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# A preliminary study on the 2-axis hybrid solar tracking method for the smart photovoltaic blind

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**Abstract**

This study aimed to investigate a tracking system applicable to the SPB and determined an indirect tracking method. The slope of PV panel tracked the sun from 0° to 90°, which does not restrict the tracking. On the other hand, the azimuth of PV panel tracked the sun from -9° to 9° due to the limitation of the rotating angle of the vertical axis. The result of this study can be used to develop the 2-axis hybrid solar tracking system for the SPB which can be adopted in the building sector.


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*Keywords*: Solar tracking system; Hybrid solar tracking method; Indirect tracking method; Smart photovoltaic blind

## 1. Introduction

A photovoltaic (PV) system can reduce carbon emissions by using sustainable energy resources and substituting for the use of fossil fuel. In the building sector, a PV system is used in the form of a building integrated photovoltaic (BIPV) system. The smart photovoltaic blind (SPB) is a device that can satisfy both electricity generation and sun-shading function, it can be installed in windows of the buildings [1]. Thus, the SPB can be distinguished from the traditional PV in terms of those multiple functions and space uses.

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To improve the electricity generation of the SPB, methods to improve PV generation through solar tracking system as well as to improve the efficiency of the PV panel and the inverter should be considered. It is difficult to improve the efficiency of the PV panel and inverter in the short term, but it is possible to effectively improve the electricity generation by introducing a solar tracking system [2]. Therefore, as a preliminary study for the 2-axis hybrid solar tracking method for the SPB, this study reviewed various solar tracking systems and determined an indirect tracking method applicable to the SPB. This study was conducted in two steps. First, in step 1, the preliminary considerations (i.e., tracker type and tracking method) for the solar tracking system was examined. Second, in step 2, indirect tracking method was considered to calculate the hourly slope of panel (SoP) and the azimuth of panel (AoP).

**Nomenclature**

| | |
|---|---|
| AoP | Azimuth of panel |
| BIPV | Building Integrated Photovoltaic |
| PV | Photovoltaic |
| SoP | Slope of panel |
| SPB | Smart photovoltaic blind |

## 2. Preliminary considerations for the solar tracking system

### *2.1. Tracker types*

As shown in Figure 1, the solar tracking system can be categorized into the 1-axis tracker and the 2-axis tracker, according to tracker types. First, the 1-axis tracker which tracks the daily east-west motion of the sun can be divided into horizontal 1-axis tracker (Type (A) in Figure 1) and vertical 1-axis tracker (Type (B) in Figure 1). The horizontal 1-axis tracker and vertical 1-axis tracker perform solar tracking centered on the horizontal and vertical axis of the PV panel, respectively.

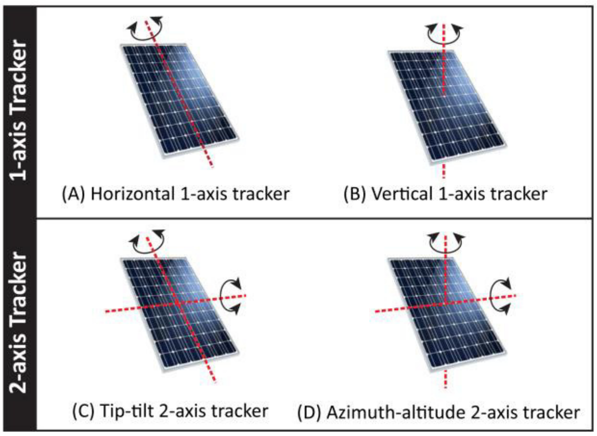


Fig. 1. Tracker types

Second, the 2-axis tracker which tracks both the east-west motion and north-south motion of the sun can be divided into tip-tilt 2-axis tracker (Type (C) in Figure 1) and azimuth-altitude 2-axis tracker (Type (D) in Figure 1). The tip-tilt 2-axis tracker performs solar tracking centered both on the rotating axis of the SoP and the horizontal axis. The azimuth-altitude 2-axis tracker performs solar tracking centered both on the rotating axis of the SoP and the vertical axis [2-5].

### 2.2. Tracking methods

The tracking method can be categorized into three types, according to control strategies: (i) direct solar tracking method; (ii) indirect solar tracking method; and (iii) hybrid solar tracking method.

First, the direct solar tracking method tracks the direction at which the measured voltage and current generated by a PV system is at the maximum power point. However, the direct solar tracking method is sensitive to temporary errors, which may result in the tracking direction to malfunction. Second, the indirect solar tracking method tracks the sun based on the PV panel position information entered into the PV system. However, the indirect tracking would require setting an accurate position for the PV panel. Third, the hybrid solar tracking method applies two tracking methods (i.e., direct and indirect solar tracking methods) at the same time so that it complements the shortcomings of each of the two tracking methods [1, 6].

### 2.3. Tracker types and tracking methods for the SPB

As shown in Figure 2, since the SPB is manufactured as a venetian blind, adjustments in the slat angle and height are possible with the azimuth-altitude 2-axis tracker (Type (D) in Figure 1). The three methods (i.e., direct solar tracking method, indirect solar tracking method, and hybrid solar tracking method) can be used to the SPB. This study implemented an indirect solar tracking method as a preliminary study on the 2-axis hybrid (direct and indirect) solar tracking method.

Meanwhile, the thickness of the SPB is determined by the thickness of the window frame. Accordingly, the rotating angle of the vertical axis is limited by the thickness of the SPB. The rotating angle of vertical axis of the prototyping model of SPB is designed between -9° and +9°. However, the rotating angle of the SoP is designed 0° to 90° and is not restricted by tracking.

Fig. 2. The prototype model of proposed SPB

## 3. Indirect tracking method for the SPB

The mathematical formula provided by American Society of Heating Refrigerating and Air-Conditioning Engineers was used to establish the database for the indirect tracking method [7]. The following two steps were conducted: (i) calculation of the hourly altitude and azimuth of the sun based on the mathematical formula; and (ii) calculation of the hourly SoP and the AoP that is perpendicular to the altitude and azimuth of the sun.

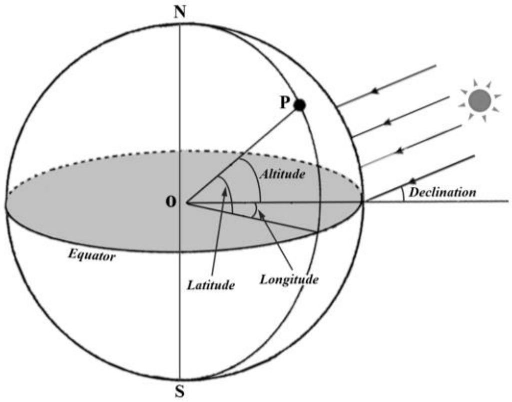


Fig. 3. The prototype model of proposed SPB

### *3.1. Hourly altitude and azimuth of the sun*

First, the altitude of the sun was calculated by using the declination, latitude, and hour angle (refer to equation (1) and Figure 3). The declination, the angle at which the virtual line connecting the center of the sun and that of the earth is formed with the equator, is calculated by using equation (2). The hour angle is calculated using equation (3). Second, the azimuth of the sun was calculated by using the declination, altitude of the sun, and hour angle (refer to equation (6)) [3, 7].

$$\alpha = \sin^{-1}(\sin\delta\cdot\sin\varphi + \cos\delta\cdot\cos\varphi\cdot\cos\omega) \tag{1}$$

$$\delta = 23.45\cdot\sin\left[\frac{360\times(n+284)}{365}\right] \tag{2}$$

$$\omega = \left\{LST + \frac{ET}{60} + \frac{\varphi - LSM}{15} - 12\right\}\times 15 \tag{3}$$

$$ET = 2.2918(0.0075 + 0.1868\cos(t) - 3.2077\sin(t) - 1.4615\cos(2t) - 4.089\sin(2t)) \tag{4}$$

$$t = 360 \times (n-1)/365 \tag{5}$$

$$h = \begin{cases} \cos^{-1}\left(\dfrac{(\cos\omega \cdot \cos\delta \cdot \sin\varphi - \sin\delta \cdot \cos\varphi)}{\cos\alpha}\right) & \text{if } \omega \geq 0 \\ -\cos^{-1}\left(\dfrac{(\cos\omega \cdot \cos\delta \cdot \sin\varphi - \sin\delta \cdot \cos\varphi)}{\cos\alpha}\right) & \text{if } \omega < 0 \end{cases} \tag{6}$$

where, $\alpha$ stands for the altitude of the sun; $\delta$ stands for the declination; $\varphi$ stands for the latitude; $\omega$ stands for the hour angle; $n$ stands for the number of days in a year (e.g., 1st, Jan.: 1, and 21th, Jul.: 202); *LST* stands for the local standard time; *ET* stands for the equation of time in minutes; *LSM* stands for the longitude of local standard time meridian; $t$ stands for the day angle; and $h$ stands for the azimuth of the sun.

### *3.2. Hourly SoP and AoP*

Considering the altitude and azimuth of the sun calculated by the mathematical formula, the SoP and AoP of the SPB perpendicular to the incident direction of the sunlight was estimated (refer to equations (7) and (8)). As mentioned in section 2.3, the rotating angle of the vertical axis was also considered in the AoP estimation process.

$$SoP = 90^\circ - \alpha \tag{7}$$

$$AoP = \begin{cases} h & \text{if } -9^\circ \leq h \leq 9^\circ \\ 9^\circ & \text{if } 9^\circ < h \\ -9^\circ & \text{if } h < -9^\circ \end{cases} \tag{8}$$

where, *SoP* stands for the slope of panel; $\alpha$ stands for the altitude of the sun; *AoP* stands for the azimuth of panel; and $h$ stands for the azimuth of the sun.

## 4. Result and discussion

As a case study, when the indirect tracking method is applied to the SPB installed in the southern direction in Seoul, South Korea, whose latitude is 37.567°, the hourly SoP and AoP on 21th July, 2015 was estimated as shown in Table 1.

The hourly SoP was determined to be 18.277° (12 AM) – 72.391° (6PM). Namely, based on the altitude of the sun, the SoP of the SPB can rotate to be the incident direction of the sunlight. Meanwhile, based on the azimuth of the sun, the AoP of the SPB cannot rotate due to the limitation of the rotating angle of the vertical axis. For example, the azimuth of the sun at 12 AM is -21.488° (the eastward), while the perpendicular incident angle of sunlight to the PV panel requires the AoP to track up to -21.488°. However, the AoP rotated eastward up to -9°. As mentioned in section 2.3, it is because the thickness of the SPB was determined considering the thickness of the window frame.

Table 1. Hourly SoP and AoP in Seoul (July 21, 2015)

| Time | Altitude (°) | Azimuth (°) | SoP (°) | AoP(°) |
|---|---|---|---|---|
| 7AM | 18.378 | -101.976 | 71.622 | -9 |
| 8AM | 30.143 | -93.514 | 59.857 | -9 |
| 9AM | 42.013 | -84.150 | 47.987 | -9 |
| 10AM | 53.640 | -72.273 | 36.360 | -9 |
| 11AM | 64.276 | -54.147 | 25.724 | -9 |
| 12PM | 71.723 | -21.488 | 18.277 | -9 |
| 1PM | 71.431 | 24.073 | 18.569 | 9 |
| 2PM | 63.659 | 55.536 | 26.341 | 9 |
| 3PM | 52.915 | 73.073 | 37.085 | 9 |
| 4PM | 41.251 | 84.711 | 48.749 | 9 |
| 5PM | 29.371 | 93.977 | 60.629 | 9 |
| 6PM | 17.609 | 102.409 | 72.391 | 9 |

## 5. Conclusion

This study performed a preliminary study on the 2-axis hybrid (direct and indirect) solar tracking method to maximize the electricity generation of the SPB. The altitude and azimuth of the sun were calculated, and were used to estimate the hourly SoP and AoP of the SPB for the indirect tracking. The SoP tracked the sun from 0° to 90°, which does not restrict the tracking, while the AoP tracked the sun from -9° to 9° due to the limitation of the rotating angle of the vertical axis.

The results of this study can be used as a preliminary data in developing the 2-axis hybrid solar tracking method for the SPB in future research. The indirect tracking system can be established in different geographic contexts by changing the geographical parameters which are used to calculate the hourly altitude and azimuth of the sun. As the final result, the SPB with the 2-aixs hybrid solar tracking system can be installed in existing buildings by substituting blinds in window. This can contribute to acquire urban energy in a society and reduce the carbon emissions from fossil fuel.

## 6. Copyright

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**Biography**

Kwangbok Jeong is a graduate research assistant and Ph.D. candidate at the Department of Architectural Engineering in Yonsei University, Seoul. He is working at the SUStainable COnstruction Management (SUSCOM) laboratory and interested in the following research areas: Life Cycle Assessment, Life Cycle Cost Analysis, Environmental Management, Green Construction Management and Decision Making Process.