SIMULATION OF YEARLY ENERGY FOR SOLAR HEATING SYSTEM

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PROBLEM

The preliminary design step is one of the most important stage of the project process of a solar concentrating facility. In order to improve performances of the **central receiver system (CRS)**, we developed a simulation tool based on Monte Carlo methods taking into account sun positions over the year to evaluate yearly energy at receiver in one simulation. With the efficient **Monte Carlo Sun Tracking (MCST)** algorithm, we obtain a fast and accurate code that permits to achieve optimization step in a reasonable time.

MODEL

The MCST algorithm evaluates the yearly energy at the entrance of a CRS receiver expressed by :

$$A = \int_{Year} \mathrm{d}t \int_{H^+} \mathrm{d}x \int_{\Omega_{sun}} \mathrm{d}\omega_S DNI \times [H(x_0 \notin (\mathcal{H} \cup \mathcal{T}))] \times \int_{2\pi} \mathrm{d}\boldsymbol{\omega}_1 f_r(\boldsymbol{\omega}_1 | \boldsymbol{\omega}_S, \boldsymbol{x}_1, \nu) \, |\boldsymbol{n}_h \cdot \boldsymbol{\omega}_1| \times \left[H(\boldsymbol{x}_2 \in \mathcal{T}^+) \right] \Big] \quad (1)$$

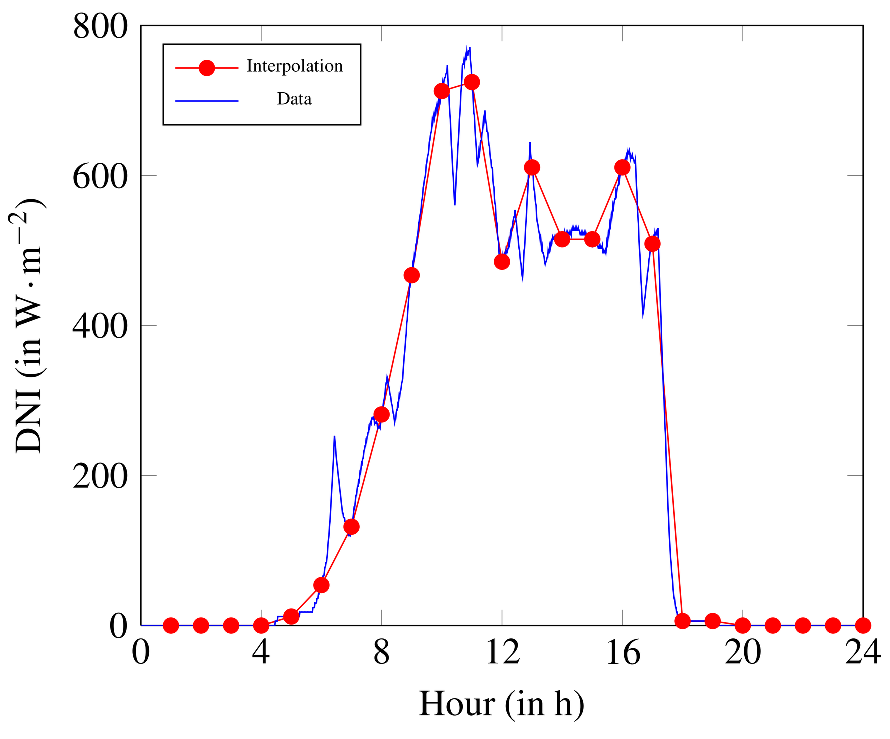
It also includes the reflection events involved in a CSP system and computes additional values characterizing CSP facility optical performances :

- Shadowing ;
- Blocking ;
- Spillage ;

As computational time is mainly devoted to update the heliostats orientation, we introduce an upgraded version with the **Multi Rays Monte Carlo Sun Tracking (MRMCST)** algorithm. For each dates, we trace 100 rays. As we obtain comparable results with less dates, this algorithm is faster than MCST.

INTERPOLATE DNI VALUES

We define each solar position with a day γ between $[1;365]$ and a time of the day η between $[7:00:00;19:00:00]$ and compute azimuth ϕ_S and elevation angle θ_S. Each sun position corresponds to a DNI value according to weather pattern. Starting from hourly radiation datasets stored in database, we interpolate data with linear interpolation (ex : 21^{th} of June 2005 in Albi [1]).

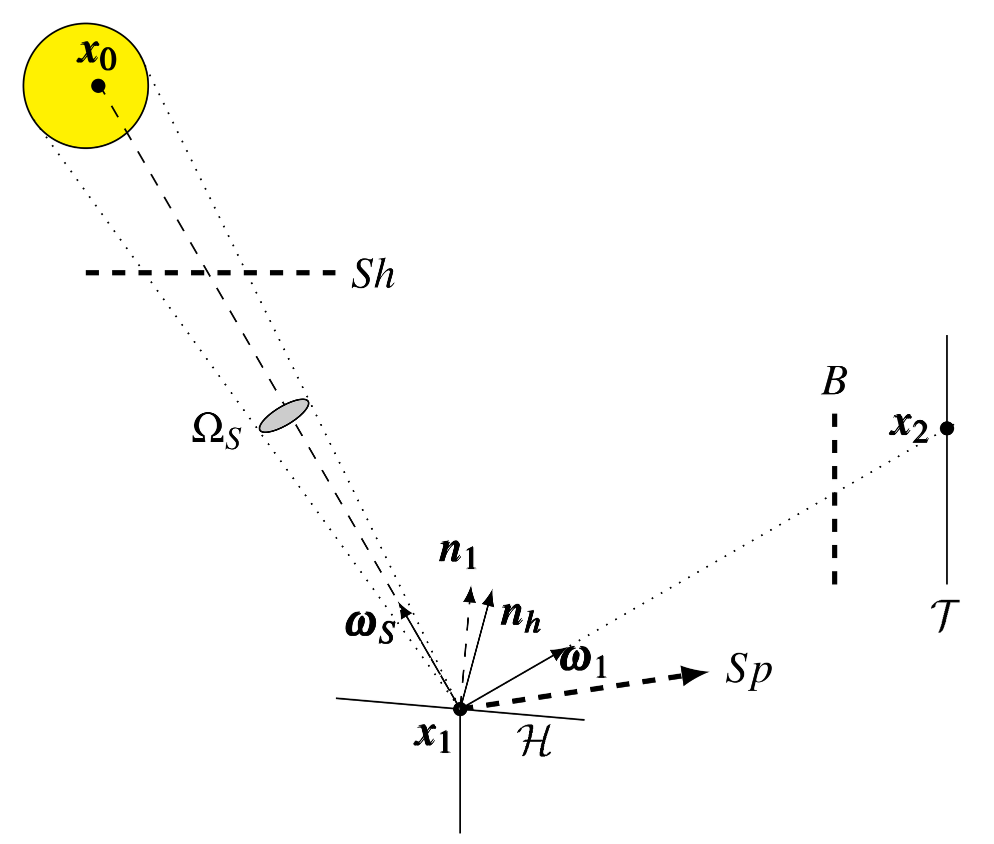


EDSTAR

EDStaR (numerical Environment of Development for Statistical Radiative simulation) is a coding environment [2]. Using Monte-Carlo methods, it takes advantages of advanced rendering techniques from computer graphics community. Three libraries are combined into the Mcm3D development environment :

- *GNU Scientific Library (GSL)* used for uniform random number sampling in the unit interval ;
- *Physically Based Rendering Techniques (PBRT)* [4] provides a C++ object library to manage complex geometries ;
- *mcm* C++ object library that handles with Monte Carlo algorithms programming .

ALGORITHM



Energy $A = 0$;
foreach *event* **do**
  Uniform sampling of δ in $[0, 365]$;
  Uniform sampling of η in $[7A.M., 7P.M.]$;
  for $i = 1$ **to** $i = N^a$ **do**
    Uniform sampling of $\boldsymbol{x}_1$ on $\mathcal{H}^+$;
    Sampling of $\boldsymbol{\omega}_0$ in solar disk $\boldsymbol{\Omega}_S$;
    Generation of $\boldsymbol{n}_h$ according to Blinn's model ;
    if *No shadowing between sun and* $\boldsymbol{x}_1$ **then**
      $\hat{w}_A = DNI |\boldsymbol{n}_h \cdot \boldsymbol{\omega}_S| \mathcal{H}^+$;
    else
      $\hat{w}_A = 0$;
      $\hat{w}_{Sh} = 1$;
      break;
    Specular reflection
    $\boldsymbol{\omega}_1 = \boldsymbol{\omega}_S + 2|\boldsymbol{n}_h \cdot \boldsymbol{\omega}_S| \boldsymbol{n}_h$;
    $\boldsymbol{x}_2 =$ intersection of $Ray(\boldsymbol{x}_1, \boldsymbol{\omega}_1)$ with geometry element ;
    if $\boldsymbol{x}_2$ *exists* **then**
      if $\boldsymbol{x}_2 \in \mathcal{T}^+$ **then**
        $A = A + \hat{w}_A$
      else
        $\hat{w}_A = 0$;
        $\hat{w}_B = 1$;
        break;
    else
      $\hat{w}_A = 0$;
      $\hat{w}_{Sp} = 1$;
      break;
    $i = i + 1$;

[a] For MCST $N = 1$, for MRMCST $N = 100$

CONCLUSION AND OUTLOOK

We present a new approach :

- To evaluate yearly energy at CRS receiver ;
- Fast and accurate ;
- Which can easily be integrated in an optimization process ;

We plan to use it with typical year DNI data to design a solar field optimized on a yearly production basis.

VALIDATION

We compare MCST results with Tonatiuh [3] to compute a testing case: a tower and 146 heliostats (9 squared mirrors of 1.6 meter sided) in a heliostats field designed with the MUEEN [5] method, following a radial staggered layout. We make some general assumptions :

- Reflections are specular ;
- CRS is located at the junction of the Greenwich meridian and the equator ;
- The target is a square with 10m ;

Firstly, we compute only one date at a time (4 dates tested at noon) to obtain a power value. Then, we randomly choose 50 dates and compute each date with Tonatiuh to approximate the average instantaneous energy received by the receiver over one year (Number of rays = 10^6).We only need to do one simulation with 50 rays to integrate over time and obtain an average instantaneous energy value. We see that EDStaR gives an estimation in accordance with Tonatiuh results for a yearly simulation done date by date even if error bars are significantly large due to the small number of dates computed. By increasing the number of dates we obtain a more precise value of the yearly energy.

Dates	Tonatiuh	MCST
Spring equinox	2.97MW	$2.97\text{MW} \pm 72\text{W}$
Summer solstice	3.19MW	$3.19\text{MW} \pm 98\text{W}$
Atumn equinox	2.98MW	$2.98\text{MW} \pm 73\text{W}$
Winter solstice	3.19MW	$3.19\text{MW} \pm 98\text{W}$
50 dates	6.329GWh_{th}	$6.323 \pm 0.623\text{GWh}_{th}$

Dates	MCST	MRMCST
50000 dates	$6.437 \pm 4.66 \cdot 10^{-2}\text{GWh}_{th}$	$6.463 \pm 4.61 \cdot 10^{-3}\text{GWh}_{th}$

COMPUTATIONAL TIME

We compare computational time[a] with Tonatiuh, knowing that it runs date by date. We evaluate as reference a "Tonatiuh equivalent" to MRMCST considering the following step execution time : 4.003s for each date, taking into account script opening (2s), pre and post-processing (2s) and tracing 100 rays (3ms).

Realizations	Tonatiuh	Tonatiuh Eq.	MCST	MRMCST
$5 \cdot 10^4$	≈ 3s	$2 \cdot 10^5$s	9s	2s
$5 \cdot 10^5$	≈ 24s	$2 \cdot 10^6$s	59s	13.9s
$5 \cdot 10^6$	≈ 156s	$2 \cdot 10^7$s	814s	91s

[a] On a desktop PC with AMD Phenom II X6 1055T 2.8GHz and 4Mo RAM

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