X SICEL 2021

Transición energética en la 4ta revolución industrial

Universidad Tecnológica de Pereira

Universidad Nacional de Colombia

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Estimation of global solar radiation using NNARX neural network based on UV index

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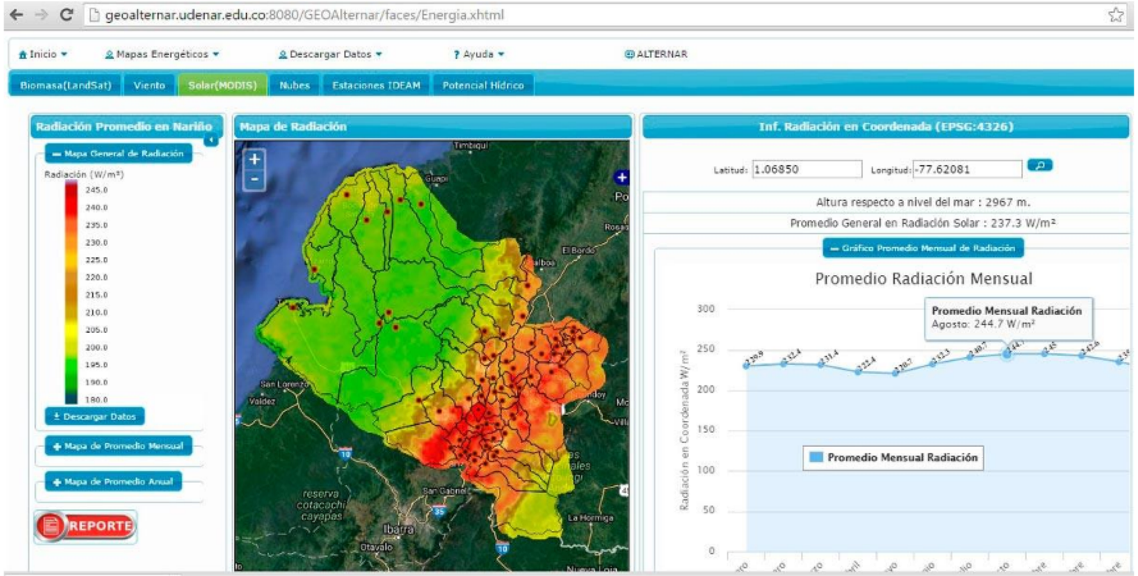
I. Motivation

Celsia (9,9 MW) – Cali-Colombia

Rural PV system – El Gran Sábalo – Nariño (2014)

- The sun energetic potential depends of the place conditions (geographical, climates).
- Studies about measuring the irradiance are carried out before investments, in order to sizing the power equipment.

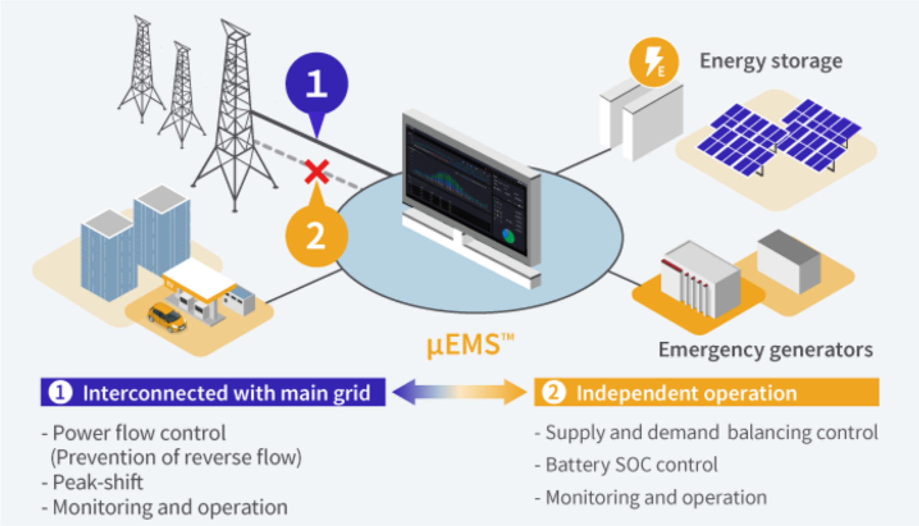
I. Motivation



Website to consulate meteorological data of wind speed, solar radiation, biomass, hydric flows 2015.

- **Databases of renewable resources** are necessary to boost the **integration of renewable energies** to the power system.
- **Estimation of meteorological variables** is a **complex task** that requires the use of artificial intelligence or other advanced techniques.

I. Motivation



Microgrid solution for power system stability and economy - Toshiba

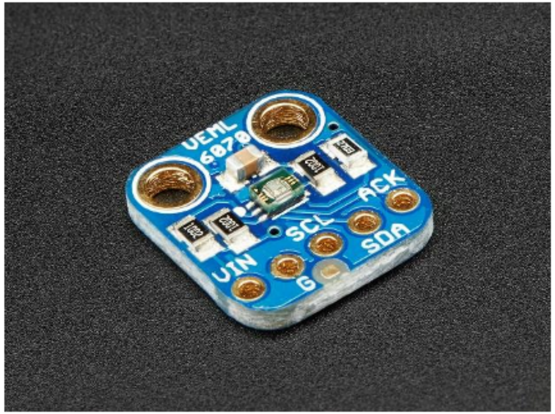
- Irradiance estimation is necessary to estimate PV production. This estimation is used for programming microgrid operation.

- PV production estimation is useful to take decisions (active power dispatch, charge and discharge scheduling for batteries).

I. Motivation

SP110 Pyranometer
Cost: >300 USD
Uncertainty: 5%

LP02-LI19 Pyranometer
Cost: >300 USD
Uncertainty: <1.8%



VEML6070 UV Index
Uncertainty: ?

There are many instruments that allow to measure irradiance

- Pyranometer, sun photometer (global radiation 400 to 1100 nm)
- UV Index sensor (200 to 370 nm)

II. Literature review

- Cruz-Colon developed a **low cost irradiance sensor** that describes the electric behaviour from a **photovoltaic module**, using an exponential model applied to a solar cell. Error 1,11%.

- Al Azuri employed square **linear regression** to estimate an empirical function between **UV and Irradiance** [2].

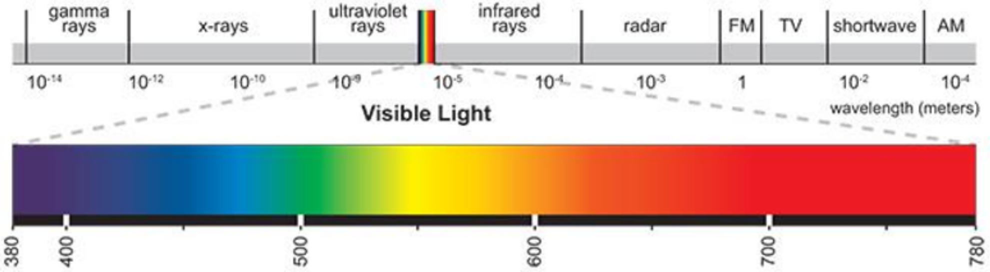
- Elhadidy found a **ratio of UV and total horizontal radiation** equal **to 3.45%** [3].

- Sayago, Ruiz and Moreno use **neural networks models** capable of estimating solar radiation through meteorological variables as **temperature, relative humidity, wind speed and rainfall. Some techniques: Wavelets with RNN, Long Short-term memory (LSTM), Feed-Forward Neural Network (FFNN). R^2 = 0.98** [4], [5], [6].

III. Theoretical aspects

Measurement Equipment

- DAVIS Vantage Pro 2.0 Meteorological Station
- Global Irradiance (sensor 6450, 400 – 1100 nm)
- UV radiation (sensor 6490, 280 – 360 nm)



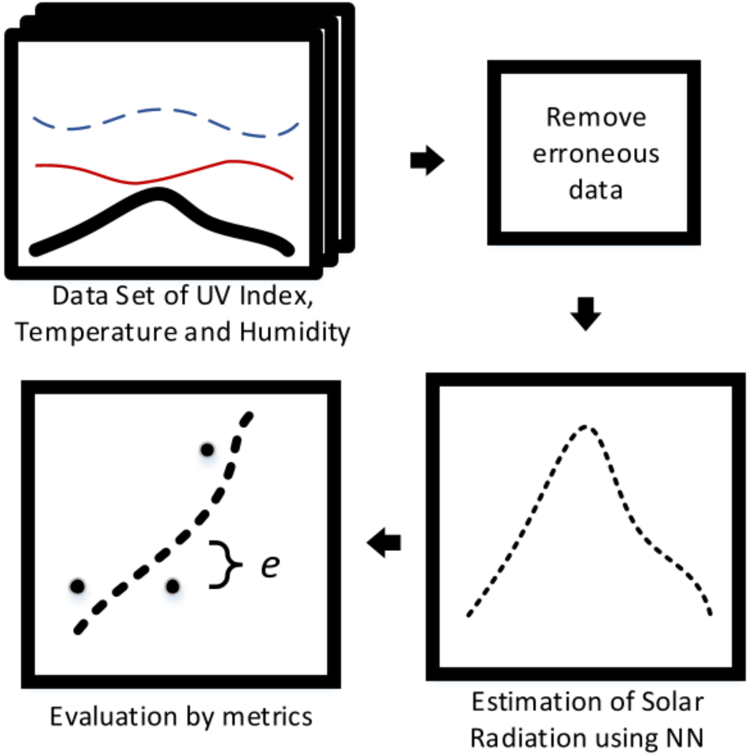
UV Radiation
sensor 6490
280 – 360 nm

Global Irradiance
sensor 6450
400 – 1100 nm

IV. Methodology

Data Recollection

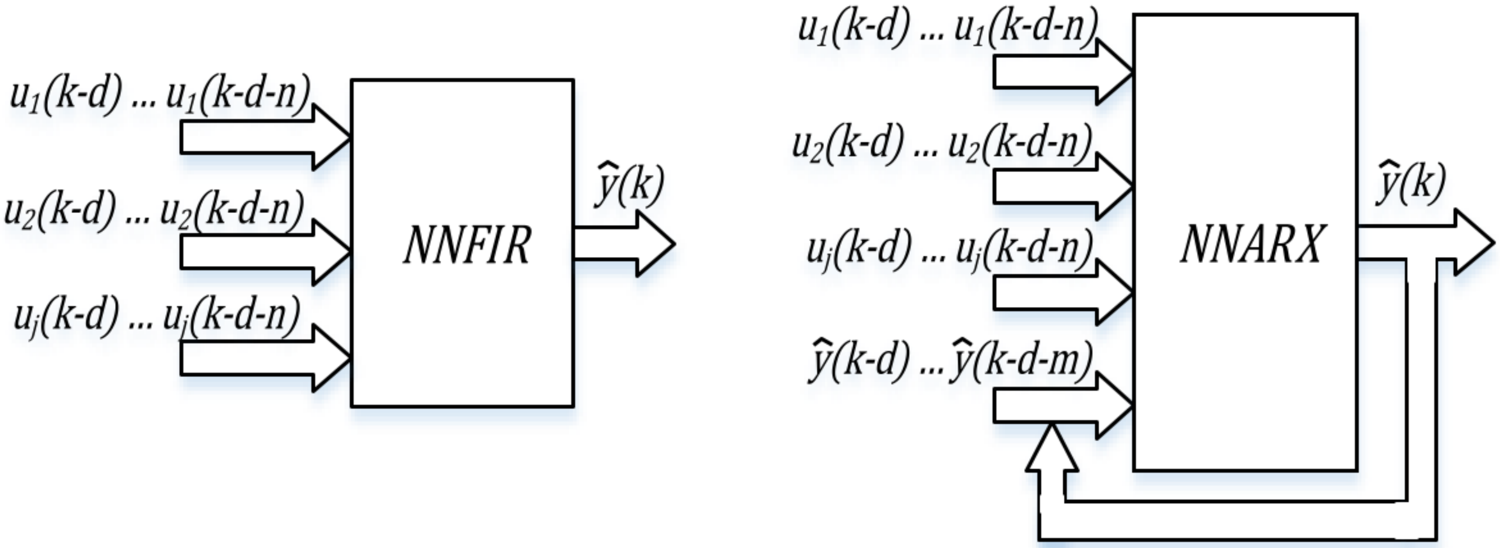
- **Location:** 1.20851008, -77.27805080 (Pasto, Colombia)
- **Data set:** A database with 305,000 data from 2013 – 2019.
- **Sampling time:** 5 minutes



Model based on ANN

Neural Network Finite Impulse Response **(NNFIR)**

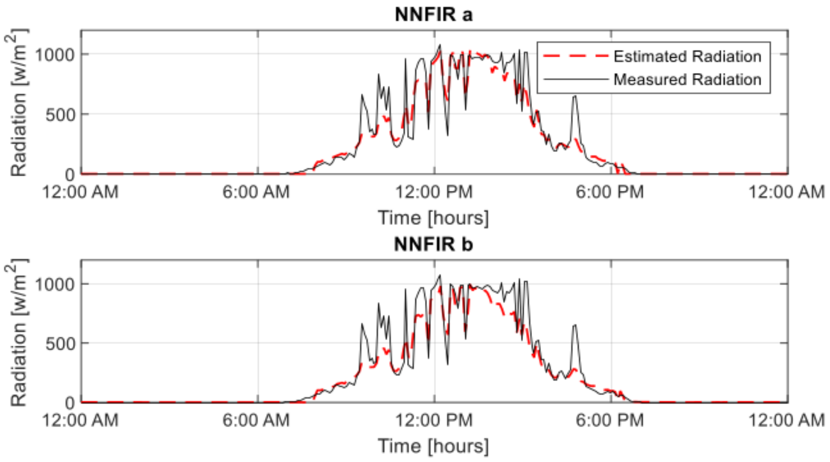
Neural Network Auto Regressive with External Input **(NNARX)**



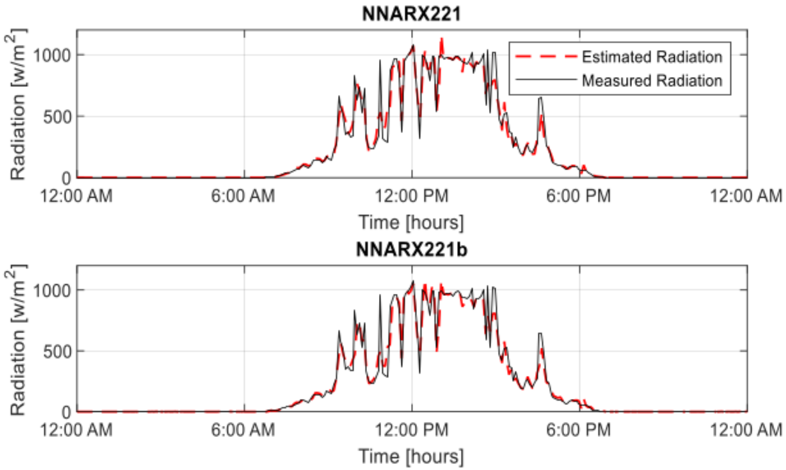
Test Models

Model	Mathematical definition
NNFIRa	$R(k) = f\big(UV(k)\big)$
NNFIRb	$R(k) = f\big(UV(k), T(k)\big)$
NNARX111a	$R(k) = f\big(R(k-1), UV(k), UV(k-1)\big)$
NNARX111b	$R(k) = f\big(R(k-1), UV(k), UV(k-1), T(k), T(k-1)\big)$
NNARX211a	$R(k) = f\big(R(k-1), R(k-2), UV(k), UV(k-1)\big)$
NNARX211b	$R(k) = f(R(k-1), R(k-2), UV(k), UV(k-1), T(k), T(k-1))$
NNARX221a	$R(k) = f(R(k-1), R(k-2), UV(k), UV(k-1), UV(k-2))$
NNARX221b	$R(k) = f(R(k-1), R(k-2), UV(k), UV(k-1), UV(k-2), T(k), T(k-1), T(k-2))$

V. Results



Solar radiation estimation using NNFIR1 and NNFIR2 structures.

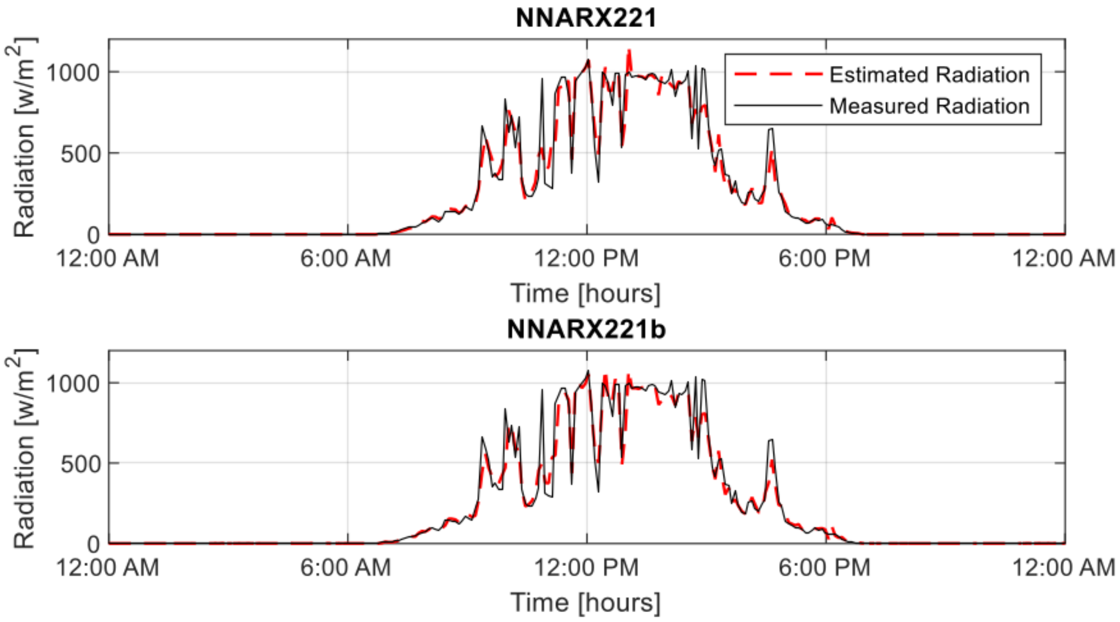


Solar radiation estimation using NNARX211a and NNARX211b structures.

NNFIRa and NNFIRb have an estimation error of $\pm\, 38.80\,\frac{w}{m^2}$ and $\pm 42.71\,\frac{w}{m^2}$, respectively.

NNARX221a and NNARX221b reduce the error between $\pm\, 26.27\,\frac{w}{m^2}$ and $\pm 24.53\,\frac{w}{m^2}$.

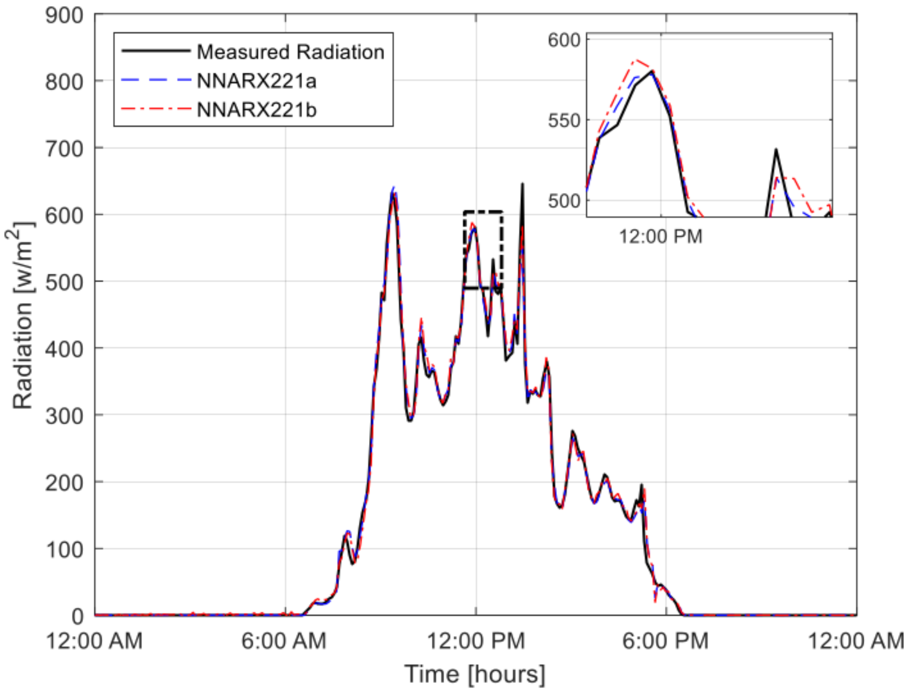
V. Results



Solar radiation estimation using NNARX221a and NNARX221b structures.

These kind of structures reduce the error between $\pm\, 26.27\,\frac{w}{m^2}$ and $\pm 24.53\,\frac{w}{m^2}$.

V. Results



Solar radiation estimation using NNARX221a and NNARX221b structures.

These kind of structures reduce the error between $\pm\,26.27\,\frac{w}{m^2}$ and $\pm 24.53\,\frac{w}{m^2}$.

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V. Results

NUMERICAL RESULTS OF ESTIMATION MODELS FOR ALL VALIDATION DATA SETS

Structure/Metric	RMSE	MAE	R^2
NNFIRa	87.855	42.526	0.92294
NNFIRb	86.863	41.301	0.92489
NNARX111a	55.835	18.624	0.96805
NNARX111b	55.532	18.643	0.96838
NNARX211a	55.066	18.314	0.96895
NNARX211b	54.809	18.347	0.96925
NNARX221a	54.710	**17.905**	0.96927
NNARX221b	**54.321**	18.069	**0.96971**

VI. Conclusions

The **best performance** corresponds to a **NNARX221** structure that makes a prediction using two past instants that include UV index and its own outputs. It shows a determination coefficient **(R^2) of 0.9697**, a **RMSE equal to 54.32** and a **MAE of 18.06 w/m²**.

The **contribution of** the auxiliary variables **(temperature and humidity**) in the estimation of solar radiation **is not relevant.** The best estimations are made only using **past and present** instants of solar **radiation and UV index.** This is particularly important since **UV index measurement equipment** usually has **a lower cost** than global radiation ones.

Can be interesting, **test other estimation techniques** based on artificial intelligence as **random forests, decision trees, short-term memories**, among others. **This methodology** and models **can be generalized** to be used with other variables or times-series where a **low-cost sensor support the measurement** of a variable.

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Questions ?

Thank you!

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