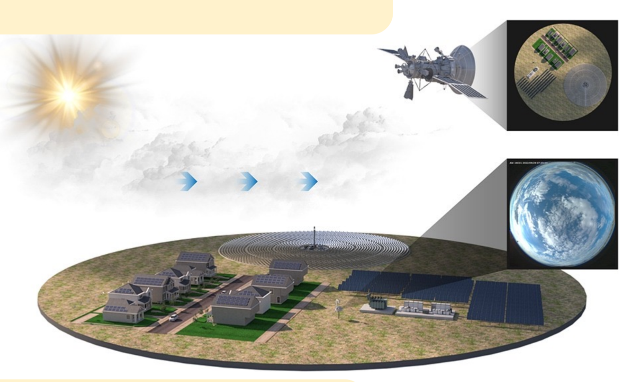
CloudGaze: Landsat Sky Image based Determination of Cloud Motion to Predict Solar Obscuration

Weijith M. Wimalasiri[1*], Isuru N. Gunarathne[1], Sulochana J. Sooriyarachchi[1], Chathura R. De Silva[1]

[1] Department of Computer Science and Engineering, University of Moratuwa, Moratuwa, Sri Lanka,

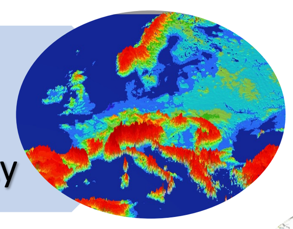
Introduction & Background

Why Solar Forecasting?

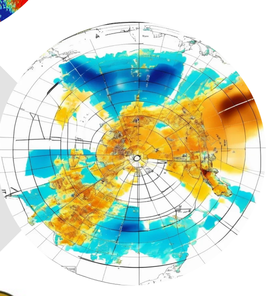


Issues with Exsisting Solutions:

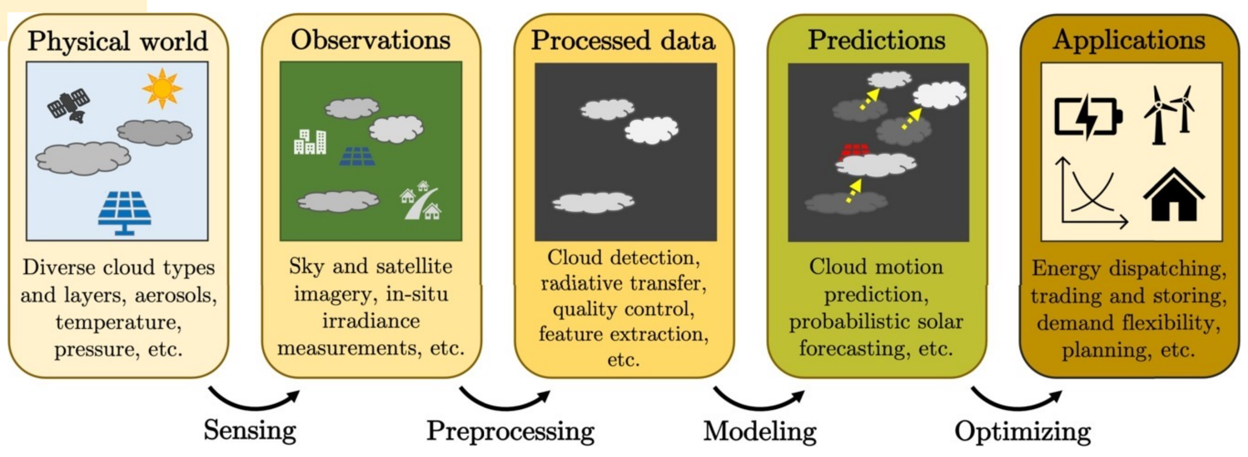
NWPS: Low Spatial and Temporal Resolutions, Computational Complexity



Satelite Based Solar Forecasting: Delay in Data Availability, Limited tracking Cloud Dynamics

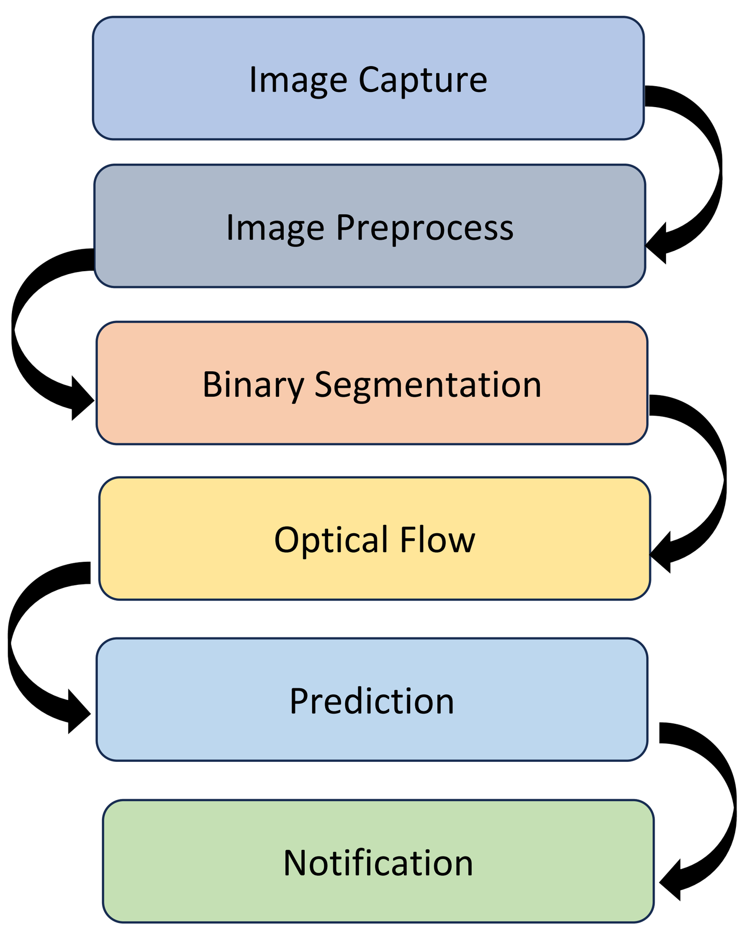


Solution:

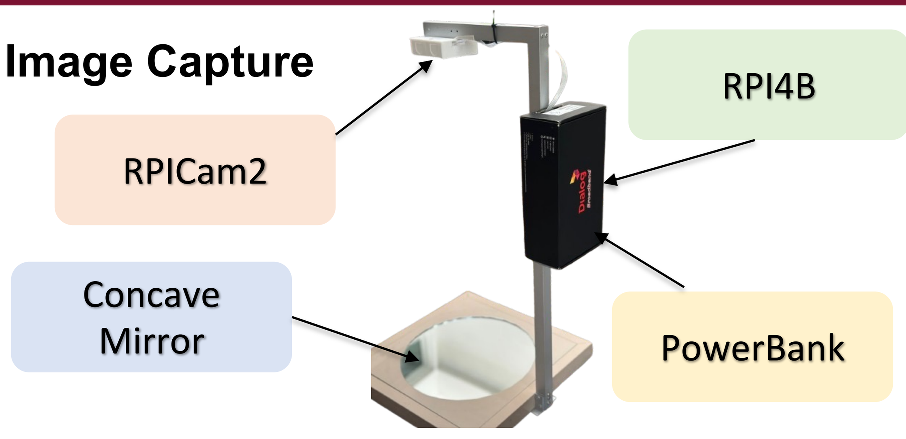


Materials & Methods

➢ **Pipeline**



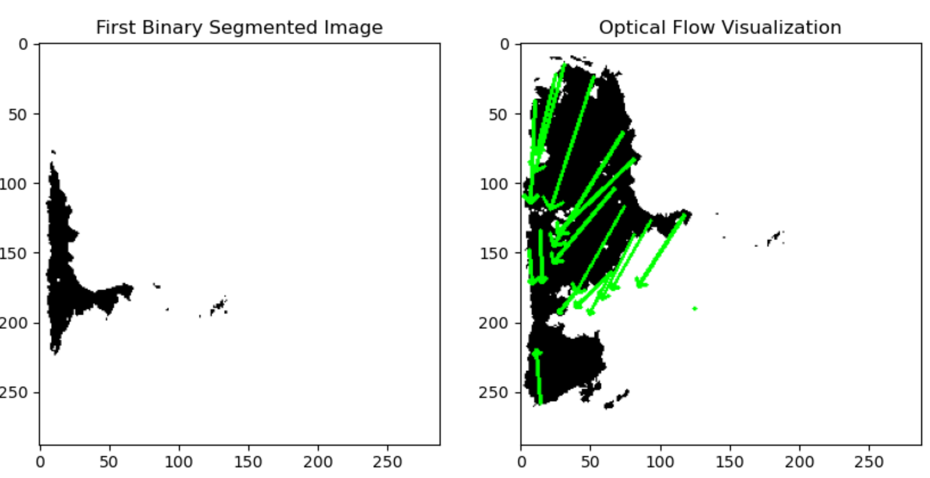
➢ **Image Capture**



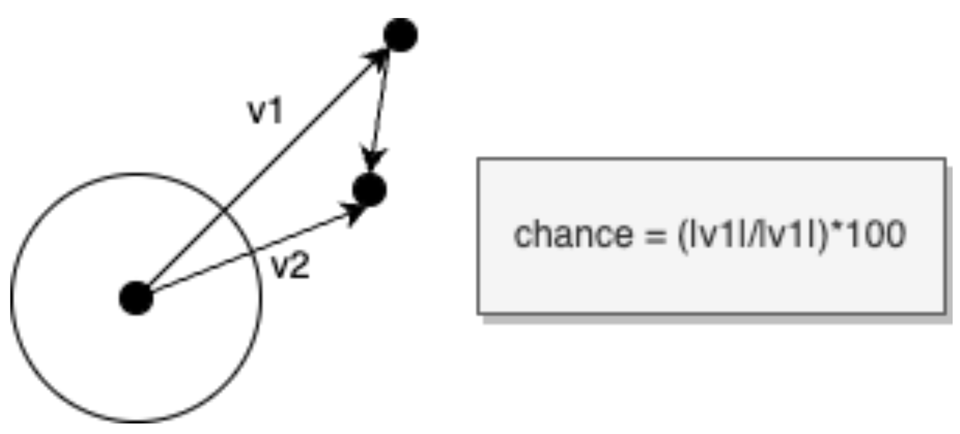
➢ **Binary Segmentation**

Binary Segmented using color thresholds in HSV color space.

➢ **Optical Flow using Lucas-Kanade Algorithm**



➢ **Prediction**



Mathematical Model

Method: Predicting Cloud Movement Using the Kalman Filter

Step 1: Define the State Variables

$$\mathbf{x} = \begin{bmatrix} x \\ v \end{bmatrix}$$

Step 2: State Transition Model

$$\mathbf{x}_{k+1} = \mathbf{A}\mathbf{x}_k + \mathbf{w}_k$$

Where:

- $\mathbf{A} = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix}$: State transition matrix.

Step 3: Measurement Model

Measurements could include:

- Cloud position (z_x): Derived from the largest contour's center.

The measurement model:

$$\mathbf{z}_k = \mathbf{H}\mathbf{x}_k + \mathbf{v}_k$$

Where:

- $\mathbf{H} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$: Maps state to measurements.

Step 4: Kalman Filter Equations

1. Prediction Step:

- Predict state:

$$\hat{\mathbf{x}}_{k+1|k} = \mathbf{A}\hat{\mathbf{x}}_{k|k}$$

- Predict covariance:

$$\mathbf{P}_{k+1|k} = \mathbf{A}\mathbf{P}_{k|k}\mathbf{A}^\top + \mathbf{Q}$$

Where $\mathbf{Q}$ is the process noise covariance.

2. Update Step:

- Compute Kalman Gain:

$$\mathbf{K}_{k+1} = \mathbf{P}_{k+1|k}\mathbf{H}^\top \left(\mathbf{H}\mathbf{P}_{k+1|k}\mathbf{H}^\top + \mathbf{R}\right)^{-1}$$

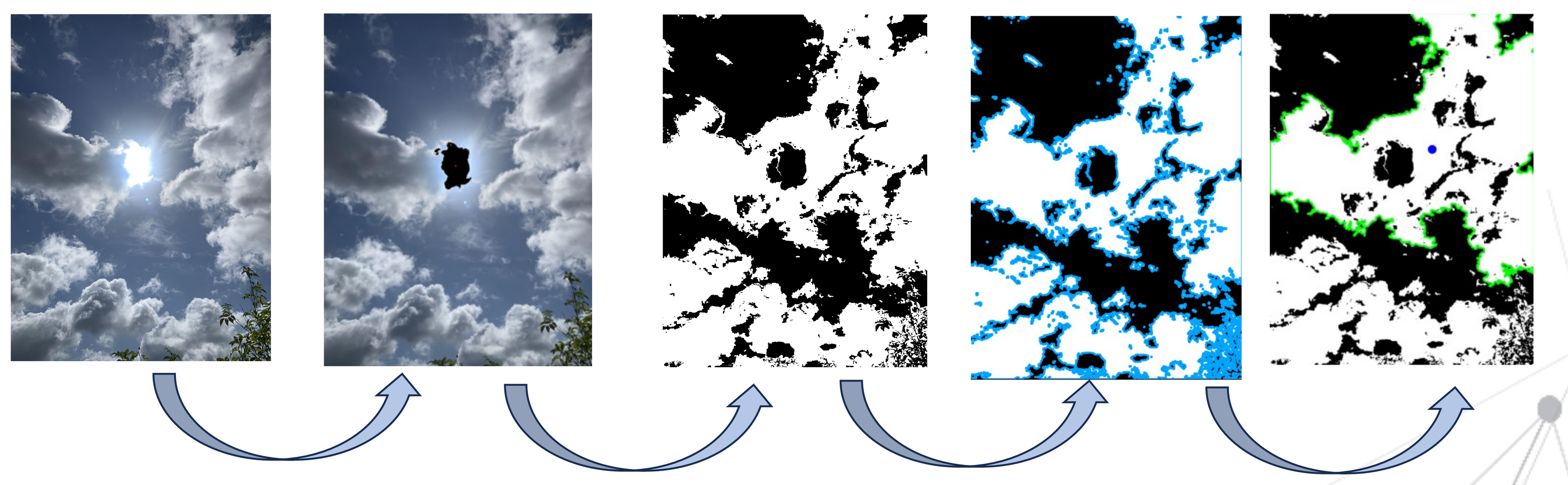
- Update state estimate:

$$\hat{\mathbf{x}}_{k+1|k+1} = \hat{\mathbf{x}}_{k+1|k} + \mathbf{K}_{k+1}\left(\mathbf{z}_{k+1} - \mathbf{H}\hat{\mathbf{x}}_{k+1|k}\right)$$

- Update covariance:

$$\mathbf{P}_{k+1|k+1} = (\mathbf{I} - \mathbf{K}_{k+1}\mathbf{H})\mathbf{P}_{k+1|k}$$

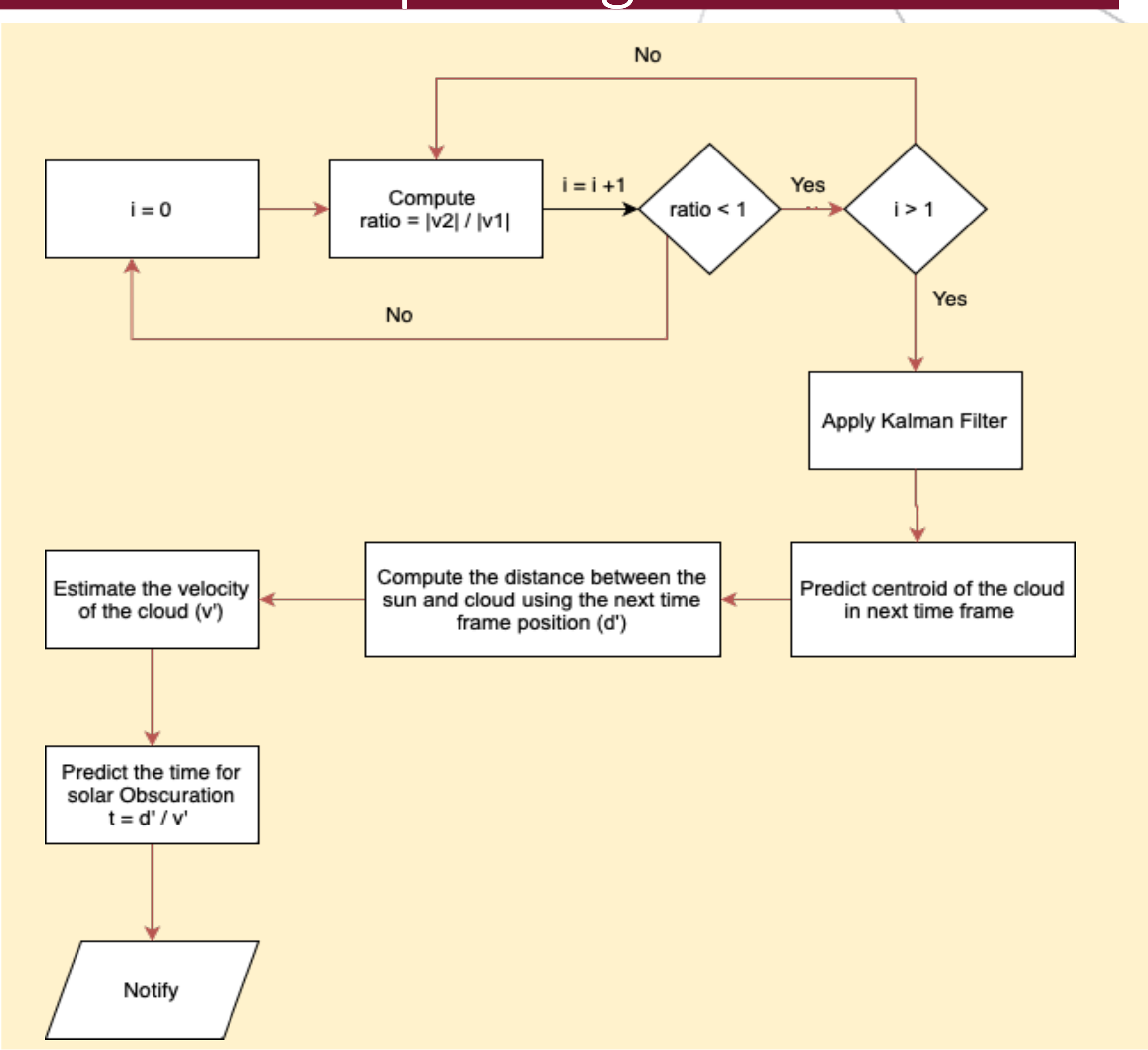
Data & Results



Upon confirmation of solar obscuration and the prediction of the time at which a cloud will cover the sun, an automated email notification is sent to the user or operator using the SMTP protocol.

As frames are captured at 10-second intervals, the most accurate prediction achieved was 40 seconds ahead of the observed timings.

Developed Algorithm



Conclusions

In conclusion, this paper demonstrates an effective approach for detecting cloud motion to predict solar obscuration using Landsat sky images. The combination of binary segmentation, motion estimation through the Lucas-Kanade algorithm, and probabilistic calculations based on cloud movement has shown promising results in predicting cloud cover.

Future Work

➢ Developing the prototype for solar tracking panels

➢ Integrate this to predict the duration of time the cloud will cover the sun.

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References

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