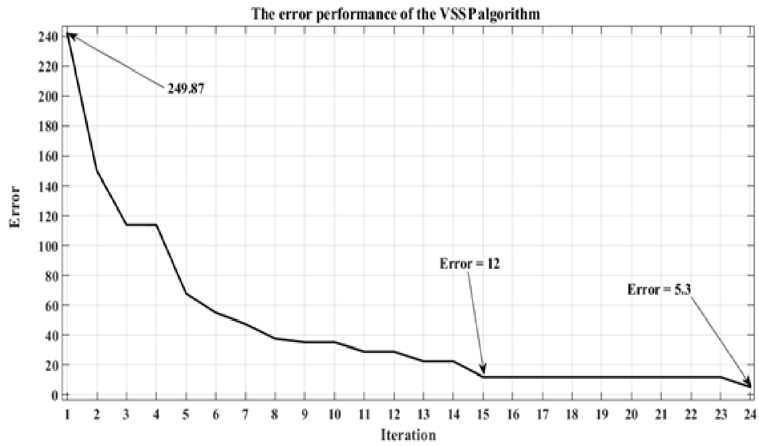

Fig. 7: The Error Behaviour of the Fit Position.

6. Conclusion

The efficiency of the system has been investigated to track the sun using an algorithm called VSSP to give an accuracy about 98.7% after 24 iterations. The VSSP algorithm characterized by low complexity and can recognize the sun as a luminous object. Tracking with the camera is accurate in determining the target despite the obstacles, where the system can follow the sun even with the clouds. The reliability of the algorithm investigated by using Matlab and Arduino as an interface between the physical network and the algorithm. The system can improve by replacing the digital camera with one has a broader range vision.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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