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Numerical Resolution of Radiation View Factors in Multi-Junction Thermoelectric Generators Via GPU-Accelerated Ray Tracing

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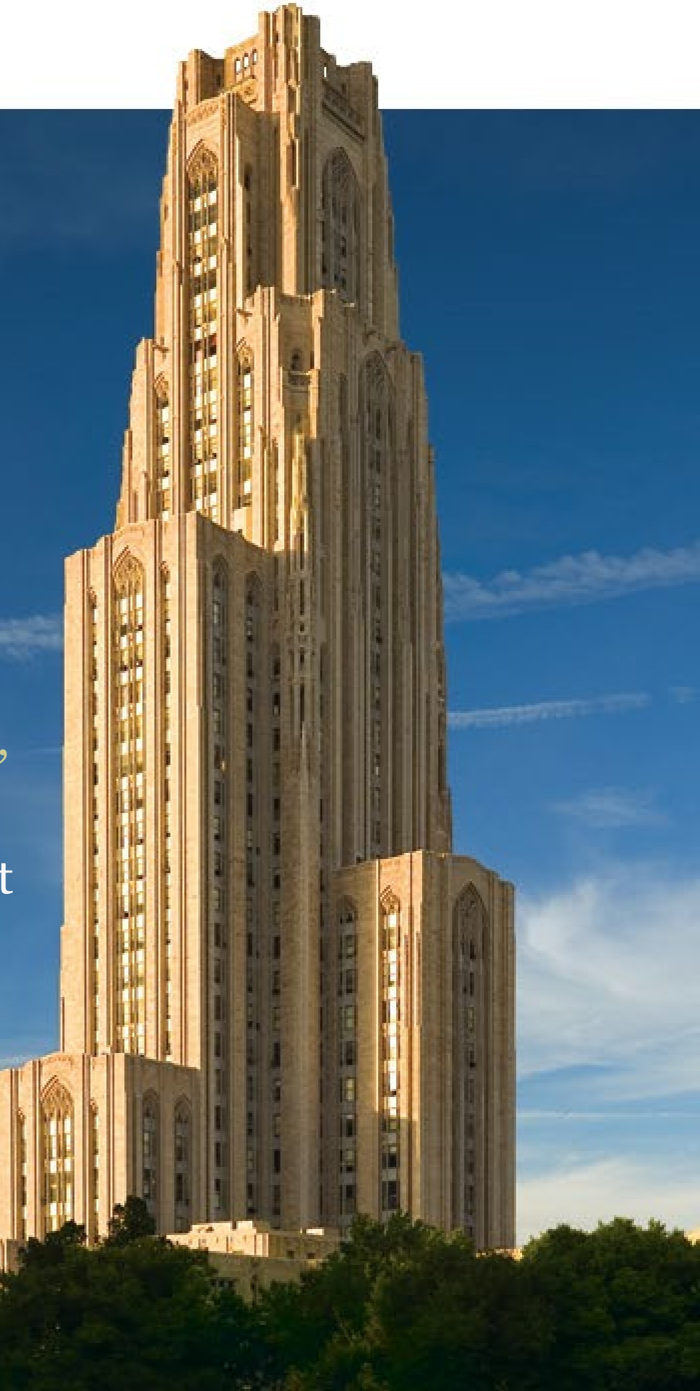


Background: Thermoelectric generators and view factors

Figure of merit for TE materials ($Z\bar{T}$):

- α : Seebeck coefficient
- σ_{el} : electrical conductivity
- K : thermal conductivity
- $\bar{T}$: mean temperature

$$Z\bar{T} = \frac{\alpha^2 \sigma_{el}}{K} \bar{T}$$

Radiation Heat Transfer Rate (Q_i):

- ε : material emissivity
- σ: Stefan-Boltzmann constant
- T_i: temperature of emitter
- T_j: temperature of receiver

$$Q_i = \varepsilon \sigma A_i F_{ij} \left(T_i^{\,4} - T_j^{\,4} \right)$$

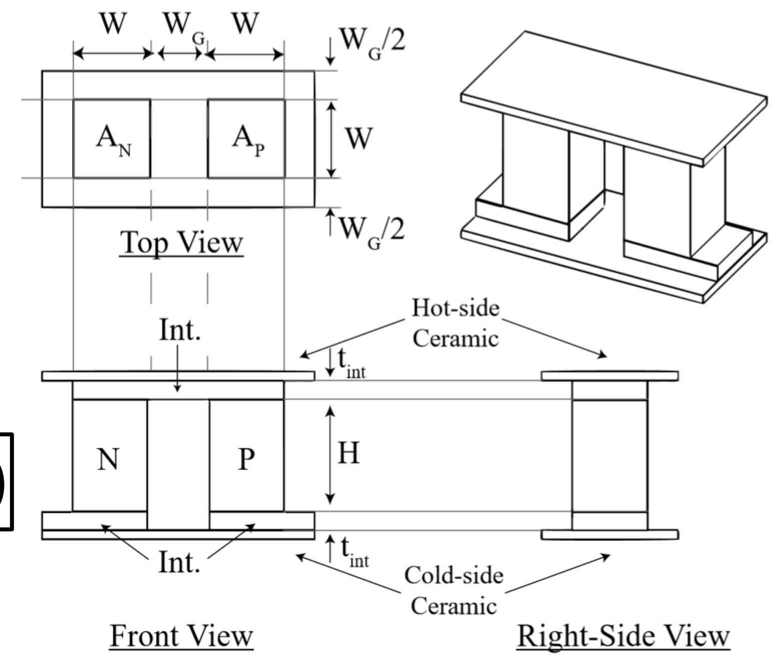


Fig 1: Single-junction thermoelectric generator (TEG) design.

Radiation view factor (F_{ij}):

$$F_{ij} = \frac{1}{A_i} \int \int \frac{\cos\theta_i \cos\theta_j}{\pi \vec{R}^2} dA_i A_j$$

Discretize The Domain

$$F_{ij} = \frac{1}{A_i} \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} \frac{\cos\theta_i \cos\theta_j}{\pi \vec{R}^2} dA_i A_j$$

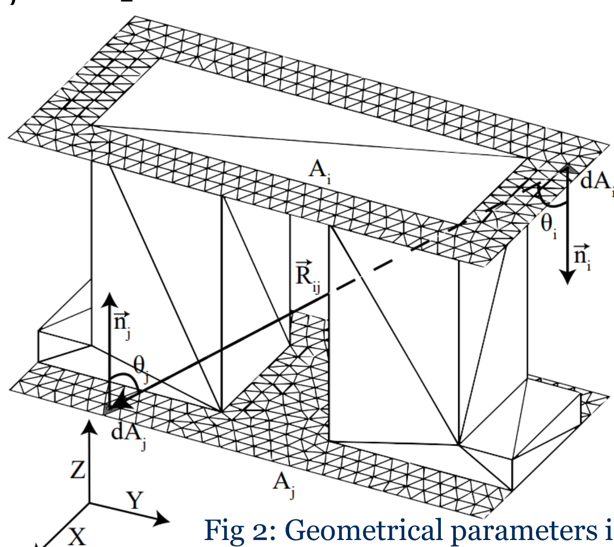


Fig 2: Geometrical parameters in a single-junction TEG.

Methodology: GPU-accelerated programming

- Rays cast from every dA_i to every dA_j
- Shadow effect handled via Möller–Trumbore (MT) ray-triangle intersection algorithm
- Parallel execution

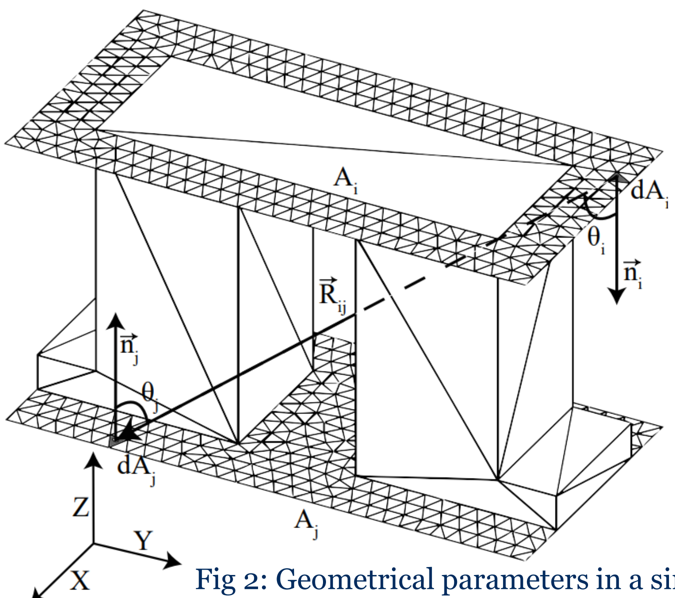
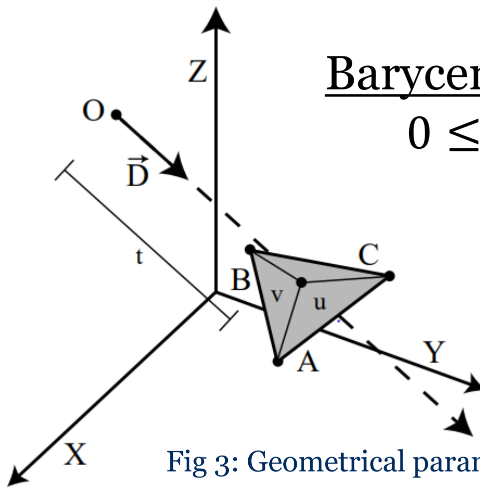


Fig 2: Geometrical parameters in a single-junction TEG.

$$F_{ij} = \frac{1}{A_i}\sum_{i=1}^{N_i}\sum_{j=1}^{N_j}\frac{\cos\theta_i\cos\theta_j}{\pi\vec{R}^2}dA_iA_j$$



Barycentric coordinates

$$0 \le u + v \le 1$$

$$\begin{bmatrix} t \\ u \\ v \end{bmatrix} = \frac{1}{\left|-\vec{D}\ \overrightarrow{BA}\ \overrightarrow{BC}\right|}\begin{bmatrix} \left|\vec{T}\ \overrightarrow{BA}\ \overrightarrow{BC}\right| \\ \left|-\vec{D}\ \vec{T}\ \overrightarrow{BC}\right| \\ \left|-\vec{D}\ \overrightarrow{BA}\ \vec{T}\right| \end{bmatrix}$$

Fig 3: Geometrical parameters in the MT algorithm.

Intersection?

$$t \le \left\|\vec{R}\right\|$$

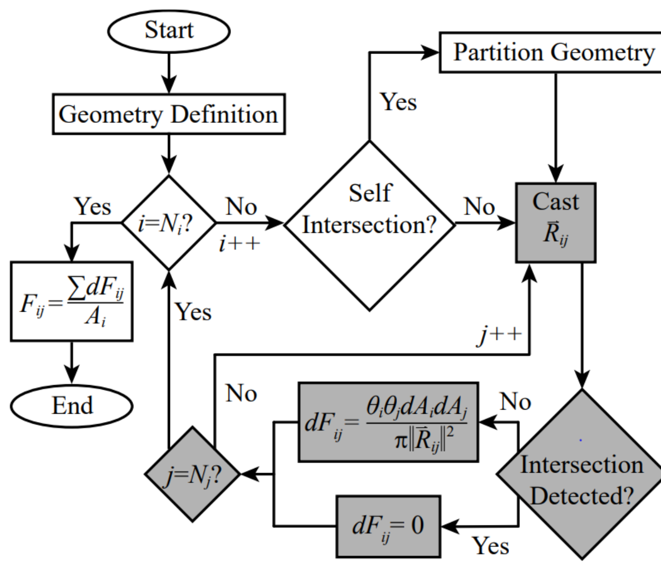


Fig 4: Computational flow chart (processes computed on the GPU are highlighted).

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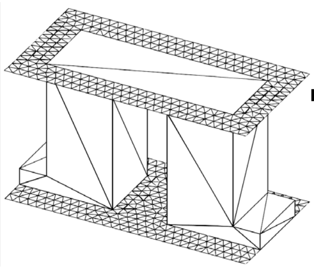
Results: Computational runtimes and trends



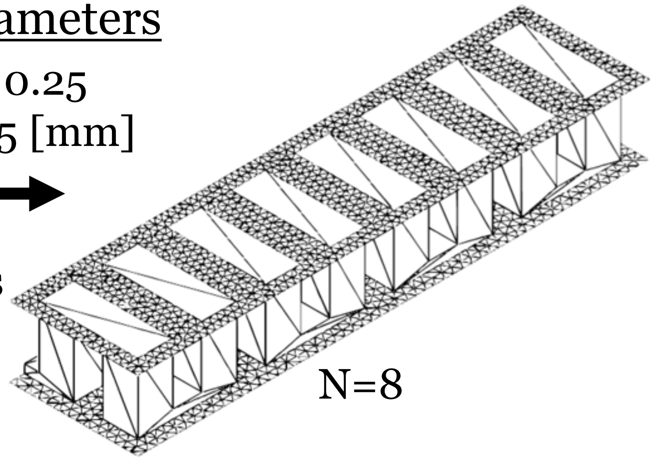
N=1

TEG Parameters

H/W = 0.25

$t_{int.}$ = 0.125 [mm]

Increase junctions



N=8

Fig 5: Multi-junction TEG design.

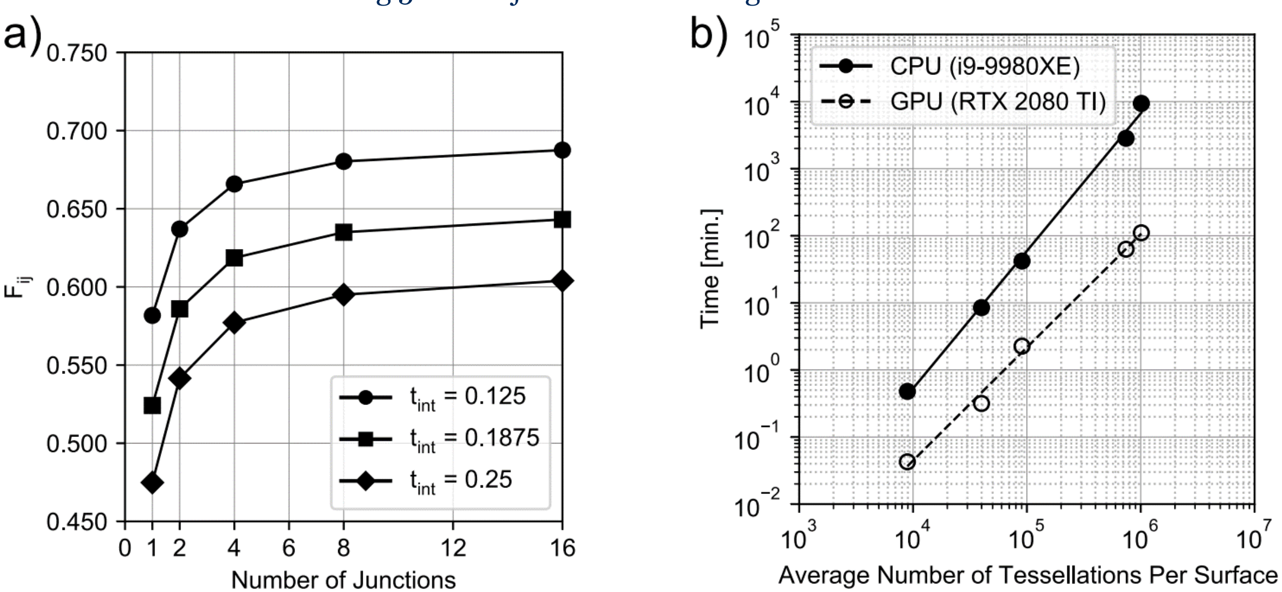


Fig 6: View factors of a TEG design with varying junction number and b) CPU vs. GPU runtimes for varying model fidelity

- Explored effect of junction number (N) on F_{ij}
- Asymptotic behavior observed for constant design parameters
- Runtime decrements with GPU-accelerated programming

Future Work

- Multi-GPU acceleration
- Efficient self-intersection algorithms
- New applications

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