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# Design and implementation of smart electronic solar tracker based on Arduino

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## Abstract

*Demand of energy increases in the global and exponential exhaustion is favored of resources by fossil fuel for electricity production with the new systems development. Compared with all other remainder energies, the specialist sun energy is the most bountiful energy and it's typically easy to be changed into electrical energy. The main thing of using solar panel is to produce electrical energy from sun's energy but the optimum energy can be generated by tracking solar panel due to the sun movement from east to west. The problem can be solved by proposed systems where the sun tracking by solar panel that based on high intensity of sun ray. This paper concentrates on tracking the sun by using servo motor coupled with solar panel. So that, the largest quantity of sun light at the incident panel along the day at any time is better than that for method of fixed panel array which is less efficient. The microcontroller Arduino (mode UNO) was programmed by using C++ language while the track of sun light processing was implemented by using light depending resistor (LDR), Chip IC H-bridge and microcontroller Arduino (UNO) circuits have been designed by using Proteus software. By circuit design and sun tracking control process, the cost reduction has been improved and high amount of energy was saved when implemented this system.*

**Keywords:** microcontroller Arduino UNO, photovoltaic panel, Proteus program, sensors LDR, servo motors

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## 1. Introduction

The electricity power production and demand are increasing continuously nowadays with the available frightening rate of consumption main traditional resources energy like natural gas, petroleum and coal. Today, fossil fuels are at the forefront of energy, accounting for 85% of all resources used in energy production. The fossil fuel resources are being gradually depleted and used them cause pollution and global warming due to greenhouse gases emitted. Therefore, the trend towards an alternative to fossil fuels has gradually begun to be replaced by sources of renewable energy. Sustainability, abundance and ubiquity all of these factors have made solar energy is the best choice of renewable energy to meet the growing need of electricity. The solar energy is widely available and cost free completely [1-3].

The photovoltaic cells are devices of solid state which are converting the sunlight to electricity also they are not causing pollution, slightly no need maintenance and not noisy devices. However the installation is expensive but it can save much energy and the cost can be reduced over long years [4]. The amount of electrical energy production proportional directly with sun light intensity that reach photovoltaic surface panel and the angle between incident sun light and the panel surface. Maximum electrical power obtained when sun light and surface PV panel perpendicular to each other which represent the optimal angle and in this case power density on surface panel is the same as for the sunlight [5]. The sun position changing continuously that make sun light and fixed surface panel no more perpendicular to each other by means the angle between them continuous changing which effects on electrical power output and in this case power density on fixed PV surface panel is lower than that of the light sun. Thus, the fixed PV panels cannot operate with same efficiency for a long time because of this situation [6-8].

Solar tracking system using to ensure that surface PV panel module with incident sun light always perpendicular to each other in order to obtain maximum power output over all day time where the mechanism of solar tracking system give PV panels ability to track or follow the sun [9-11]. Power is captured by solar tracker of single axis when structure is rotating along horizontal axis in one direction from east to west elevation movement is better than fixed panel

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where the electricity can be increased by 27% to 32% while for dual axis full capacity can be received at same time [12]. The maximum sun light can be captured when using solar tracker in dual axis with movement in two directions azimuth and elevation, the reports showed that the output electricity is increased by 40% to 50% by using dual axis solar tracker [13, 14].

Several previous works have been done in this field of solar tracking system with various methods and techniques. In [15], proposed mechanism in parallel mode using for solar tracker decoupled of two axes where driving torque highly decrease by utilizing solar tracker and no need using reducers with great decreasing ratio. In [16], Scanning curve and electro-luminescence using for tested PV model in order to calculate the power losses results from salient dirt, mechanical and thermal effect. In [17], classification and presentation several types of solar tracking systems according to the methods and techniques of driving, the research reached to optimal solution when using devices with intelligent driver. Designed and implemented solar tracking system in order to improve efficiency of the energy for PV panel was discussed in [18]. Proposed guidance stationary of a two-dimensional solar tracking model that depending on series time based feature planed under restriction bound satellite attitude of conjugation control dealing in [19].

In this paper, development design and simulation utilized in solar tracker dual axis model, the system installed and the data collected from practical implemented in Iraq exactly Baghdad city. The system using one time as a fixed model and another time as tracking model. The optimal power obtained when using tracking case as clear in the results, that is return to effect algorithm schedule on system performance additional to that the system proposed also provide the best rate data transfer and regular distribution.

## 2. Sun's Position Determination

The position of object for exact location relative to sun in sky can be determined by several established equations. The angular position of the sun relying on time local and longitude for correction of time solar. The first step in calculation of sun position is to determine time solar which is depending on the sun angular motion apparent. The elevation in the sky becomes maximum for the sun at the noon solar time. Solar time is used for angle determination of the sun needs to do two thinks for local time, firstly, all local longitude (Lcal) should be corrected by comparison with longitude of meridian standard (Lrd) and secondly, standard time (T) correction represents discrepancies between mean and apparent solar times. Time in minutes is difference between solar and standard time [20, 21].

$$\text{Solar time-Standard time} = 4(\text{Lrd} - \text{Lcal}) + T \quad (1)$$

The T parameter can be defined by:

$$T = 229.2[0.000075 - 0.040891 \sin(2D) - 0.014615 \cos(2D) - 0.032077 \sin(D) + 0.001868 \cos(D)] \quad (2)$$

$$D = (k - 1) \frac{360}{365} \quad (3)$$

where k is the days of year or Julian date.

The angle of declination  $\delta$  is the sun angular position with equator respect at solar noon. This angle is decisive to determination the solar position and is varies seasonally [22].

$$\delta = 23.451 \sin\left(360 \frac{284+k}{365}\right) \quad (4)$$

The hour angle ( $\beta$ ) is the next sun's position serious characteristic which represents the sun displacement angle when the sun local meridian east or west, it's positive in afternoon and negative in the morning. The following formula acts as an hour angle and because the rotation of earth  $15^\circ$  every hour so that:

$$\beta = 15(\text{time solar} - 12) \quad (5)$$

the altitude ( $\theta$ ) plays a big role for the sun position which has relationship in calculation of incident angle ( $\phi$ ) which is the angle between the vertical and component beam of solar.

$$\phi = \cos \theta \cos \delta \cos \beta + \sin \theta \sin \delta \tag{6}$$

The next is the angle of elevation ( $\gamma$ ) which represents the angle between the horizontal and solar component beam which is determined by subtraction 90o from incidence angle [23, 24]. Then the angle of azimuth ( $\delta$ ) can be calculated, if the function sign  $-1$  means hour angle is negative and  $+1$  if it is positive.

$$\delta = \text{sign}(\beta) \left| \cos^{-1} \left( \frac{\cos \phi_z \sin \theta - \sin \delta}{\sin \phi_z \cos \theta} \right) \right| \tag{7}$$

The calculation is remaining that related to location daily of the sunrise and sunset of the sun. The hour angle sunset ( $\beta_{hh}$ ) explains the sun angular displacement at the meridian local sunset.

$$\beta_{hh} = \cos^{-1}(-\tan \theta \tan \delta) \tag{8}$$

The hour angle sunrise ( $\beta_{hr}$ ) is hour angle sunset but in negative (for hour angles west of meridian local is positive and east is negative, all the above equations can be shown in Figure 1 [25]. Figure 2 explains the operation of the proposed system; it represents the circuit hardware for solar tracking that can be used for azimuth and elevation tracking. It consists of three stages LDR sensors, comparator and relay with servo motor drive port. The principle operation of this electronic circuit is depending on the creating error voltages among 4 LDRs. The high voltage when LDR is lighted while the lower voltage when LDR shadow. The voltage difference between two sensors is amplified by using differential amplifier and the voltage error feedback can be represented by [26]:

$$v_{NS} = -\frac{R_6}{R_3} v_N + \left( 1 + \frac{R_6}{R_3} \right) \frac{R_5}{R_4 + R_5} V_N \tag{9}$$

or

$$v_{NS} = \frac{R_6}{R_3} (v_N - v_S) \tag{10}$$

The second stage is the comparator which is used as switch to turn the relay on, then the motor rotates where the comparator is used to compare the threshold values with voltage error.

$$v_{th1} = \frac{R_9}{R_9 + R_7} V_{CC} \tag{11}$$

$$v_{th2} = \frac{R_9}{R_9 + R_7} (-V_{CC}) \tag{12}$$

Last stage is relay and drive of servo motor which is consist of two pairs of Darlington component where finally direction of rotation motor is depending on the largest current gain and relay actuate.

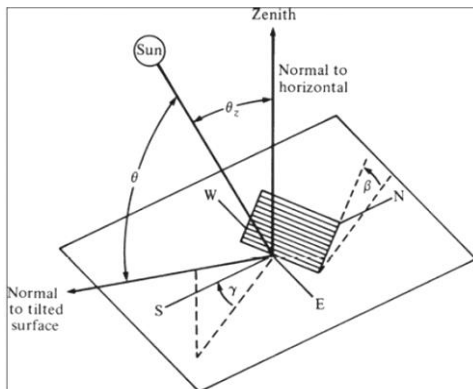


Figure 1. Collector geometry of tracking system

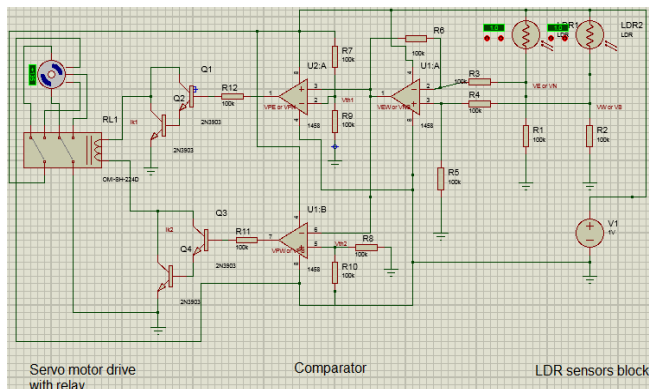


Figure 2. Complete sun tracker circuit diagram for tracking in azimuth or elevation directional control

Under blocks diagram premises the flow chart in Figure 3 is designed for control algorithm in order to allow the prototype and all the LDR sensors checking position. Depending on flow chart shown in Figure 2, the variation in radiation of solar incident on the LDRs (North = VN is the voltage respect to LDR1, South = VS is the voltage respect to LDR2, East = VE is the voltage respect to LDR3, West = VW is the voltage respect to LDR4). The reason to build a suitable module to equipment performances is that the proposed scheme requirements and the sensors block response against the effect of radiation variation for movements in both directions azimuth and elevation (checking the response of servo motor). The radiation of the tracker movement over predominates is available and doesn't equal to zero during hours of daylight and it's zero value from nightfall to next day morning so when the day over the west is the final position of tracker and before measuring of new day starting. Additionally, to avoid weak components available because of vibrations of mechanical parts due to continuous motors stop and moving so every 10 minutes spaced measurements in order to saturate the system and capture frequency by this way is reducing.

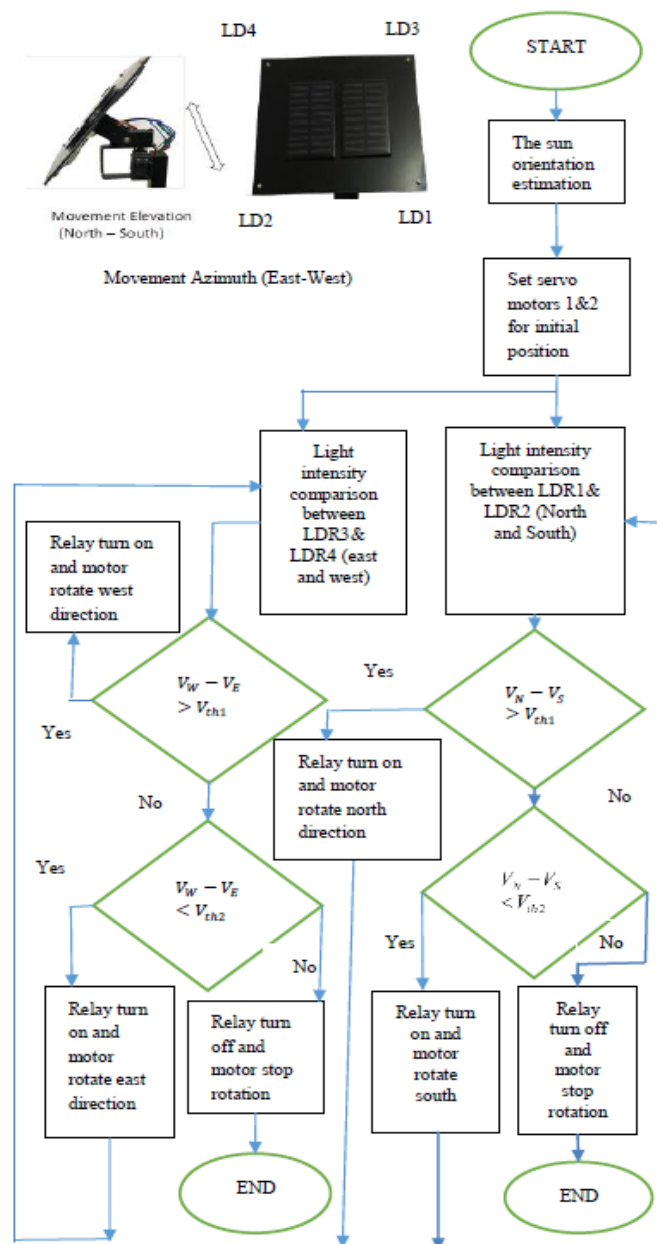


Figure 3. Flow chart diagram explains solar tracking prototype

### 3. Hardware Description

Below are short definitions for components that using in system prototype.

#### 3.1. Light Dependent Resistor (LDR) Sensors

LDRs are also named as photo conductors or photo resistors and the photoconductivity is the principal of thier working. LDR resistance is increased with decrease light intensity and vice versa. Solar energies catch by purpose sensing which are done by using LDRs before providing the input analog to Arduino.

#### 3.2. Servo Motor

Servo mechanism is the principle work of dc motor which has 3 wires and maximum angle of 180° can be rotated, in this work using 5 V motor. There are two servo motors using for both elevation and azimuth directions because the system is working in dual axis. Arduino provides output of PWM to these servo motors for operation.

#### 3.3. Solar Panel

Solar energy is a group of photovoltaic cells that produce electrical energy from sun light energy and convert the received light energy from sun into electrical energy. Solar panel extracts high-energy emitted from the sun. They are widely applications of solar panel in industrial area, domestic and street lights.

#### 3.4. Arduino

Arduino type ATmega 328p is a microcontroller that using in this work for motor position control. Arduino has 14 input/output digital ports that provide signals of PWM to servo motor by 6 of them and 6 input ports as analogue, also contains oscillator crystal of 16 MHz and cable USB for push through program. The Arduino advantages are independent platform, construction robust and low price. Table 1 shows the components description of the system prototype depending on their functions.

Table 1. Components of System Prototype Description

Components	Description
Solar panel	15x15 inch squares dimension, 35 watt ratings and thin film material.
Arduino UNO	ATmega328 operations tracking controller electronic Programmable, 16MHz clock, 6 inputs analogue and 14 inputs digital pin.
Servo motor	HXT900 Servo 9gr, 0.6A, 5v
LDR	GM 9516 photodiodes semiconductors Light responsible for signal sending to Arduino result movement activation.

### 4. Algorithm of Solar Tracker

The closed loop improvement of solar tracker blocks diagram is described in Figure 4. The main aim is to get the largest perpendicularity between the incident sun rays and the panel photovoltaic surface. Controller feedback is depending on platform of Arduino and the sensors are depending on LDR sensors and operational amplifier. The comparator input is the output intensity and LDR sensors are received the amplified and feedback generated error voltage which is variance between North-South and East-West response sensors and this leads to imbalance case. These radiation variations with activity of two by two effect on the comparator and make it sense, actuator linear being extended rod or back move to get maximum performance in movement elevation or allows the driver is turning by means of servo motor for effectiveness improving in movement of azimuth. The controller makes panel of photovoltaic and radiation solar monitored by sending differential signal when occurs the difference that allows change in position of solar panel until obtained zero error voltage practically. All data pair (elevation and azimuth) apprehend and stored by platform of Arduino and after that being explicated, it activities motors movement [3-5].

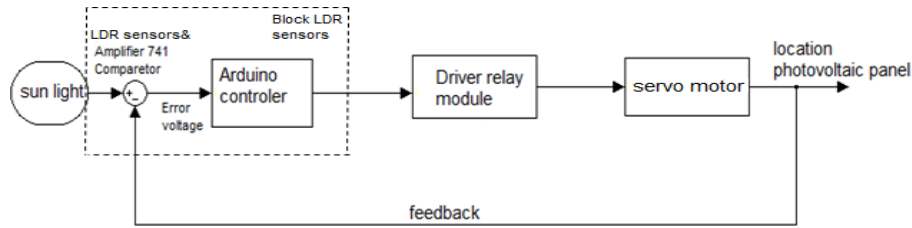


Figure 4. Block diagram of closed loop solar tracking system

**5. Prototype Fabrication and Simulation Circuit**

The Proteus program using level functional of tracker for electric scheme through implemented of this model. The parts of programming are sevided in to three sections of input sensors, H-bridge, Arduino for input signals and comparison LDRs voltages and the last one is for section movement related with servo motors. The analog part of Arduino can be described as follow: A0 pin = sensor1 input, A1 pin = sensor 2 input, A2 pin = sensor 3 input, A3 pin = sensor 4 input.

Compiler Arduino contains the written code and software is compiled also. Input sensors are represented by four LDR with their results and are simulated for five cases beside the H-bridge provides the output voltage of these sensors. When LDR1 at position1 (right and bottom) is getting sun light, the LDR1 sends the signal to Arduino after that both DC servo motors received this signal from Arduino and both servo motor (bottom and top) will rotate in clockwise direction. The same process is done for LDR2 at position 2 (left to bottom) when is getting sun light. At position 3 (left and top), when LD3 is getting sun light and its voltage is greater than other three LDRs voltages the same process will be done. LDR4 sends the signal to Arduino and both DC servo motors receive signal from Arduino then opposite process will be done in this case compare to positions 1 and 2 where both DC servo motors (top and bottom) will rotate anticlockwise direction. The Arduino is programmed by using C++ language. The direction of DC motors rotation is depending on LDR conditions, two DC servo motors are used in the system of tracking dual axis where the elevation direction control is using one motor (MOTOR X) and azimuth direction control is using another motor (MOTOR Y). In Table 2, all situation tracking cases are shown and they are represented by using Proteus program for circuit shown in Figure 5. Table 3 shows the four sensors LDR measurements output voltage at real time. The sensor LDR voltage output is not stable due to the various of low intensity where these readings were taken for sunny day.

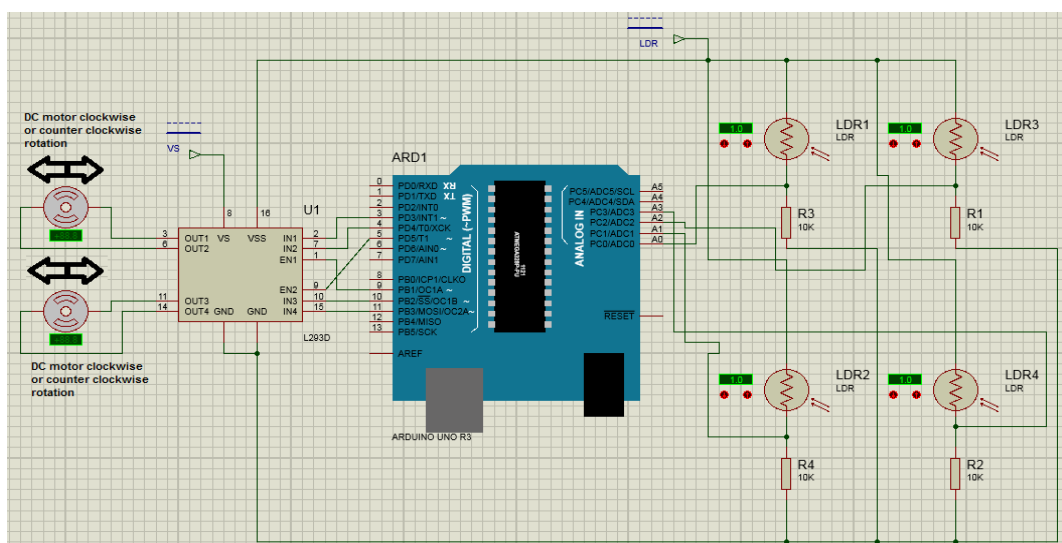


Figure 5. The circuit represented of all cases of solar tracking system simulated by using proteus program

Table 2. The 5 Situations Available for LDR Sensors in Solar Tracking System

Case No.	LDR highest voltage	LDR light intensity	Action of the system
Case 1	LDR2,LDR3 and LDR4 < LDR1	LDR1=16.2 LUX LDR2,LDR3 and LDR4 = 0.2 LUX	Motor x rotates counter clockwise response for (elevation control) and motor y rotates clockwise response for (azimuth control).
Case 2	LDR1,LDR3 and LDR4 < LDR2	LDR2=16.2 LUX LDR1,LDR3 and LDR4 = 0.2 LUX	Motor x rotates clockwise response for (elevation control) and motor y rotates counter clockwise response for (azimuth control).
Case 3	LDR1,LDR2 and LDR4 < LDR3	LDR3=16.2 LUX LDR1,LDR2 and LDR4 = 0.2 LUX	Motor y rotates clockwise response for (elevation control) and motor x rotates counter clockwise response for (azimuth control).
Case 4	LDR1,LDR2 and LDR3 < LDR4	LDR1=LDR2 = LDR3 = LDR4=16.2 LUX	Motor y rotates counter clockwise response for (elevation control) and motor x rotates clockwise response for (azimuth control).
Case 5	LDR1=LDR2 = LDR3 = LDR4	LDR1=LDR2 = LDR3 = LDR4=16.2 LUX	Motor x and motor y do not rotate and remain in same position.

Table 3. Sensors LDR Output Voltage

Reading No.	LDR1	LDR2	LDR3	LDR4
1	0.69	0.91	2.63	0.94
2	0.92	1.19	2.79	1.17
3	3.54	2.12	1.9	0.57
4	2.14	2.53	2.72	3.21
5	2.37	2.38	2.74	2.39
6	2.76	2.76	2.87	2.65
7	2.43	2.43	2.79	2.12
8	2.5	2.56	2.95	2.76
9	3.53	3.57	3.24	3.49
10	2.77	2.74	2.72	2.62
11	2.59	2.56	3.14	2.33
12	2.63	2.78	3.18	2.60
13	3.73	3.79	3.22	3.84
14	2.74	2.71	3.28	2.72
15	2.66	2.65	3.50	2.79

### 5.1. Implementation Results

The finishing model hardware and a lot of system planned were implemented as shown in Figure 6. This module is supported at height of 1.5 feet where for tracker control is higher that should be increased panel altitude and installed in atmosphere open air. The accomplishment of hardware used panel photovoltaic (PV) 35 watt and it is type mono crystalline while using motors for rotation in both elevation and azimuth directions are static magnetic servo motors which are moving in steps to follow the position correction. The system input consists of 4 LDRs fixed at PV panel that send signal to Arduino UNO controller at the analog pins of A0 to A4. The 4 LDRs are taken as pair where if less intensity on one sensor rather than the others then on the node, voltage difference is occurred and send to related channel of Arduino for necessary action taken and the servo motors will rotate PV panel to the highest intensity of LDR position.

Validation and test of experiment: The sun tracker performance was verified and scheme control of feasibility was illustrated, solar tracking system prototype laboratory was installed and tested. This work was done in Baghdad city, Iraq where the experimental outcomes have been done on 13<sup>th</sup> and 14<sup>th</sup> of April 2018 which were sunny days by installing system of the proposed devices on the roof of building. At the same time, output power data was collected at time between 7:30 a.m. to 6:30 pm.

The latitude of Baghdad is 33.34 degree north, so for fixed module and in order to get maximum solar radiation, the face of PV panel is fixed in direction of south at 33.34 degree tilt angle. The sun tracker with PV panel test experiment shows in Figure 6 while for solar tracking system, the panel moves freedom in two directions elevation and azimuth angle. (YOKOGAWA FX106) recorder paperless is employed in this work to display current and voltage values that measured in real time which are produced by PV panel. The earth moves 15 degree per hour, so it can be developed the system by means of reducing power consumption to make tracking

servo motor not turn on all time. This characteristic is done by estimating algorithm for time schedule in order to track the sun every half hour. The values of output voltage, current and power for fixed module and for various times are registered in Table 4, while Table 5 shows the results of solar tracking module of dual axis PV panel rotation. The experimental data in Tables 4 and 5 were used for plotting graphical power output as shown in Figure 6.

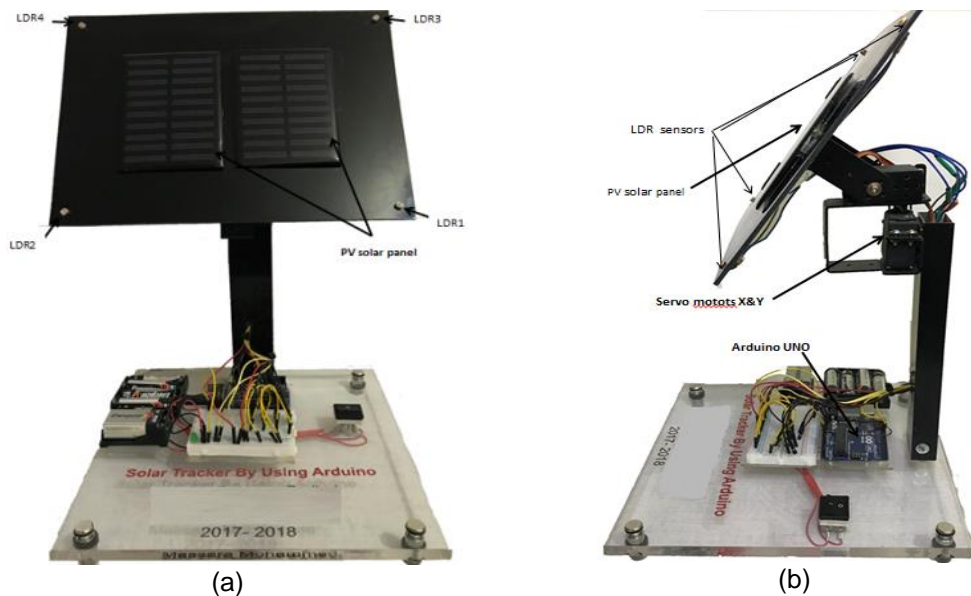


Figure 6. Proposed solar tracking system: (a) front view and (b) side view

Table 4. Results for PV Panel for fixed Module

Time	Current (A)	Voltage (V)	Power (W)
7:30	0.04	3.8	0.15
8:30	0.13	4.43	0.58
9:30	0.41	11.81	4.84
10:30	0.77	14.42	11.10
11:30	1.31	17.37	22.75
12:30	1.43	18.10	25.88
13:30	1.53	18.75	28.35
14:30	1.37	18.05	24.73
15:30	1.09	15.24	16.61
16:30	0.79	11.82	9.34
17:30	0.51	7.01	3.58
18:30	0.11	2.11	0.23

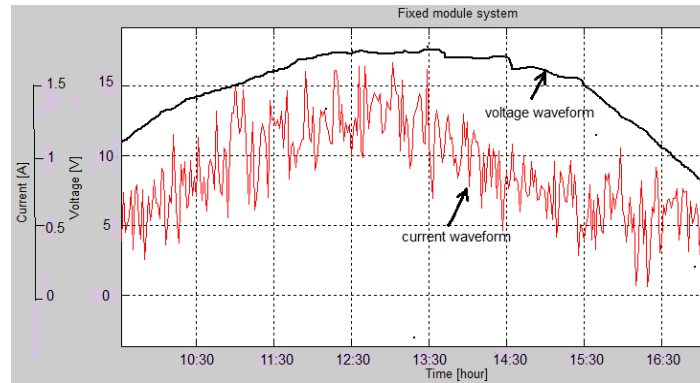
Table 5. Results Obtained for Dual Axis Tracking Module

Time	Current (A)	Voltage (V)	Power (W)
7:30	0.19	7.2	1.37
8:30	1.3	8.43	10.96
9:30	1.23	14.94	18.38
10:30	1.35	16.76	22.63
11:30	1.45	17.58	25.49
12:30	1.61	18.32	29.50
13:30	1.65	18.83	30.71
14:30	1.49	18.61	28.06
15:30	1.21	16.54	20.01
16:30	1.11	16.1	17.87
17:30	0.72	15.01	10.81
18:30	0.51	7.11	3.63

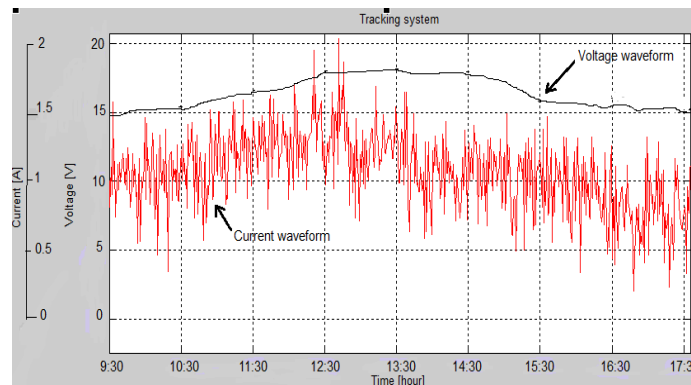
## 5.2. Experimental Results

This work was done in Baghdad city (Iraq) where the experimental outcomes have been done on 13th and 14th of April 2018 which were sunny days by installing the proposed system devices on the roof of building. The time for collection of data power output between 7:30 a.m. to 6:30 p.m. The measurement results of production current and voltage waveforms for tracking and fixed systems are shown in Figure 7 while Figure 8 shows the comparison between two output powers for both systems. It can be seen clearly from Figure 7 (a) (fixed system), the current and voltage were registered maximum values (1.53 A and 18.57 V) at afternoon time (13.30), and the minimum values of currents and voltages were recorded at the beginning and end of the day which are 7:30 AM and 6:30 PM. The same action was happen for dual axis solar tracking system as shown in Figure 7 (b) where it reaches maximum values for current and voltage (1.63 A and 18.83 V) at time of 13.30 also the minimum values of current and voltage were registered at same time of fixed system module.





(a)



(b)

Figure 7. Characteristic of current and voltage output as a function of time measurement: (a) PV Fixed system, (b) solar tracking system

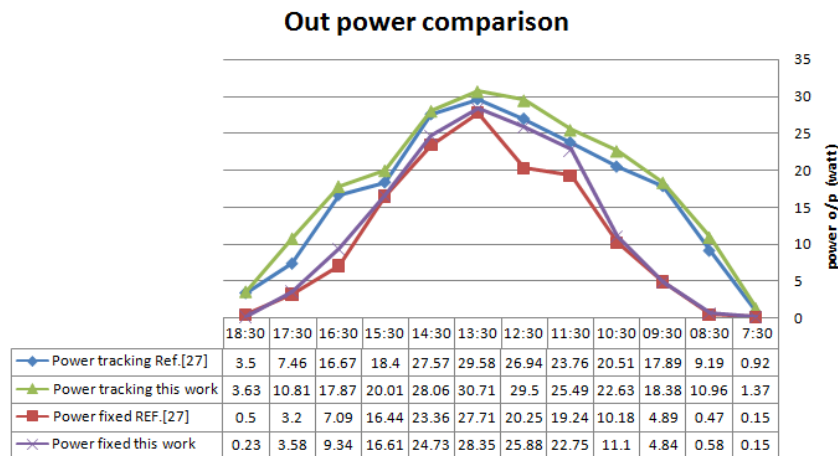


Figure 8. Comparison between fixed and solar tracking system based on output power generating with other related power

As shown in Figure 8, the performance of fixed and tracking systems reaches the peak at noon that is because both PV panels are faced almost the same trend, but a small difference in angle. The output power reaches maximum values at afternoon time (13.30) which were recorded as 31.06 watt and 28.35 watt for tracking and fixed system respectively. The tracking system has important factor for evaluating which is gain of energy, the gain energy means that extent the tracking system to increase the resulting energy compared with a fixed system.

The generated energies for tracking and fixed systems were 97.63 w-h and 76.42 w-h respectively, so  $(97.63-76.42)/76.42=0.2775$ , or 27.75% obtained for generated gain energy. However, for tracking system energy, the calculation of consumption energy of motor rotation should be taken in consideration where the consumption energy of motor was 0.7 w-h, so the tracking system gain energy was  $(97.63-76.42-0.7)/76.42=0.2683$ , or 26.83%. Figure 8 also explain comparison of this proposed system included fixed and tracking model with other related work [27], the results obtained approximately same Because the coordinates of the latitudes of the globe are the same for the both places where the results were taken even though they are in two different countries.

## 6. Conclusion

This paper presents modern prototype and effective photovoltaic solar tracker based on platform of Arduino. The following control effective logic can be moved regularly independent for different situations of radiation. The proposed system hardware design, simulated using Proteus program and recorder paperless (YOKOGAWA FX106) is employed in this work to register values of voltage and current that produced by PV panel along the day. The practical results collected by installing proposed hardware system in Iraq exactly Baghdad city. The comparison of results obtained shows that energy about 26.83% gains by applying the prototype of solar tracking development module over fixed module. These results are presenting the device effectiveness and the ability to use in buildings (plots, garden area, flat roofs, etc.).

The production photovoltaic centers are utilizing models scale and correct developing encapsulation for electronic and electric components of direct sustain equipment up to weather conditions. It is accomplished engaging features provide such as an accessible and effective cost control execution and the two axis ability to move together within their own domains. Additional for ability to regulate the precision of tracking, it findings empirical guide to believe work research that provide improve applications of solar energy. Beside the dual axis of solar tracking system, there are several other techniques available for production solar power tracking system such as concentrator parabolic dish, concentrator central receiver and tower power which are high efficient and more production of electricity, but the worse think for these techniques is costly and expensive setup. If the proposed system that using in this research paper compared with all the above systems of solar tracking will find our system of dual axis solar tracking is higher efficient, easy setup and effectivly lower cost.

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