Parametric splines for non-imaging optics

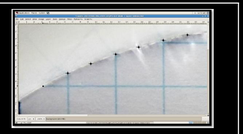
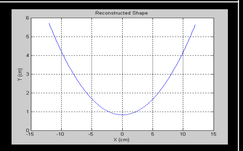
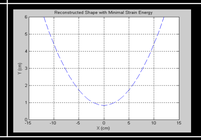
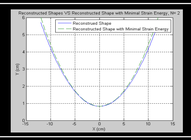
Authors: Dawei ZHOU, Mengxing NI and Xin WU
Supervisor: Dr Andrew ALLISION
Co-supervisor: Dr Braden Phillips

SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING
THE UNIVERSITY of ADELAIDE

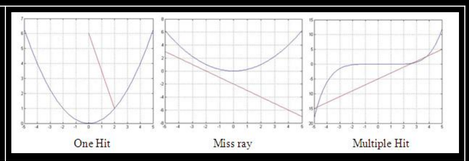
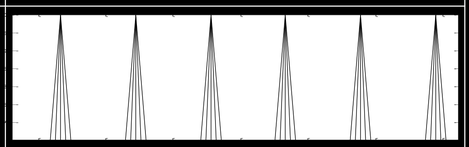
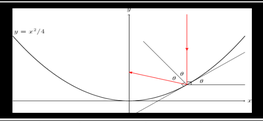
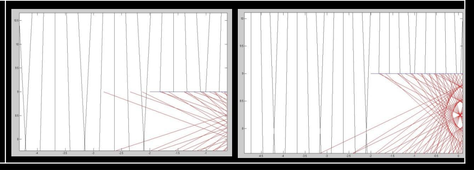
Introduction and Background

As the shortage of the foil energy resource nowadays, the project of Parametric Splines for Non-imaging Optics is to design a part of the solar system-shape which approaches to improve the efficiency of the system, so that in some way to relieve the energy resources crisis. The shape is required to maximize the collected solar energy and minimize the stored strain energy. This project applies MATLAB to approach shape design and testing theoretically, whilst the designed shape model provides more intuitive experiment result via ray tracing test.

Shape Design

Step 1:	Method 1: Set Boundary Conditions Method 2: Collect Data from Real Model	$X(0)=W;\ Y(0)=0;$ $X\left(\frac{\pi}{2}\right)=0;\ Y\left(\frac{\pi}{2}\right)=H;$ $\frac{dx}{dt}(0)=0;\ \frac{dy}{dt}\left(\frac{\pi}{2}\right)=0;$ An example of Boundary conditions  Using GIMP to collect data
Step 2:	Generate Shape: Obtain coefficients of shape —polyfit() function Create shape based on coefficients —polyval() function	p = 0.0084 -0.0983 0.4217 -0.7435 0.1471 1.1064 0.0004 $p(x)=p_1x^n+p_2x^{n-1}+\ldots+p_nx+p_{n+1}.$ $=.0084x^6-0.0983x^5+0.4217x^4+0.1471x^3+1.106x+0.0004.$ 
Step 3:	Minimise Strain Energy: The reason is that the shape with minimal strain energy is closer to the real shape on the model.	According to Euler Bernoulli function (Smith, 1974), then convert the equation into MATLAB. • Y- The polynomial function • V – Work of deformation • α - Bendy coefficient • k – the curvature of the rod • d_s – The differential element of arc length Work of deformation can be written as follow: $V=2\alpha\int_0^a \frac{Y''(x)^2}{[1+Y'(x)^2]^{5/2}}dx$
Step 4:	Generate the final shape	 

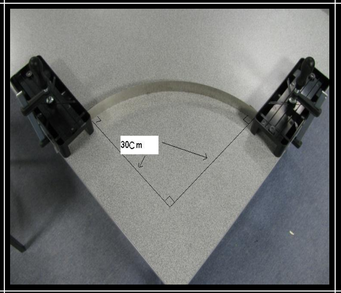
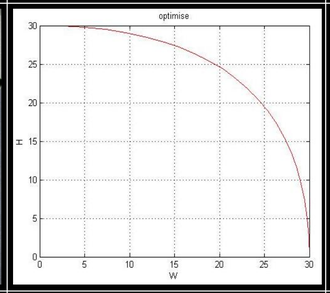
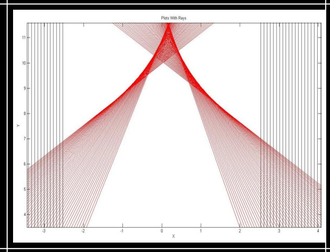
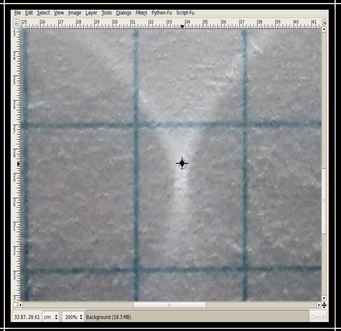
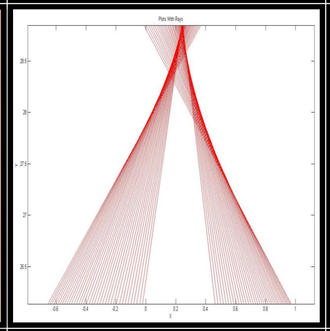
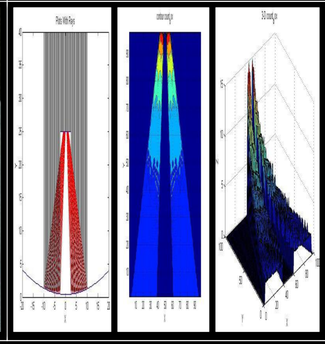
Ray Tracing

Conditions of the incoming ray	•One hit point •Missing ray •Multiple rays	 One Hit Miss ray Multiple Hit
Define the initial rays	Set the positions and directions of initial rays	
Calculate the hitting points and reflected direction	Check the intersection between the incoming ray and the reflect sheet	 The reflected rays' angle = 2 × (normal line's angle) – π/2 + (input ray's angle);
Remove the inefficient Rays	Check whether the reflected rays intersect with the collector	

Objectives

- Calculate the parameters for sets of splines that minimise stored energy.
- Carry out ray-tracing analysis to determine the most suitable optical shapes.
- Optimise the choice of boundary conditions to give the shapes with the best performance.

Comparison and Results

	Practical	Theoretical	Results
Shape			➢ 90% of points match ➢ The shape satisfies the boundary conditions
Caustic in general			➢ The shapes of caustic in practical and theoretical are exactly same
Location of caustic			➢ The locations of central caustic (Focus) are almost identical. In practical, the location is 28.61cm, whilst the location is around 28.7cm in theoretical.
Shape with collector			➢ Practical result shows two beams of reflected rays clearly. ➢ Theoretical results express the prefect simulation on MATLAB, especially the intensity for Contour version.

Reference

1. Smith, DR 1974, VARIATIONAL METHODS IN OPTIMIZATION, published at London, pp. 206 – 209.

Conclusion

This poster reveals the whole project briefly. It includes the understanding of the project from group members, main method and theory that we applied on shape design and ray tracing, also several experiments to verify our achievement, and providing the conclusion from analysis. This project takes less than one year, but it reaches the most requirements, such as finding the 'true' shape and dealing with minimal strain energy, achieving ray tracing simulation. The data from this project is also valuable, ray tracing simulation and counting box can both indicate the importance of caustic in solar energy field. However, there are still lots of areas need to improved and developed.

Future Work

This project is contemporarily finished in this year. However, if the big picture of this project is analogous to a pizza, then what we have done just seems like one of slices. This project connects to other groups from mechanical engineering and solar energy engineering. The relationship between us is that we provide Mathematical theory and software simulation; mechanical engineers provide material and construct support and solar energy engineering focuses on solar panel, such as collector. Once we are integrated, the final complete system can be successfully created.