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Research Article

Design of Solar Insolation Level Detector and Data Logger

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Abstract

The Sun is the ultimate source of energy for the Earth. Its energy is both clean and free of cost. So maximizing the use of solar energy help to take the load off from fossil fuels like petrol, diesel, etc. and limit the emission of carbon dioxide hence preventing the pollution. It is also necessary to find out the area where this energy is more, so that the solar panel can be installed in such area to get maximum outcome. So to measure solar insolation level at a particular area we have designed a system. This system will measure the incident power per unit area and will also give the duration of maximum sunshine. The system comprises of photodiode, RTC (Real Time Clock), Servo Motors, Microcontroller and LCD. Photodiode gives output proportional to sun intensity. This output is then processed and converted into the unit of insolation level as watt per meter square. Then the value is sent to microcontroller, the output of photodiode and corresponding time is saved in the MicroSD card. We are continuously logging data by reading output of photodiode after particular interval of time. Before the data is logged, set of LDRs track the sun so that Direct Normal Incident radiation is only measured. While data is logged, it is stored in MicroSD card in the form of excel sheet (.csv).

Keywords: *Solar Tracker, LDR, Arduino, MicroSD card, Insolation, Servo motor, OPT101, RTC, CSV file*

1. Introduction

Solar energy is very large inexhaustible source of energy. The power from the sun hindered by the earth is approximately 1.8*10^11 MW, which is manifold thousands of times larger than the present consumption rate on the earth of all commercial energy sources. Thus solar energy could supply all present and future needs of the world on a continuous basis such can be the most promising unconventional energy sources.

In addition to its size, solar energy has two other factors in its favor, first unlike fossil fuel and nuclear power, it is a clean source of energy. Second it is free and available in adequate quantities in almost all parts of the world where people live. The sun as we know is the back bone of living kingdom, it's all because of which there is life on the earth. The solar radiation matters most on the life of the animals and human.

Trackers are the devices that align solar panel or module towards the sun. These devices follow the sun's path throughout the day by changing their orientation. Tracking maximizes energy capture.

Amount of energy captured depends upon angle of incidence (angle made by rays to the line perpendicular to the surface) between incoming light rays and module. When angle of incidence is minimum, captured power is maximum. Concentrated solar systems have optics that directly accepts sun rays, so solar tracker must be aligned correctly. All concentrated solar systems have trackers as these systems are unable to produce energy unless directs rays fall on them.

There are two types of sun trackers single-axis and dual-axis. Single axis tracker moves back and forth in east-west direction. Because of axial tilt of the Earth, the inclination of Sun's trajectory in the sky varies over the course of the year. Single axis tracker cannot follow Sun's trajectory. Dual axis mechanism can track sun in continuous manner as it can move in two different (east-west and north-south) directions i.e. it follows Sun's exact trajectory.

Insolation is the amount of solar radiation received on given surface area during given time. It is also called solar irradiation and expressed in terms of "hourly irradiation" if recorded during an hour or " daily irradiation" if recorded during a day. Insolation is measured in Mega Joules per square meter (MJ/m^2) or Watts per square meter (W/m^2).

Direct insolation is solar irradiance measured at given location on Earth with surface element perpendicular to Sun's radiation excluding Diffused insolation. On the other hand, diffused insolation is sunlight that has been scattered by atmospheric components. Direct insolation has a definite direction but diffuse insolation doesn't. Global insolation comprises of both direct and diffuse insolation. During clear sky, direct insolation is 85% of global insolation and diffuse insolation is about 15%. As Sun goes lower diffuse radiation goes on increasing up to 40% when Sun is 10^o above the horizon.

2. Literature Survey

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Most of the radiation instruments, generally used for meteorological purposes, have thermal detectors. These instruments are exposed outside throughout the year under all environmental conditions and at different locations with changing climatically conditions. Accordingly, the World Meteorological Organization (WMO) has classified the radiation instruments into different groups.

2.1 Pyranometer

Pyranometer is an instrument which measures either global radiation or diffuse radiation falling on a horizontal surface. Primarily the pyranometer consists of a 'black' surface which heats up when exposed to solar radiation. The pyranometer consists of a 'black' surface which heats up when exposed to solar radiation. Its temperature increases until the rate of heat gain by the solar radiation equals the rate of heat loss by convection. The hot junction of a thermopile is attached to the black surface while the cold junctions are located under a guard plate so that they do not receive the radiation directly. As a result, an EMF is generated and is usually in the range of 0 to10 mV can be read, recorded or integrated over a period of time and is a measure of the global radiation.

2.2 Pyrheliometer

Pyrheliometer is used to measure direct normal incidence irradiance falling on a surface normal to the Sunrays. In contrast to pyranometer, the black absorber plate is located at the bottom of the collimating tube. The tube aligned with direction of the sunrays with the help of a two axis tracking mechanism and an alignment indicator. Thus the black plate receives only direct incident beam radiations and small amount of diffused radiations falling within 5 degree 'acceptance angle' of the instrument.

2.3 Sunshine Recorder

The duration of bright sunshine in a day is measured by means of a sunshine recorder. The sun's rays are focused by a glass sphere to a point on a card strip held in a groove in a spherical bowl mounted concentrically with the sphere. Whenever there is bright Sunshine, the Sunlight burns formed is intense enough to burn a spot on the card strip. Through the day as the sun moves across the sky, the Sunlight burns moves along the strip. Thus, a burnt trace indicating the duration of sunshine is obtained on the strip.

2.4 Microcontroller and Sensor based

A Microcontroller-Based data acquisition system for solar radiation measurement was designed (Mukaro and Carelse, 1999). In this system ST62E20 8-bit microcontroller is used. The system uses the SolData silicon-cell pyranometer as the solar radiation sensor. The output data from the sensor is collected and converted by means of on-chip ADC and stored in a serial EEPROM and then uploaded to a portable computer.

A microcontroller-Based solar energy measurement system was designed (Awasthi and Dubey, 2012). The system is designed using AVR atmega16 microcontroller and PIN photodiode sensor. Using Ethernet module ENC28j60, the system sends the energy unit to TCP/IP stack.

2.5 Microprocessor based sun tracker

A single axis solar tracking system using stepper motor was designed (Sreenivasa and Mahesh, 2012). Tracker is designed using ARM7TDMI Processor. LPC2148 ARM processor fetches the input from the LDR and gives the command to stepper motor to tackle change in the position of sun.

A dual axis tracking mechanism in both east-west and north-south direction was designed (Bingol, Altintas and Oner, 2006). Voltage divider consisting of resistors and LDRs are used to take control signal. PIC16C71 microcontroller having on-chip ADC is used. Assembly level language is used for programming.

A low power solar tracking system in single axis regardless of motor speed was designed (Ponniran, Hashim and Joret, 2011). DC-geared motor is used to rotate the solar panel. Microcontroller PIC16F877A is use to control the movement of motor via relay and relay controls the clockwise and anti-clockwise rotation of motor. Two LDRs separated by divider is used as the light sensor.

2.6 Solar Parameter based

A low cost data logger was designed for solar energy parameters (Akposionu and Nwokoye, 2012). 8-bit MCU embedded platform is used for the data logging. An LN35 linear transducer IC is used as temperature sensor device. Solar panel of dimension 6'x18' coupled to a constant load driver circuit used as the solar irradiation variation sensor unit.

3. Hardware

Fig.1 shows the block diagram of system developed. Tracking the position of the sun and measuring the insolation undergoes various steps. Power supply circuit is used as main source and further divided in order to give supply to microcontroller and servo motors etc. Voltage regulators are used to provide separate voltages to different sections.

Four light dependent resistors (LDR) are used to track the Sun's position. Two LDR's are used for horizontal movement and remaining two for vertical movement. The clockwise and anti-clockwise rotation of servo motors depends on the values of two LDR's scanned at a time.

For controlling the system, microcontroller Atmega328 acts a central control unit which controls the motors used and other peripherals interfaced. The OPT101 photodiode sensor is used to measure the insolation level. The output voltage of sensor is proportional to the incident radiation. To get the direct normal incident radiation, sensor is covered with a pipe. The output voltage is given to the analog pin of microcontroller. The microcontroller takes the analog value from the sensor and converts it into digital value by using on-chip ADC. The output voltage of sensor is calculated and converted into the insolation unit watt per square meter (W/m^2) by calibrating the system with the conventional radiation instrument. Along with the sensor output, the time and date of particular output is stored in the MicroSD card by the microcontroller.

Real Time Clock (RTC) DS1307 is used to provide the accurate time and date for this application.

4GB MicroSD card is interfaced with the microcontroller which stores the insolation level along with date and time. Along with storing the output in MicroSD card, it is displayed on LCD. The LCD is operated in 4-bit mode to save the digital pins of microcontroller.

The open source Arduino development environment is used for the programming of the system. Using the function provided by the Arduino, excel sheet (.csv file) of insolation level and corresponding time and date is created in the MicroSD card. Data recorded is continuously logged in the excel sheet. Creation of excel sheet makes the analysis and storing of insolation information easy.

3.1 Photodiode Sensor

A photodiode is photo detector capable of converting, light into either current or voltage, depending upon the mode of operation.

OPT101 is monolithic photodiode with on chip trans-impedance amplifier. Output voltage increases linearly with light intensity. The amplifier can be used in single or dual power supply operation mode making it ideal or battery operated operations. Photodiode is operated in the photo-conductive mode for excellent linearity and low dark current.

3.2 Light Dependent resistor

A photo resistor or light dependent resistor (LDR) is resistor whose resistance decreases with increasing incident light intensity; in other words, it exhibits photoconductivity.

Two LDR's are connected in series for both horizontal and vertical movement i.e. one leg of each LDR is tied together, remaining leg of one LDR is connected to power supply and that of other is to ground. This makes voltage divider circuit which divides the voltage equally across two LDRs.

When light on both LDRs is same, their resistance is nearly same. Hence the voltage between common point and the ground is nearly half of the biased voltage i.e. threshold voltage. When light on the ground side of LDR is more, its resistance decreases. Thus common point voltage falls below threshold voltage. Similarly, when light on power side LDR is more, the common point voltage crosses the threshold value.

3.3 ATmega328p Microcontroller

Microcontroller is small size computer on a single IC containing processor core, memory and programmable input-output peripheral.

Microcontrollers are designed for the use of embedded applications, in contrast with microprocessor which are used for personal computers and other general purpose applications.

Atmega328 is a low power, high performance; CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. Atmega328 provides 32 K bytes of in-system self programmable memory with read while write capability and 1Kbyte EPROM.

3.4 Servo Motor

Servo refers to an error sensing feedback control which is used to correct the system performance. Servo or RC Servo Motors are DC motors equipped with a servo mechanism for precise control of angular position. The RC servo motors generally have a rotation limit from 90° to 180°. But servos do not rotate continuously. Their rotation is restricted in between the fixed angles.

Two Servo motors are used in the tracking system for the rotation on 2 Axes. Motor has three connections. Vcc, Ground and control pin. The control pin is connected to PWM pin of the controller. The supply is given through the voltage regulator.

3.5 Real Time Clock (RTC)

The Real Time Clock (RTC) is a widely used device that provides accurate time and date for many applications. The RTC chip uses internal battery, which keeps the time and date even though the power is off.

DS1307 serial RTC is a low power, full BCD (Binary Coded Decimal) clock/ calendar. Also it has 56 bytes of NV-SRAM. Address and data are transferred serially through an I2C, bidirectional bus. The DS1307 has a built in power sense circuit that detects power failure and automatically switches to the backup supply. Time is kept continuously while the part operates from the backup supply.

3.6 MicroSD card module

It interfaced with microcontroller with SPI (Serial Peripheral interface) standard. The module is designed for dual voltage power supply. The interface module can be used with two logic level i.e. CMOS 3.3V or TTL 5V.

3.7 Liquid Crystal Display

LCD is used to display the insolation level and the current time and date at the instant of Sun's illumination. A Digchip make 16 character × 2 line JHD162A liquid crystal display was used in the system developed. The display is a 16 pin which works with maximum power supply of 5.0V and the data can be sent in either 4 bit, 2 operations or 8-bit, 1 operation so that it can be interfaced to 8-bit Microcontroller

3.8 Power Supply

A 12 V adapter was used for deriving power from the AC mains. The servo motor works with 6V dc power supply and the controller, sensors, RTC and the LCD works with 5V DC power. The LM7805 positive regulator is used for providing 5V DC voltage and LM7806 positive regulator is used for providing 6V DC voltage.

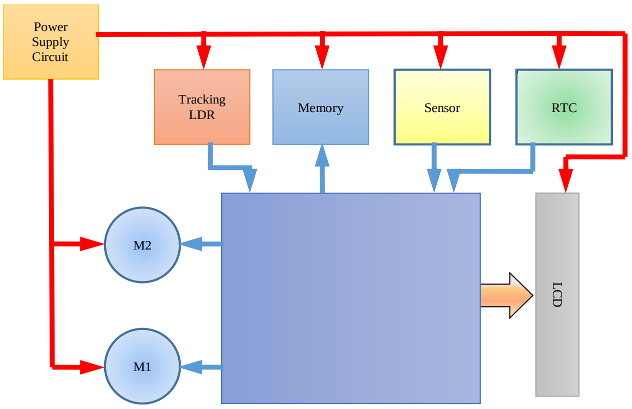

Fig.1 Block Diagram of the system

Table1 Insolation Reading of the system taken on 03/04/2014.

	A	B	C	D	E	F	G	H
1	Date	Month	Year	Hour	Minute	O/P(mV)	O/P(W/m^2)	
2	3	4	2014	14	9	4261	766.98	
3	3	4	2014	14	12	4229	761.23	
4	3	4	2014	14	15	4223	760.21	
5	3	4	2014	14	18	4209	757.76	
6	3	4	2014	14	21	4187	753.72	
7	3	4	2014	14	24	4179	752.27	
8	3	4	2014	14	27	4154	747.86	
9	3	4	2014	14	30	4131	743.63	
10	3	4	2014	14	33	4117	741.17	
11	3	4	2014	14	36	4103	738.55	
12	3	4	2014	14	39	4093	736.75	
13	3	4	2014	14	42	4082	734.92	
14	3	4	2014	14	45	4070	732.74	
15	3	4	2014	14	48	4058	730.56	
16	3	4	2014	14	51	4045	728.2	
17	3	4	2014	14	55	4039	727.02	
18	3	4	2014	14	58	4038	726.84	
19	3	4	2014	15	1	4025	724.66	

4. Implementation of the system

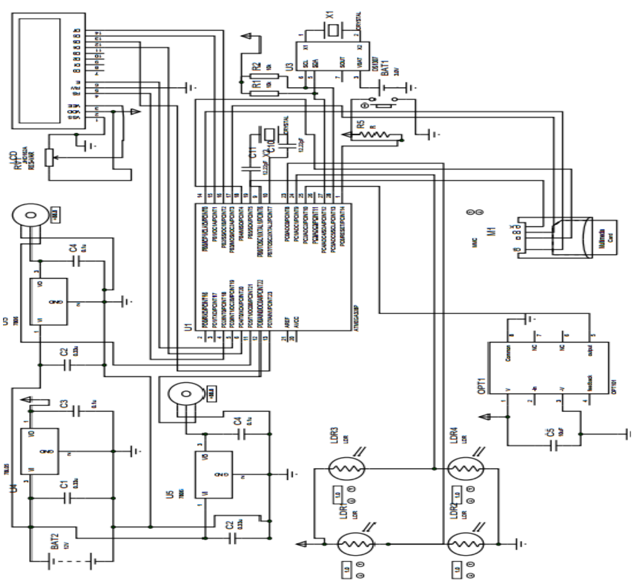

Fig.2 Schematic of the system

The schematic for the system is shown in Fig.2. The system consists of four LDRs, ATmega328p microcontroller, two servo motor, RTC, MicroSD card module, OPT101 sensor and LCD. LM7805 Voltage regulator is used to supply 5V to microcontroller and peripheral devices. Two separate LM7806 voltage regulators are used to supply 6V to each servo motor.

A control pin of each servo motor is connected to PWM pin of the microcontroller. Output of photodiode sensor and common point of each LDR set is connected to analog pin of the microcontroller. RTC is interfaced using I2C using SCL and SDA pins. MicroSD card is interfaced using SPI. LCD is interfaced using digital pins of the microcontroller in 4-bit mode of operation.

5. Results

The developed system was tested at latitude 18°32′36.315″ and 73°48′15.177″ longitude on the 3rd April, 2014.

An embedded system put together with software as well as hardware and the tracking system was developed after step by step procedures. To obtain this data, simple experiments were performed. Readings were taken from 2:00pm to 3:00pm for tracking mode of operation and is shown in Table 1. The excel sheet is created of the readings.

Table2 Conventional Radiation Instrument Readings taken on 03/04/2014.

	A	B	C	D	E	F	G
1				NIP			
2	3/4/2014	13:10:00	Ch	0.466	J/m2	776.67	W/M2
3	3/4/2014	13:20:00	Ch	0.456	J/m2	760.00	
4	3/4/2014	13:30:00	Ch	0.459	J/m2	765.00	
5	3/4/2014	13:40:00	Ch	0.446	J/m2	743.33	
6	3/4/2014	13:50:00	Ch	0.456	J/m2	760.00	
7	3/4/2014	14:00:00	Ch	0.455	J/m2	758.33	
8	3/4/2014	14:10:00	Ch	0.456	J/m2	760.00	
9	3/4/2014	14:20:00	Ch	0.442	J/m2	736.67	
10	3/4/2014	14:30:00	Ch	0.437	J/m2	728.33	
11	3/4/2014	14:40:00	Ch	0.437	J/m2	728.33	
12	3/4/2014	14:50:00	Ch	0.437	J/m2	728.33	
13	3/4/2014	15:00:00	Ch	0.434	J/m2	723.33	
14	3/4/2014	15:10:00	Ch	0.425	J/m2	708.33	
15	3/4/2014	15:20:00	Ch	0.411	J/m2	685.00	
16	3/4/2014	15:30:00	Ch	0.386	J/m2	643.33	
17	3/4/2014	15:40:00	Ch	0.37	J/m2	616.67	

The readings of the system developed were compared with the conventional radiation instruments. The table 2 shows the readings on using the conventional radiation instrument.

The graph is developed using the readings of both developed system and the conventional radiation instrument and is shown in fig.3. The graph is helpful is comparing the readings of developed system with the conventional one. The graph helps in analysis and determining the efficiency of the system developed.

Conclusions

Designed prototype is a low cost microcontroller based system which automatically tracks the sun. The principle used is very easy and simple to implement. Hardware required for the design is not very costly and easily available in the market. It tracks the sun in such a way that only normal rays are incident on the Photodiode. As the tracker is activated after certain amount of time the power required to drive the motors is very small. The value obtained from the photodiode along with the corresponding Date and Time are stored in the MicroSD card in excel sheet.

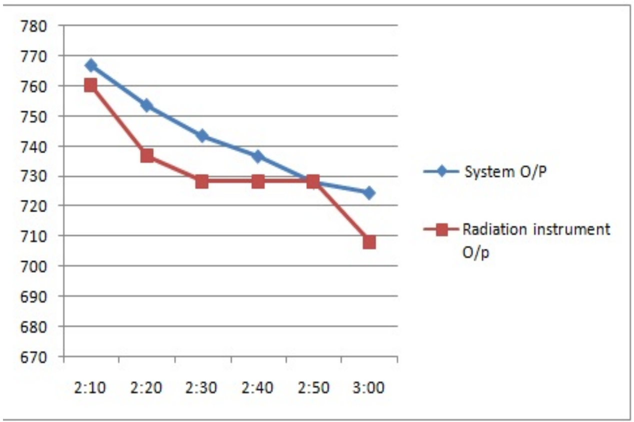

Fig.3 Insolation (W/m^2) vs. Time (Hr: min) plot for developed system and conventional instrument taken on 03/04/2014.

The values from our system are compared with conventional system. We can replace the sensor and mount a solar panel to get maximum energy. We can also use different solar instruments to get maximum throughput.

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