UNIVERSITI PUTRA MALAYSIA

# DESIGN AND DEVELOPMENT OF A SOLAR TRACKING SYSTEM FOR THE UPM SOLAR COLLECTOR

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# DESIGN AND DEVELOPEMENT OF A SOLAR TRACKING SYSTEM FOR THE UPM SOLAR COLLECTOR

By

KHALID OSMAN DAFFALLAH AHMED

Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Science and Environmental Studies
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*to my parents*

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## LIST OF SYMBOLS AND ABBRIVIATIONS

| | |
|---|---|
| *ADC* | Analog to Digital converter |
| $A_i$ | Binary coefficients |
| $A_k, B_k$ | Parameters for the equation of time (equation 2.15) |
| $A_z$ | Azimuth angle |
| $a_0 .. a_6$ | Parameters for the declination angle equation (equation 2.4) |
| $B$ | Year angle |
| $C_k, S_k$ | Parameters for the equation of time (equation 2.14) |
| *CMOS* | Complementary metal oxide semiconductor |
| $D$ | Drain of the *MOSFET* |
| *DAC* | Digital to analog converter |
| $e(t)$ | Error signal |
| *EQT* | Equation of time |
| *FET* | Field effect transistor |
| $G$ | Gate of the *MOSFET* |
| $I/O$ | Input / Output |
| $I_L$ | Load current |
| $K_D$ | Derivative constant |
| $K_I$ | Integral constant |

| | |
|---|---|
| $K_P$ | Proportional constant |
| $K_u$ | Ultimate gain |
| $L$ | Latitude angle |
| *MMPT* | Maximum power point tracker |
| *MOSFET* | Metal oxide semiconductor field effect transistor |
| $N$ | Number of days |
| $n_0$ | The spring equinox time |
| *PID* | Proportional Integral Derivative controller |
| *PV* | Process variable<br>Photovoltaic Sensor |
| $Q_1$ | East West incident angle |
| $Q_2$ | North South incident angle |
| $R_L$ | Load resistor |
| $R_i$ | Input resistor |
| $S$ | Source of the *MOSFET* |
| *SP* | Set point |
| $T_d$ | Derivative time |
| $T_I$ | Integration time |
| $T_{sn}$ | Solar noon time |
| $T_u$ | Ultimate period |
| $t$ | Time in days from the spring equinox |

| | |
|---|---|
| $t_H$ | Hold period |
| $t_S$ | Sample period |
| $V_c$ | Control voltage |
| $V_{in}$ | Input voltage |
| $V_{out}, V_0$ | Output voltage |
| $V_{pv}$ | Output signal from photovoltaic sensor |
| $V_{REF}$ , $V_r$ | Reference voltage |
| $V_{+SAT}$ | Saturation voltage |
| $V_s$ | Voltage signal for charging the capacitor |
| $V_{\sup ply}$ | Power supply voltage |
| $W$ | Parameter for the declination angle equation (equation 2.4) |
| $\alpha$ | Altitude angle |
| $\delta$ | Declination angle |
| $\phi$ | Longitude angle |
| $\phi_0$ | Longitude of the local time zone |
| $\theta_z$ | Zenith angle |
| $\tau$ | Number of days equivalent to 1461 days |
| $\omega$ | Hour angle |
| $\omega_s$ | Hour angle at sunset |

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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**Chairman: Professor Mohd. Yusof Sulaiman, Ph.D.**

**Faculty: Science and Environmental Studies**

In solar energy system, sun tracking can significantly improve the efficiency of any solar array. Solar trackers periodically update the orientations of devices such as reflectors, solar panels or equipment to the actual position of the sun. From these points of view, we designed and developed a tracking system for the UPM solar collector.

The system uses a software called WorkBench in association with two data acquisition and control cards. The UPM solar collector uses two modes of tracking, passive and active tracks. The switch from active to passive is done automatically by comparing the irradiation to a preset value of 300 $Wm^{-2}$. A manual tracking is also provided. This is required for initialization, shutdown, maintenance and emergency tasks. For the purpose of tracking, two independent stepper motor shafts are attached to the receiver.

For the active tracking, the output voltages from two sun position sensors were used to activate the stepper motors. These two sun sensors convert the light intensity into voltage signals. Then by using the WorkBench software these signals are converted into logic signals to control the movement of the stepper motors.

The passive tracking was carried out by utilizing the position angles of the sun. These angles were then resolved into two components for the east west and north south tracking. The WorkBench software was then used to convert these two components into voltages. The voltage was calibrated against a reference voltage produced by potentiometers attached to the motor shafts. The output from the comparison was used to control the movement of the stepper motors.

Finally, the accuracy of the system was tested by taking the output resistance from a light dependent resistor attached to the receiver. The data indicated that the tracking is satisfactory since the output resistance from the light dependent resistor was approximately constant on a cloudless periods.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**REKABENTUK DAN PEMBANGUNAN SISTEM PENGESANAN SURIA UNTUK PENGUMPUL SURIA UPM**


Oleh

**KHALID OSMAN DAFFALLEH AHMED**


**Mac 1999**


**Pengerusi:** **Profesor Mohd. Yusof Sulaiman, Ph.D.**

**Fakulti:** **Sains dan Pengajian Alam Sekitar**



Dalam sistem tenaga suria, penjejakan matahari boleh membantu meningkatkan lagi kecekapan sebarang kemudahan susunan suria. Pengesan suria ini dari semasa ke semasa akan memperbaharui orientasi peranti seperti pemantul, panel suria atau peralatan untuk kedudukan sebenar.matahari. Dari segi inilah kami telah merekabentuk dan membangunkan sistem penjejakan untuk pengumpul suria UPM.

Sistem ini menggunakan perisian yang dipanggil "WorkBench" digabungkan dengan dua kad pemperolehan dan pengawalan data. Pengumpul suria UPM menggunakan dua mod penjejakan, iaitu jejakan pasif dan aktif. Penukaran dari aktif ke pasif dilakukan secara automatik dengan membandingkan penyinaran dengan satu nilai yang telah ditetapkan iaitu 300 $Wm^{-2}$. Penjejakan secara manual juga disediakan. Ini diperlukan untuk kerja-kerja pemulaan,

pembernhentian, penyelengaraan dan kecemasan. Bagi tujuan penjejakan, dua shaf motor pelangkah bebas dipasang.

Bagi penjejakan aktif, hasil dari dua penderia kedudukan matahari digunakan untuk mengaktifkan motor pelangkah. Kedua-dua penderia mahatari ini menukarkan cahaya keamatan kepada isyarat voltan. Kemudian dengan menggunakan perisian WorkBench, isyarat-isyarat ini akan ditukarkan kepada isyarat-isyarat logik untuk mengawal pergerakan motor pelangkah.

Penjejakan secara pasif dilakukan dengan menggunakan sudut kedudukan matahari. Sudut-sudut ini kemudian dileraikan kepada dua komponen bagi arah timur-barat dan utara-selatan. Perisian WorkBench digunakan untuk menukarkan komponen-komponen tersebut kepada voltan. Voltan-voltan ini ditentukurkan terhadap suatu voltan rujukan yang dihasilkan oleh meter-meter keupayaan yang dipasangkan kepada shaf-shaf motor. Hasil dari perbandingan ini digunakan untuk mengawal pergerakan motor-motor pelangkah tersebut.

Akhir sekali, ketepatan sistem ini diuji dengan mengambil hasil rintangan daripada satu perintang cahaya yang telah pasangkan kepada penerima. Data yang diperolehi menunjukkan bahawa proses menjejak ini agak memuaskan memandangkan hasil rintangan yang diperolehi dari perintang cahaya hampir malar pada waktu cuaca cerah (tidak berawan).

# CHAPTER I

# INTRODUCTION

In solar energy system, sun tracking is employed to obtain concentrated or uniform solar irradiation. Concentrating solar collectors have well known advantages over fixed angle collectors. Solar trackers are designed for aligning components such as reflectors, solar panels or equipment with the direct beam of the sun. Tracking flat plate photovoltaic arrays provide about 33% more power than fixed arrays.

The tracking system essentially has a sensor and controller. Functions of the tracking controller is to allow the tracking mechanism to follow the sun with a certain degree of accuracy, return the collector to its original position at the end of the day, and allow the manual control for testing, repair, and cleaning.

There are three general categories of sun trackers including passive, microprocessor and electro-optically-controlled units (Lynch and Salameh, 1990; Deambi and Chaurey, 1992). Passive systems track the sun without any electronic controls or motors. These trackers contain a fluid such as freon within a frame of pipes. When the array is misaligned, the sun heats the freon on one side of the frame more than the other. This temperature difference causes the heated freon to evaporate. It may push a piston or may simply flow to the other side of the array and move it by gravity. This kind of tracker though simple, can only provide moderate accuracy tracking. They can get stuck in the wrong position or move in the wind.

Microprocessor controlled sun tracking units use mathematical formulas to predict the sun's location, and therefore, need not sense the sunlight. They are highly accurate, but are complex and expensive. To determine position they use stepper motors or optical encoders. These devices do not sense the sun; therefore they must be precisely aligned during installation. The controller must be programmed with the site latitude, longitude, and time, but should operate automatically once started. They are often used in large systems in which one controller controls many solar arrays. For high precision tracking, open loop microprocessor type controllers should be periodically recalibrated. Many microprocessor controlled sun trackers use electro-optic sensors for self-calibration.

In general, electro-optical trackers are simpler and less expensive than microprocessor types. One system uses four photo resistors with cylindrical shades as a sun sensor. Its controller contains only differential amplifiers, comparators and output components. A problem frequently encountered is that it does not always track correctly.

In our present study, we designed and developed a tracking system for the UPM solar collector. The UPM solar collector (situated at latitude 3.15° N, longitude 101.7° E), with rim angle $60^0$, tilt angle 0°, radius of curvature 27.9 m, and aperture area of 1834 $m^2$), uses a fixed spherical reflector. Consequently, the amount of solar energy entering the UPM solar collector aperture is not uniform and depends on the angle of incidence of the sun radiation with respect to the axes of the collector (Sulaiman et al., 1998). In accordance with spherical geometry the reflector concentrates the variable energy into a linear focus as shown in Figure 1. Tracking in this case is required to align a receiver that acts as the energy exchanger along the movable linear focus as shown in Figure 2. Therefore, the UPM solar collector requires a unique design for its solar tracking system. In addition, the design has to take into consideration the bridge structure used for the receiver support. Plate 1 shows the UMP solar collector, the support structure, Boom, Turning device and the Motor. The Bowl is submerged in the ground. For tracking, most system uses the pivotal type suspension where the azimuth position of the sun is determined by the tilt angle of the bowl of the collector. For the equatorial region, this is not appropriate because the sun executes a declination of 26.5° in the south and 20.4° in the north. Thus new tracking software and a turning system have to be developed for this situation.

The objective of this study is to construct a lab model of a two axes tracking system for horizontal receiver support, to design a software for passive tracking, and to test the accuracy of the passive tracking.

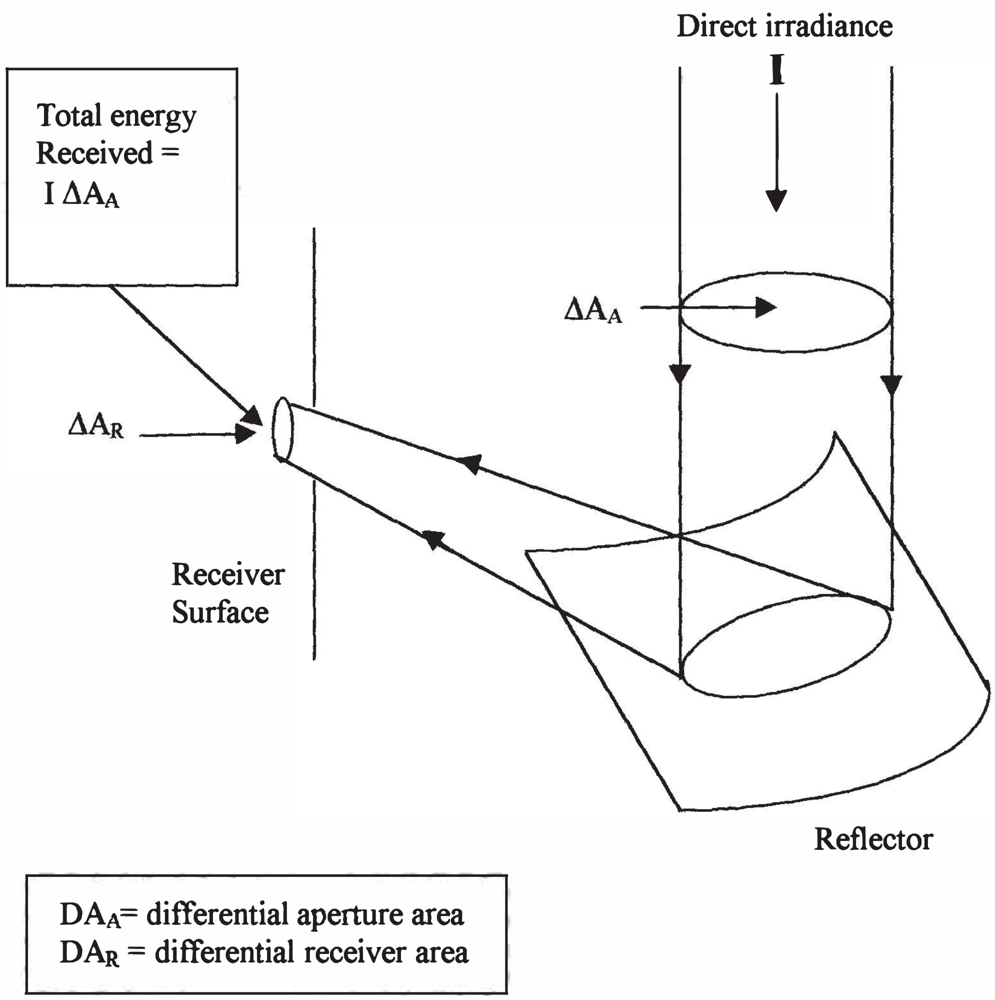


Figure 1: Concentration of Variable Energy into A Linear Focus

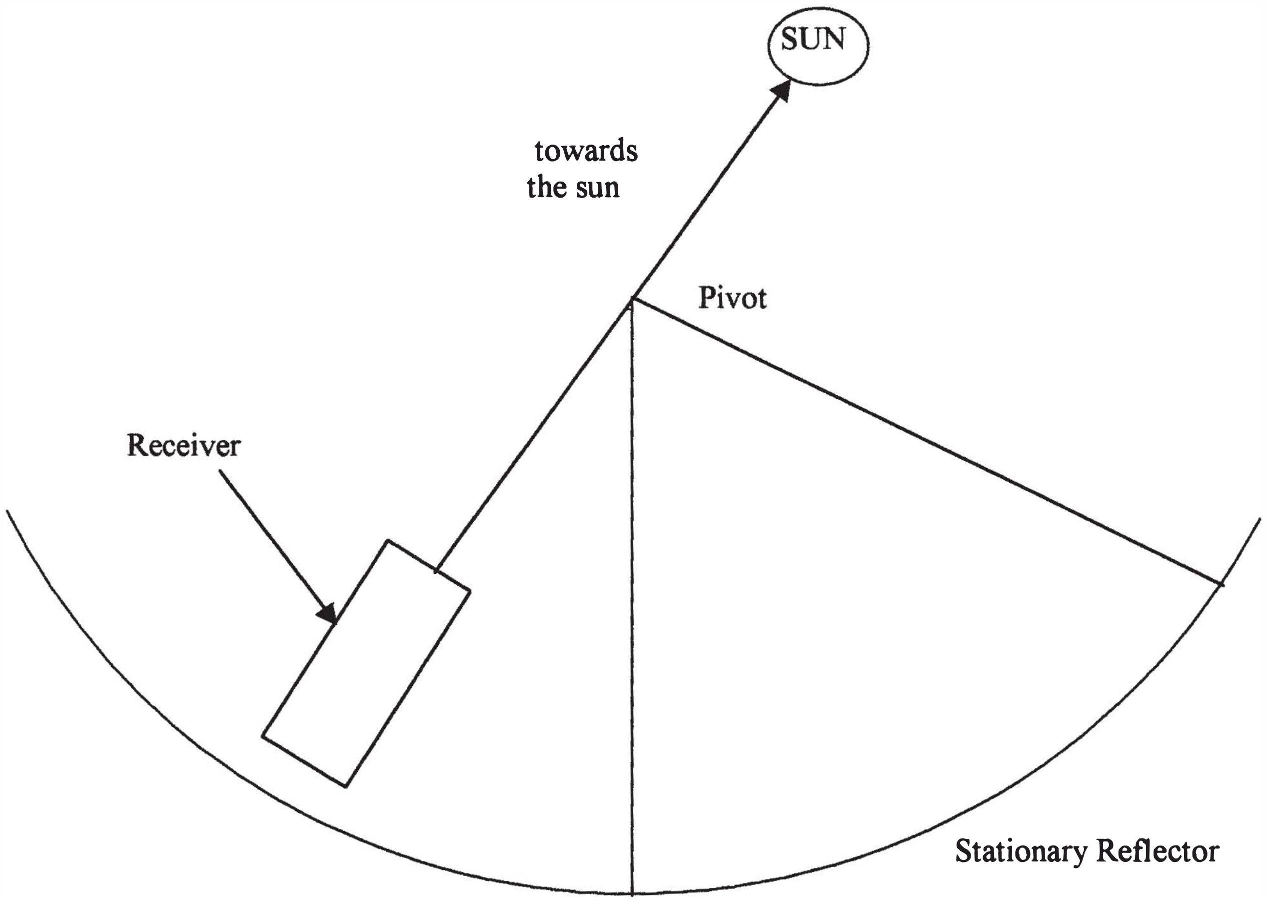


Figure 2: Stationary Reflector/Tracking Absorber (SRTA) System

## Principle of Tracking

The UPM solar collector uses two modes of tracking – passive and active tracks. In addition, a feature is provided to allow the receiver to be manually tracked with the aid of switches. Two independent movements of stepper motor shafts attached to the receiver (Sulaiman et al., 1997), one in east - west and the other in the north - south directions constitute the tracking as shown in Figure 3. In the active tracking, the stepper motors are activated by signal from two sun position sensors that are positioned in parallel with the shafts of the stepper motors respectively. In the passive tracking, the resultant angles of the sun at any time from the east west and north south planes are calculated and converted into voltage signals. The passive mode is used when there is substantial overcast rendering active tracking ineffective.

## The Control Software

For mode conversion, analogue to digital signal conversion and signal acquisition and control, use is made of a control software WorkBench in association with 2 data acquisition having 16 analog inputs and 8 analog outputs. The cards are also provided with 16 and 8 digital I/O channels respectively. WorkBench can be programmed to do data acquisition and control tasks by connecting functions or icons on a worksheet. Mathematical and logical functions are available for use in the analysis. Data can be displayed in charts (graphical) or meters (numerical).