Implementation of Solar Energy Tracking System

Lecturer. Dr. Manal H. Jassim
University of Technology / Department of Electrical Engineering, Baghdad, Iraq
manaljassim@ymail.com
Ali Reyadh Waheed
Collage of AL Mustaqbil / Department of Computer Science, Hela

Abstract :

Solar energy is one of the best option for electrical energy generation as it is available everywhere and it is renewable. To generate electrical energy from solar energy the solar photovoltaic panels are used. The solar photovoltaic panels are low-efficiency devices, they convert small amount of solar energy. In order to extract more of solar energy and hence increasing the efficiency of the solar photovoltaic panels, a tracking systems are used to track the sun position and let the solar photovoltaic panels facing the sun as long as possible. In our work the simulation design and control of a single axis tracking system is presented, practical implementation of the single axis tracking system has been presented. The single axis tracking system has the ability to rotate the solar photovoltaic panels in horizontal axis and in both clockwise and anticlockwise directions. The amount of the horizontal rotation is directly obtained from the voltage difference between two photosensors fixed on the positive and negative sides of the x-axis of the solar photovoltaic panel. The rotation of DC motor has been controlled by the 89C51 microcontroller. This tracking system makes the solar photovoltaic panels perpendicularly facing the sun and therefore more solar energy extracted and so the efficiency of the solar photovoltaic panels increased.

Keywords: Solar energy, tracking system, micro-processor8051, Solar Cell, DC motor Driver

بناء نظام تتبع طاقة شمسية

م.د. منال حمادي جاسم
قسم الهندسة الكهربائية
الجامعة التكنولوجية

طالب ماجستير علي رياض وحيد
قسم علوم الحاسبات
بغداد كلية المستقبل الأهلية – الحلة

الخلاصة:

ان الطاقة الشمسية هي إحدى الخيارات المثلى لتوليد الطاقة الكهربائية وذلك لتواجدها بكل مكان . ولتوليد الطاقة الكهربائية من الممكن استعمال مصفوفة الخلايا الشمسية الفوتوضوئية. وتعتبر هذه المصفوفات أجهزة واطئة الكفاءة فهي تمتص مقدار قليل من الطاقة الشمسية. ولغرض امتصاص اكبر مقدار من الطاقة الشمسية وزيادة كفاءة مصفوفة

الخلايا الشمسية الفوتوضوئية يستعمل جهاز تتبع وذلك لتتبع موقع الشمس وجعل مصفوفة الخلايا الشمسية الفوتوضوئية تواجه الشمس لأطول فترة ممكنة. لقد تم في هذا العمل تقديم محاكاة تصميم والسيطرة لنظام تتبع احادي المحور في عملنا هذا. وكذلك تم تقديم التطبيق العملي لنظام التتبع احادي المحور. يمتلك نظام التتبع احادي المحور القدرة لتدوير مصفوفة الخلايا الشمسية الفوتوضوئية بمحور افقي وبكلا الأتجاهين اتجاه دوران عقارب الساعة والأتجاه المعاكس لدوران عقارب الساعة. كما ويؤخذ مقدار الدوران الأفقي مباشرة من فرق الفولطية بين حساسين ضوئيين مثبتين على الجانبين الموجب والسالب للمحور السيني لمصفوفة الخلايا الشمسية الفوتوضوئية. ويتم السيطرة على محرك التيار المباشر بواسطة المسيطر الدقيق (89C51). يجعل نظام التتبع هذا مصفوفة الخلايا الشمسية الفوتوضوئية تواجه الشمس عموديا وبذلك تمتص مقدار اكبر من الطاقة الشمسية وبذلك تزداد كفاءة مصفوفة الخلايا الشمسية الفوتوضوئية.

1. Introduction

Renewable energy resources will be an increasingly important part of power generation in the new millennium. Besides assisting in the reduction of the emission of green house gases, they add the much- needed flexibility to the energy resource mixture by decreasing the dependence on fossil fuels [1].

Recently, photovoltaic (PV) system is well-recognized and widely-utilized to convert the solar energy for electric power applications. It can generate direct current (DC) electricity without environmental impact and emission by the way of the solar radiation. The DC power is converted to AC power with an inverter, to power local loads or fed back to the utility [2]. PV systems consist of a PV generator (cell, module, and array), energy storage devices (such as batteries), AC and DC consumers and elements for power conditioning [3]. The need of the tracking system for solar PV panel arises to extract maximum solar energy. The single axis solar PV panel is characterized by the capability to move in horizontal direction. The horizontal motion of the panel is obtained by taking the difference voltage between two sensors oriented on both sides of the X-axis; the (8051) microcontroller has been used to control the rotation of DC motors.

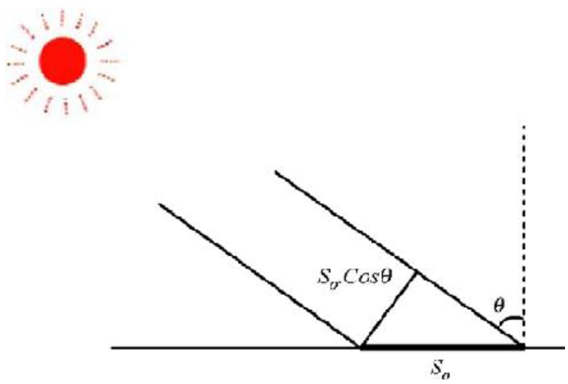


Fig .(1) the vertical and horizontal axes and the incidence angle of the sunlight.

This tracking system makes the solar PV array more efficient by keeping the panel’s face perpendicular to the sun and therefore extracts maximum solar energy resulting into an increase in the overall efficiency. A solar tracker is a device that orients photovoltaic array toward the sun. In flat-panel photovoltaic (PV) applications trackers are used to minimize the angle of incidence between the incoming light and a photovoltaic panel. This increases the amount of energy produced by the photovoltaic array [4]. There are two ways for maximizing the rate of useful energy: one is by optimizing the conversion to the absorber level, and the other by decreasing the losses by properly choosing the absorber materials; increasing the incident radiation rate by using mechanical tracking systems .Basically, the tracking systems are Electro-mechanical devices, driven by motors or actuators, which orient the panel in order to follow the sun path on the sky [5]. The positions of the Sun on its path along the year represent an input data in designing the solar trackers. The Earth describes along the year a rotational motion following an elliptical path around the sun. During one day (24 hours), the Earth also spins around its own axis describing a complete rotation, which generates the sunrises and the sunsets **(Figure .1**). The variation of the altitude of the sun on the celestial sphere during one year is determined by the precession motion, responsible for a declination of the Earth axis in consideration with the plane of the elliptic yearly path; the value of this angle is 23.5º (**Figure .2**) this motion generates the seasons because of the alternative exposure of the Northern and Southern hemisphere to the sunrays trajectory [6].

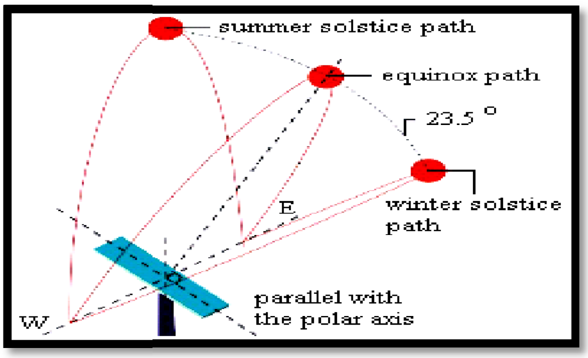
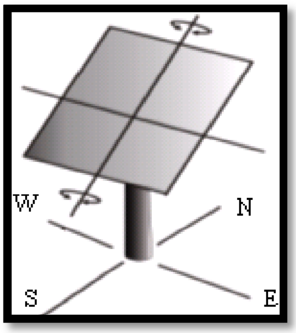


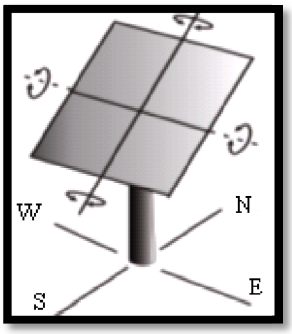
Fig .(2): Solar orientation principle

For the design process of the tracking systems, there are taken into consideration two rotational motions: the daily motion (360º), and the yearly precession motion (2×23.5º).

In these conditions, there are two fundamental ways to track the sun by one axis, or by two axes [6]. This fact determines two types of solar tracking systems as shown in **Figure (3)**



(a) Single axis tracker



(b) dual axis tracker

Fig .(3) Basic solar trackers

The single-axis tracking systems pivot on their axis to track the sun, facing east in the morning and west in the afternoon. The tilt angle of this axis equals the latitude angle of the location because this axis has to be always parallel with the polar axis. The dual-axis trackers combine two rotational motions, so that they are able to follow very precisely the sun path along the period of one year [6]. Another criterion for the solar tracker classification refers to its activity type. According to this criterion there are two types:

1.1 Passive tracker

Passive tracker head in Spring/Summer tilt position with panels on light blue rack pivoted to morning position against stop. Dark blue objects are hydraulic dampers. The most common Passive trackers use a low boiling point compressed gas fluid that is driven to one side or the other to cause the tracker to move in response to an imbalance [7].

1.2 Active trackers

Active trackers use motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction. In order to control and manage the movement of these massive structures special slewing drives are designed and rigorously tested [7].

Sun's Angles

Some of angles that describe the position of the sun in the sky are defined below [8]:

A. Hour angle (H)

The angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15º per hour, morning, afternoon positive[8]

$$H = (12 - M) * 15° \qquad \text{.................................(1)}$$

M is the local time, for instance 8 am is equal to M = 8, while for 2 pm is equal to M = 14

B. Declination angle (D)

The angular distance of sun's rays north or south of the equator, north declination being designated as positive

$$D = 23.45 \sin\left[\frac{360(284+n)}{365.2563}\right] \qquad \text{.................................(2)}$$

n is the day number in year starting from the first day of January.

C. Elevation angle (A)

It is the angle between the horizontal and the line of the sun (the complement of the zenith angle).

Sin (A) = sin (D)*sin (L) + cos (D)*cos (L)*cos (H) ……………………………… (3)

L is the latitude angle, L = 33.3° for Baghdad.

D. Azimuth angle (Z)

The angular displacement from south of the projection of beam radiation on the horizontal plane, displacement east of south are negative and west of south are positive.

$$Sin(Z) = \frac{\cos(D) * \sin(H)}{\cos(A)} \qquad \text{………………………………(4)}$$

Equations (3) and (4) are used to compute the angles (A) and (Z) respectively, whereas the stored data of these angles are computed each hour from sunrise to the sunset. **Figure (4)** shows sun angles.

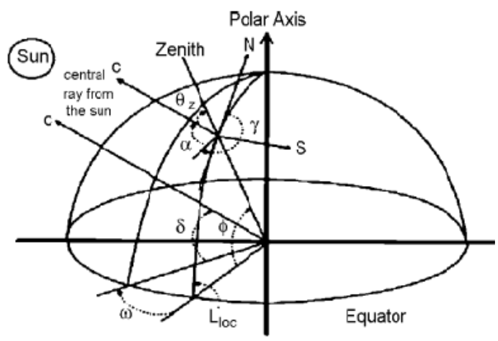


Fig .(4) sun angles

1.3 Photosensors

Photocells are sensors that allow us to detect light. They are small, inexpensive, low-power, easy to use, and Break down over time. For that reason they often appear in toys, gadgets and appliances. They are often referred to as CdS cells (they are made of Cadmium-Sulfide), light-dependent resistors (LDR), and photoresistors. Photocells are basically a resistor that changes its resistive value (in ohms Ω) depending on how much light is shining onto the squiggly face [9, 10].

2. The proposed Single Axis Tracking System

Here we will focus on the design, program, and implementation of a single axis sun tracker system using 8051 microcontroller. Proteus Virtual System Modeling (VSM) software offers the ability to co-simulate both high and low level microcontroller codes in the context of a mixed mode SPICE circuit simulation. It combines mixed mode SPICE circuit simulation, animated components and microprocessor models to facilitate co-simulation of complete microcontroller based designs. With VSM, it is possible to develop and test such designs before a physical prototype is constructed. The designer can interact with the design using on-screen indicators such as LED and LCD displays and actuators such as switches and buttons. The simulation takes place in real time, e.g., a 1GHz Pentium III can simulate a basic 8051 system clocking at over 12MHz. Proteus VSM also provides extensive debugging facilities including breakpoints, single stepping and variable display for both assembly code and high level language source.

3. Simulation and Hardware Implementation of the Tracking System

The goal of the tracking system is to keep solar panel facing the sun all off the day time. For this reason we need to determine the position of the high intensity of the sun light. The proposed tracking system algorithm based on obtaining the voltage difference between two photoresistors placed at the positive and negative x-axis sides of the PV panel and rotate the PV panel according to this value.

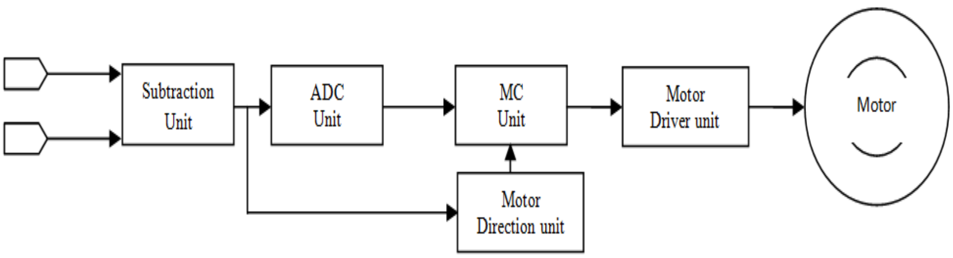


Fig .(5) the block diagram of the proposed system

The design of tracking system consists of sensing unit, subtraction unit, ADC unit, motor direction unit, microcontroller unit, and one DC motor and driver (rotation unit).**Fig .(5)** shows the block diagram of the proposed systems.

3.1 Sensing unit

This unit consists of two photoresistors placed to the left and right sides of the solar cell as shown in **Figure.(6)**. S1 and S2 are used to monitor the movement of the sun from east to west during the day time. Each photoresistor produces a miliamper current signal proportional to the incident light on its surface.

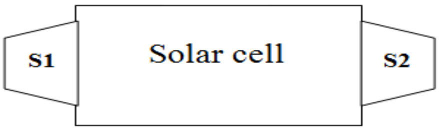
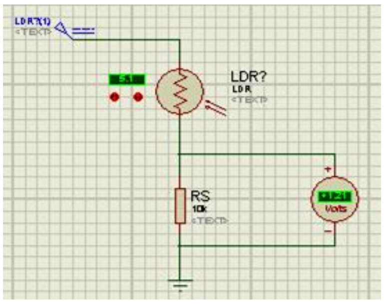
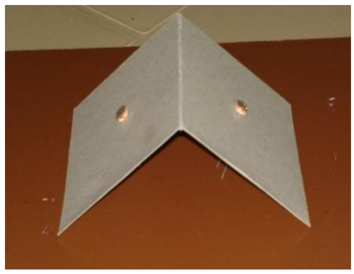


Fig .(6) Photoresistors orientation

Figure.(7-a) shows the connection of the photoresistors as a voltage divider with a series resistor. When the incident light on the photo resistor increased, it resistance decreased and the voltage drop across it, will be decreased, and so voltage drops across the series resistor will be increased.



(a)



(b)

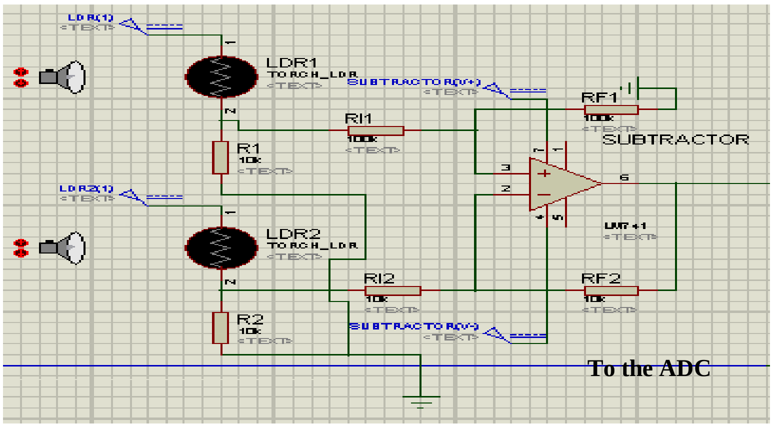
Fig.7 (a) Connection of photoresistor (b) orientation of photoresistors

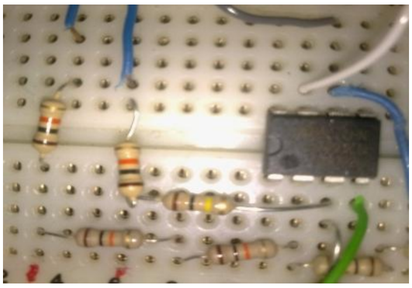
The hardware implementation of the sensing unit the input to the system is two analog voltages obtained from two photoresistors each are oriented in 45 degrees from the vertical axis (to confirm a sufficient difference between the two photoresistors)[3]. Each photoresistor was connected in series with a 10 KΩ resistor, to form a voltage divider of a 5v dc supply. When the intensity of the light increases the resistance of the photoresistor decreases, and hence the voltage drop across it decreases. **Figure.(7-b)** shows the orientation of the photoresistors.

3.2 Subtraction unit

The value of the DC motor rotation depends on the difference voltage of each the photoresistors. The LM741 will be used to subtract the voltages of the photo resistors. The subtraction unit consists of:

1- LM741 operational amplifier connected as subtrecter.
2- Input resistors and feedback resistors to keep the difference between the photoresistors without amplification, **Figure.(8-a)** show the simulation design of subtraction unit and **Figure.(8-b)** show the hardware implementation of the subtraction unit.





(a) (b)

Fig.8 (a) simulation design of subtraction circuit (b) hardware implementation of Subtraction circuit

3.3 Analog to Digital Converter (ADC) unit

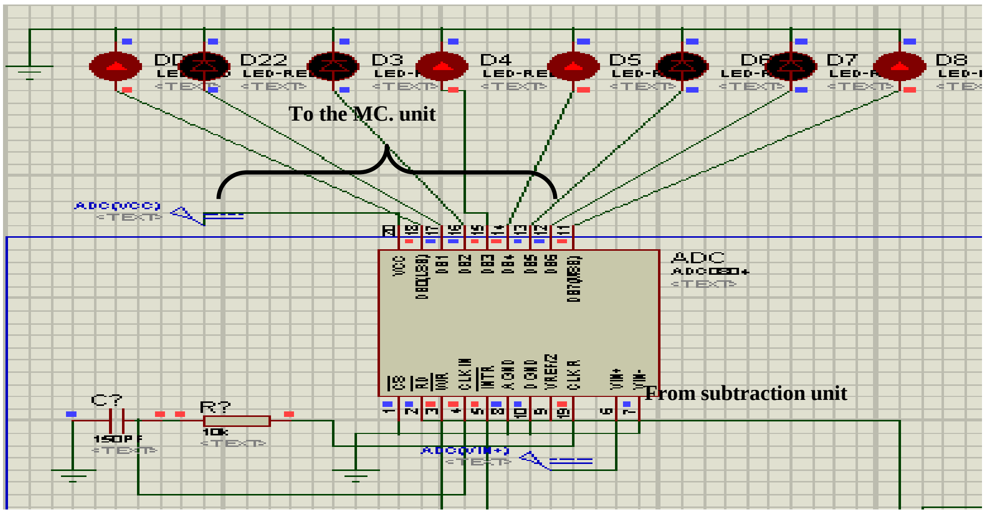
The output from the subtraction unit is to be supplied to the microcontroller unit so that it must be converted from analog to digital form using the analog to digital converter unit .The ADC unit used is the (0804), which is 8 bit ADC and has the following features:

- Conversion time . . .< 100μs.
- Easy interface to most microprocessors-no interfacing logic required.
- Will operate in a "stand alone" mode.
- Differential analog voltage inputs.
- Works with band gap voltage references.
- TTL compatible inputs and outputs.
- On-Chip clock generator.
- Analog voltage input range (single + 5V supply) . . .0 to 5 volt.
- No zero-adjust required.

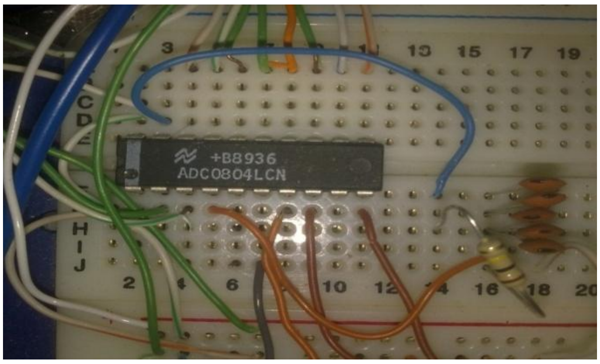
To practically connect the ADC0804 the functions of the chip pins must be known. These functions are as follows:

The pins labeled CS, RD, and WR, are control signals from the microcontroller to switch on the ADC and read data from it. The pin labeled INTR, is the interrupt signal sent from the ADC to the microcontroller to acknowledge that the conversion is completed, so that the microcontroller will send a read signal to read the digital data from the ADC. The pins labeled DB**0** to DB**7** are the digital data from the ADC unit to the microcontroller unit. The pins labeled CLKr, and CLKin are the clocking pins when connected, the ADC will operate by the internal frequency. **Figure (9-a)** shows sample of simulation design and **Figure (9-b)** shows hardware implementation of the ADC unit.

The digital output from the ADC unit will be inputted to microcontroller unit that will send control signals to rotate the DC motor according to the digital input according to the software program of the microcontroller.



(a)



(b)

Fig.9 (a) Simulation connection of the 0804ADC (b) The hardware implementation of the ADC unit

3.4 Motor Direction Unit

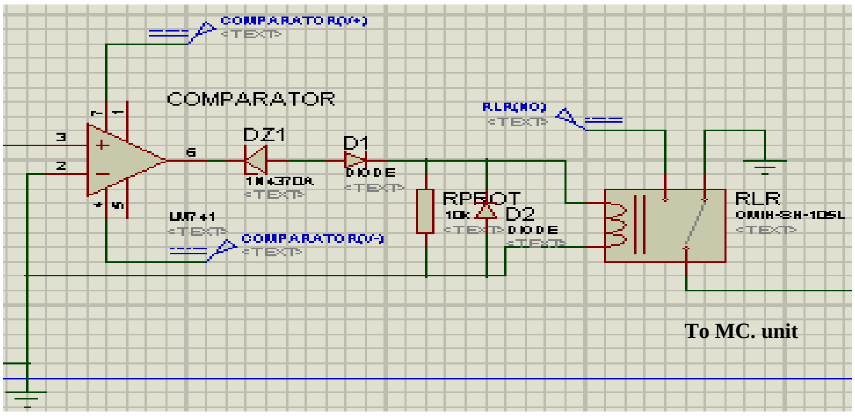
This unit is responsible for deriving the solar panel in the direction of the sensor for which the voltage signal is the maximum one through issuing the correct direction command. The direction unit consists of:

1- LM 741 operational amplifier connected as a comparator.
2- Zener diode to limit the output from the comparator to (+, - 5 volt).
3- Silicon diode to allow the +5 volt pass to the relay (S1>S2) and prevent the -5 volt from passing to the relay (S1< S2).
4- Relay with its pins are connected to +5 volt, and GND to provide the logic 1, and logic 0 signals to the microcontroller.

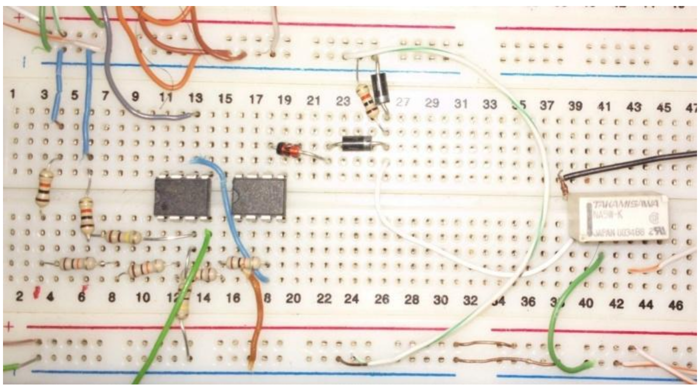
The direction unit will determine the direction by comparing the output from the subtraction unit with 0 volt (GND):

- If the voltage is greater than 0 volt, then the output is positive voltage that will pass to zener diode to limit the voltage to a 5 volts then it is applied to a diode that will be forward biased and passes the signal to relay. The relay output logic will be 1 (5 volt) signal to the microcontroller unit, which will rotate the DC motor to the clockwise direction.
- If the voltage is less than 0 volt, the output is negative signal that will pass to zener diode to limit the voltage to a -5 volt then it will be passed to the diode that will be reversed biased and will forbid the signal from passing to the relay. The relay will stay in the normal close condition (connected to the GND) and will output logic 0 signal (0 volt) to the microcontroller unit, which will rotate the DC motor to the anticlockwise direction.

The microcontroller will check if pin p1.2 is logic 1 (this means that the output from the relay is 5v) it will rotate the DC motor into clockwise direction else if it was logic 0 (this means that the output from the relay is 0v), it will rotate the DC motor into the anticlockwise direction. **Figure 10(a)** shows the simulation design of the direction unit and **Figure .10(b)** shows the hardware implementation of the direction unit.



(a)



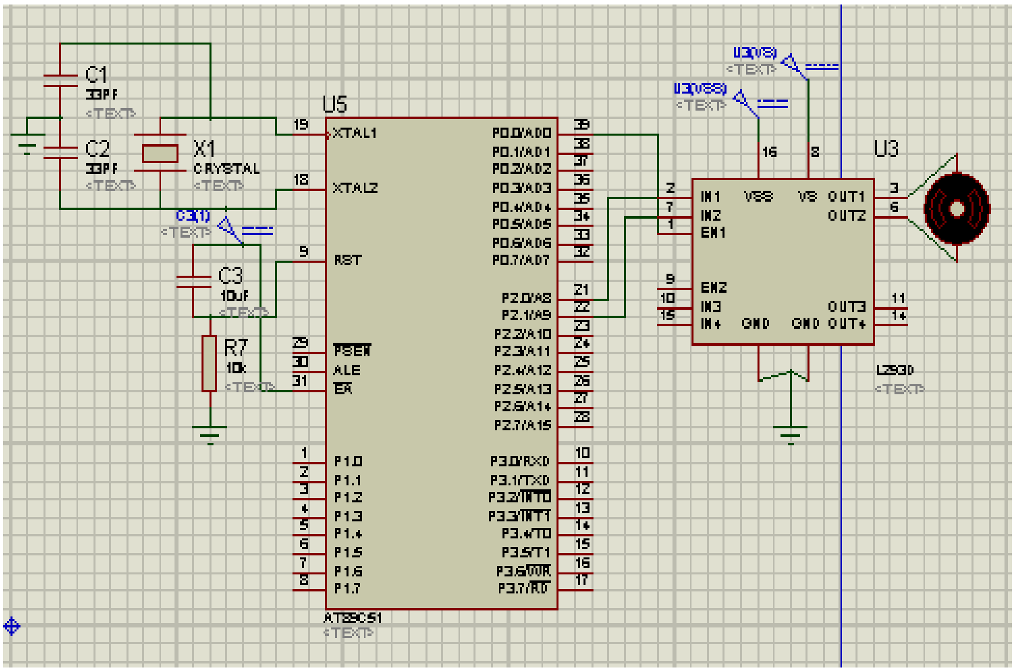
(b)

Fig .10 (a) The simulation design of the direction unit (b) The hardware implementation of the direction unit

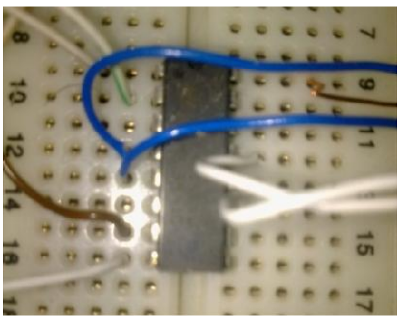
3.5 Motor and Driver Unit

This unit is responsible for rotating the solar cell. It consists of one DC motor, for the horizontal axis and, DC motor deriver L293D used to provide the sufficient amount of power required for rotating the DC motors. The motor used in this work is a 5 volt, 70 rpm DC motor with built in gear box.

The driver used in this work to drive the DC motor is the L293 DC motor deriver, which is an integrated circuit motor driver that can be used for simultaneous, bidirectional control of two small motors. The L293 comes in a standard 16-pin, dual-in line integrated circuit package **Figure .11(a)** shows the simulation design of the motor driver unit and **Figure .11(b)** shows the hardware implementation of the motor driver unit



(a)



(b)

Fig .11 (a) The connection of the DC motor and driver (b) The hardware implementation of the DC motor and driver

3.6 Microcontroller unit

This unit is the Intel 89C51 microcontroller and it is the brain of the system because it is responsible for the following:

1- Sending control signals to turn on the analog to digital converter.
2- Reading digital data from the analog to digital converter.
3- Sending control signals to the DC motor driver to rotate the motor according to the amount of the digital data obtained from the analog to digital converter.
4- Setting the delay timers between the tracking iterations.
5- Monitoring the rotation limit of the solar cell, and resetting the solar cell to the default position.

Figure .(12) shows the connection of the 89C51 microcontroller to the analog to digital converter and the DC motor driver.

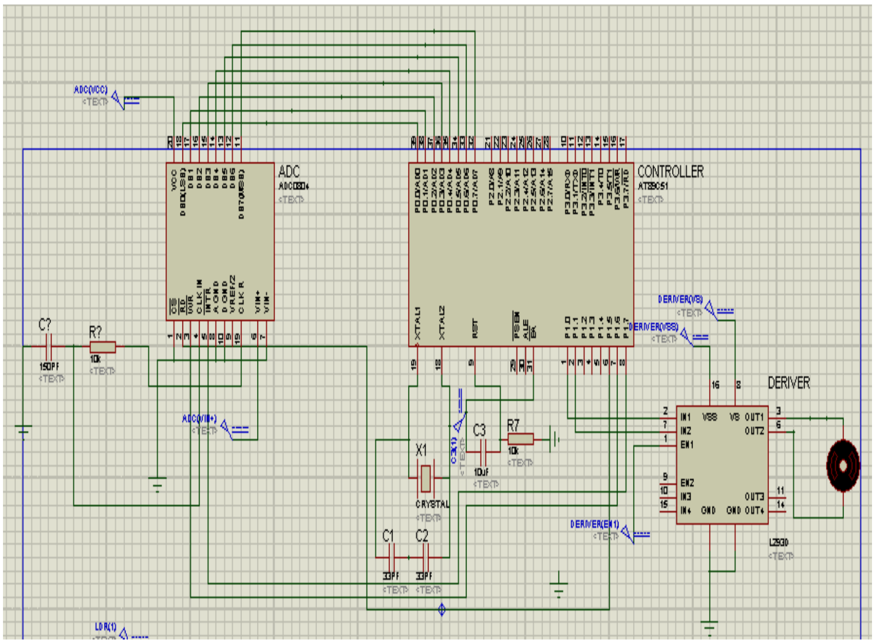


Fig .(12) The connection of the 89C51 microcontroller to the ADC & DC motor

The microcontroller will rotate the DC motor according to the digital data obtained from the ADC unit by a method known as PWM , which is made by a software program downloaded to the microcontroller, and according to the direction which obtained from the direction unit. The microcontroller unit is used to control the prototype is the MCT (Microcontroller Trainer) shown in **Figure.(13)**

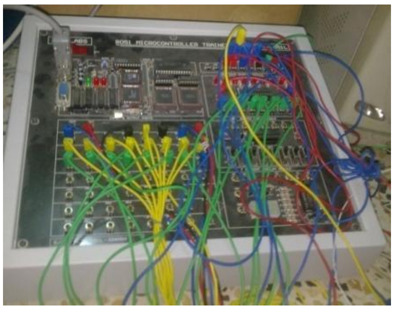


Fig .(13) the Microcontroller Trainer

4. Mechanical part

The mechanical part of the prototype consists of DC motor, two gears one for the DC motor and the other is to the base of the solar panel. The gears connected to each other by a strap. **Figure .(14)** shows the warm gears connected by a strap.

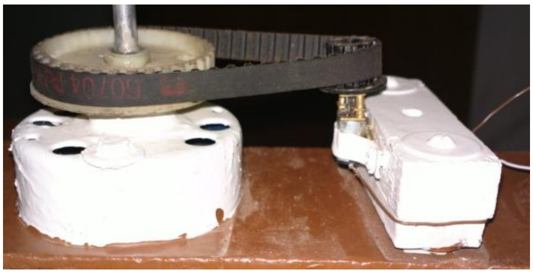


Fig .(14) the gears connected by a strap

The solar panel tilted by 33.5 degree (the latitude angle of the sun in Baghdad is 33.3 degree approximately chosen 33.5 degree). The value of the tilting angle is selectable according to the place where the system is used. When the microcontroller sends control signals to the DC motor; it will rotate the DC motor gear. This rotation will be passed to the base gear through the strap, causing the panel to rotate.

5. The complete simulation Design of single axis tracking system

Figure .(15) shows the complete simulation design of the single axis tracking system.

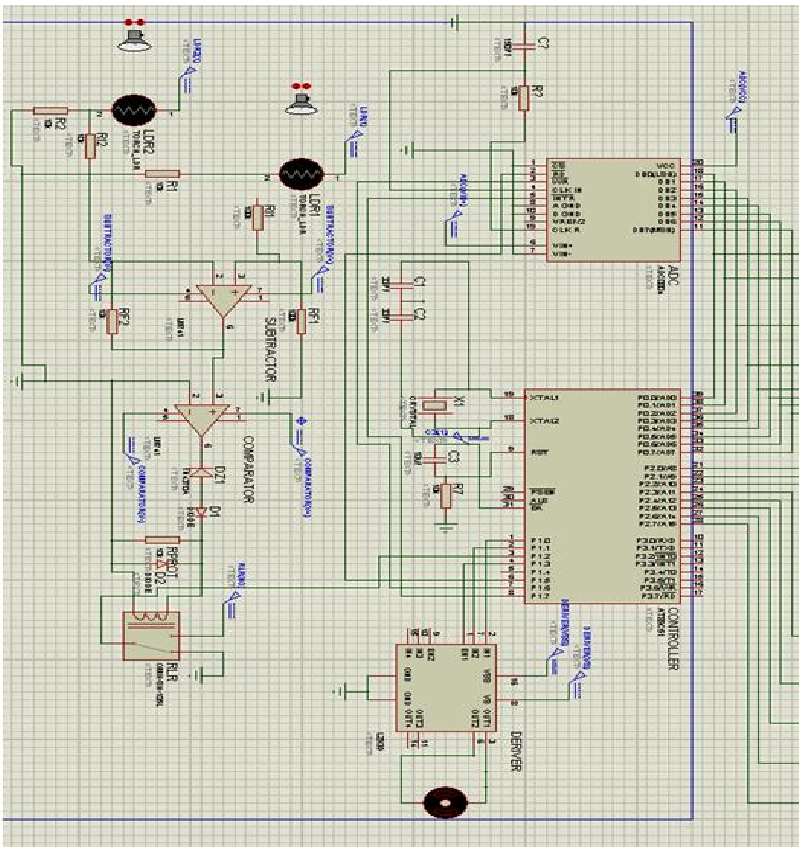


Fig .(15) The complete simulation design of the single axis tracking system

6. The Prototype Hardware Implementation

The prototype of single axis tracking system has been practically implemented according to the algorithm explained the prototype shown in **Figure.(16)**.

Fig.16 The proposed prototype

7. Software program of the single axis tracking system

This program is written by using the MCU8051-IDE emulator program and downloaded to the 89C51 microcontroller, and it is leading the 89C51 microcontroller to apply the algorithm mentioned. **Figure .(17)** shows the flowchart of the software program.

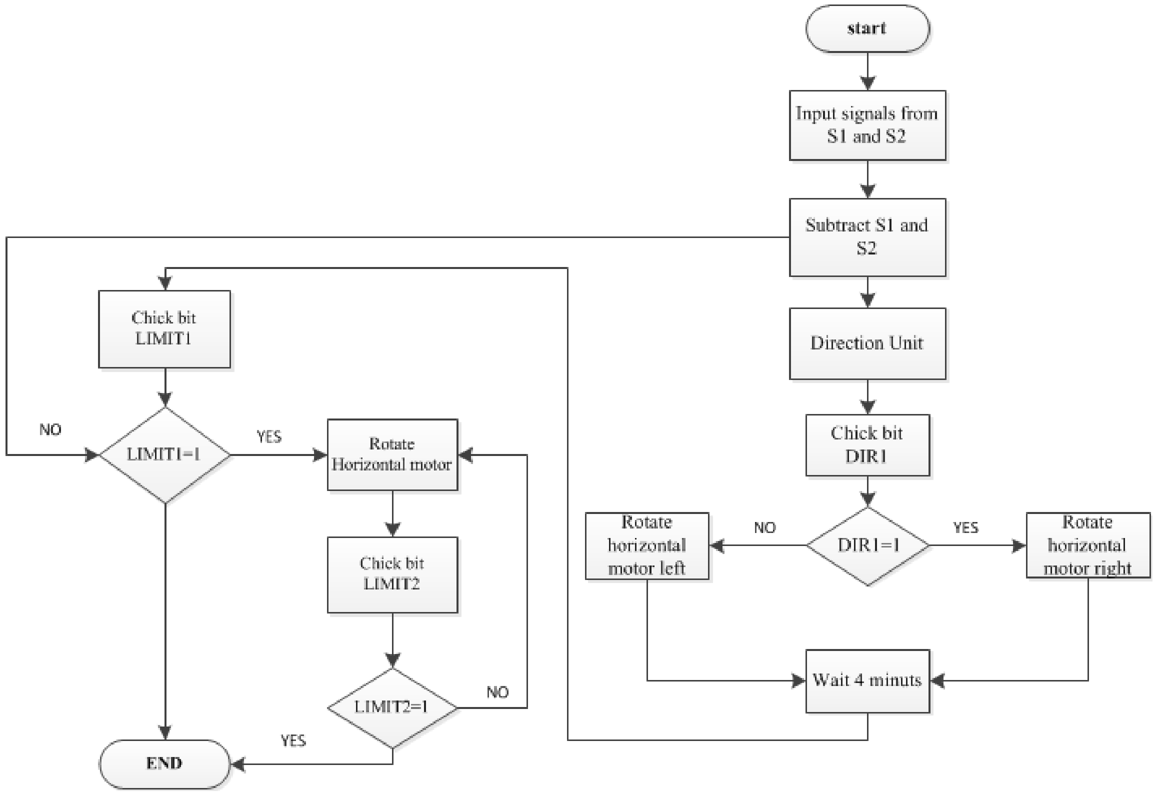


Fig .(17) Flow chart of Single tracking system

8. The System Results

Table.1 illustrates the results obtained after testing the prototype by using two solar panels of the same output power (approximately), the first panel is fixed (without tracker) and the other panel is the tracker solar panel. The test was done in 25 July, and the results gained every 1 hour from (6 am) to (6 pm). The result is illustrated in **Table.1**.

Table .1 the obtained results

Time	Power (W)	
	Fixed panel	Tracker panel
6 am	0.1554	1.7531
7 am	0.5356	2.138
8 am	0.943	2.3714
9 am	1.5162	2.6127
10 am	2.0356	2.73
11 am	2.6748	2.914
12 midday	2.948	2.975
1 pm	2.8462	2.9581
2 pm	2.4487	2.872
3 pm	2.176	2.7691
4 pm	1.871	2.729
5 pm	1.441	2.7091
6 pm	1.197	2.649
Average power	1.89904	2.90087

9. Discussion of practical results

The results illustrated in table.1 shows that the obtained power from the fixed and tracker panels are approximately equal at the midday time (12 clock) that is because of the sun will be perpendicular to both of the fixed and tracker panels at midday. But the obtained power of the tracker panel at any other hour is more than the power obtained from the fixed panel at the same hour. The average collected power from the fixed panel was 1.89904W/h while the average collected power from the tracker panel was 2.90087W/h that means the average power increased by 1.00176W/h when the tracker is used.

10. Conclusions

In this work the single axis sun tracking system for PV array was designed by using proteus simulation program and practically implemented. So it is based on the direct evaluation of the concentration of sun light by using photo sensors. The following conclusions are drawn:

1. The proposed simulation design based on a single axis solar photovoltaic panel tracker is capable to track the sun throughout the year.

2. Kinematics of the mechanical part of the tracking system is simple and can easily be controlled by the microcontroller using the digital data (which is originally the difference voltage between the two sensors) from the ADC.

3. Two sides of free rotation (East and West) are feasible. The 89C51 microcontroller has been used to control the position of DC motors which ensure point to point intermittent motion resulting from the DC motor.
4. The presented single axis solar panel tracking system keeps the solar photovoltaic panel perpendicular to the sun throughout the day and thereby improving the efficiency of the solar system.
5. As a result of the high resolution tracing system, the percentage power obtained from the solar panel is increased by 34.533% and that is the aim of using the solar tracking system.

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