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SOLAR THERMAL ENERGY
RESEARCH GROUP

Investigating the use of light diffraction for the closed-loop control of heliostats

M. Claassen & Dr. W.J. Smit

Solar Thermal Energy Research Group (STERG)
Stellenbosch University

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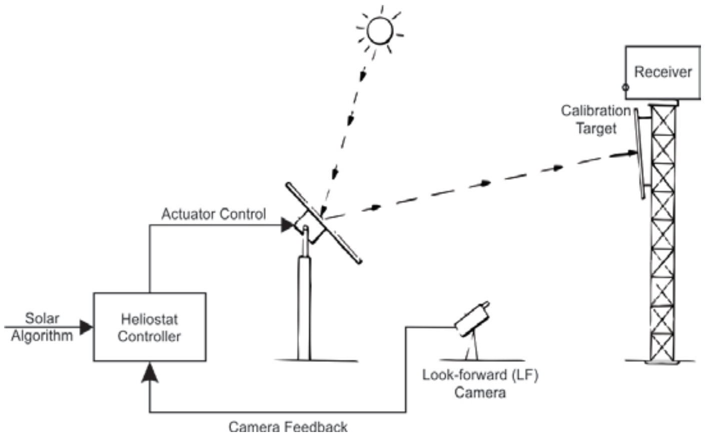
CENTRE FOR RENEWABLE AND SUSTAINABLE ENERGY STUDIES

Introduction to CRSs

- Central Receiver Systems

Background on Heliostat Control

- Open-loop control

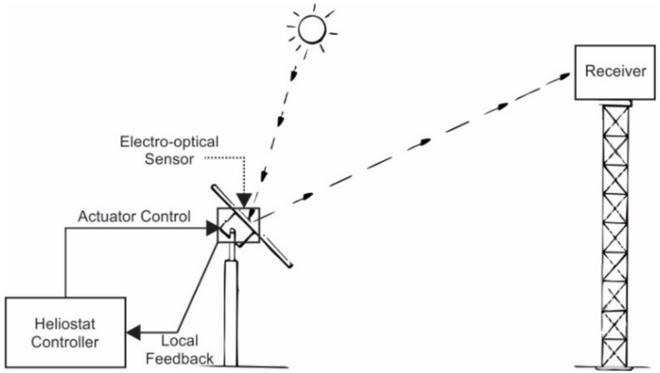


- No aiming feedback during operation requires drives with very tight tolerances which are costly

- Deterministic and non-deterministic error sources cause drift requiring calibration, which is time consuming

Background on Heliostat Control

- Closed-loop (local-feedback)



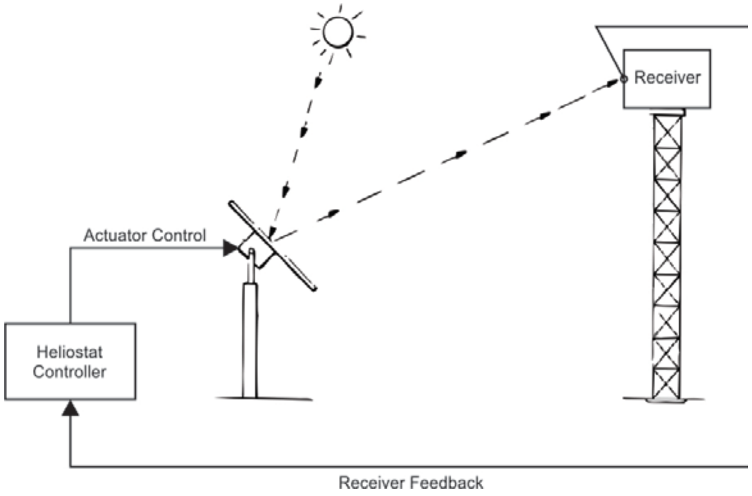
- Real-time alignment feedback negates the need for expensive drives with tight tolerances

- Mounting sensors on every heliostat can be expensive, esp. for large helio fields

- Sensors usually also require regular calibration

Background on Heliostat Control

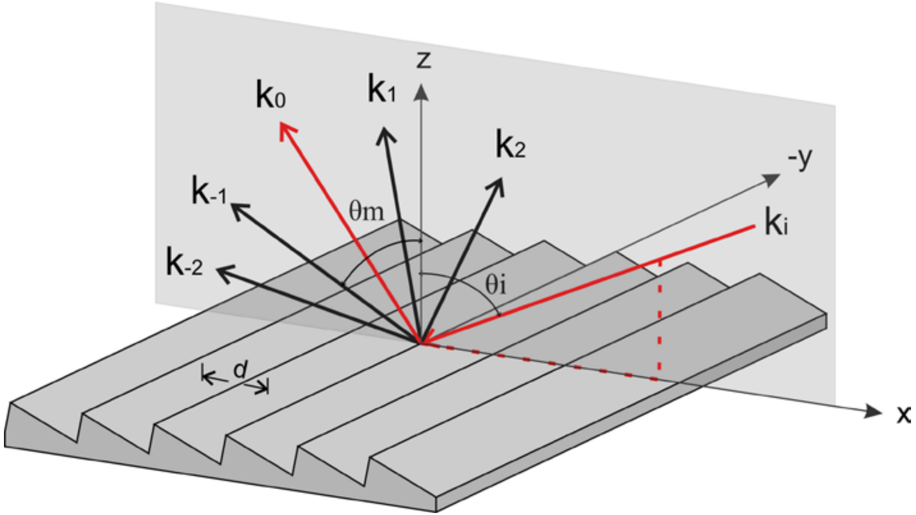
- Closed-loop ('Receiver-feedback')



- Real-time alignment feedback negates the need for expensive drives with tight tolerances
- Does not require sensors on every heliostat
- Multiple/ All heliostats can be controlled simultaneously

Diffraction

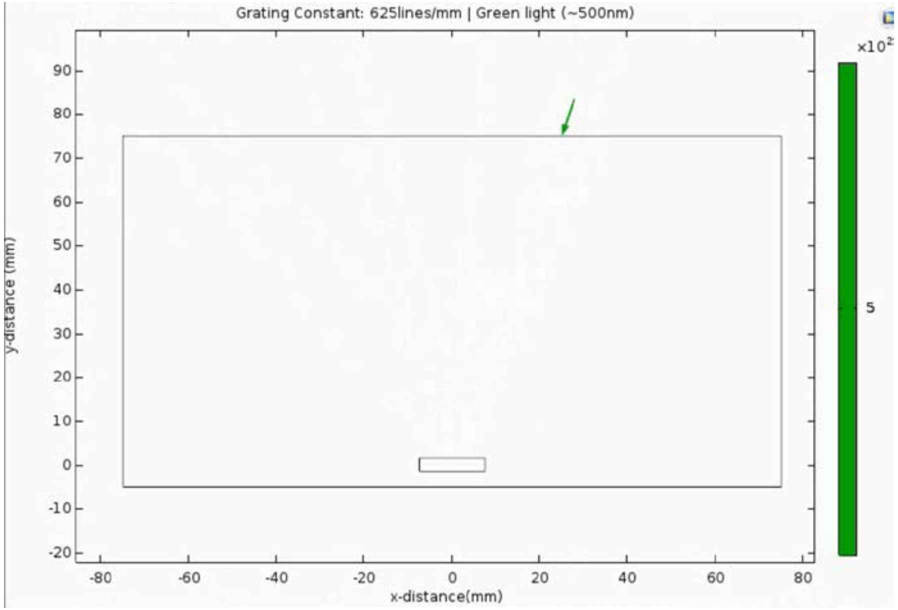
- 1-D (Linear) diffraction grating

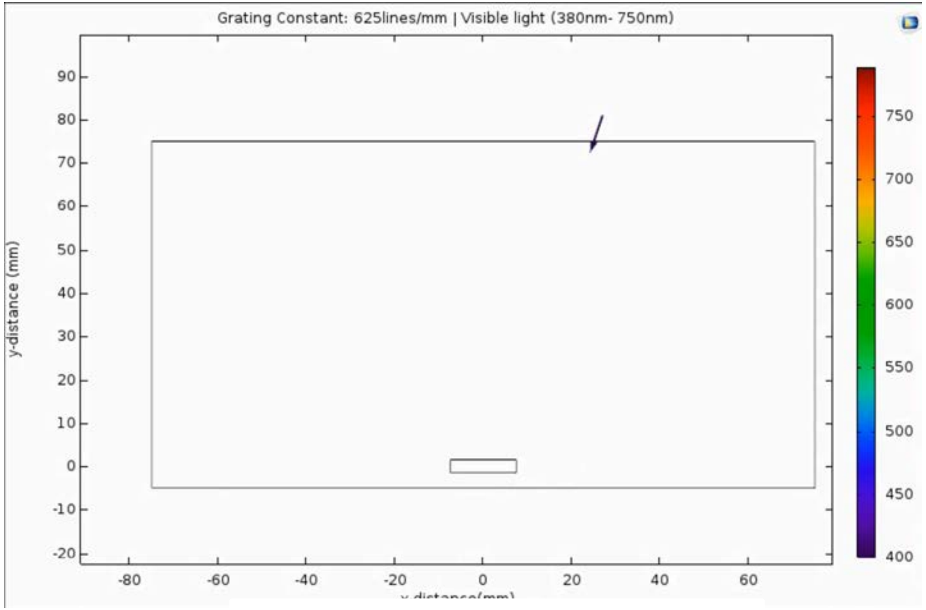


$$\sin\theta_m = m\frac{\lambda}{d} - \sin\theta_i \qquad m = 0, \pm 1, \pm 2 \ldots$$

Diffraction

- Diffraction gratings



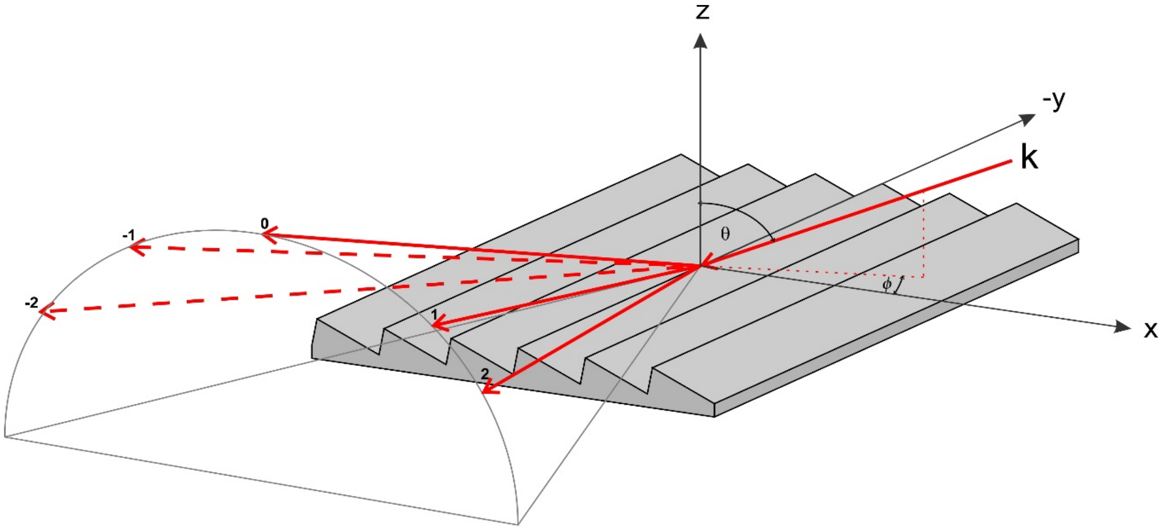


$$\sin\theta_m = m\frac{\lambda}{d} - \sin\theta_i$$

$$\sin\theta_m(\lambda) = m\frac{\lambda}{d} - \sin\theta_i$$

Diffraction

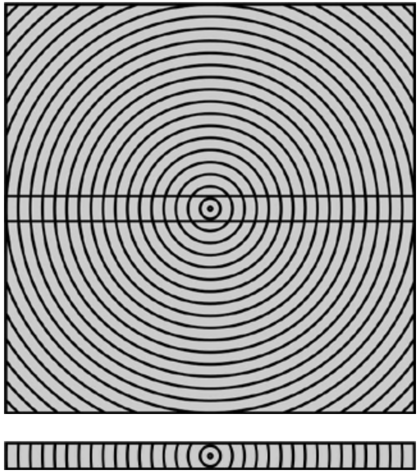
- 1-D (Linear) diffraction grating

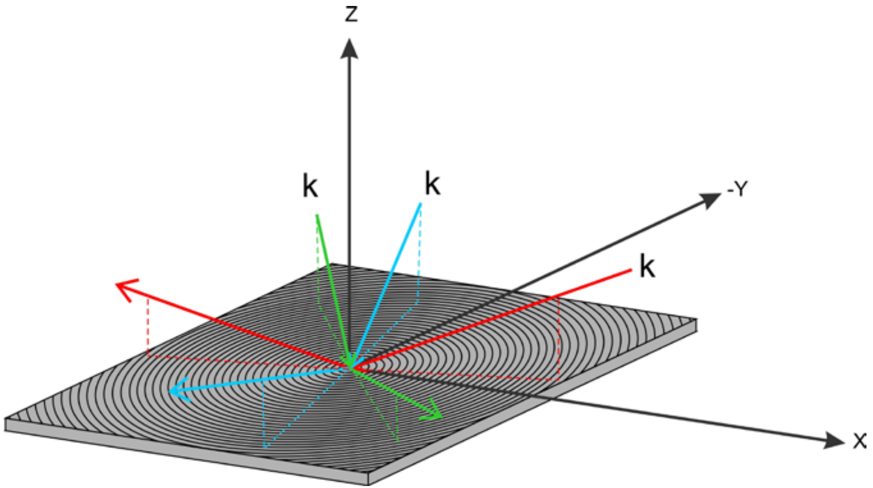


$$\cos\phi_i\,(\sin\theta_m - \sin\theta_i) = \frac{m\lambda}{d}$$
$$d(\sin\phi_m - \sin\phi_i) = 0$$

Diffraction

- Circular diffraction grating

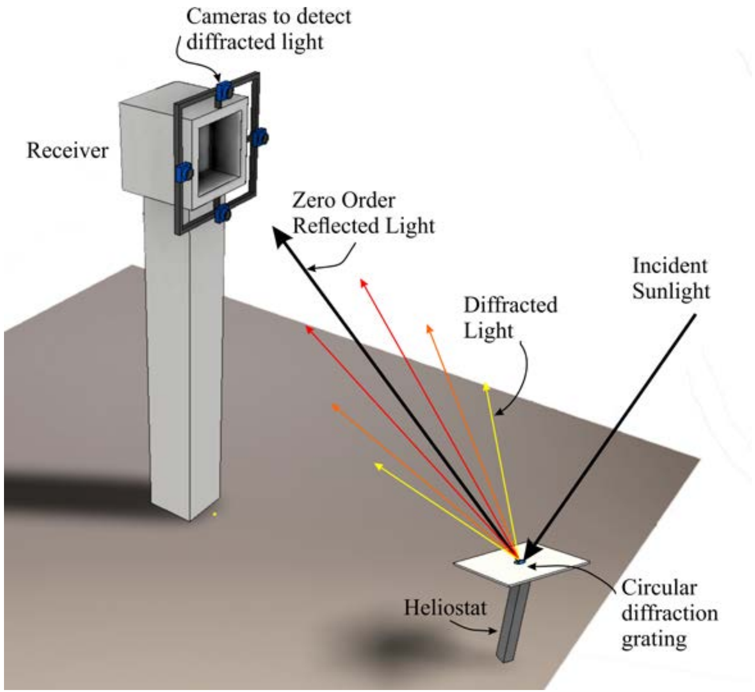




$$\sin\theta_m = \sin\theta_i + m\frac{\lambda}{d}$$

Method

- Overview



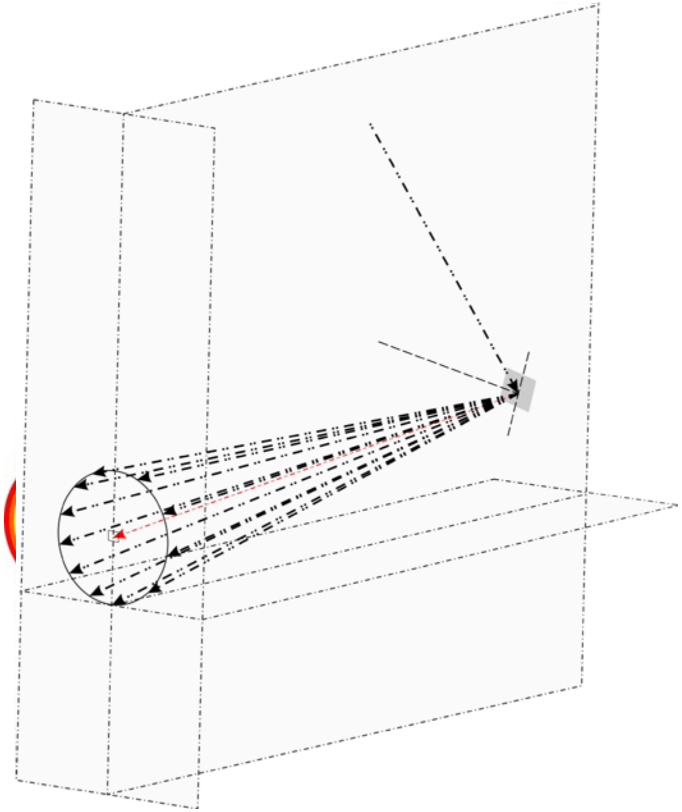
- Aim: Determine direction of the spectral propagation order (direction of the zeroth propagation order coincides with the reflected beam from heliostat).

- Camera senses the colour of diffracted light from some propagation order (1st), infers wavelength

- The light diffracted in the direction of the camera has a functional relationship with the zeroth order.

Method

- Determining $k_{m=0}$: One camera viewpoint
  - 1Camera observes diffracted light and observes a specific colour, inferring the wavelength
  - Since the circular diffraction grating diffracts light into a cone, there are an infinite directions for the zeroth order reflected beam, but is constrained to lie on a surface of a cone with vertex angle 2θ and with axis along the camera-grating vector
  - Set of all possible incident vectors is the reflection (Snell's law) of the set of all possible reflection vectors and therefore also lies in a cone with angle vertex 2θ. Its axis is the reflection of the camera-grating vector.



Method

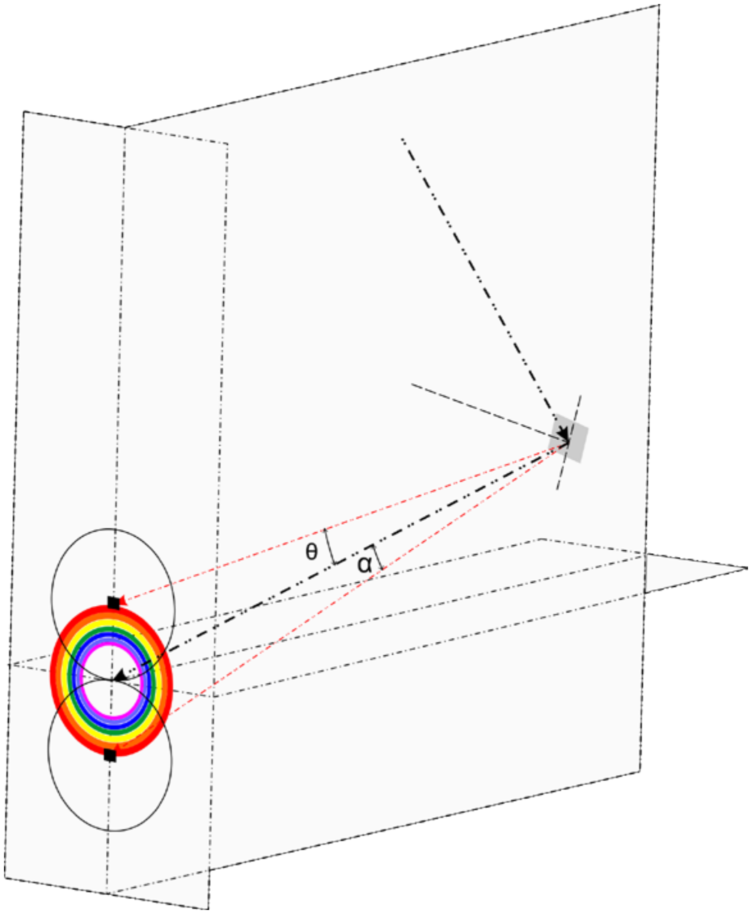
- Determining $k_{m=0}$:
  Two camera viewpoints

Special case: Incident light, grating normal and cameras lie in a plane.

- 2 Camera each observes diffracted light and each observes a specific colour, each inferring the wavelength.

- For each viewpoint, there are an infinite number of directions for the zeroth order reflected beam, but is constrained to lie on a surface of a cone

- The intersection of the bases of the cones is the unique solution for the direction of the zeroth order

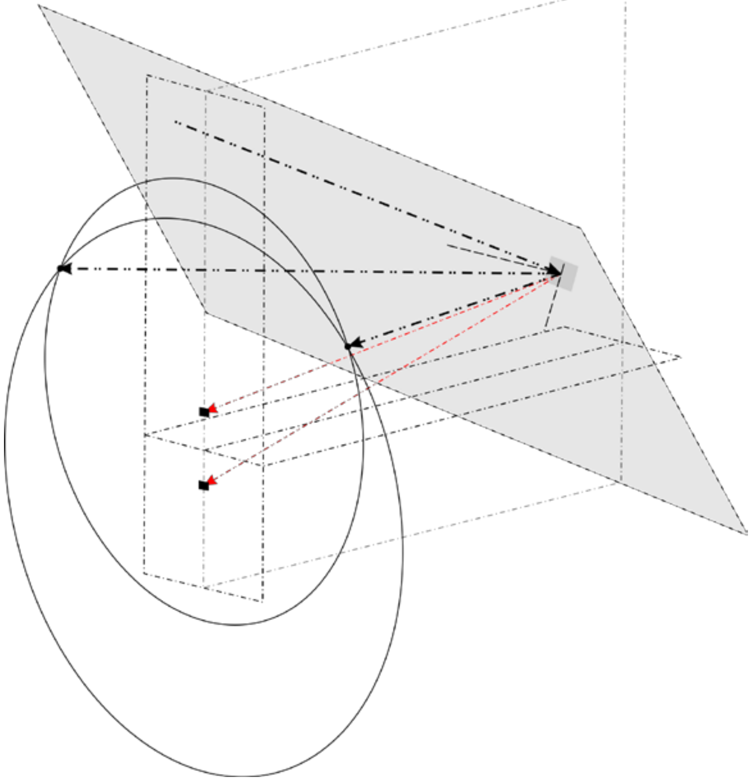


Method

- Determining $k_{m=0}$:
  Two camera viewpoints

General case: Incident light lies in a an arbitrary plane

- The set of possible reflection vectors again lie along the surface of a cone for each viewpoint, but in this case there are two intersections.
- Therefore there is not a unique solution for the direction of the zeroth order vector

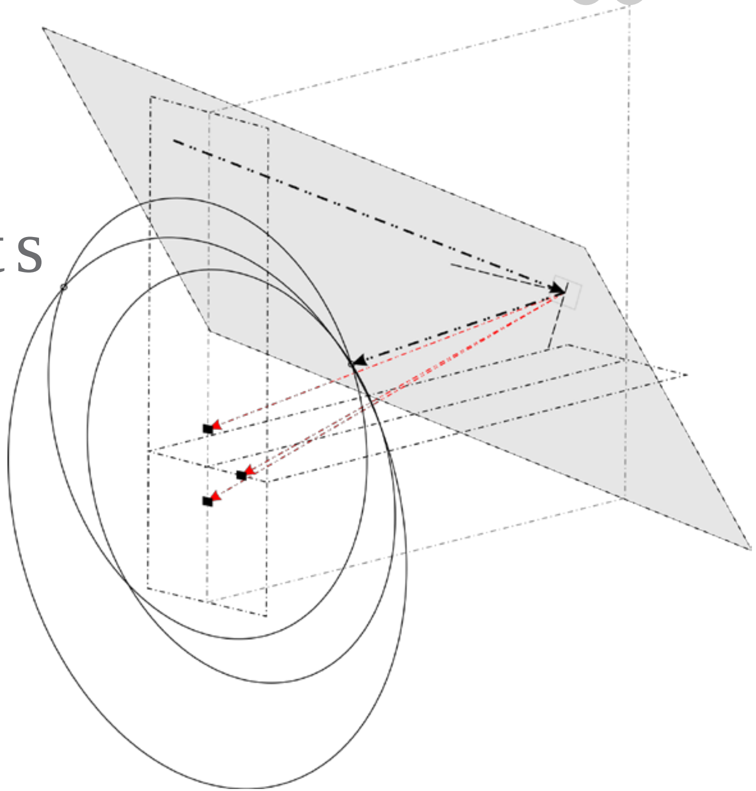


Method

- Determining $k_{m=0}$:
  Three camera viewpoints

General case: Incident light lies in an arbitrary plane

- Adding a third camera viewpoint will constrain the direction of the spectral order to a unique solution (direction)

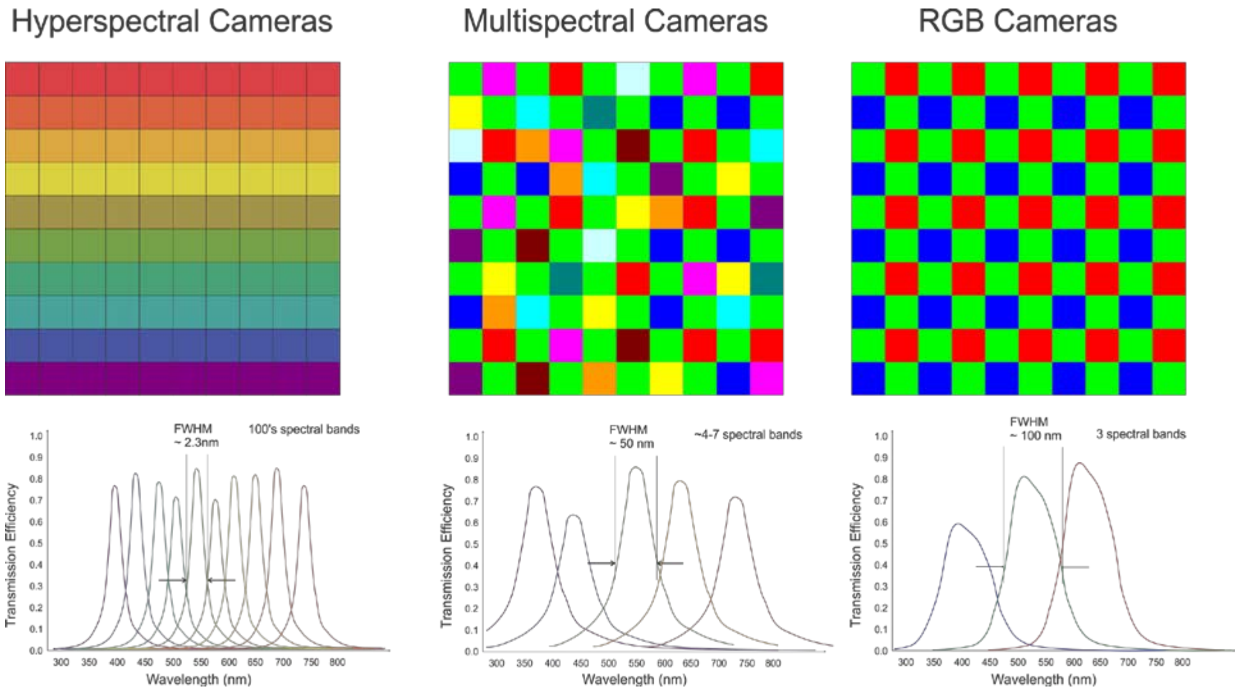


Challenges and Future Work

- Determine Wavelength observed?

Tracking accuracy required ~ 2 mrad

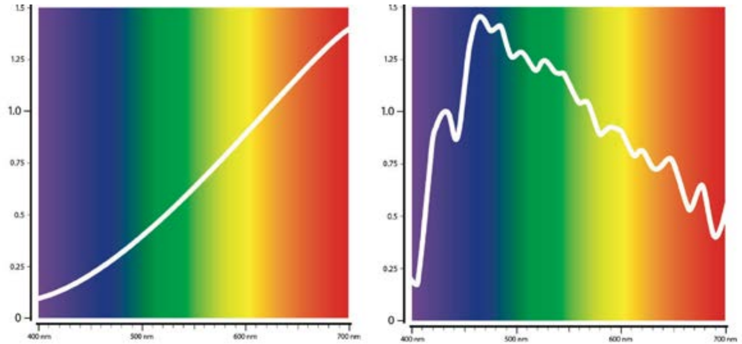
Resolve wavelength Observed: 3 nm



Challenges and Future Work

- Determine Wavelength observed?

RGB →



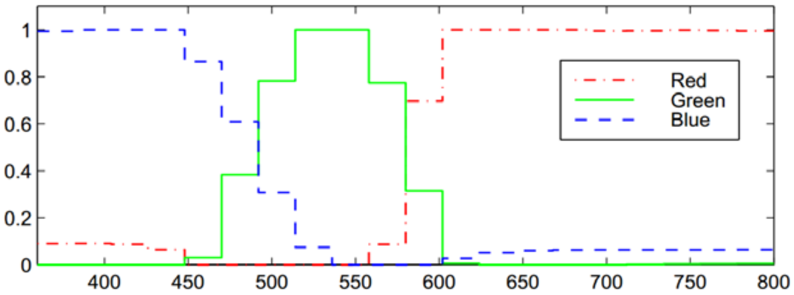
constrain

↓

$$As = c$$

RGB →

$$A \in R^{3\times -n} \text{ and } s \in R^n$$



Challenges and Future Work

- Manufacture of Diffraction Gratings
  - Single Point Diamond Turning
    - Can achieve grating resolution, but expensive
  - Photolithography
    - Cheap, but can't achieve grating resolution
  - Holographic

Conclusion

- The method is possibly a low cost solution for controlling heliostats
- Can control multiple heliostats simultaneously
- Challenges:
  - Resolving a wavelength
  - Manufacture of circular diffraction grating?

Thank You

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Dr W.J. Smit

Centre for Renewable and Sustainable Energy Studies (CRSES)

CONTACT DETAILS:

mclaassen@sun.ac.za
Solar Thermal Energy Research Group (STERG)
Stellenbosch University
South Africa

visit us: concentrating.sun.ac.za