1.0 INTRODUCTION

Sunlight that reaches the Earth is spread out over such a large area. Basically, the Sun does not deliver that much energy to one place at one time [1]. Solar energy received at a place depends on several conditions. They actually act as limitations in solar energy capturing process. These includes the time of the day, the season of the year, the latitude of area and the clearness or cloudness of sky. Via Concentrating Solar Power (CSP) technology, the solar energy is multiplied from several time to few thousand time as it is concentrated onto a certain size of area before it is converted into electric power. The concentrated sun irradiation is multiplied several times (which is around 600 to 1000 times) producing very high temperature. The temperature is in the range of 800°C to 1000°C [8].

The Concentrating Solar Power system can be divided into two types of system which are line focusing and point focusing. The point focusing system produces higher temperature concentration.
as sun irradiation is focused on one point compared to line. It also has higher efficiency compared to its counter system [8]. Examples of point-focusing CSP technology are dish-stirling and concentrated solar tower (CST) system. There are Malaysian researches involving heliostat. In 2001, UTM suggested a design for a single layer sun-ray concentrator, a non-imaging focusing heliostat. The design uses several small mirrors to form a heliostat to reduce first order image defect [2]. Malaysia University of Science and Technology (MUST) worked on residual aberration for non-imaging focusing heliostat in 2003 [3]. Universiti Tun Abdul Razak (UTAR) derived general formula of system for all existing-method on-axis sun-tracking system in 2009 [4]. In 2011, they did a comparison between the two methods of sun tracking, which are Azimuth-Elevation and, Spinning-Elevation methods [5].

This work is part of the feasibility study and CST mini model generation project and is aimed to develop a template using MATLAB programming for the calculation of the heliostat position with respect to the heat absorber mounted at the top of the CST via azimuth-elevation mode. This is done by calculating sun position vector and heliostat normal vector based on the calculated sun position by implementing the developed MATLAB code. The developed code will then be utilized by other UTeM team to realize the azimuth-elevation mode of sun tracking of the heliostat of mini CST project. The input from the user will be the Cartesian coordinate of the heliostat and absorber by taking the absorber tower frontal surface and its base as the origin and also the date. The result will be in vector form and will change automatically according to the Sun movement. These values will be programmed in the micro controller which will control the motion system of the heliostat.

2.0 EXPERIMENTAL

The theory behind sun-tracking procedures and its corresponding calculation are well understood. The related calculations are inter alia sun position, azimuth angle, heliostat normal, the Sun irradiation redirection vector.

An analytical calculation of a sample case is then done as reference values to ensure that the output values from to-be-developed code are correct. Only after achieving this, the code can be developed.

Every calculation step which is taken from the theory part should be converted to MATLAB code. The input should be the date (no. of month and no. of day are entered separately), the Cartesian coordinate of heliostat, the Cartesian coordinate of the tower, Latitude is set as a fixed value in this code, which is the latitude of UTeM. Whereas outputs are sun position and heliostat mirror normal vector. The code is developed for the utilization between 7 a.m. and 7 p.m. as the Sun is assumed to be only available during this time range.

The verification of the result is done by testing the code of several different dates and comparing the outputs with analytical calculation for several cases of different dates with selected solar time. The accuracy of the calculated numerical results will be found and stated afterwards by comparing them with analytical calculated results. The code is then ready to be used after all the verification processes are done.

Theory of Sun Position and Heliostat Normal Calculation

The components of heliostat normal vector are inter alia sun position $\mathbf{S}$ and redirection of Sun ray vector $\mathbf{R}$ and angle of Sun ray incidence on mirror and angle of redirection of the Sun ray towards the receiver (since angle of incidence and reflection have the same value) or denoted as $\theta$. Refer Figure 1.

In a two-component gel, it is easy to modify the molecular structure of either of the two components.
It is important to note the coordinate system used before calculations are proceeded. Based on the Figure 2, heliostat or mirror and receiver or also known as absorber vectors utilize the tower base as reference. The vectors are denoted as \( \overrightarrow{m} \) and \( \overrightarrow{r} \) respectively and these vectors are user’s input. The x-axis lies right under the tower base itself, whereas z-axis coincides with the front surface of the tower. If both axes are observed from the side view of the tower, y-axis lies in the middle of the tower if it is observed from bird’s eye view.

Based on Figure 2, sun position vector \( \overrightarrow{s} \) and heliostat normal vector \( \overrightarrow{n} \) take the center of the heliostat as the origin. These two vectors are the output of the developed program. In other words, there are two different origin used in the calculation.

To calculate sun position for a certain day, the date of the day must be known and be provided to determine the nth day of the year. With the known solar altitude \( \alpha_s \) and azimuth angle \( \gamma_s \), the sun position vector \( \overrightarrow{s} \) with respect to horizontal surface at any point on the Earth can be determined using below formula:

\[
\begin{align*}
S_x &= S_x = \sin \alpha_s, \\
S_y &= S_y = \cos \alpha_s \sin \gamma_s, \\
S_z &= S_z = \cos \alpha_s \cos \gamma_s
\end{align*}
\]

The law of specular reflection is applied in the redirection of the Sun ray calculation. This law states that the angle of incidence is equal to the angle of reflection.

Receiver vector, \( \overrightarrow{r} = \left( \frac{n_0}{n_0} \right) = \left( \frac{x_0}{x_0} \right) \)

Mirror vector, \( \overrightarrow{m} = \left( \frac{m_0}{m_0} \right) = \left( \frac{x_m}{x_m} \right) \)

Redirection of the Sun ray vector,

\[
\overrightarrow{R} = \frac{(x_0-x_z)+(a_0-a_z)j+(n_0-n_z)k}{(x_0-x_z)^2+(a_0-a_z)^2+(n_0-n_z)^2}
\]

The scalar point between the vectors of \( \overrightarrow{s} \) and \( \overrightarrow{R} \) results in cosines of two-time angle of incidence \( \theta \) like in following expression:

\[
\cos 2\theta = \overrightarrow{s} \cdot \overrightarrow{R} = R_x \sin \alpha_s + R_y \cos \alpha_s \sin \gamma_s + R_z \cos \alpha_s \cos \gamma_s
\]

\( \overrightarrow{N} \) is a normal vector of heliostat at a moment, at which sun ray arrives parallel to the vector \( \overrightarrow{s} \) and the ray is reflected onto the receiver or absorber. It can be calculated via addition of incidence \( \overrightarrow{s} \) and reflection vectors \( \overrightarrow{R} \) and via division of the added vector values with the suitable scalar quantity:

\[
\overrightarrow{N} = \left[ \frac{(R_x+S_x)+((R_y+S_y)+(R_z+S_z))k}{2 \cos \theta} \right]
\]

where component x is denoted by unit vector \( \hat{x} \), component y is denoted by unit vector \( \hat{y} \) and component z is denoted by unit vector \( \hat{z} \) along north, east and zenith direction respectively.

### 3.0 RESULTS AND DISCUSSION

In developing the code, several important parameters which determine the sun position and the resulting heliostat normal such as the date of a certain day, heliostat and receiver position are set as variables, so that user can determine the input as needed. For example, the date must be keyed in to
The work has produced a MATLAB program to calculate the sun position vector and the corresponding heliostat normal vector, at which the sun ray will be redirected onto the receiver hourly for a time range from 7 a.m. to 7 p.m. The program's functionality has been proved via several verifications and its accuracy which is 0.0005 has been stated and verified.

However, the generated code is only for a single heliostat utilization and also to calculate the sun position hourly. In addition, the code is in M-file form. Therefore, future works may include calculation not only for a single mirror, but for n mirrors and the calculation may be carried out for every minute instead of hourly to guarantee a more precise sun position and corresponding heliostat normal vector. Moreover, this work may be converted to 'Graphic User Interface' (GUI) form to make it interactive and user friendly.

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References