Irradiance Forecasting Using the Local Ensemble Transform Kalman Filter, Satellite Images, and Ground Sensors

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Summary

Motivation: Intra-hour irradiance forecasts are required for integrating PV power into the electrical grid.

Idea: We combine satellite derived irradiance estimates with a cloud motion field in a data assimilation framework to create intra-hour irradiance forecasts.

Results: Combining cloud motion information from numerical weather prediction, optical flow, and satellite images can improve irradiance forecasts by 22% for 45 minute forecasts.

Previous work: satellite images & ground data

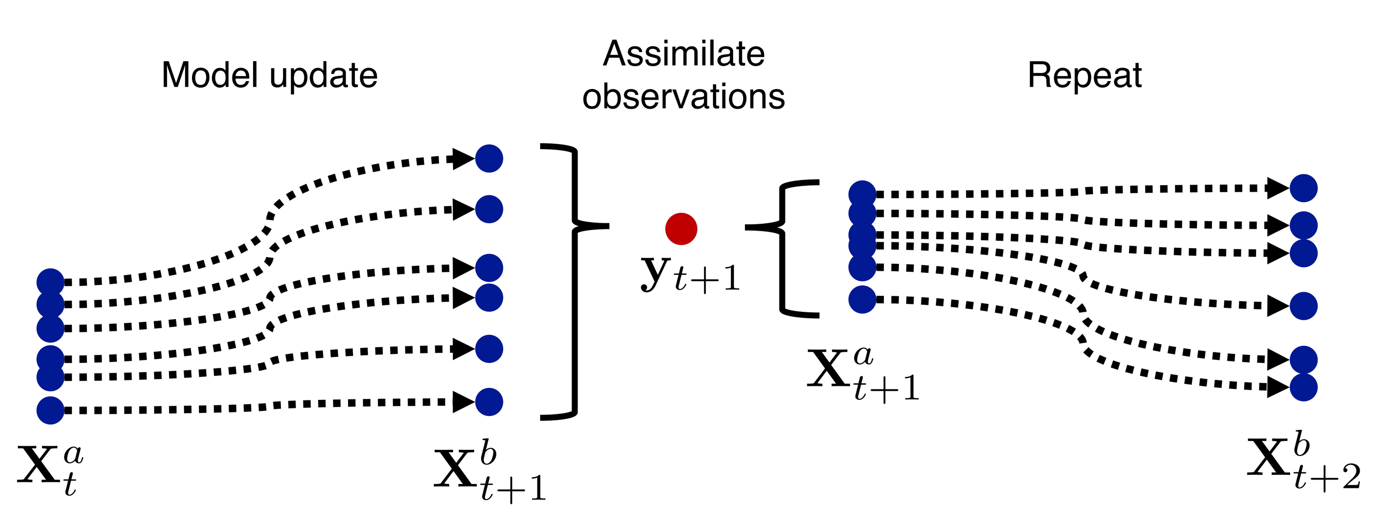
- Normalized irradiance data are derived from two sources: GOES-15 images and ground irradiance measurements from sensors and PV systems.
- Optimal interpolation (OI) combines satellite derived irradiance estimates over a large area with sparse, accurate irradiance measurements.
- OI reduces error by as much as 50% compared to GOES-15 derived estimates, see poster number 752: *Data assimilation of rooftop solar power data to improve satellite derived irradiance nowcasts* by A. T. Lorenzo [1].

Forecasting model

- An advection model, $\frac{\partial \psi}{\partial t} = -\nabla \cdot (\vec{C}\psi)$, is used to create forecasts from the satellite derived normalized irradiance field, ψ.
- This advection model requires a cloud motion field, $\vec{C}$.
- We use a simplified model rather than a full numerical weather model due to lower computational cost and ease of data assimilation.
- The forecasting model requires an initial irradiance estimate and a cloud motion field.

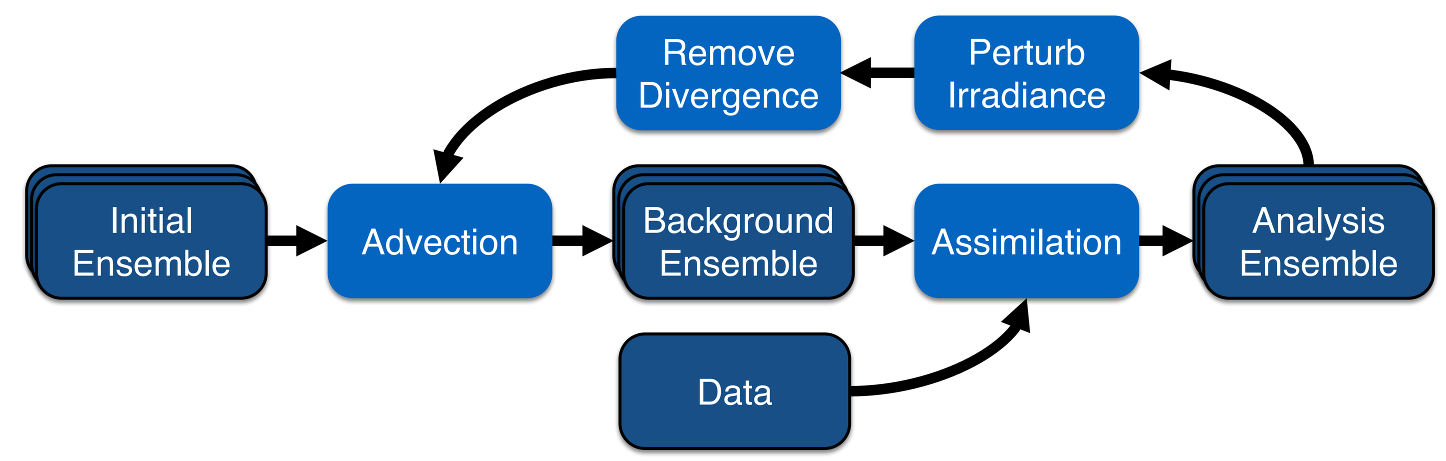
Essentials of the LETKF

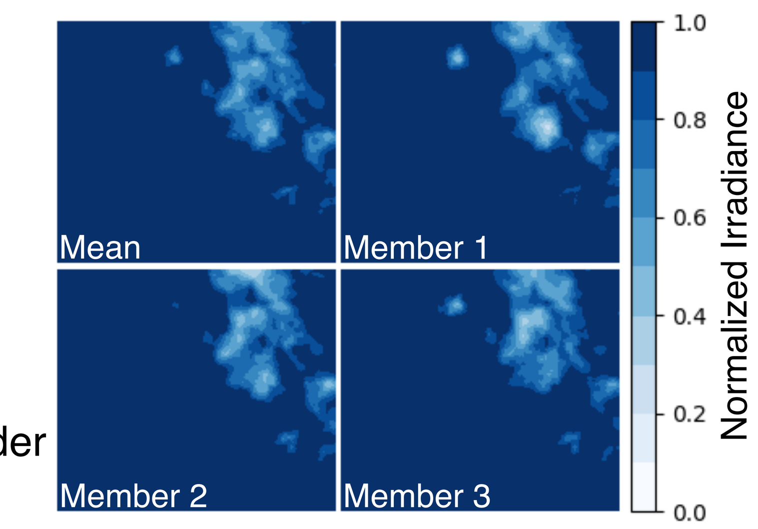
- The ensemble based data assimilation allows us to combine different sources of data and quantify the uncertainty of our forecasts.
- Ensemble spread is used to calculate forecast uncertainty.
- The forecasting model updates ensemble members independently.



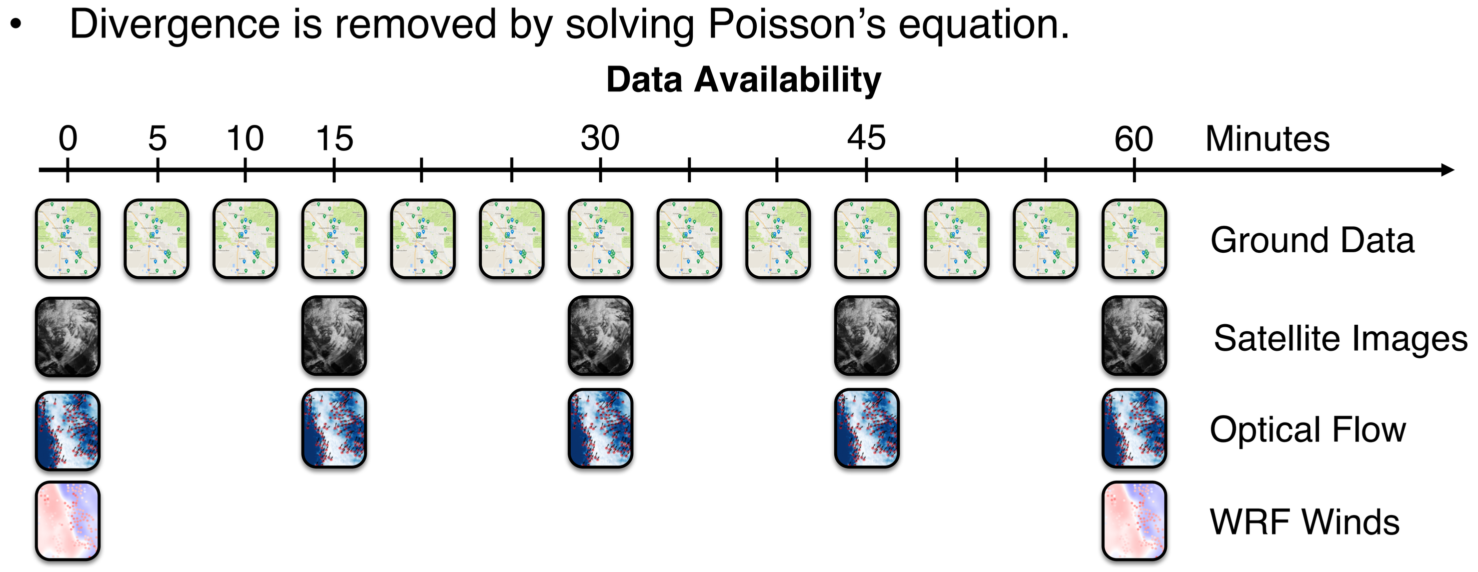
- In the Local Ensemble Transform Kalman Filter (LETKF), assimilation is performed in the ensemble space.
- The ensemble space is a low dimensional space spanned by the ensemble, performing assimilation in this space lowers computational cost.
- Localization is performed by truncating state and observation vectors to those near the assimilation position.

Ensemble forecasting system

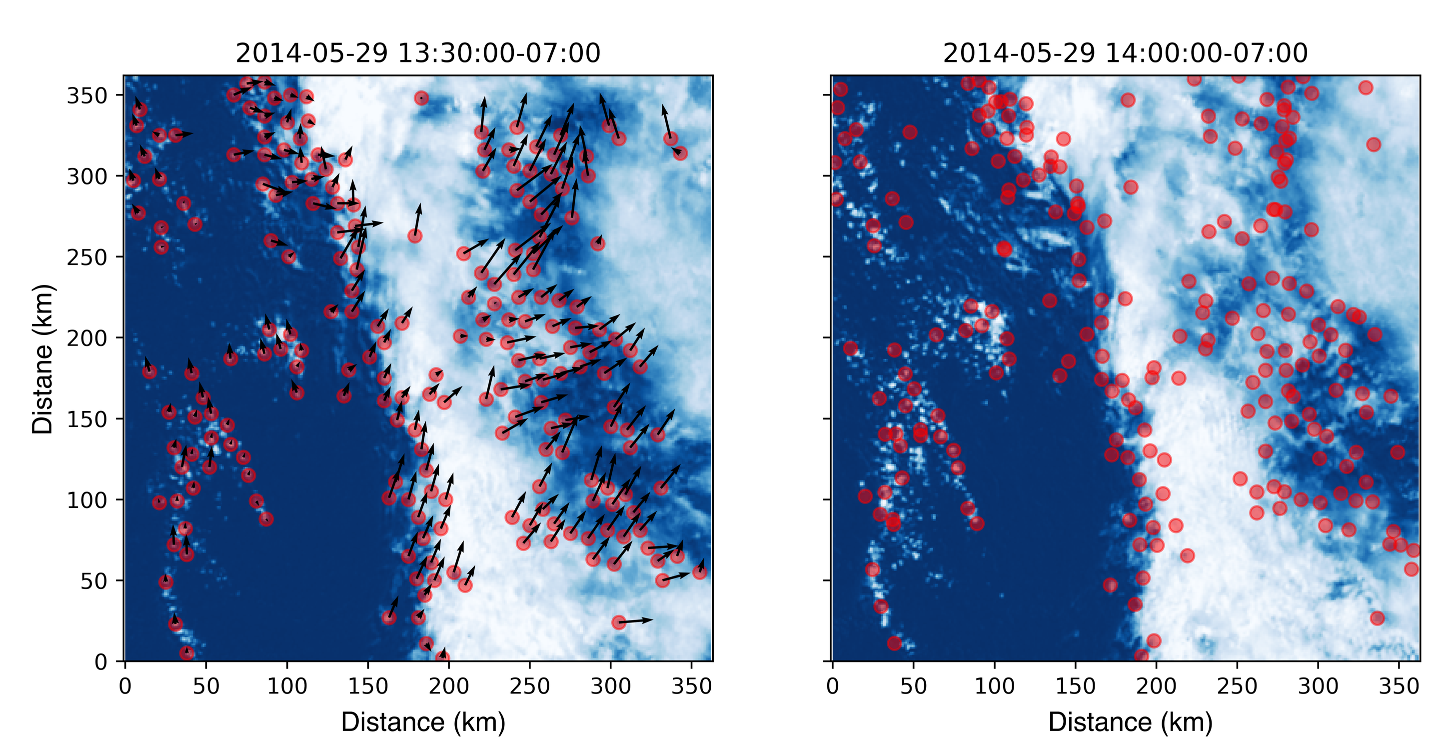




- Ensemble includes irradiance and cloud motion fields.
- The Local Ensemble Transform Kalman Filter (LETKF) is used to reduce computational cost with a large state and small ensemble number [2].
- Irradiance fields are perturbed using a smooth random field targeting clouds in order to increase the ensemble variance.
- Data assimilation introduces additional divergence.
- Divergence is removed by solving Poisson's equation.

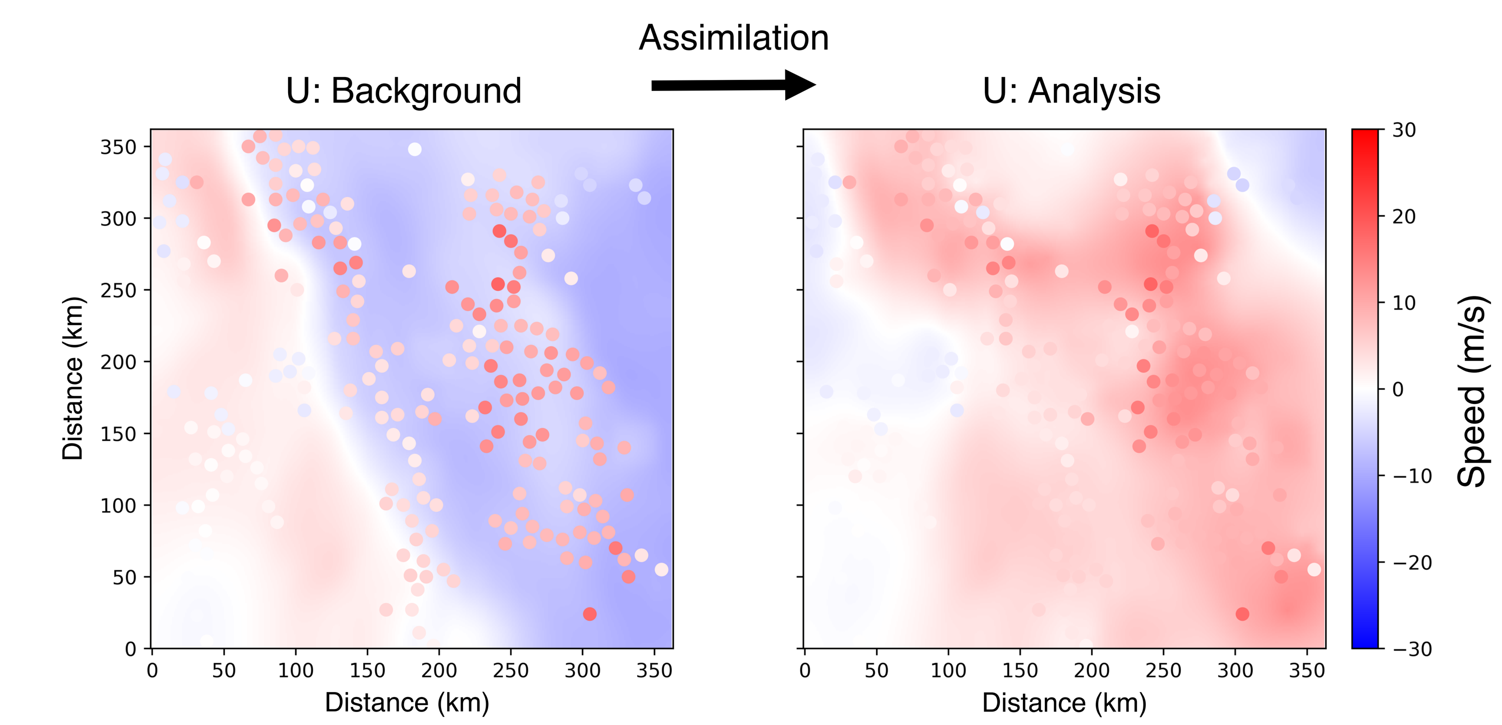


- Ground Data: rooftop solar, custom ground sensors, calibrated sensor.
- Satellite Images: GOES-15 visible band, 1 km^2 resolution.
- Optical Flow: uses current and previous satellite image to calculate flow [3].
- WRF Winds: from Arizona Regional WRF Model forecasts [4].
  - Assume clouds move with same velocity as WRF winds (U, V)
  - U and V taken from the model level with highest relative humidity
  - U and V then interpolated to the advection grid and smoothed

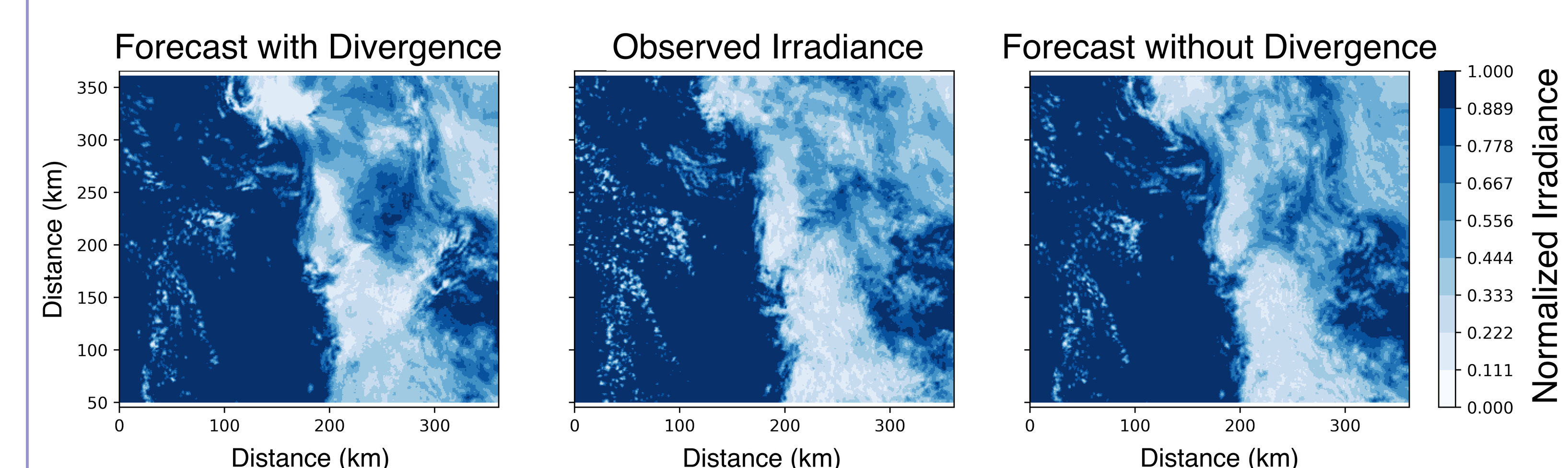


Preliminary results

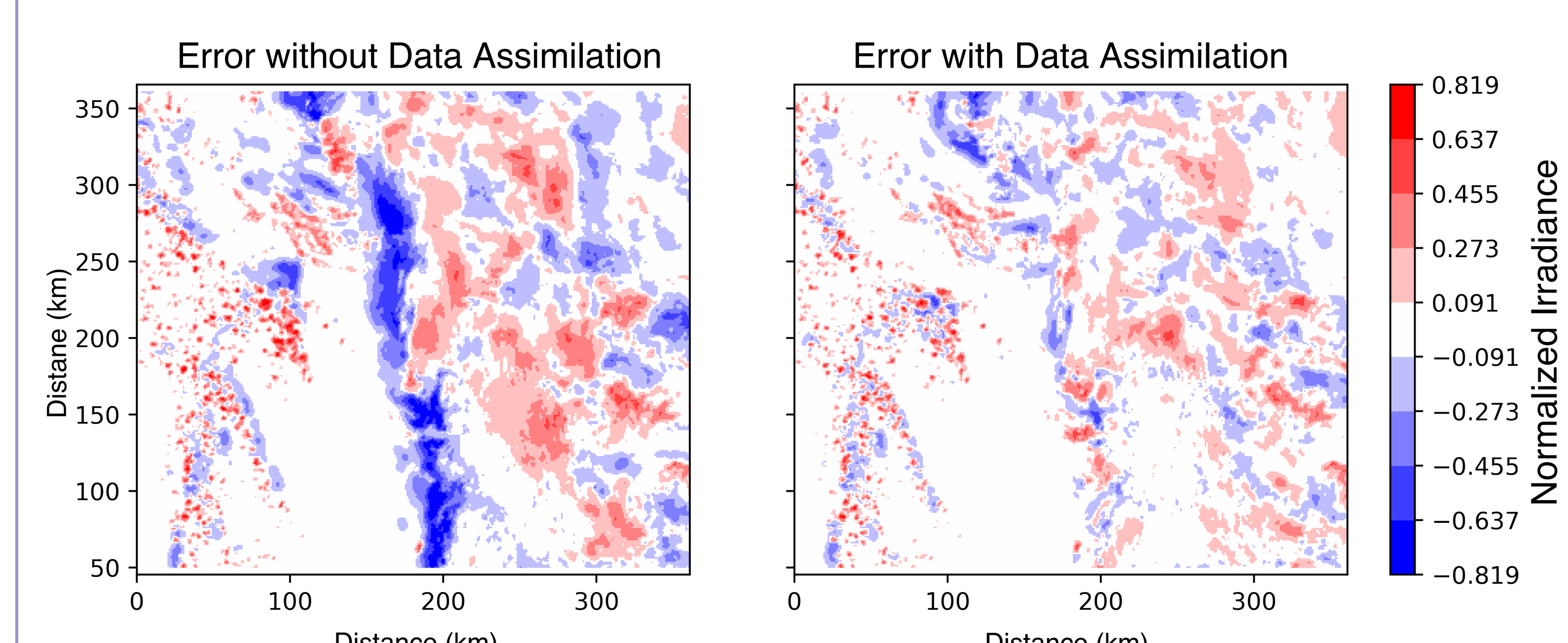
- Assimilation of optical flow vectors (scatter points) improves the accuracy of WRF derived cloud motion fields (Background).



- Examples of forecasts made from cloud motion fields



- RMSE is calculated based on the difference between the forecasted irradiance field and the observed satellite derived irradiance field.
- Error is calculated in a 45 by 60 km box containing all ground sensors.
- Error is reduced by 15%, 20%, and 22% for forecast horizons of 15, 30, and 45 minutes for the day shown here (5/29/2014).



References

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2. Hunt, B., Kostelich, E., Szunyogh, I., 2007. Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter. Physica D: Nonlinear Phenomena 230(1), 112-126.
3. Bradski, G., 2008. The OpenCV library. Dr. Dobb's Journal of Software Tools. https://github.com/opencv
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