

Real-Time Flux Map Generation and Aiming Optimization for Solar Tower Systems Using Fast Interpolation and Optimization Algorithms

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The performance and reliability of solar tower systems strongly depend on accurate prediction and control of the solar flux distribution on the receiver. High-fidelity ray-tracing simulations provide accurate flux maps, but their computational cost makes them unsuitable for real-time operation, particularly for advanced control and digital-twin applications in concentrating solar power (CSP) plants. Here, computationally intensive optical simulations are moved offline: a database of flux maps is used to interpolate flux distributions for arbitrary solar positions, and the reconstructed maps are then provided to fast optimization algorithms, including Particle Swarm Optimization (PSO), to compute heliostat aiming strategies under realistic operational constraints.

METHODOLOGY

During operation, flux maps for the current solar position are reconstructed from the offline database by interpolation. To account for real operating conditions, the reconstructed maps are rescaled using real-time measurements of direct normal irradiance (DNI) and heliostat reflectance [1], through a linear correction of the flux intensity (Eq. 1). This rescaling accounts for real-time variations in DNI and heliostat reflectance at negligible computational cost.

$$Flux_{scaled} = F_{interp} \cdot \frac{DNI_{real}}{DNI_{ref}} \cdot \frac{\rho_{real}}{\rho_{ref}} \quad (\text{Eq. 1})$$

The reconstructed flux maps are used as input to three optimization approaches: Greedy search, TABU search, and Particle Swarm Optimization, the latter being a population-based swarm-intelligence algorithm. All three share the same computational pipeline and objective function, enabling a fair comparison of their performance. The objective minimizes deviation from a desired thermal power within a specified receiver region while promoting spatial homogeneity of the flux distribution. Candidate solutions are evaluated on precomputed flux maps, so no additional optical simulation is required during optimization. The methods were developed for the solar field of IMDEA Energy, Móstoles, Spain [2], considering 162 heliostats and one flux map per heliostat for each simulated solar position in the preliminary database. The aiming grid is a 5×5 square mesh covering 40×40 cm, with the real receiver represented by the central 25×25 cm square (Fig. 1). A more detailed model allowing the aiming-point positions to vary is also under development to further reduce the optimization error.

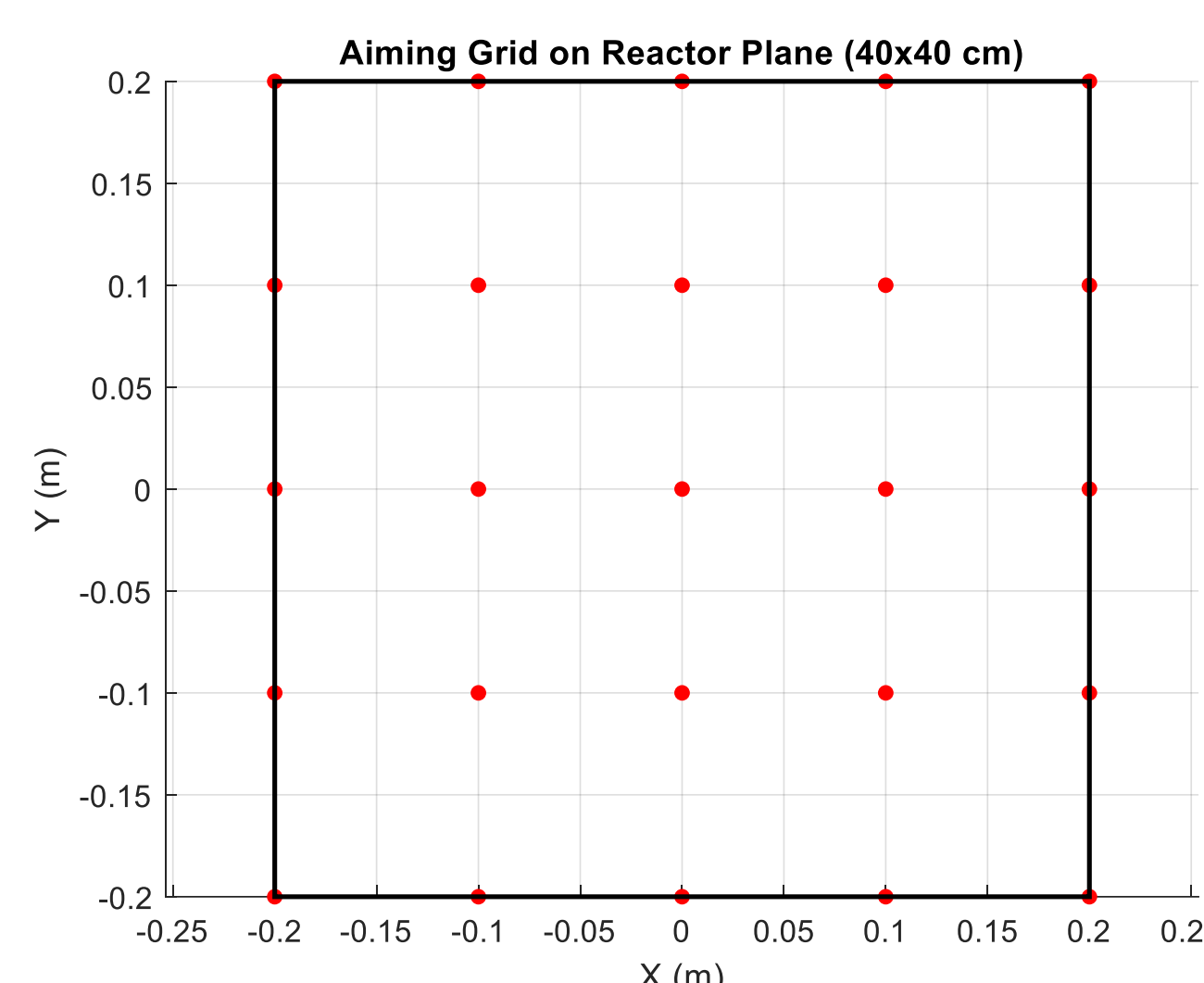


Fig. 1: Aiming grid used to develop the pointing strategies to the receiver.

RESULTS

The framework was evaluated for a representative heliostat field. For the baseline configuration of 162 heliostats, all optimization algorithms converge within a few seconds, enabling near real-time operation (Table 1). The Greedy method is the fastest (1.58 s), whereas TABU achieves the lowest power error (0.20%) and flux standard deviation (14.55 kW/m²), highlighting the trade-off between computational speed and flux quality (Fig. 2).

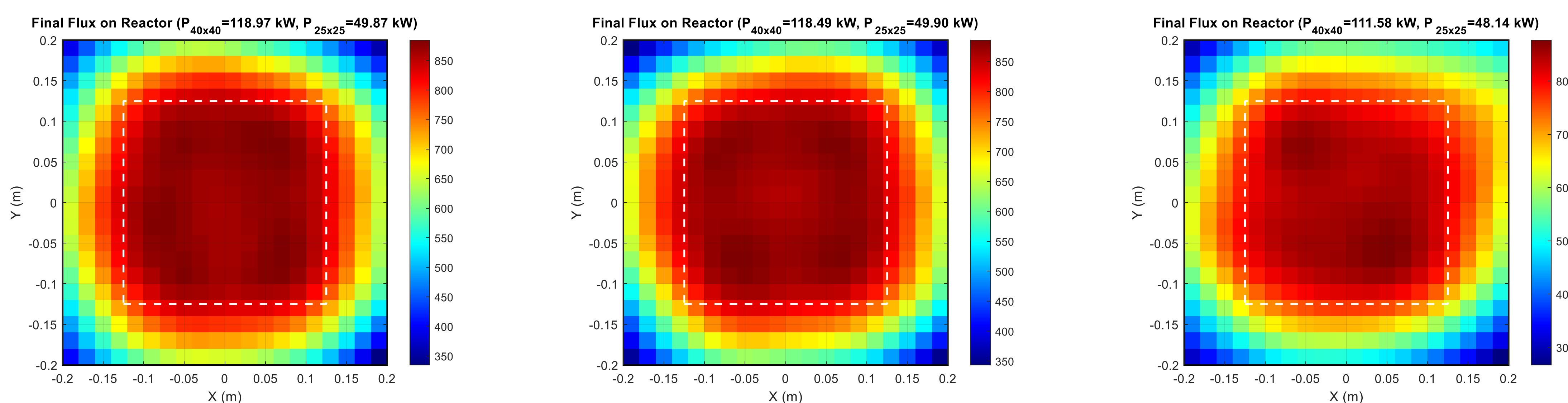


Fig. 2: Flux maps obtained with the Greedy, TABU and PSO algorithms, respectively from left to right.

Table 1: KPIs used to compare the different methods: run time, error between achieved and target power, and flux standard deviation.

Algorithm	Time (s)	Power error (%)	Flux STD (kW/m ²)
Greedy	1.58	0.26	15.15
TABU	4.98	0.20	14.55
PSO	5.55	3.71	26.51

To assess scalability, the methodology was extended to larger synthetic datasets containing up to 10,000 flux maps, closer to the scale of medium-to-large solar fields. Despite the substantial increase in problem size, a modified faster version of the Greedy algorithm ran in under two minutes. Including flux-map reconstruction, the complete workflow remains below the 5-minute update horizon assumed for the aiming strategy. Further improvements are expected to reduce computation time.

REFERENCES

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ACKNOWLEDGEMENTS

The authors acknowledge support from the SUN-to-LIQUID II (GA No. 101122206) and ASTERIX-CAESAR (GA No. 101122231) projects, funded by the European Union; the ACES4NET0-CM project (TEC-2024/ECO-116), funded by the Comunidad de Madrid; and the AGATA project (PID2023-153368OB-I00), funded by MICIU/AEI/10.13039/501100011033 and ERDF/EU.