CPV in the built environment

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Introduction and objectives

We are developing a concentrated photo-voltaic system for the built environment. Apart from generating electrical energy using small and efficient triple-junction PV cells, we aim at preventing direct sunlight from entering the building, while diffuse daylight can still provide sufficient ambient lighting. Thus, additional energy is saved because the building needs less cooling. Our target market consists of greenhouses and other buildings with glass roofs or skylights, like shopping centres. In this poster, we present a light, fast and accurate routine to compute the position of the Sun, and a model that predicts the energy yield, mutual shading and the energy flux that passes between the units and falls on the ground, for a field of CPV modules.

An accurate position for the Sun

We present a C routine called *SolTrack* [1] that can compute the position of the Sun in topocentric coordinates, both in a horizontal and in an equatorial system. The code is based on the Fortran library *libTheSky* [2] and includes corrections for aberration and parallax, and a simple routine to correct for atmospheric refraction [3]. We compared the performance of our code to detailed calculations using VSOP 87 [4] and an accurate model for atmospheric refraction [5]. This was carried out for 100,000 random moments in the next 100 years (between 2014 and 2113) when the Sun is above the horizon in the Netherlands. We find that the error in position is $0.0036 \pm 0.0038°$, which is sufficient for solar tracking of CPV systems under all conditions. The achieved accuracy would result in 0.095% of loss of power if the circular solar image would fall outside a PV chip by that amount. The code can compute a million positions in 2.28 ± 0.04 s on a single 2.67 GHz CPU core when only horizontal coordinates (azimuth and altitude) are computed, and takes 2.80 ± 0.05 s if refraction-corrected parallactic coordinates are also calculated.

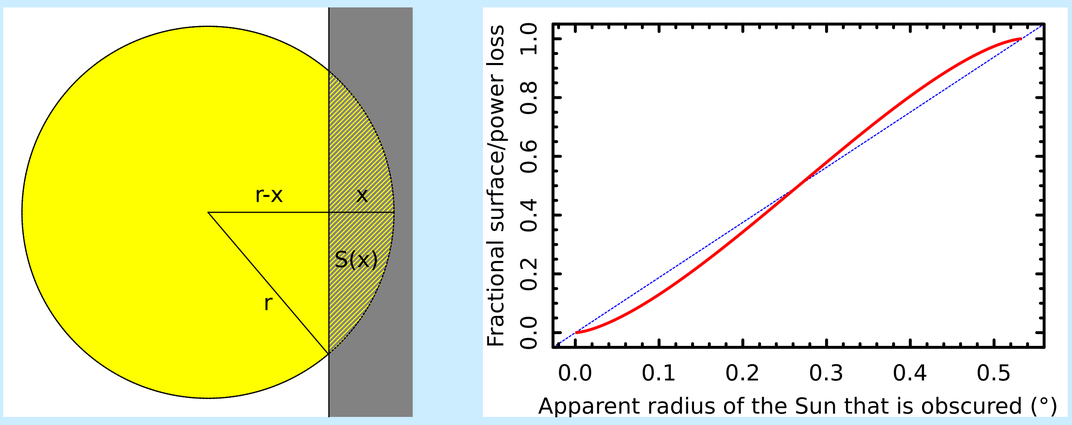


Figure 1: Loss of solar power when part of the Sun's image falls outside a PV cell due to inaccurate pointing (red line). At a pointing error of 0.07°, 8% of solar power is lost.

Comparison to PSA and SPA

When compared to the PSA *SunPos* routine [6], which is also lightweight and freely available, our code is 20 times more accurate and 10% faster (see Table 1). When correcting equatorial coordinates for refraction, our code is 11% slower than SunPos. We also compared the performance of the code to the NREL *SPA* routine [7], which is more elaborate and has a more restricted licence. SPA is 37% more accurate than SolTrack, but also seven times slower. Here, we computed only the Sun's position in SPA (no rise and set times or incident radiation) and corrected equatorial coordinates for refraction in our code, which is not available in SPA.

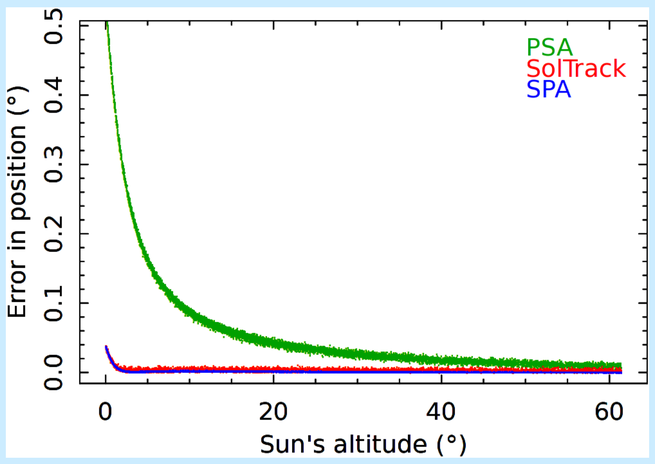


Figure 2: Comparison of the accuracies of PSA (green), SPA (blue) and SolTrack (red), as a function of altitude. The red data points are partially covered by the blue ones.

The high accuracy and low computational cost allow a flexible use of SolTrack, ensuring that the code can run on inexpensive, low-spec embedded systems like the STM32F4 DISCOVERY boards, on simple systems with leightweight operating systems like the Raspberry Pi, on PLCs and on standard PCs or servers. In addition to SolTrack, we are developing a *closed-loop* system that allows feedback from sensors near the PV cell in order to correct for discrepancies that arise due to *e.g.* an imperfect installation of the system, or mechanical deformations. In addition, we have designed an algorithm that takes into account non-perfect alignment, for example because the system is aligned with the main axes of the building, rather than the north-south axis.

Table 1: Comparison of the accuracy and timing between the *PSA*, *SPA* and *SolTrack* routines.

	PSA	**SPA**	**SolTrack**
Accuracy	$0.073 \pm 0.091°$	$0.0023 \pm 0.0037°$	$0.0036 \pm 0.0038°$
relative	19.7	0.62	1.00
Power loss	8.2%	0.048%	0.095%
CPU time	2.53 ± 0.09 s	20.0 ± 0.2 s	2.28 ± 0.04 s
relative	1.11	8.77	1.00

Modelling a field of CPV units

We developed a code to model a field of CPV units (Fig. 3), in order to determine the influence of their mutual distance on the energy yield, and the amount of sunlight that reaches the ground. In particular, we simulate the mutual shading between the CPV units. In addition, we can visualise what happens if *e.g.* we do not track the Sun all the way to the horizon, in favour of a tighter grid of CPV modules, or how the yield changes as a function of geographical location. Figure 4 shows that a tighter grid not only allows less direct sunlight to fall on the ground, but also has a decreased electrical yield, due to increased shading.

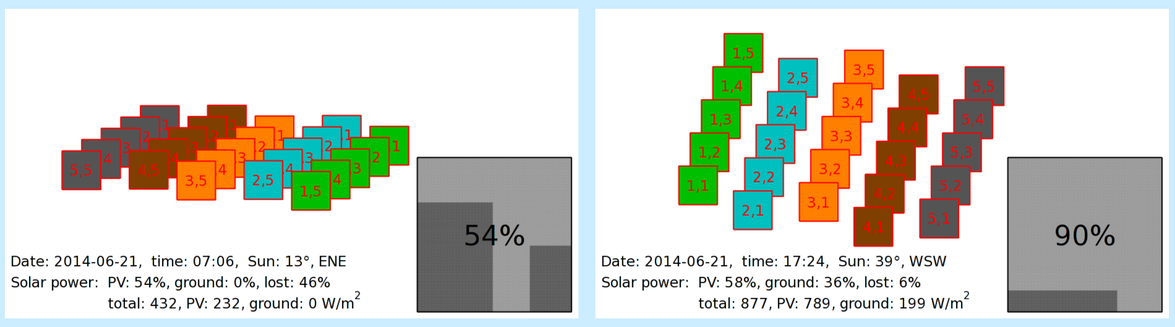


Figure 3: A small horizontal field of CPV units in a honeycomb configuration, as seen from the Sun for Arnhem on 21 June at 7:06 and 17:24 local time. The central unit is monitored by the numbers at the bottom and shading inset on the lower right. In the morning only 54% of the lens is illuminated due to mutual shading, and no direct sunlight falls on the ground. In the afternoon, there is less mutual shading, but more sunlight reaches the ground.

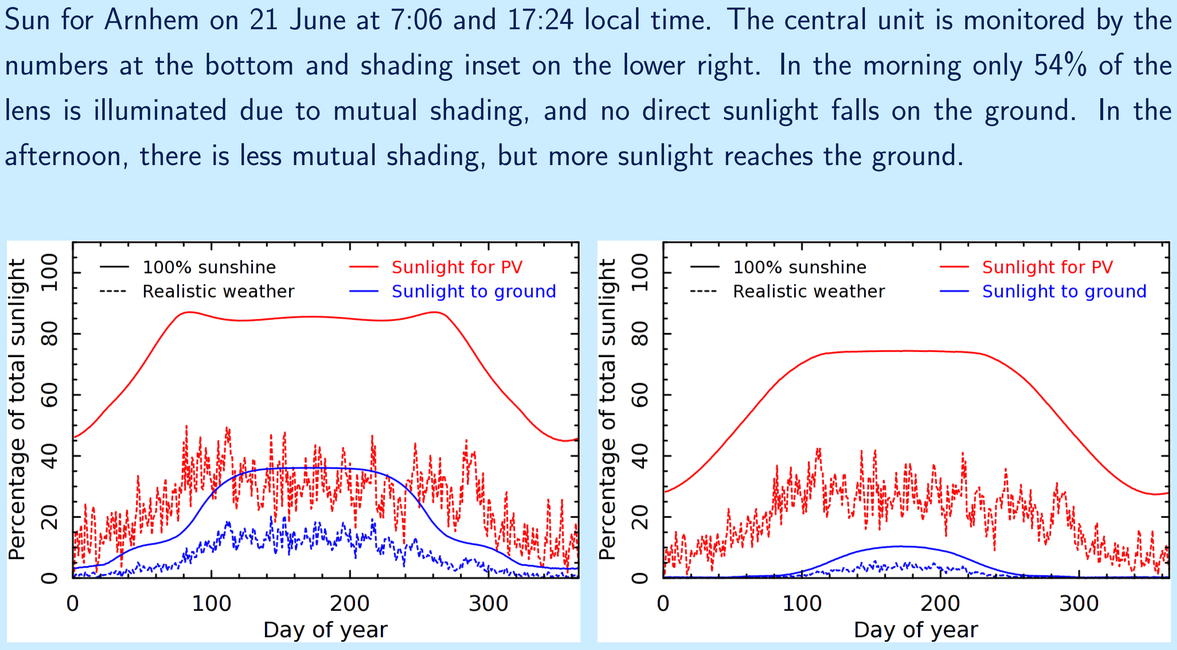


Figure 4: Energy yield (red lines) and solar flux passing to the ground (blue) as a function of the day of year, for perfect (solid lines) and realistic (dashed) weather in the Netherlands. The CPV units measure $\mathbf{1}\times\mathbf{1}\times\mathbf{1}$ m. In the left-hand panel, they are spaced 1.6 m apart and cannot collide. In the right-hand panel, the spacing is 1.23 m and the units can touch if they malfunction.

Conclusions and future work

- Using a simple prescription for atmospheric refraction significantly improves the accuracy of the Sun's computed position, and hence the yield of solar energy for CPV, without additional computational cost;
- We are developing a closed-loop system to correct for an imperfect orientation of the units and mechanical inaccuracies;
- A detailed model of a field of CPV units allows us to determine the optimal constellation for a specific purpose, and find an acceptable consensus between the electrical yield and the flux of sunlight that falls on the ground.

References

[1] *SolTrack:* http://soltrack.sf.net
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[7] I. Reda, A. Andreas, NREL SPA, *Solar Energy* 76(5), 577, 2004.