Origami Solar-Tracking Concentrators

Tainon Chen
Prof. Pei-Cheng Ku
Introduction: Solar Cell Semiconductors

- Conventional solar cells use crystalline silicon
  - ~$5.7 / m^2 for Si
- Newer semiconductors are more efficient, but more expensive
  - ~$8,200 / m^2 for GaAs
Introduction: Solar Cell Tracking Array

- Increases effectiveness of light collection by modifying tilt of concentrator
- Can tilt concentrator ±60° relative to normal
Fixed-Tilt Flat Panels Based on Origami Micro-Concentrators
Introduction: Simple Parabolic Concentrators

- Composed of a single parabola
- All incoming rays parallel to axis are reflected to focus
- Nonparallel rays are reflected unpredictably

- Parabolic Reflector, Wikipedia
Introduction: Compound Parabolic Concentrators

- Abbreviation: CPC
- Rotate two parabolas by angles +θ and -θ
- Overlap parabolas so that focus of each parabola intersects shape of the other

- Nonimaging Optics, Wikipedia
Compound Parabolic Concentrator Creation
Compound Parabolic Concentrator Creation
Compound Parabolic Concentrator Creation
Introduction: CPC Variations

- Ideal 3D CPC has circular base
  - Difficult to manufacture

- CPCs with polygonal bases are more easily created
  - Trade-off due to decrease in ray collection effectiveness

- Nonimaging Optics, Wikipedia
- A Comparison of Compound Parabolic and Simple Parabolic Concentrating Solar Collectors, Los Alamos Scientific Laboratory
3D Concentrator Sides and Corners
3D CPC Concentrator
Introduction: Project Scope

- Optimize origami concentrator design
  - Use two overlapping (compound) parabolas to generate 2D shape
  - Combine 2D models for 3D square-based concentrator
  - Determine limitations of dimensions imposed by tracking array
  - Simulate light collection
Methods: 2D Concentrator Creation

- Use **parabola coefficient** to generate two parabolas
- Rotate parabolas in opposite directions by **angle**
- Horizontally translate parabolas by **separation**
- Shift concentrator base according to **base position**
- Find the maximum **height factor**, and adjust concentrator height accordingly
Parabolas with Coefficients 0.01:0.01:1
Parabolas with Separation Distance 0:0.01:1
Concentrators with Angles 1:1:45
Concentrators with Base Positions 0:0.01:1
Concentrators with Height Factors 1:-0.01:0
Methods: Determining Optimal Height

- All five parameters, except height factor, are set arbitrarily
  - Other four parameters: parabola coefficient, parabola separation, angle, base position
- Increasing height factor always increases CF
- Concentrators are placed in close proximity on tracking array
  - Too tall: concentrators collide within ±60°
  - Too short: lower CF
Binary Search for Optimal height
Methods: Determining Light Collection

- Simulated light follows law of reflection, assuming sidewalls were perfect reflectors
- All incident rays perpendicular to base
- Delaunay triangulation to determine slope of 3D concentrator
Determining 2D Ray Collection
Methods: Concentration Factor

- Concentration factor (CF): measure of effectiveness of light collection
  - Also reflective of cost-saving of concentrator

\[
CF = \frac{\text{Rays Collected}}{\text{Total Rays}} \times \frac{\text{Top Area}}{\text{Base Area}}
\]
Methods: CF Cases - No Concentrator

- \[ CF = \frac{\text{Rays Collected}}{\text{Total Rays}} \times \frac{\text{Top Area}}{\text{Base Area}} \]

- No concentrator
  - \( \text{Rays Collected} == \text{Total Rays} \)
  - \( \text{Top Area} == \text{Base Area} \)
  - \( CF = 1 \)

- “Base case”: No cost savings
Methods: CF Cases - Example Concentrator

- \( CF = \frac{\text{Rays Collected}}{\text{Total Rays}} \times \frac{\text{Top Area}}{\text{Base Area}} \)

- Concentrator with \( \frac{\text{Top Area}}{\text{Base Area}} = 2 \), which collects 80% of rays
  - \( \frac{\text{Rays Collected}}{\text{Total Rays}} = 0.8 \)
  - \( \frac{\text{Top Area}}{\text{Base Area}} = 2 \)
  - \( CF = 1.6 \)

- Less semiconductor is used, but not all the light can be collected
  - Still more effective than base case
Results

- **Parameters**
  - Parabola coefficient
  - Angle
  - Parabola separation
  - Base position
  - Height factor

- **Outputs**
  - Light collection ratio
  - Top-to-base ratio
  - Concentration factor
Results: Parabola Coefficient

- Parabola coefficient did not affect concentration factor
- All parabolas are geometrically similar
Results: Light Collection, Angle = 1
Results: Light Collection, Angle = 15
Results: Light Collection, Angle = 30
Results: Light Collection, Angle = 45
Results: Light Collection

- As angle increases, changes in parabola separation lead to greater changes in light collection.
- Light collection approaches a constant 1 as base position approaches 1.
Results: Top-to-Base Ratio, Angle = 1
Results: Top-to-Base Ratio, Angle = 15
Results: Top-to-Base Ratio, Angle = 30
Results: Top-to-Base Ratio, Angle = 45
Results: Top-to-Base Ratio

- As angle increases, changes in parabola separation lead to greater changes in top-to-base ratio.
- Top-to-base ratio increases exponentially as base position decreases exponentially.
Results: Concentration Factor, Angle = 1
Results: Concentration Factor, Angle = 15
Results: Concentration Factor, Angle = 30
Results: Concentration Factor, Angle = 45
Results: Concentration Factor

- As angle increases, changes in parabola separation lead to greater changes in concentration factor.
- At higher angles, CF is less sensitive to changes in separation.
Results: Concentration Factor

- As angle increases, changes in parabola separation lead to greater changes in concentration factor.
- At higher angles, CF is less sensitive to changes in separation.
Discussion

- Proposed a square-based concentrator design to increase ease of manufacturability
- Analyzed effects of different parameters on 2D concentration factor
- Convert promising 2D concentrator designs to 3D
- Measure concentration factor, and verify using Multiphysics software
Thank you for listening!