PREDIÇÃO DE SÉRIES TEMPORAIS DO RESERVATÓRIO DA USINA HIDRELÉTRICA DE SOBRADINHO ATRAVÉS DE REDES NEURAIS RECORRENTES NARX

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Introduction

- Brazil's electricity generation system is a large hydro-thermo-eolic system;
- The National Interconnected System (SIN) consists of the interconnection of the electrical systems;
- The Brazilian Electricity Sector (SEB) consists of three fundamental pillars: expansion planning, operation planning and scheduling, and the accounting and settlement process of energy transactions in the short-term market (Souza et al, 2014);
- Currently, the National Electric System Operator (ONS) uses the NEWAVE model to carry out the medium and long-term planning of the electric system (Souza et al, 2014);
- The development of methodologies to assist both prediction of reservoir level and prediction of a plant's affluent flows is very important, given the importance of determining the volume of water available for electricity generation.
Introduction

- Forecasting future information is a very complex but necessary task in many sectors of the economy;
- The prediction of time series consists of defining the next point in a series of data, from a historical memory of data previously occurred in a given context, through non-linear models;
- In this context, Machine Learning, through the Artificial Neural Networks (RNA), becomes a great ally in the studies referring to reservoir data;
- RNAs are tools that compute data in a manner similar to that performed by networks of biological neurons (Haykin, 2009).
Introduction

- These systems offer an alternative in solving complex problems because they are able to learn from examples, deal with incomplete data, deal with non-linear problems, and these, once trained, can carry out predictions and generalizations almost instantaneously;
- A new paradigm of neural network design has been proposed under the name of Automatic Machine Learning (AutoML), where the idea is to solve problems without human intervention (Thornton et al, 2012);
- AutoML has been applied in this work to find the hyperparameters automatically;
- In this sense, this work aims to implement and compare the performance of the neural networks FTDNN (Focused Time Delay Neural Network) and NARX (Nonlinear AutoRegressive model with eXogenous inputs) in the prediction of the time series of useful volumes and natural flows related to the Hydroelectric Power Plant Sobradinho.
Dynamic Neural Networks

- Dynamic artificial neural networks are extensions of the MLP network (Multi Layer Perceptron) capable of modeling the dynamics of a process, from a time series (Souza et al, 2014);
- An MLP network can be transformed into a dynamic network by the inclusion of time delays or feedback loops (Souza et al, 2014);
- We call the FTDNN (Focused Time Delay Neural Network) the dynamic neural network built with the inclusion of input delay (Takens, 1981):
  - $x(n)$ is the sample of the time series in time $n$,
  - $d_e$ is called the embedding dimension and $\tau$ is called the embedding delay,
Recurrent Neural Networks (NARX)

- It is possible to represent a non-linear discrete time system through several models, among them we have the NARX (Nonlinear AutoRegressive model with eXogenous inputs) models;
- This model uses a feedback loop to model the process dynamics and is mathematically represented by:

\[ y(n + 1) = f[y(n), ..., y(n - d_y + 1); u(n), ..., u(n - d_u + 1)] \]

where \( y(n) \in \mathbb{R} \) and \( u(n) \in \mathbb{R} \) represent, respectively, the input and output of the model at time \( n \), whereas \( d_y \geq 1 \) and \( d_u \geq 1 \), where \( d_u \leq d_y \), are called the immersion dimension and context dimension, respectively (Chen, 2013).
Multi-step ahead Prediction (MPA)

- When we are interested in a long-term prediction, we use a multi-step ahead prediction (MPA):
  - Recursive prediction
  - More complex
  - Prediction tends to infinity becomes a dynamic modeling task
  - Feedback of prediction errors
Metodology

- The algorithms of the FTDNN and NARX models were implemented using MATLAB 2015a software;
- Two (2) time series were used for the Sobradinho HPP reservoir, located in the municipality of Sobradinho and Casa Nova in the state of Bahia:
  - Useful volume: 225 monthly records from 1999-2017;
Metodology

- Each data set was divided into one set for training (85%) and one for validation (15%);
- Due to the complexity of the time series prediction problem, it is not possible to construct a global prediction algorithm;
- We used a heuristic search to find the hyperparameters (Menezes, 2012);
- To perform the search, we define the search interval for each of the hyperparameters.
- To evaluate the best neural model, we used the Normalized Mean-Squared Error (NMSE) index:

\[
NMSE = \frac{\sum_{n=1}^{N}(x(n) - \hat{x}(n))^2}{\sum_{n=1}^{N}(x(n) - \bar{x}(n))^2}
\]
The Cao method was used to estimate the best values for the immersion dimension for each series.
Metodology

- Nonlinear autocorrelation was used to estimate the best values for the immersion delay for each series.
Search algorithm and ranges

**Parâmetros** | **Intervalo de busca**
--- | ---
Taxa aprendizagem | 0,1 - 0,3
Número de épocas | 50 - 300
Dimensão imersão | 2 - 12
Atraso de imersão | 1 - 6
Dimensão de contexto | 2 - 12
Neuônios na 1ª camada | 4 - 12
Neuônios na 2ª camada | 2 - 12
Results

- The maximum of 10 search cycles was chosen due to the low variance in results and the very high computational cost;
- The table below shows the hyperparameters found for each of the series.

<table>
<thead>
<tr>
<th>Parâm./Séries</th>
<th>FTDNN</th>
<th>NARX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volúme útil</td>
<td>Vazões naturais</td>
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<tr>
<td>Taxa aprendizagem</td>
<td>0,15</td>
<td>0,275</td>
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<tr>
<td>Número máximo de épocas</td>
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<td>Dimensão imersão</td>
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<td>12</td>
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<tr>
<td>Atraso de imersão</td>
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<tr>
<td>Dimensão de contexto</td>
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<td>-</td>
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<tr>
<td>Neurônios na 1ª camada</td>
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<td>8</td>
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<tr>
<td>Neurônios na 2ª camada</td>
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<td>12</td>
</tr>
<tr>
<td>NMSE</td>
<td>19,5</td>
<td>17,07</td>
</tr>
</tbody>
</table>
Results

Result of the prediction for the useful volume series using the NARX network
Results

Result of the prediction for the natural flow series using the NARX network

![Graph showing predicted vs. real flow rates over time](image-url)
Conclusions

This work compared the performance of two types of neural networks, FTDNN and NARX, in the prediction task of the influent flow and reservoir level of a hydroelectric plant. The results demonstrated the superiority of the performance of the NARX recurrent neural network in the application in question in relation to the dynamic network FTDNN. In addition, it can be concluded that the performance of the NARX neural networks in the prediction of the series chosen were satisfactory if we consider a short prediction horizon, around 24 months. Thus, this model can be used to provide predictions that will serve as a subsidy in the determination of the hydroelectric dispatch of the Sobradinho plant.
Future Works

The next related works are:

- Implement ELM network model and obtain results;
- Implement NARX-ELM network model and obtain results;
- Compare results obtained with the various models implemented.
BIBLIOGRAPHY


Thank you!