Microcontroller-Based Sun Path Tracking System

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Abstract

The objective of this paper is to design and construct a solar tracking system based on a microcontroller. The system design depends on some mathematical equations to send three signals to drive circuit to change the position of the solar cell by changing the polarity of two motors. These mathematical equations are used to compute the solar height angle (elevation) and the solar horizon angle (azimuth), whereas the usage of the fixed solar cells does not accomplish the desired object, that means the use of fixed solar cells does not grant a suitable output during a day and a season, where the sun position differs at the morning to the noon and at the setting of the sun, this is due to the spherical shape of Earth and to its rotation around the sun.

The solar cell is controlled vertically and horizontally at period equal to one hour, whereas the stored data that denote of the sun position is computed each hour from the sunrise to the sunset, the amount of the stored data is different from a day to another, this variation is produced by the difference of day length during the year, whereas the amount of computed data at the summer is more than the amount of computed data at the winter. The microcontrollers vouch for processing the data and issue the commands to actuators to change the orientation of the solar cell. All obtained results are very acceptable, when the system has tested in certain days. By using the microcontroller, the project efficiency is improved, and the cost of hardware is reduced.

Keywords: Microcontroller, Solar cell, DC-motor, Elevation and Azimuth angles, Encoder.

منظومة تعقب مسار الشمس بالأعتماد على المسيطر الدقيق

الخلاصة

الهدف من هذا البحث هو تصميم وتركيب منظومة تتبع الشمس بالأعتماد على المسيطر الدقيق. تصميم المنظومة يعتمد على بعض المعادلات الرياضية لأرسال ثلاث أشارات لدائرة المسوق لتغيير موقع الخلية الشمسية بواسطة تغيير القطبية لمحركين. هذه المعادلات الرياضية تستخدم لحساب زاوية أرتفاع الشمس (المسقط الرأ سي) وزاوية أفق الشمس (زاوية السمت)، حيث أن أستخدام خلية شمسية ثابته لاتعطي الأهداف المرغوبة، هذا يعني بأستخدام خلية شمسية ثابته لانكسب أخراج مناسب خلال اليوم والفصل، حيث موقع الشمس يختلف من الصباح الى الظهر، هذا بسبب كون الأرض تشبه الكرة وبسبب دوران الأرض حول الشمس.

الخلية الشمسية مسيطر عليها عمودياً وأفقياً خلال فترة تساوي ساعة واحدة، حيث أن البيانات المخزونة تحسب وفقاً لموقع الشمس من الشروق الى الغروب، كمية البيانات المخزونة تختلف من يوم لأخر، هذا التغير ينتج بسبب الفرق في طول اليوم خلال السنة، حيث أن كمية البيانات المحسوبة في الصيف أكثر من كمية البيانات المحسوبة في الشتاء. حيث يعطي المسيطر الدقيق للعملية البيانات وأصدار الأوامر الى المشغلات الميكانيكية لتغيير موقع الخلية الشمسية. كل النتائج التي حصل عليها مقبولة جداً، عندما

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أختبرت المنظومة في أيام معينة. حيث بأستخدام المسيطر الدقيق، تحسنت كفاءة المنظومة، وقلة كلفة الأجزاء الصلبة (الدوائر الألكترونية).

1- Introduction

There are many ways to track the sun during its movement, some of them are depending on the manual work belongs to the human, it needs to the existence observer during the whole day to watch the sun direction and move the solar cell toward the sun. This way is not practical and inaccurate. Electrical circuits can be used for driving a stepper motor but it can be adapted to drive an ordinary geared brush-motor, using only one set of the two driving circuit, and a simplified microcontroller program [1, 2]. Generally, the automatically tracking ways can be divided to:

A-Feedback Automatic Tracking Way

This way operates automatically, whereas the photocells are used widely to identify the sun position, with respect to the solar cell, and then the angular error between the sun position and the solar cell is computed, next the error signal is received by the controller to produce the actuating signal, that vouch for rotating the motor, sometimes two motors are used to track the elevation and azimuth angles [3].

The electrical tracking is commonly done by feedback control, computer control or by passive control. Feedback control uses an element to sense whether focus is achieved, and if it is not, it activates the tracking system in an appropriate direction until focus occurs. For two-axis tracking can use two sets of detectors (photocell, thermocouple).

The solar tracker is an outdoor electro-mechanical device that follows the sun relative motion within the day, the solar tracker controller use mathematical computation for the sun's position in the sky and counts electronic pulses (feedback) to determine actual array (moving part of the solar tracker) position [4].

The actual tracking of collectors is achieved through a drive operating on a mechanical linkage or pulley-cable system [5].

Computer control uses stored information about the suns position to control the position of individual concentrators or banks of concentrators in large-scale systems such as those used in power production [6, 7].

Passive control uses the received suns energy to run the tracking system directly. Various systems have used a low-boiling point material such as Freon, which moves from changing weight distribution or pressure, depending on the design reorients the shut slats or louvers over a surface in order to control the insulation available to the surface, or in some cases plastics with large coefficients of thermal expansion have been used to orient solar devices [8].

B- Programmed Automatic Tracking Way

In this way, the solar cell is rotated by constant rotational velocity (15°/h), this is accomplished by programmed motor at constant ratio (the angular velocity of the sun) to rotate the collector, and then tracking the sun movement from the sunrise to sunset. But this way needs to periodic adjustment [9].

There are other means of this way, for example, where the electrical energy doesn't exist. It may to construct an automatic mechanical tracking system to grant the angular velocity of the sun (15°/h) by using a turret filled with sand with weight put on the sand and fastened by mineral wire to the rotation center, then the hole at the bottom of the turret is organized to grant constant ratio of sand streaming [10].

There is another hydraulic technique, depends on solenoid movement inside a cylinder filled with oil. This requires adjustment at least every hour or two, because of aerial bubbles inside the cylinder, in addition to another mechanical problems [11].

There is another method, by using group of weights tied up coiled wire to the rotation axis. By using the thermal extension of a metal put on absorption surface, when the sun rays reflects on the surface, next the weights will come down, that cause rotating the rotation base of the solar collector. This technique is modified by using a pendulum as a timer with frequency (1.5 sec) and a gear with (60nib), the gear rotation is controlled every (1.5 sec). This tracking system operates by falling a weight tied up coiled wire on a pulley to transfer the movement through a group of gears to the axis rotation of the collector [11].

In this project the microcontroller is used as programmable interface controller to dominant the tracing process, where the microcontroller can be programmed to make decisions (performs functions) based on predetermined situations (I/O-line logic) and selections [12].

In this work the microcontroller is used instead of microprocessor because the last is concerned with rapid movement of code and data from external addresses to the chip; the microcontroller is concerned with rapid movement of bits within the chip. The microcontroller can function as a computer with the addition of no external digital parts; the microprocessor must have many additional parts to be operational [13].

The control of tracking systems is used to increase the efficiency of solar cells, and can be done in many ways.

2- Sun's Angles [14, 15, 16]

Some of angles that describe the position of the sun in the sky are defined below.

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 15° per hour, morning, afternoon positive.

$$H = |(12 - M)| * 15^\circ \qquad (1)$$

Where (M) is the local time, for instance (8 A.M) is equal to $M = 8$, while for (2 P.M) is equal to $M = 14$.

B- Declination angle (D)

Is the angular distance of sun's rays north (or south) of the equator, north declination being designated as positive.

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

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

C- Elevation angle (A)

The angle between the horizontal and the line of the sun, i.e. the complement of the zenith angle.

$$\sin(A) = \sin(D) * \sin(L) + \cos(D) * \cos(L) * \cos(H) \qquad (3)$$

Where (L) is the latitude angle, $L = 33.3^\circ$ 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.

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

Where the angles (A) and (Z) are very important in this project. The mathematical 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.

3- Solar Tracking System Design and Implementation

Fig. 1 shows the general control block diagram of the system. The hardware of the system consists of Microcontroller, Real time clock, Address latch and EPROM (AM27C512). These ICs` are the heart of system, Fig. 2, illustrates the sub-block diagram of these hardware components interfaced together. The Microcontroller vouch for executing the control program, and then issues the commands to the drive circuit to change the polarity of the motors that indicate their movement of the Azimuth and Elevation angles.

A- The microcontroller 8052 µc

The microcontroller 8052µc, has sixteen address line multiplexed with eight data lines 8-bits address/data contained in port 0 and the remaining address lines (8bits) contained in port 2, and four banks each bank consists of 8-registers (R_0 through R_7), also contains two general registers (A, B).

B- The Real Time Clock (RTC)

The Real Time Clock (DS1287) is the time and data source, whereas, the microcontroller reads the minutes, hours, day of month, and the month from RTC continually as long as the system is in operating state, to accomplish the tracking process without variation of the solar cell through the position of the sun in the sky .The (DS1287) has two interface modes, Intel and Motorola interface modes, because the microcontroller is Intel component, the DS1287 is selected in the Intel interface mode by connecting the MOT pin in DS1287 to GND (0 logic) to allow the bus cycle between the 8052 µc and DS1287 to be chimed .

C- The Address Latch 74573

The address latch 74573 serves as demultiplexer to demultiplex the address from the data .The address is enabled to be driven to the EPROM by ALE pin in the 8052 µc, this pin is activated continuously as long as the program have been fetched to access the EPROM locations which contains the instruction codes.

D- The EPROM 27512

The program container (EPROM) contains the control program, its size ranges between 2K to 64K bytes when it is connected to 8052µc microcontroller. To access all locations in the 64K program memory, 16-address line should be connected to EPROM then microcontroller fetches the instruction from EPROM by driving the PSEN pin within it low, this pin is connected to OE in the EPROM to enable it to output the instructions code. After fetching the instruction code to the µc, the PSEN pin is driven high, and then executes the instruction.

To avoid any problem of losing the stored data, it should be stored in EPROM then if the power is cut off, the stored data in EPROM will not be lost. This is done to guarantee the stored data will not be lost, rather than using common RAM to be utilized to store the data which represents the hourly sun position during the whole year.

E- Binary counters (MC14516B)

Four MC14516B counters are used to count the pulses coming from the horizontal and vertical position sensors. Each MC14516B counter is only four bit so two counters are interfaced together for each sensor to perform 8-bit up/down counter. P1.5 of microcontroller is used to clear the counters, while P1.6 for up/down counter.

F- Parallel peripheral interface (8055PPI)

This chip is utilized in the designed system to connect the output of the horizontal sensor counter, and the vertical sensor counter as follows:

. Port A is connected to horizontal sensor counter.

. Port B is connected to vertical sensor counter.

. Port C is connected to drive circuit.

G- Schmitt triggers (7414)

The function of this chip is just for smoothing the sensors output, at 5 volt in the high level and 0 volt in the low level.

H- Three to eight line decoders (74138)

This component is just utilized to select which PPI or Real Time Clock is enabled in read or write operation.

I- Drive circuit and D.C motors

The drive circuit is the main part of the actuator, where the actuator is distributed to two parts, the drive circuit, and the motors. The drive circuit consists of three transistors and relays to control the direction and operate the motors.

Design of the drive circuit

The D.C motor requires 12V, whereas the microcomputer system cannot provide this voltages and currents. To control the direction (by changing the polarity) of a D.C motor, three transistors were used as switches to change the polarity and enabling the D.C motor to operate by voltage supplied by an external power supply, Fig. 3 illustrates the designed drive circuit. Where:

$Q_1=Q_2=Q_3$ are Transistors type NPN 945.

$R_1=R_2=R_3=300\Omega$ Resistor ¼ Watt

$D_1=D_2=D_3$ are Diodes type 1N 4004 (1 Ampere)

Transistors Q_1, Q_2, and Q_3 are used as switches to control the direction of rotation by changing the polarity of D.C motor. D_1, D_2, and D_3 are used as protection elements of the reversed currents to the microcontroller.

Controlling of D.C Motors

A major reason for D.C machines in electromechanical control systems is the ease of speed control. The polarity of the applied voltage determines the direction of rotation. D.C machines are capable of providing large power amplifications, but the utilized motors are just its direction is controlled, by utilizing the single addressable microcontroller ports and I/O ports of parallel peripheral interface component (PPI), the rotation control of two motors operates easily, also the external timers, table (1) shows how PC.0 through PC.2 are connected to the drive circuit. P1.0 is connected to the vertical initial solar cell position indicator, while P1.1 is connected to the horizontal initial solar position indicator as shown in table (2). P1.5 is connected to the reset input of the counters, while P1.6 is connected to the up/down input of the counters as depicted in table (3).

The types of utilized motors to rotate the solar cell horizontally and vertically are special motors with certain voltage and current input. By using these components the position control process is not more accurate, the best types of motors for this job are the stepper motors because of their accuracy and precision. According to the number of pulses coming to the drive circuit of the stepper motor, the rotation is done.

J-Shaft Encoder

The rotation control process is not accomplished without shaft encoder components, to read the angle continually, when the motors are in rotation status, the signal that is coming from the opto-copular is the feedback signal of the system. This process is accomplished by photocell, emitting diode and pierced disk, this disk contains 180 slot on the whole of the circular disk, every slot indicates to 2 degrees, that means, there is an error with 2 degree for each slot. The reason of containing the disk 180 slots is referred to the two following reasons:

1. Impossibility of performing disk with 360 slots.
2. The internal registers of the microcontroller are 8-bit wide.

When the disk rotates between the emitting diode and photocell (within opto-copular sensor), the light that is emitted by the emitting diode will pass or prevented through the photocell depending on the status of slots, permit or forbid the light to pass through the emitting diode to photocell.

The main usage of the opto-copular sensor is to sense the amount of rotation of the Azimuth and the Elevation motor, the Azimuth sensor output is connected CLK_1 within the external counters.

There are two other sensors utilized, one is mounted to sense the initial Azimuth position (Azimuth Angle 0) and the other to sense the initial Elevation position (Elevation Angle 0). The output of the first sensor (Azimuth position sensor) is connected to P1.1, and the output of the second (Elevation position sensor) is connected to P1.0, the function of these sensors just is important to identify the initial position of the solar cell, this initial position is considered at the north side. Fig. 4 illustrates the mechanical part contains of shaft encoder and the opto-copular.

4- Testing, Discussion, and Conclusions

After connected each component of solar energy system, certain programs are written to test:-

- The microcontroller circuit (8052c, 74573 address latch, and EPROM)
- The real time clock, to read the seconds and display them on port 1 into the microcontroller.
- The PPI ports in operations input and output, reading from port A and display this value on port B, and port C.

At the end, all the system components, which make up the solar tracking system, are tested in certain days in September, to record the output of the solar cell with load (50/55W). This system test process is done for checking the qualification of the designed solar tracking system by measuring the voltage and current of solar cell (in both fixed and moved cell measurement) under load into two different weather days, one in sunny bright day and the other test in cloudy day.

Table (5) and table (6) are showing the results of first and second tests. As denoted from two tables (table (5) and table (6)), the output of the fixed and moved solar cell in the first test (table (5)) was greater than the output of the fixed and moved solar cell in the second test (table (6)). This is because the second test is occurred in weather was cloudy and the sun position had been inclined something.

Table (4) shows the average power that received from the tracking system in both cases moved and fixed solar cells. It's clear that, the average received power from moved solar cell is greater than (approximately twice) received power from fixed solar cell.

Also by referring to Fig.5 and Fig. 6, the output of the moved solar cell was high in the early hours to arrive it's the maximum value 51.6561 W in the first test and 49.989 W in the second test at the middy (at the hour 13:00). Also the solar cell qualification is improved by control its movement side of the sun position. Fig. 7 and Fig. 8 shows the photographs of vertical view of electronic part system and horizontal view of mechanical part system respectively.

The microcontroller based solar tracking system is designed and constructed to improve the solar cell qualification with less cost and more simplicity than the other tracking systems based on the Microprocessor.

This system is experimented in suitable days, to ensure falling great amount of sun radiation on the solar cell, either to compare the output voltage of two solar cells, one has fixed position, and the other is controlled with vertically and horizontally movement. The obtained results show clear difference between the outputs of each solar cell obtained and can be observed by referring to system experiments. This designed system excels from the microprocessor-based systems with the following advantages.

1. Less expensive than the microprocessor-based systems.
2. Simpler than the microprocessor-based systems.
3. Less power loss than the microprocessor-based systems.

Because by utilize microcontroller system don't need to monitor, VGA, hard disk, floppy disk, key board, mouse, or DMA which are important for microprocessor-based systems, all these components will loss power. But in microcontroller system, just need to processor to fetch instructions and execute them, also consists of I/O ports necessary to send or receive data, in this system the illustrated components for microprocessor-based system are not necessary for this job.

The output voltage can be utilized to operate some domestic objects, and the output voltage or current can be increased depending on the connection of the solar cells (parallel or serial), i.e., when they are connected in parallel form the current will be increased, vice versa if they are connected serially the voltage will be increased.

Generally, by using the microcontroller, the effect of the hardware components and cost can be reduced.

To develop this paper in future to be in its best form, these points are illustrated as follows:-

1. To reduce the size of control software, it is recommended to use certain math co-processor to be able to execute mathematical equations, this reduce the size of software, which referred to the large amount of stored data within the program segment.

2. To use the microcontroller-based as DC to AC inverter to utilize the solar cell output to operate some Ac loads, this is accomplished by inverting low THD AC voltage from DC voltage supplied by the solar cell. This THD AC voltage can be supplied to UPS systems, and any industrial applications require low THD (Total Harmonics Distortion) AC voltage.

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Table (1) Microcontroller pins controls the motors

P1.5	P1.6	DESCRIPTION
1	X	Clear the counters
0	1	V. Counter & H. Counter count Down
0	0	V. Counter & H. Counter count Up

Table (2) Microcontroller pins related to counters

PC.0	PC.1	PC.2	THE STATE OF THE MOTORS
0	1	1	Azimuth Motor On (Right)
1	1	0	Azimuth Motor On (Left)
0	0	1	Elevation Motor (Up)
1	0	0	Elevation Motor (Down)

Table (3) Microcontroller pins related to the position of solar cell

P1.0	P1.1	INDICAEOR DESCRIPTION
0	0	The solar cell is moving vertically and horizontally.
0	1	The solar cell is at the north side horizontally position
1	0	The solar cell is at the north side vertically position
1	1	The solar cell is at the zero angle vertically & horizontally

Table (4) average received power

No. of Test	Type of Solar Cell	Average Received Power (watt)
1	Moved	47.603
	Fixed	24.693
2	Moved	46.095
	Fixed	24.183

Table (5) the obtained power from the both fixed and moved solar cell in the first test

Time (hour)	Obtained power from moved cell (watt)	Obtained power from fixed cell (watt)
8:00	33.989	2.743
9:00	47.918	7.811
10:00	48.363	19.135
11:00	49.615	31.763
12:00	50.883	43.652
13:00	51.656	49.554
14:00	50.264	48.779
15:00	48.201	30.354
16:00	48.023	23.746
17:00	47.896	8.832
18:00	46.825	5.253

Table (6) the obtained power from both fixed and moved solar cell in the second test

Time (hour)	Obtained power from moved cell (watt)	Obtained power from fixed cell (watt)
8:00	30.576	2.463
9:00	44.867	7.473
10:00	46.938	18.118
11:00	48.864	29.997
12:00	49.573	44.632
13:00	49.989	49.612
14:00	49.352	48.965
15:00	48.732	30.357
16:00	47.856	23.287
17:00	47.331	6.985
18:00	42.965	4.122

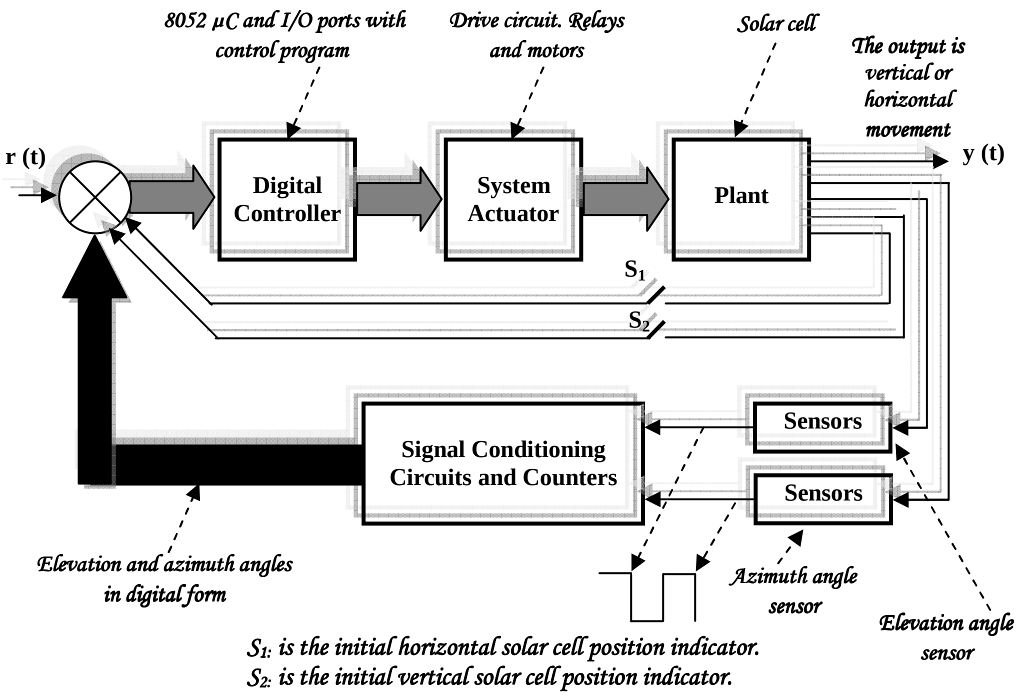

Figure (1) The general block diagram of the system

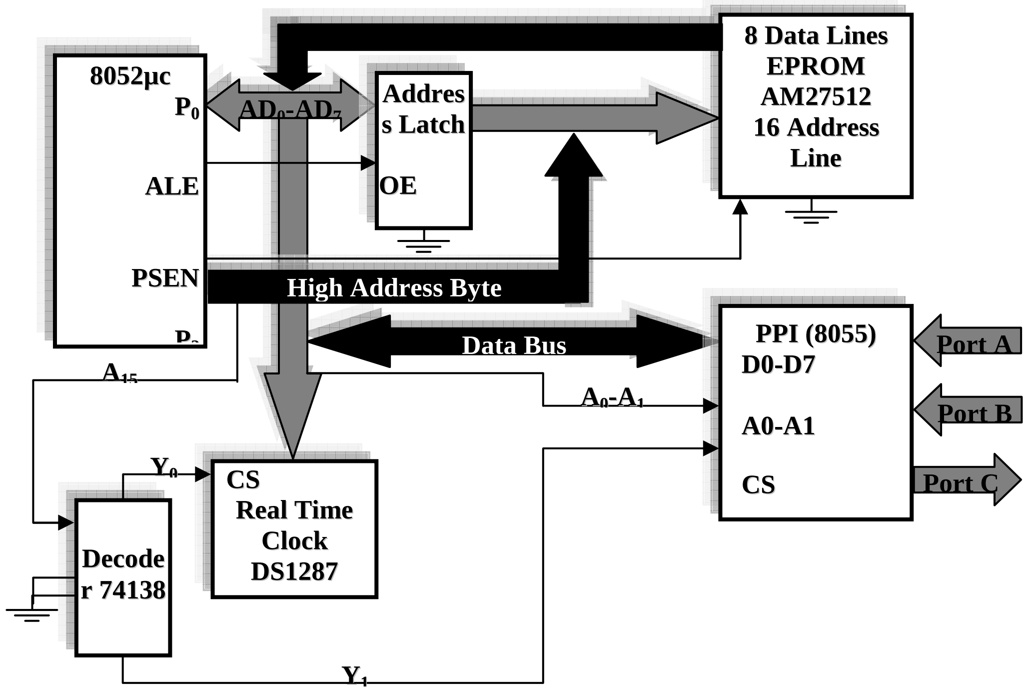

Figure (2) the sub block diagram of the system

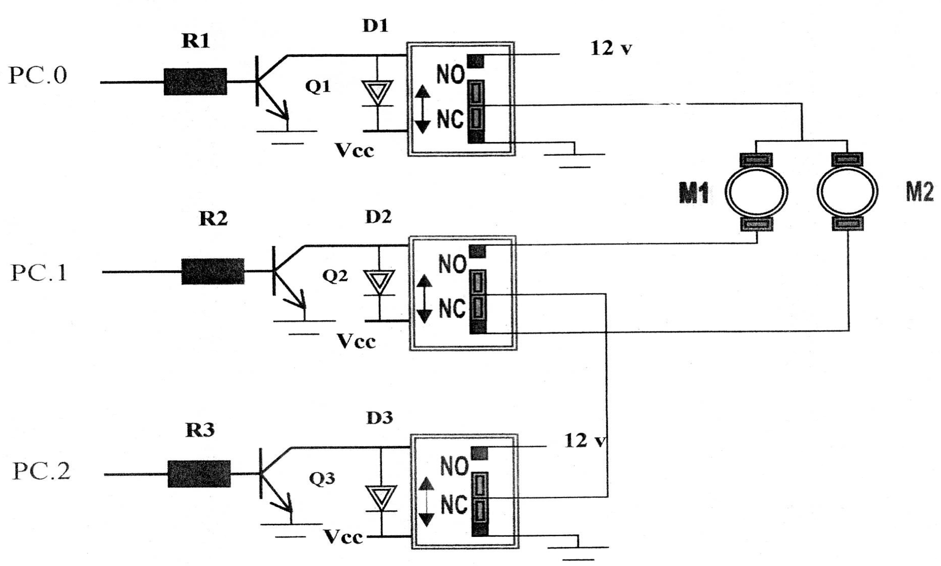

Figure (3) Designed Drive Circuit

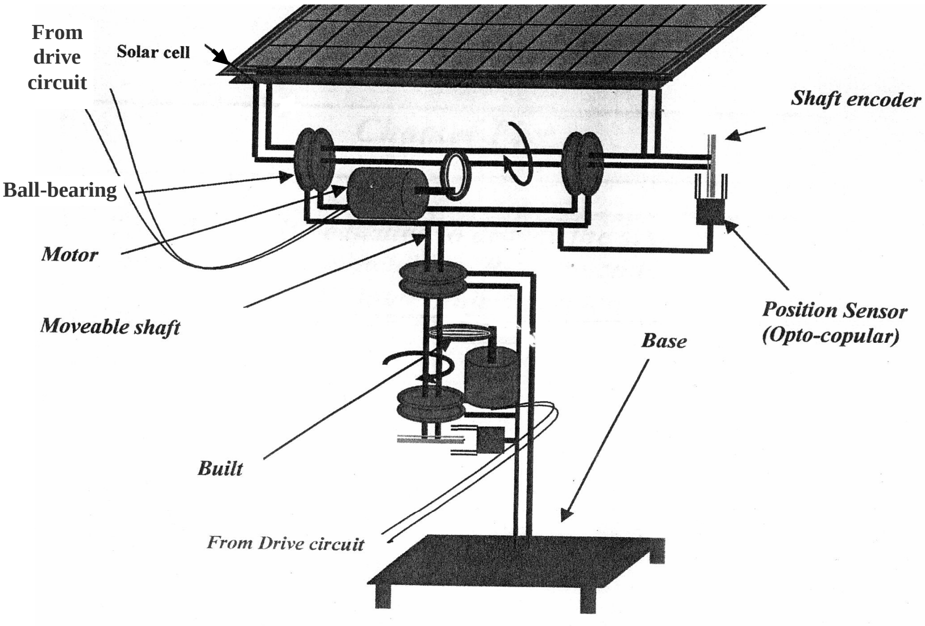

Figure (4) The Mechanical Part

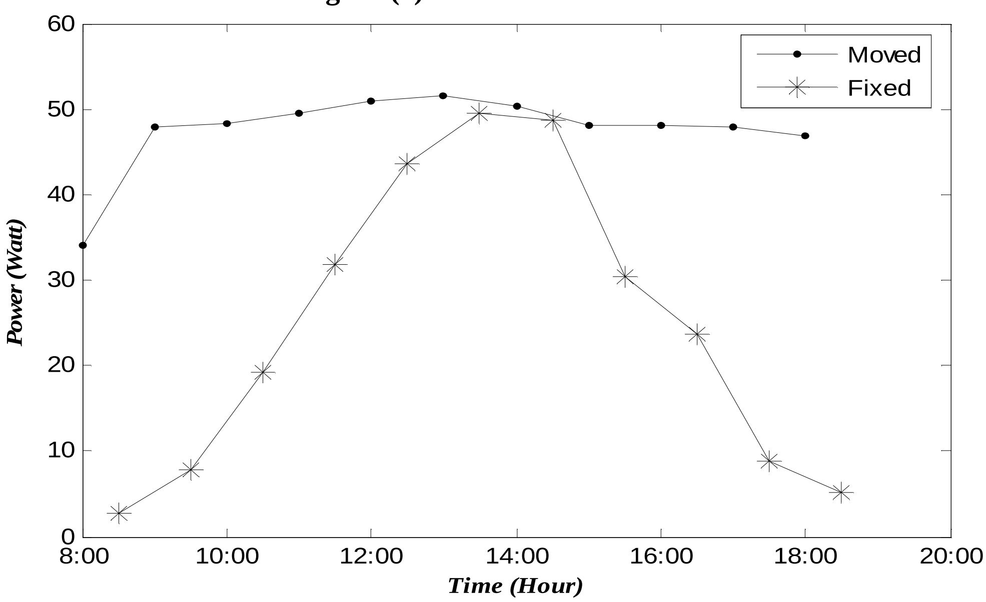

Figure (5) The obtained reading from the fixed and moved solar cell in the first test

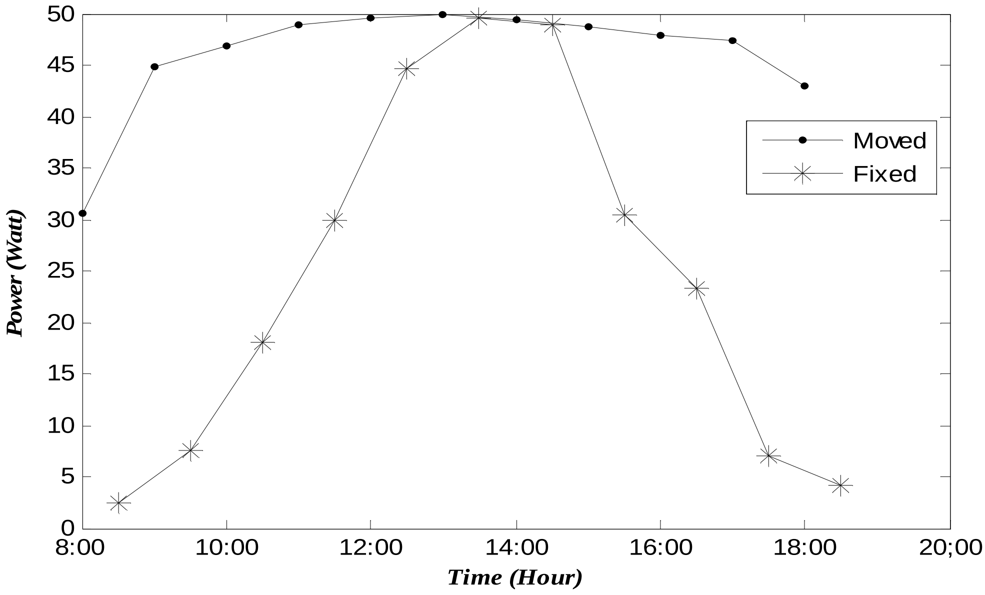

Figure (6) The obtained reading from the fixed and moved solar cell in the second test

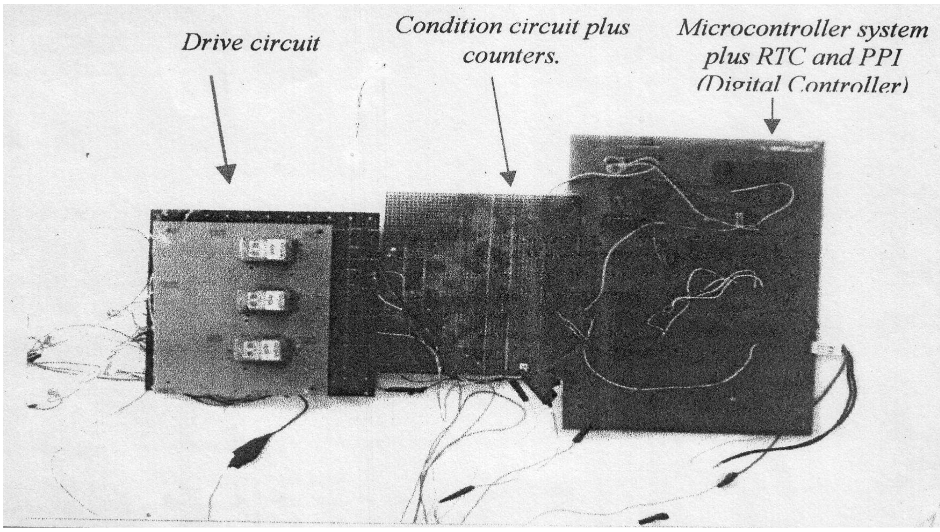

Figure (7) Vertical view of electronic part system

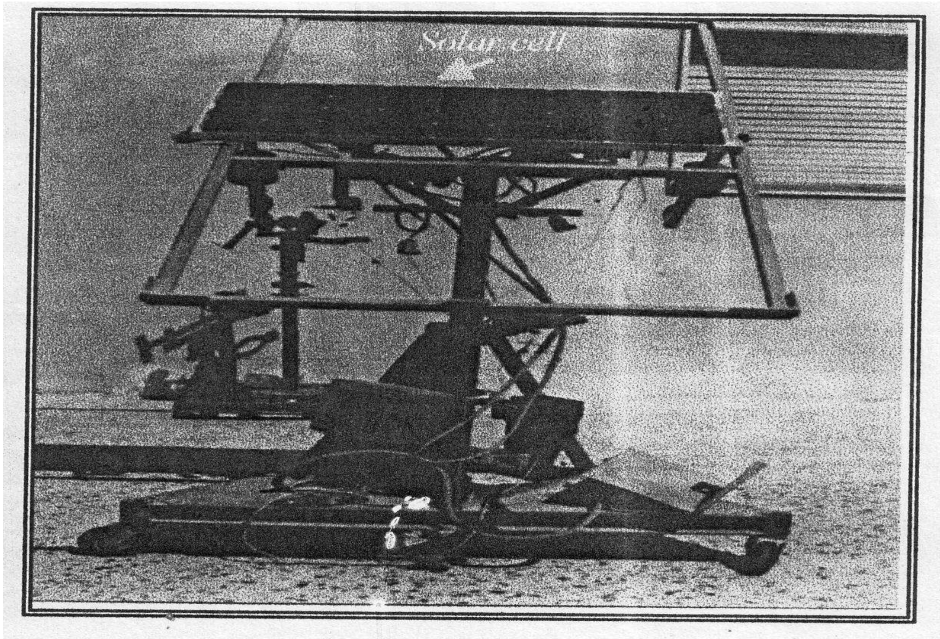

Figure (8) Horizontal view of mechanical part system