Carnegie Mellon University
Electrical & Computer Engineering

Ph.D. Thesis Defense

Computational Imaging For Long-Term Solar Irradiance Forecasting

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Zoom Meeting

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ABSTRACT

The intermittency of solar energy, due to occlusion from cloud cover, is one of the key factors inhibiting its widespread use in commercial, residential, and utility-scale settings. Hence, real-time forecasting of solar irradiance for grid-connected photovoltaic (PV) systems is necessary to mitigate voltage fluctuations, limited time to adjust between energy sources and ultimately, energy disruptions.

Images of the sky provide rich context of cloud patterns around a localized PV site and if these images are captured in sequence, provide a copious amount of data for inference. The stochastic nature of the trajectory of cloud patterns are very difficult to forecast which in-turn makes foresight into when solar energy will decrease, difficult. However, by leveraging learning-based frameworks coupled with other sources of data such as global horizontal irradiance (GHI), we open the world of solar irradiance forecasting to the field of computational imaging to increase forecasting accuracy and present an exciting advance to state-of-the-art methods.

Limitations of traditional solar irradiance forecasting methods using sky images initially stem from limitations of the imaging systems themselves. Existing imagers provide non-uniform spatial resolution of the sky with a higher detail and resolution at the zenith and significantly lower-resolution near the horizon – severely limiting long-term prediction. To that end, we make the following contributions to the theory, hardware, and algorithms of computational imaging for long-term solar irradiance forecasting are made.

Initially, we present a learning-based framework that forecasts future sky image frames with higher precision than previous methods. Our key contribution within this work is the derivation of an optimal warping algorithm that counters the adverse effects of non-uniform spatial resolution present in traditional sky imagers. We show that by warping these images to a new space, the model more accurately determines cloud evolution for longer time horizons.

Secondly, we present a catadioptric imaging system that maintains wide-angle imagery and uniform spatial resolution of the sky without the need of any warping-based algorithms. This catadioptric system optically redistributes pixels without the need of any digital warping which preserves resolution and accurate pixel information. Finally, we present both learning and non-learning based algorithms that exploit the benefit of our catadioptric imaging system which achieves accurate long-term prediction of solar irradiance and sun occlusion by clouds.

Together, these contributions provide a fundamental advance to solar irradiance forecasting using core computational imaging.

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