Tarım Makinaları Bilimi Dergisi (Journal of Agricultural Machinery Science)
2011, 7 (4), 387-392

Design and Construction of a Sun Tracker System with Analog-Digital Combination Control Method and Feasibility of its Using in Solar Crop Dryers

Akbar JODEYRI GALICHE, Asghar MAHMOUDI, Hosein BEHFAR
University of Tabriz, Faculty of Agriculture, Department of Agricultural Machinery, Tabriz-IRAN
a_mahmoudi@tabrizu.ac.ir

Received (Geliş Tarihi): 09.05.2011 Accepted (Kabul Tarihi): 09.07.2011

Abstract: To increase energy efficiency of solar collectors, reduction in their effective area due to sun motions in the sky, can be prevented by tracking of sun path. In this regard, a prototype active sun tracker system, based on microcontroller and electro-optical sensors was designed and constructed. Driving motors were of the stepper motors. Sensors selected from solar cells and system control method was combination of analog-digital controls. In order to evaluating system, the output voltage of a solar module in fixed and tracking states, both in laboratory and real conditions was used. The results showed that the tracking system was more effective in collecting solar energy than fixed one. This system tracked the sun with ±2.5° precision and kept the collector perpendicular to sun radiation. Also the output power during the day, excluding drops in dawn and dusk that was the result of radiation crossing through a thick atmosphere layer, remained approximately fixed. Finally a suggested design of this system for using in crop dryers presented.
Key words: Crop dryers, solar energy, sun tracker

INTRODUCTION

The so-called energy crisis of the 1970s and its lingering financial consequences have made most pepple positively aware of the vulnerability of our energy-based economy (Longrigg, 1986). Drying is important to the food industry as it consumes up to 10% of the total energy use in that sector (Mujumdar, 1997).

Due to the negative enviromental effects that conventional energy production cause, an alternative source of energy has to be developed. This new source has to be pollution and hazardous by-product free. One of the few energy options that meet these criteria is solar energy. However, for solar energy to be a viable source the efficiency of present collection methods has to be increased. This is where the importance of a sun-tracking system comes into play. By tracking the sun, such that the sun,s rays always strike normal to the array,s surface, more energy can be received.

Several methods of sun following have been surveyed and evaluated to keep the solar panels, solar concentrators, telescopes or other solar systems perpendicular to the sun beem. An ideal tracker would allow the array to accurately point towards the sun, compensating for both changes in the altitude angle of the sun (throughout the day), latitudinal offset of the sun (during seasonal changes) and changes in azimuth angle. Sun-tracking systems are usually classified into two categories: passive (mechanical) and active (electrical) trackers.

Passive solar trackers are based on thermal expansion of a matter (usually Freon) or on shape memory alloys. Usually this kind of trackers is composed of couple of actuators working against each other which are, by equal illumination, balanced. By differential illumination of actuators, unbalanced forces are used for orientation of the apparatus in such direction where equal illumination of actuators and balance of forces is restored. Passive solar trackers, compared to active trackers, are less complex but work in low efficiency and at low temperatures they stop working.

Major active trackers can be categorized as microprocessor and electro-optical sensor based, PC controlled date and time based, auxiliary bifacial solar cell based and a combination of these three systems. Electro-optical solar trackers are usually composed of at least one pair of anti-parallel connected photo-resistors or PV solar cells which are, by equal intensity of illumination of both elements, electrically balanced so that there is either no or negligible control signal on a driving motor. In auxiliary bifacial solar cell, the bifacial solar cell senses and drives the system to the desired position and in PC controlled date and time based, a PC calculates the sun positions with respect to date and time with algorithms and create signals for the system control.

Poulek (1994) designed and tested a single axis passive solar tracker based on shape memory alloy actuators.The actuator can easily be deformed even under 70°C and works as a heat engine. Solar radiation energy focused by a lens is used to heat one of two actuators. It was concluded that the tracking accuracy of the tracker with simple lens is ±5°.

Clifford and Eastwood (2004) presented a novel passive solar tracker modeled with computer. They mentioned that although the expanding metals generated deflections were small, the corresponding forces were large. Their passive solar tracker design incorporates two bimetallic strips made of aluminum and steel, positioned on a wooden frame, symmetrically on either side of a central horizontal axis. The bimetallic strips are shaded so that the strip further from the sun absorbs solar radiation while the other strip remains shaded in a similar fashion to the design. The designed solar tracker had the potential to increase solar panel efficiency by up to 23%.

Poulek and Libra (1998) designed a solar tracker based on a new arrangement of solar cells connected directly to a reversible DC motor. Solar cells, both sense and provide energy for tracking. Sensing/ driving solar cells are balanced to each other. The rotary axle of the tracker was oriented in the N-S direction. The area of the auxiliary solar panel of the tracker is about 2% of the area of the moved solar collectors while collectable energy surplus is up to 40%.

Mwithiga and Kigo (2005) designed and constructed a dryer with limited sun-tracking capability that operated manually. The dryer consisted of a gauge 20 mild steel flat absorber plate formed into a topless box. The drying unit was bolted onto a shaft which in turn was mounted on to a stand so as to face E-W direction. A selector disc on the stand allow the tilt angle that the drying unit made with the horizontal, to be easily adjusted in increments of at least 15°. This way, the collector plate could be intermittently adjusted in order to track the sun during the day. Four dryer settings for tracking the sun were created. The dryer was set at an angle of 60° to the horizontal facing east at 8.00 a.m. They adjusted the angle of the dryer made with the horizontal either one, three five or nine times a day when either loaded with coffee beans or under no loud conditions. The results showed that the solar dryer can be used to successfully dry grains. Drying of coffee beans could be reduced to 2-3 days opposed to sun drying without tracking system, which takes 5-7 days and the temperature inside the chamber could reach a maximum of 70.4°C.

Solar tracker systems are used mainly in developed countries and often in large industrial complexes which produce electrical energy. In countries such as iran, because of using fossil energies, this technology has not been developed. The purpose of this research is evaluation and comparing tracker system with fixed system and evaluating the possiblity of using it on solar crop dryers.

MATERIALS and METHOD

Since this research is based on a sun-tracking application is seemed appropriate that the sensors be solar cells. While other light sensitive sensors would have been effective, by using solar cells future applications (such as running the device of its own collected solar power) may benefit from the extra cells in the array.

The design of the sensor array (Figure 1) consisted of the four sided semi-pyramidal structure, which had a solar cell mounted on each side, to determine the position of the sun. And a solar module in top of semi-pyramidal structure to evaluate the system.

This structure assures that when the pyramid is pointing directly at the sun the four sensors will have the same voltage reading. By having the sensors set at 45° angles, when the pyramid is not pointing directly at the sun the voltage will increase on the side(s) which is the most exposed to the sun. This allows for comparisons to be made between opposing sets of sensors, which in turn can be used to control the direction of movement of the array. To determine the degrees-per-step of motors, sensitivity analysis of a solar cell is used.

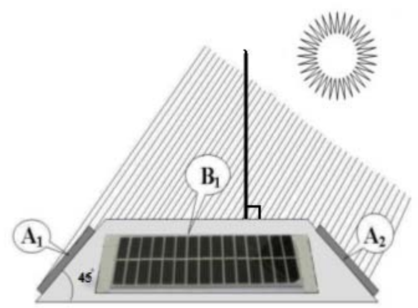

Figure 1. Sensor arrey (side view)

Table 1. Sensitivity analysis

Voltage	Angle of Incidence
3.78	0
3.78	1
3.78	2
3.78	3
3.78	4
3.77	5
3.76	6
3.76	7

From the table above it can be seen that there is no change in the voltage received until the cell is at an angle of incidence of 5°.Therefore, it is possible that the array can be 4 degrees out of phase and still receive maximum power. This factor is of great importance when selecting motors for the positioning system. To be accurate in receiving maximum energy from the sun, when a new alignment occurs the array will need to move no more than 4 degrees. If the motors rotate more than this the array will not be able to line up accurately to receive maximum energy.

From the sensitivity analysis of a solar cell it was observed that for the system to be 100% accurate the motors would have to rotate less than 4 degrees-per-step. By the way, for getting triple amount of torque, a gearing system was used.Since the chosen stepper motors have a 7.5 degree-per-step ratio. This gearing system effectively decreases the number of degrees-per-step from 7.5 to approximately 2.5. This is more than adequate to allow accurate positioning of the array.

Choice of Control Method: The best method for controlling an application such as this is to use complete software control. Under complete software control, there is no need for a translator circuit external to the microcontroller. Also, using software control greatly reduces the number and cost of components, But for developing the possibility of omitting noises due to momentary changes of radiation intensity and increasing the sensitivity of sensors, the control circuit was equipped to digital and analog systems. The output voltage of opposing sensors pass from a low-pass filter and then one of the voltages is reversed and added to the other one. In this stage, the subtracted voltage of two sensors are added to a reference voltage (-2.5 v), which is produced by LM336 IC. After this stage, it is reversed and enters the analog to digital input of microcontroller (Figure 2).

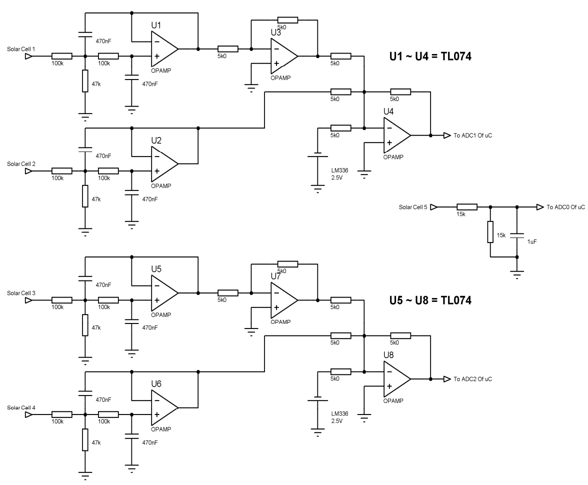

Figure 2. Analog section of control circuit

Software: In software control stage, ATmega16 microcontroller was chosen as the control chip.

The system code was written using the programming language QBASIC and after compiling and producing Hex file on BASCOM software, it was passed to programmer software (Pony Prog). Then by STK200 programmer and through a ISP port, the program Hex file was loaded in microcontroller.

Automatic Alignment: For this reason, at first stage the voltages of sensors pass from analog section of control circuit (Figure 3) and then reach to A/D of microcontroller. It is necessary to mention that the base of AVCC was selected as a reference voltage (+5V) of A/D section of microcontroller. When the voltages of opposing sensors are equal, A/D section of microcontroller will count 512 (+2.5V) and when the voltages of opposing sensores are unequal, the entrance voltage of A/D will be less or more than +2.5V.

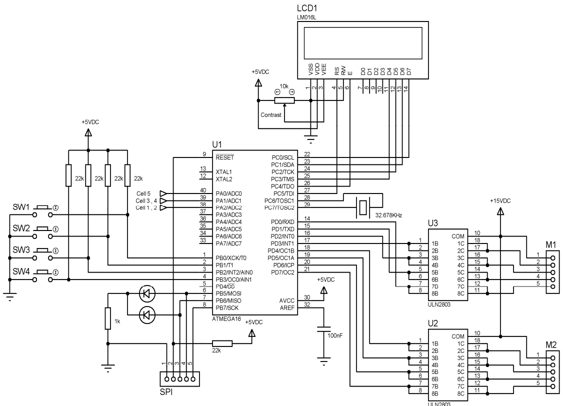

Figure 3. Digital section of control circuit

An example of this would be that if sensor A1 (Figure 4) has a greater voltage reading than sensor A2, then Motor A (Figure 5) would be required to rotate clockwise until both sensors read the same value. However, if sensor A1 has a smaller voltage reading than A2, then Motor A would be rotate counterclockwise. The same technique applies for Sensors B1/B2 and Motor B.

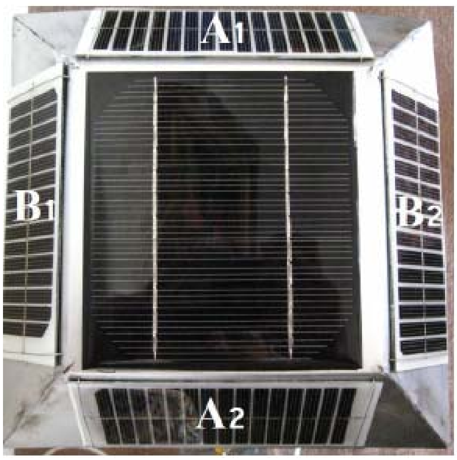

Figure 4. A_1 , A_2 , B_1 , B_2 Sensors

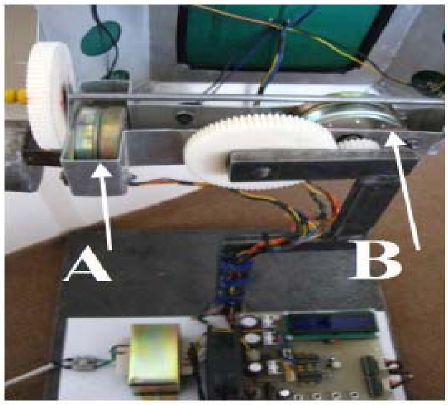

Figure 5. A and B stepper motors

RESULTS and DISCUSSION

The first series of tests involved using a portable floodlight, which was setup at different positions around the array, such that a number of different voltage readings could be obtained. Values were recorded for both the tracking array and stationary array. The aim of this series of tests was to simulate different positions of the sun and observe the differences between the two systems. The light source was set up at 19 positions (A-S) inside of a spherical area above the sensor structure (Figure 6). The following graph (Figure 7) provide the results of the tests.

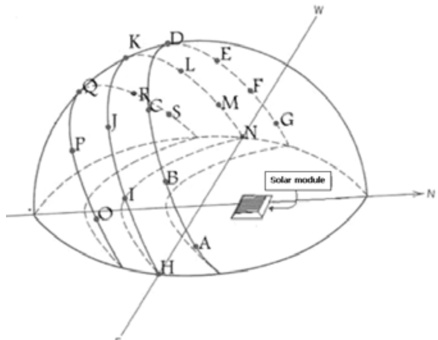

Figure 6. Light source positions

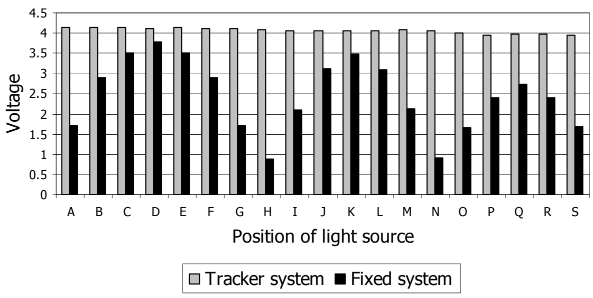

Figure 7. Voltage received for various light positions

From the results of this series of tests it is obvious that the sun-tracking system is more effective in collecting solar energy. While the stationary system is able to obtain large amounts of solar energy when the sun is reasonably overhead (light positions C,D,E,K), the values obtained for the light positions (H,N) are extremely small. This light positions closely match where the sun would be when rising and setting, so from the above results the stationary system has been proven inefficient during these time periods. Although the data obtained from the laboratory experiments has proven that the sun-tracking system is more efficient than the stationary system, it is still beneficial to observe the system in a real world situation. The following table and graph provide the data for a whole day test with the system.

Table 2. Voltage received for sun-tracking and fixed

Increase in tracking system %	Voltage Received(volts) Sun-Tracking system	Fixed system	Time of Day
0.37	5.53	4.03	07:00
0.29	6.66	5.16	07:30
0.23	6.80	5.52	08:00
0.16	6.81	5.89	08:30
0.13	6.82	6.03	09:00
0.11	6.82	6.14	09:30
0.08	6.83	6.32	10:00
0.08	6.85	6.35	10:30
0.08	6.86	6.37	11:00
0.08	6.86	6.38	11:30
0.07	6.86	6.39	12:00
0.07	6.87	6.45	12:30
0.06	6.86	6.46	13:00
0.05	6.84	6.49	13:30
0.07	6.83	6.38	14:00
0.07	6.83	6.38	14:30
0.07	6.81	6.36	15:00
0.08	6.85	6.33	15:30
0.08	6.82	6.33	16:00
0.08	6.81	6.32	16:30
0.08	6.81	6.28	17:00
0.11	6.73	6.06	17:30
0.15	6.71	5.86	18:00
0.24	6.64	5.36	18:30
0.30	6.52	5.00	19:00
0.31	5.32	4.07	19:30

The data obtained from the real world test closely matched the data that had been obtained from the laboratory tests. As can be seen from the above graph, the sun-tracking system collects the maximum amount of solar energy possible across the entire day, where as, the stationary system only collects maximum energy when the sun is overhead. These findings matched what had been observed in the laboratory tests with the only difference being that the laboratory tests did not factor in the decrease in the amount of available solar energy at dawn and dusk. that was the result of radiation crossing through a thick atmosphere layer.

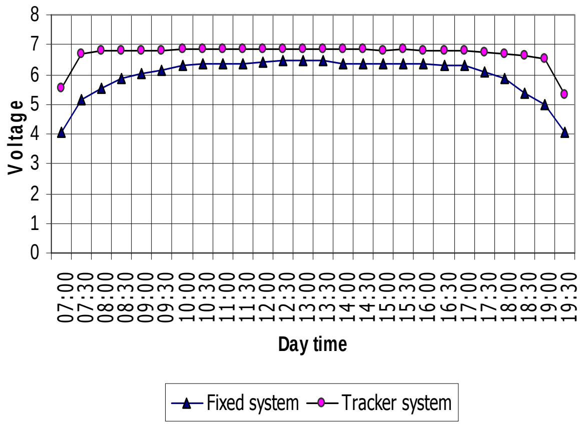

Figure 8. Voltage received: sun-tracking system vs fixed system

CONCLUSIONS

In this research, an active sun tracker system with analog-digital combination control method which is special one regarding the method of control was designed and produced. The results of experiments showed that tracker system is more efficient than fixed system in collecting solar energy. This system tracked the sun with ±2.5° precision and kept the collector perpendicular to the solar radiation. Tracker system keeps the resieved power fixed during the day. The result will be fixed temperature of working fluid in solar dryers. In addition for increasing received energy and increase of efficiency of dryer collector, the use of solar tracker systems will be useful. Howevere, regarding that solar thermal collectors are often produced of heavy materials and alignment them needs more energy, using tracker systems in cocentrating mirrors of collector is a good suggestion. Figure 9 shows a suggestive design for using tracker systems in dryer collectors. In this design, two concentrating mirrors whose length and width are equal with dryer collector have been used. By tracking the sun from sunrise to sunset the mirrors concentrate the sun's radiation on the collector and increases the radiation intensity. In general, for receiving more energy, we can install solar tracker system on collector. By this way, the difficulties related to transportation, increase of cost and site of installation of collectors (due to their large size) are solved.

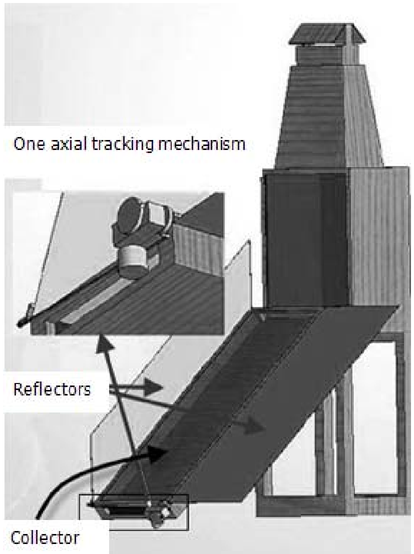

Figure 9. Suggestive design for using tracker system in dryer collectors

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