28th IEEE PHOTOVOLTAIC SPECIALISTS CONFERENCE
ANCHORAGE HILTON EGAN CONVENTION SENTER ANCHORAGE, ALASKA SEPTEMBER 15-22, 2000

ON-SITE BIPV ARRAY SHADING EVALUATION TOOL USING STEREO-FISHEYE PHOTOGRAPHS

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ABSTRACT

It is difficult to estimate precisely total irradiance on photovoltaic (PV) arrays without consideration of the effect of shadow by surroundings, especially for building integrated photovoltaic (BIPV) systems in urban area. The accurate evaluation of actual irradiation on the arrays may contribute to the verification of the performance of PV systems.

In this research, the authors propose the method of calculating the shading factor by applying the photo survey method using fisheye photographs to capture whole surroundings. The shading factor is defined as the ratio of actual irradiation on PV arrays to ideal irradiation with no shading modules. Actual irradiation on a certain array can be calculated easily by using the shading factor.

INTRODUCTION

Recently, BIPV systems are increasing in Japan. Generally, BIPV systems are greatly affected by shadow, because they are installed in urban area, and it is difficult to estimate actual irradiation on PV arrays. The accurate evaluation of actual irradiation on the arrays may contribute to the verification of the performance of PV systems.

To estimate actual irradiation, the authors defined the shading factor, and propose the method of calculating it by applying the photo survey method using fisheye (hemispherical) photographs. It could be applied to our loss evaluation algorithm for grid-connected PV systems, SV method [1], as a meta input.

THE SHADING FACTOR

The shading factor is defined as the ratio of actual irradiation on PV arrays to ideal irradiation with no shading modules.

$$k_{HS}(t) \equiv \frac{g_A(t)}{g(t)} \quad (1)$$

$k_{HS}(t)$: The shading factor
$g_A(t)$: Actual irradiation on PV arrays
$g(t)$: Ideal irradiation with no shading modules

Multiplying irradiation with no shading modules by it, we calculate actual irradiation on PV arrays easily.

$$g_A(t) = g(t) \times k_{HS}(t) \quad (2)$$

The shading factor depends on time. Total irradiance on PV arrays in a period is calculated by using an average of $k_{HS}(t)$ in same period.

$$G_A = G \times K_{HS} \quad (3)$$

G_A : Total irradiation on the arrays
G : Total irradiation
K_{HS} : An average of $k_{HS}(t)$ in a period

ESTIMATING THE SHADING FACTOR

The shading factor is calculated by using irradiation and the ratio of shadow area in the array($r_S(t)$) from the equation below.

$$k_{HS}(t) = \frac{(1 - r_S(t))g_b(t) + g_d(t) + g_r(t)}{g_b(t) + g_d(t) + g_r(t)} \quad (4)$$

$g_b(t)$: Direct irradiation
$g_d(t)$: Diffuse irradiation
$g_r(t)$: Reflection irradiation

ESTIMATING THE RATIO OF SHADOW AREA IN THE ARREY

The $r_S(t)$ is estimated through the flow diagram in Fig. 1. The ratio of shadow area in the array is determined by the ratio of the number of shadowed modules to total number of modules. To estimate the position of shadows, we apply the photo survey method with fisheye photographs.

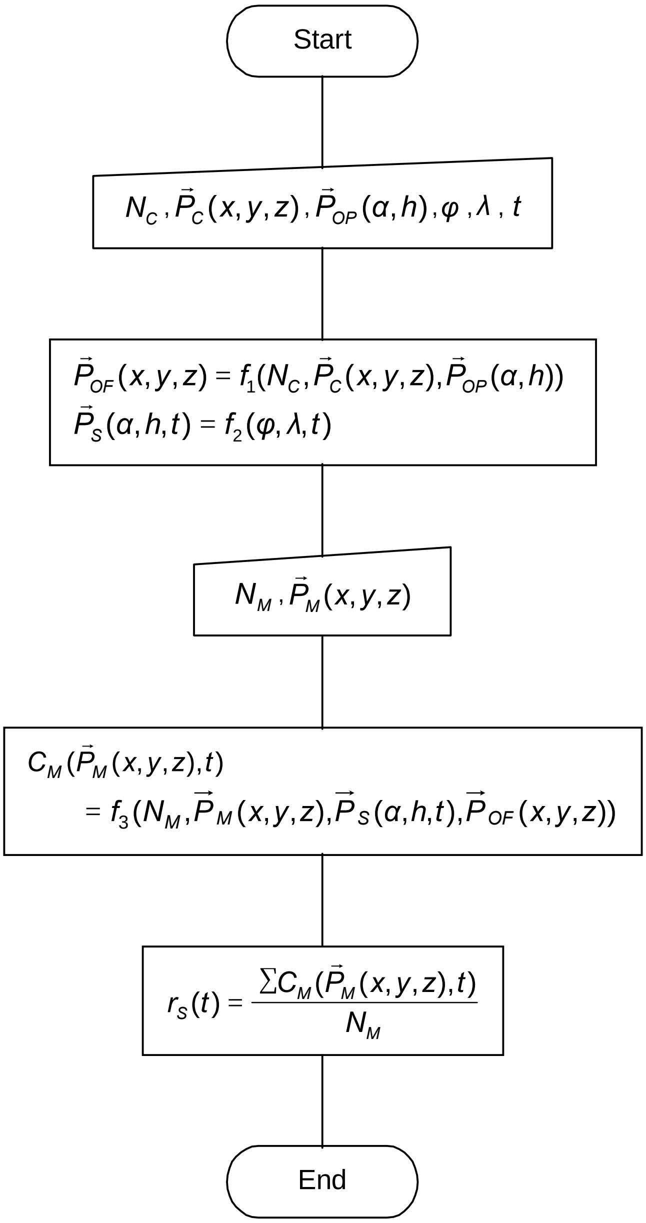

Fig. 1. The flow diagram of estimating $r_S(t)$ by using fisheye photographs

N_C : Number of camera positions
$\vec{P}_C(x,y,z)$: Camera position
$\vec{P}_{OP}(\alpha,h)$: Object position in fisheye photographs
φ : Latitude
λ : Longitude
t : Time
α : Azimuth angle
h : Altitude angle
$\vec{P}_{OF}(x,y,z)$: Object position in field
$\vec{P}_S(\alpha,h,t)$: Sun Position
$f_1(\ )$: The expression to calculate $\vec{P}_{OF}$ and the function of N_C, $\vec{P}_C$, $\vec{P}_{OP}$
$f_2(\ )$: The expression to calculate $\vec{P}_S$ and the function of φ, λ, t
N_M : Number of modules
$\vec{P}_M(x,y,z)$: Module position
$C_M(P_M(x,y,z),t)$: Module condition ($C_M = 0$: shadowless module, $C_M = 1$: shadowed module)
$f_3(\ )$: The expression to calculate $\vec{C}_M$ and the function of N_M, $\vec{P}_M$, $\vec{P}_S$, $\vec{P}_{OF}$

FISHEYE PHOTOGRAPH

Fig. 2 is an example of fisheye photograph. The fisheye photograph has wide-angle view of horizontal angle of 360 degrees and vertical angle of 180 degrees. We can get the view of whole surroundings easily by using it. And because of its unique projection, altitude and azimuth angles of objects can be determined from it easily.

Fig. 2. Fishye photograph

ESTIMATING THE POSITION OF SHADOWS

To estimate $r_S(t)$, we need positions of shadows on the array. Fig. 3 is conceptual flow of estimating the position of shadows.

The first step is taking some fisheye photographs from different places around the PV installation, and to calculate the height and position of obstacles by using the trigonometrical survey. The pair of camera's positions is flexible and is not necessarily fixed on arrays. Generally, the estimation of shadows is needed many photographs. But this estimation is needed only a few fisheye photographs to analyze shadows, because of using the trigonometrical survey. The next step is to calculate the position of Sun. The last step is estimating the positions of shadows from the relation between the position of Sun and obstacles.

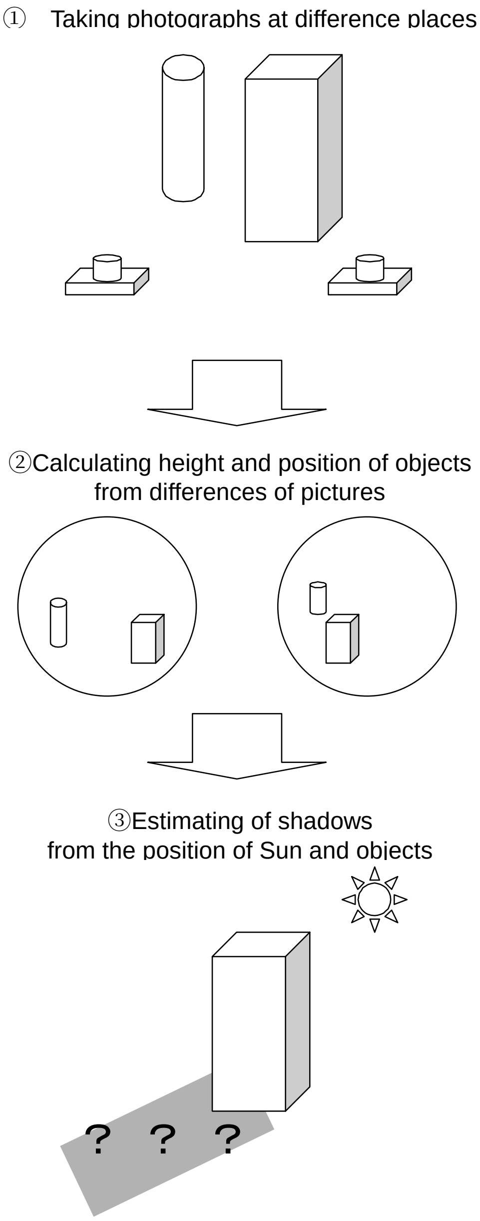

Fig. 3. Conceptual flow of estimating positions of shadows

CALCULATING HEIGHT AND POSITION OF OBJECTS

The conceptual diagram for estimating the height and position of obstacles is shown in Fig.4. Point P is the target point. Point. A and B indicate the camera positions. Dotted lines exist on the basic field of this calculation. Input values are altitude angle h_A and h_B and azimuth angle α_A, α_B of P to A and P to B estimated from fisheye photographs and the distance between A and B

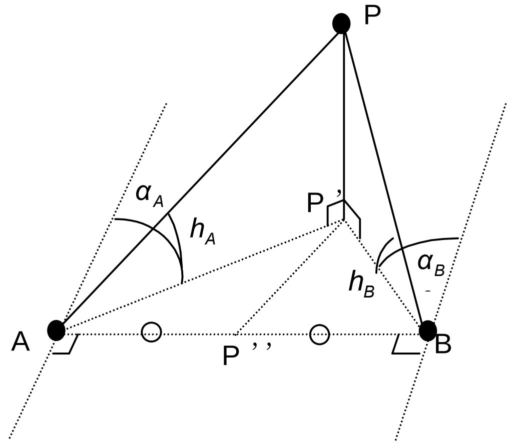

Fig. 4. The conceptual diagram for estimating the height and position of obstacles

Equations (5) and (6) are derived from Fig. 4.

$$AB = | P'A \sin\alpha_A - P'B \sin\alpha_B | \tag{5}$$

$$P'A \cos\alpha_A = P'B \cos\alpha_B \tag{6}$$

Equations (7) and (8) come from equation (5) and (6).

$$P'A = \frac{AB}{| \sin\alpha_A - \frac{\sin\alpha_B}{\cos\alpha_B}\cos\alpha_A |} \tag{7}$$

$$P'B = \frac{AB}{| \sin\alpha_B - \frac{\sin\alpha_A}{\cos\alpha_A}\cos\alpha_B |} \tag{8}$$

Also, equation (9) is derived from Fig. 4.

$$PP' = P'A \tan h_A = P'B \tan h_B \tag{9}$$

From Equation (7), (8) and (9)

$$PP' = \frac{AB}{| \sin\alpha_A \quad \frac{\sin\alpha_B}{\cos\alpha_B}\cos\alpha_A |}\tan h_A$$

$$= \frac{AB}{| \sin\alpha_B \quad \frac{\sin\alpha_A}{\cos\alpha_A}\cos\alpha_B |}\tan h_B \tag{10}$$

Distances from A to P and B to P and the height of P can be estimated.

ESTIMATING SHADOWS

Positions of shadows are estimated from latitude and azimuth angle of Sun, α, h and a height of remarkable point, PP' calculating from previous chapter.

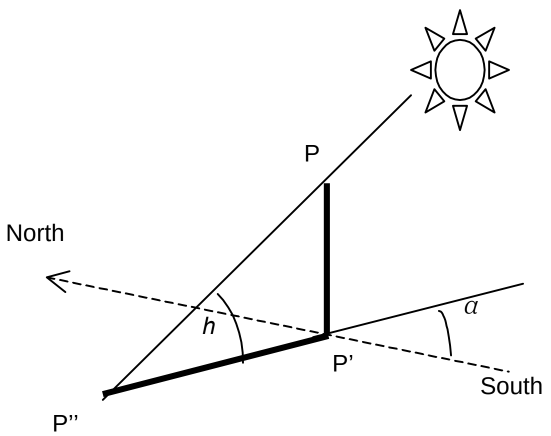

Fig. 5. Conceptual diagram of estimating shadows

From Fig. 5, equation (10) is derived.

$$P'P'' = \frac{PP'}{\tan h} \tag{10}$$

Assuming east-west direction is x-axis and south-north direction is y-axis, coordinate of P' is following equation.

$$X = \frac{\sin\alpha}{\tan h} PP' \tag{11}$$

$$Y = \frac{\cos\alpha}{\tan h} PP' \tag{12}$$

Calculating each points of each objects, shadows are can be estimated.

THE RESULT OF ESTIMATING SHADOW

Shadow estimation of rectangle box was attempted. Fig. 6 shows the result of the estimation. This figure view is directly overhead of the rectangle box. The parts of black lines are the shadows of the estimation and the parts of red lines are actual shadow. The errors of the estimation are less than 6% for the length of shadow and less than 3.5% for the direction. These results seem to indicate the validity of estimating shadow.

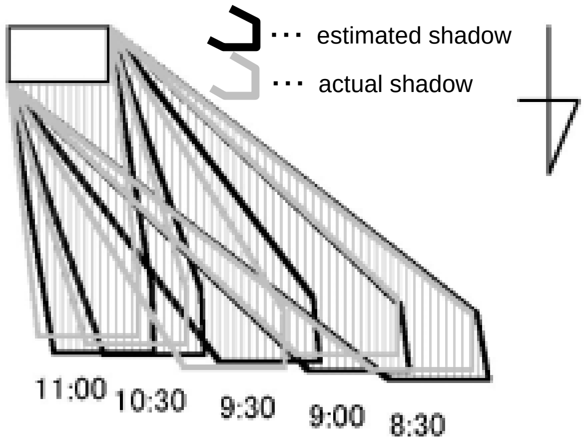

Fig. 6. the result of the shadow estimating of the rectangle box

CONCLUSIONS

The authors proposed the method of calculating shading factor by applying the photo survey method using fisheye (hemispherical) photographs to capture whole surroundings, and showed the flow of estimating it, and the validity of shadow estimation. The future direction of this study will be to calculate the shading factor and investigate the validity of it.

REFERENCES

[1] Kurokawa et al., “Sophisticated Verification of Simple Monitored Data for Japanese Field Test Program”, 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion, 1998