Short-Term Solar Energy Forecasting Using Wireless Sensor Networks

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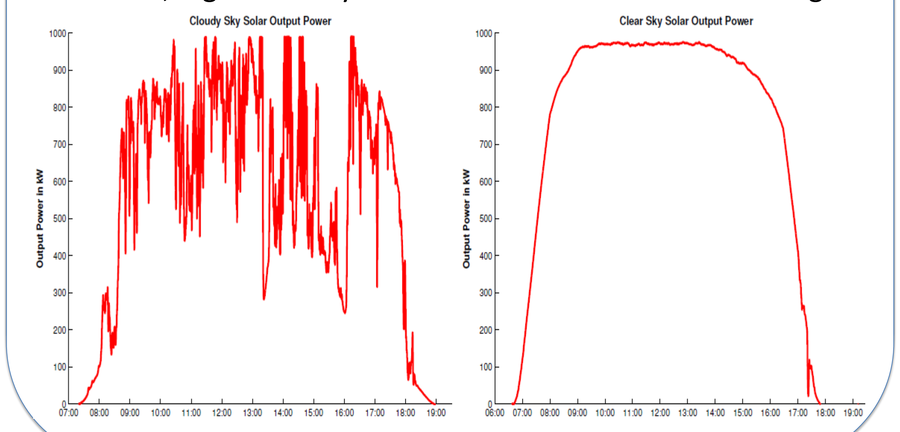
Abstract

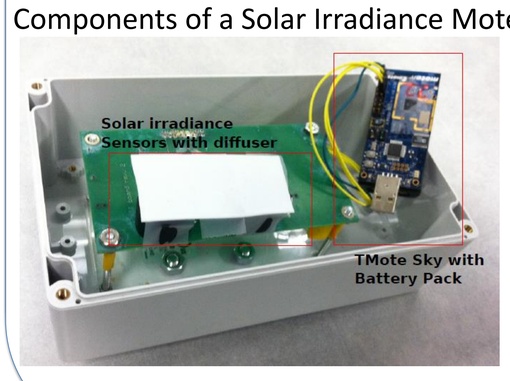
Variability and uncertainty in power output is a major concern and forecasting is, therefore, a top priority. We propose a sensing infrastructure to enable sensing of solar irradiance with application to solar array output forecasting. This poster shows the potential of our prediction system as a low cost, high accuracy tool for short-term solar forecasting.

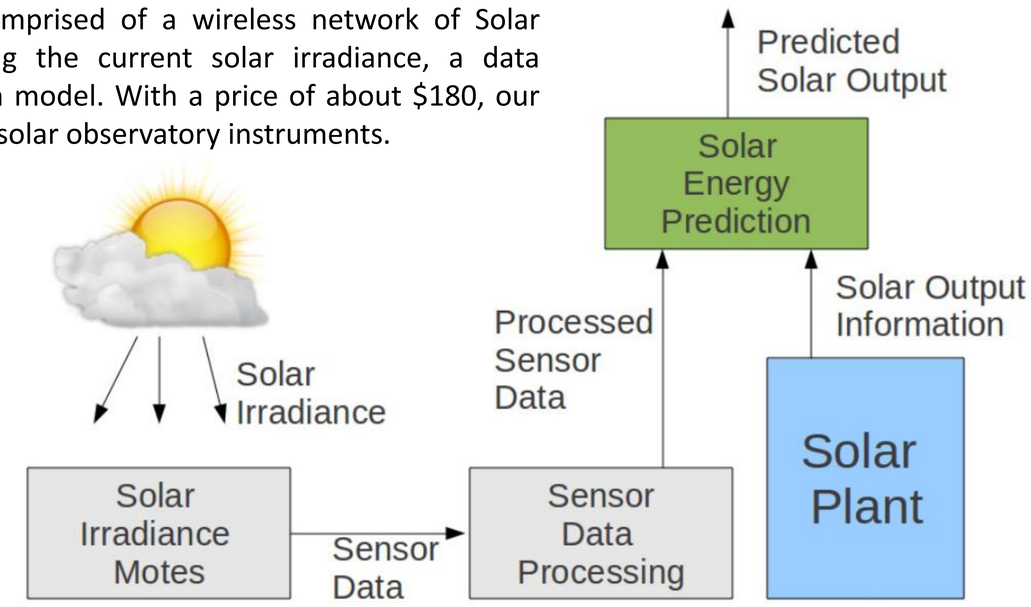


Prediction System Infrastructure

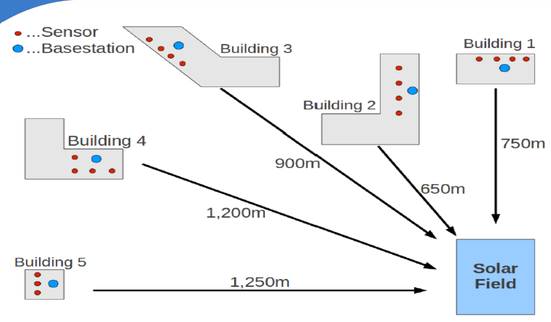
The deployment of our solar prediction system, is located near a 1 MW solar plant. Our prediction system is comprised of a wireless network of Solar Irradiance Motes (SIMs) measuring the current solar irradiance, a data processing system, and a prediction model. With a price of about $180, our SIM cost only a fraction of common solar observatory instruments.

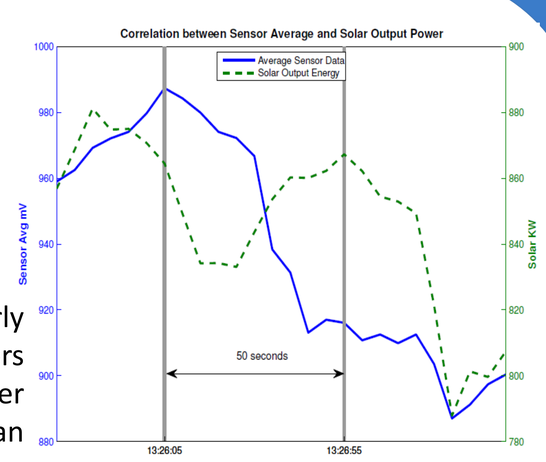
Components of a Solar Irradiance Mote:



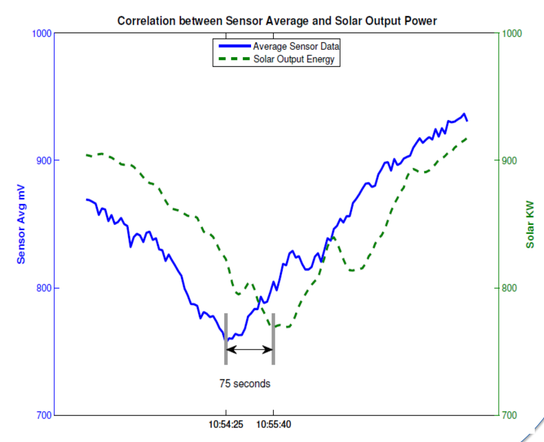


Solar Irradiance Motes





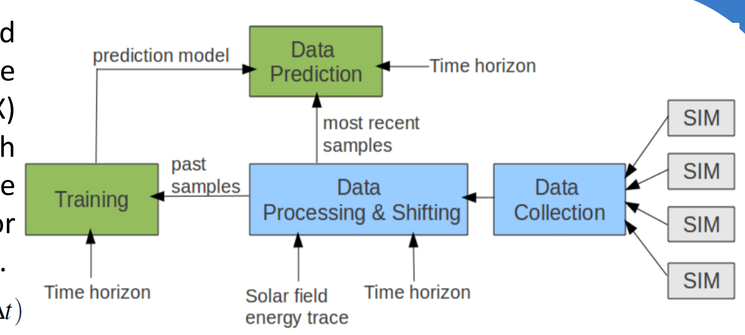
Our sensor deployment functions as an early warning system for approaching clouds. Sensors record a cloud phenomenon 1-2 minutes earlier then the solar field. This gives our system an advantage for output power prediction.

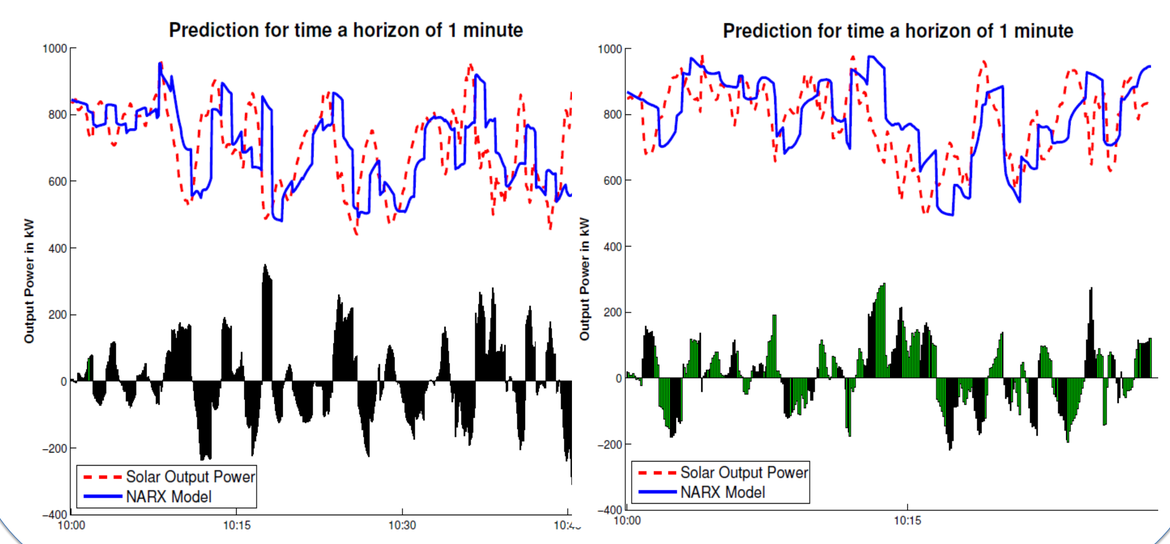


Solar Energy Prediction System

Our prediction model is based on a Nonlinear Autoregressive with External Input (NARX) Neural Network (ANN) which predicts a series of *n* future values based on past sensor and solar plant output values.

$$\hat{y}(t+\Delta t) = f(y(t), y(t-\Delta t), \ldots, y(t-n\Delta t)$$
$$x(t-\Delta t), \ldots, x(t-n\Delta t))$$



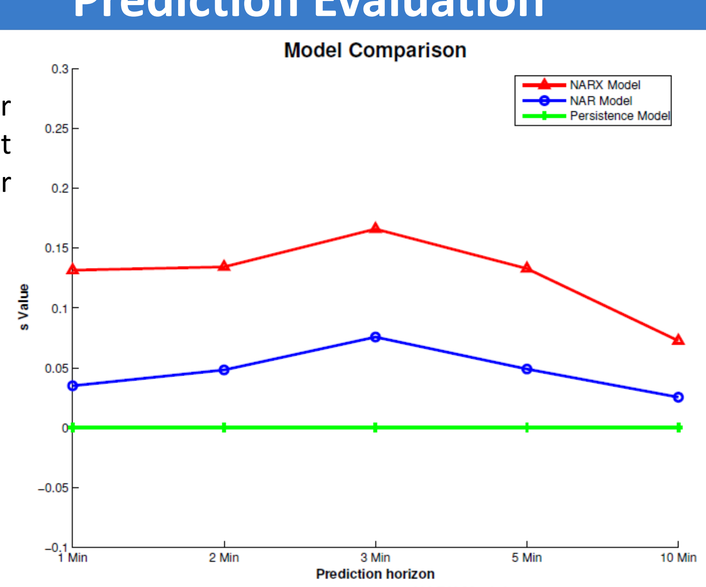


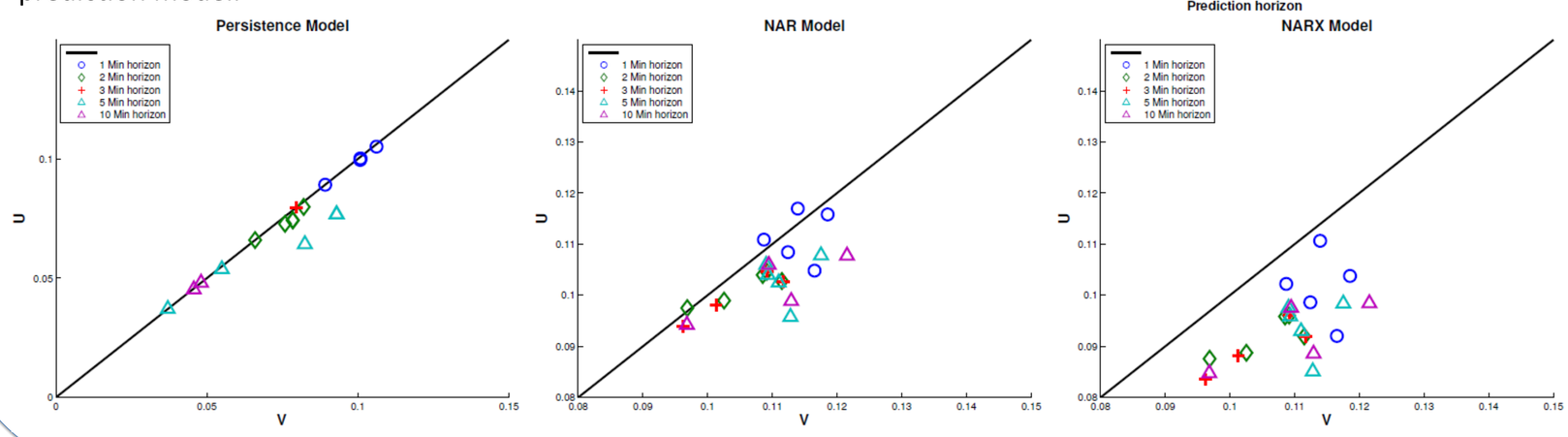
Prediction Evaluation

We compare the prediction results of our NARX ANN to a Nonlinear Autoregressive Neural Network with no external input (NAR) that predicts the solar field output only based on a time series of the solar plant energy trace.

$$\hat{y}(t+\Delta t) = f(y(t), y(t-\Delta t), \ldots, y(t-n\Delta t))$$

For training and valuation data sets we are only considering data with a high variability of more then 100 kW per minute. For practical usage of solar energy, predicting times of high variability caused by open and closed cloud cover is a critical issue. The evaluation results show that our system is able the perform short-term prediction on high variability data 2-3 times better compared to a time series prediction model.





The comparison metric we use involves a clear sky persistence model which predicts the next time step y(t+1) by comparing the measured irradiance to the clear sky irradiance. The clear sky persistence model is based on the data of a clear day without any clouds.

$$P(t+1) = P_{clr}(t+1)\frac{P(t)}{P_{clr}(t)}$$

Solar irradiance at the ground level has a high variability which, mostly depends on the current solar position and the cloud coverage. We use a variability metric so that the diurnal variability is neglected.

$$V = \sqrt{\frac{1}{N}\sum_{t=1}^{N}\left(\frac{P(t)}{P_{clr}(t)} - \frac{P(t-1)}{P_{clr}(t-1)}\right)^2}$$

To take account of the uncertainty, we use a metric which is very similar to the Root Mean Squared Error but a normalization of the error is made in respect to P*clr*(t).

$$U = \sqrt{\frac{1}{N_w}\sum_{t=1}^{N_w}\left(\frac{\hat{P}(t) - P(t)}{P_{clr}(t)}\right)^2}$$

By determining the uncertainty U and the variability V we can calculate the metric s to evaluate the quality of forecast models.

$$s = \frac{V-U}{V}$$

A value of s=1 means the prediction is perfect, a value of s=0 means the variability dominates the forecast.

References:
S. Achleitner, T. Liu, A. Kamthe, A. Cerpa,. Solar Energy Forecasting Using Wireless Sensor Networks, In Review for ACM SenSys 2013.
R. Marquez and C. F. M. Coimbra. Proposed metric for evaluation of solar forecasting models. Solar Energy Engineering, 135(1):188–197, 2013.
R. Marquez and C. F. M. Coimbra. A novel metric for evaluation of solar forecasting models. *ASME Journal of Solar Energy Engineering*, 2012

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