Thesis Proposal: Implementation of a novel control theory-based training algorithm for recurrent neural networks

1 Introduction

System identification (SI) is the subject of modeling dynamical systems from experimental data. Recurrent neural network (RNN) models are among the most commonly used structure in the context of nonlinear SI.

Although such models have a powerful and universal approximation ability, they present some disadvantages. The main drawback of the simple (or vanilla) RNN is that when using a standard gradient-based algorithm to perform the training, the so-called vanishing gradient problem arises, and the solution gets stuck at a bad point. The introduction of LSTMs and GRUs cells solved this problem by creating a shortcut for gradient propagation. However, those kinds of RNNs need to introduce many parameters. Moreover, all sort of multi-layer RNN structures implicitly defines a state-space model whose dimension of the state space grows with the number of layers of the network. This characteristic does not allow for independently controlling the model's complexity and the system's order, which is a significant disadvantage of the considered models.

To overcome the drawbacks mentioned above, we propose a novel RNN architecture based on the approximation of the system's regression form description, which we name Regression-RNN (R-RNN). The choice of such a structure is motivated by nonlinear control theory results, thanks to which we can argue that the proposed network is at least as general as the state-space form RNN models mentioned above. Unfortunately, it is likely that the novel proposed model structure suffers from the vanishing gradient problem, just like the standard RNN version. To achieve the goals of both preserving the model structure and effectively training the proposed R-RNN, we pursue the following strategy:

- Rewrite the optimization problem in such a way that the functional gets simpler, at the cost of introducing more optimization variables and adding constraints;
- Employ a novel optimization algorithm, originally proposed by the SIC group, based on results from control theory to solve the optimization problem.

Tests on a single-layer R-RNN have shown an accuracy increase of 300% with respect to the single-layer vanilla RNN and LSTM models, with comparable training times.

2 Objectives of the Thesis

The objective of the proposed thesis is to:

- Understand and learn the structure of an R-RNN model.
- Implement an efficient version of the proposed training algorithm for multi-layer R-RNN in python using the TensorFlow package (or an equivalent one).
- Test the implemented software on both simulation and real-world nonlinear system identification problems.

Contacts:

- **Sophie Fosson**: sophie.fosson@polito.it
- **Simone Pirrera**: simone.pirrera@polito.it
- **Diego Regruto**: diego.regrutotomalino@polito.it