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On the Ability to Identify the Knee Joint Position Under Neuromuscular Electrical Stimulation Using Long Short-Term Memory Neural Networks

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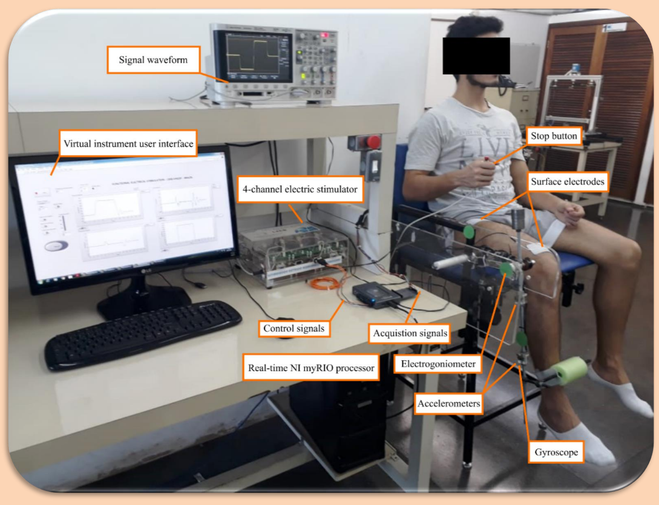
Abstract

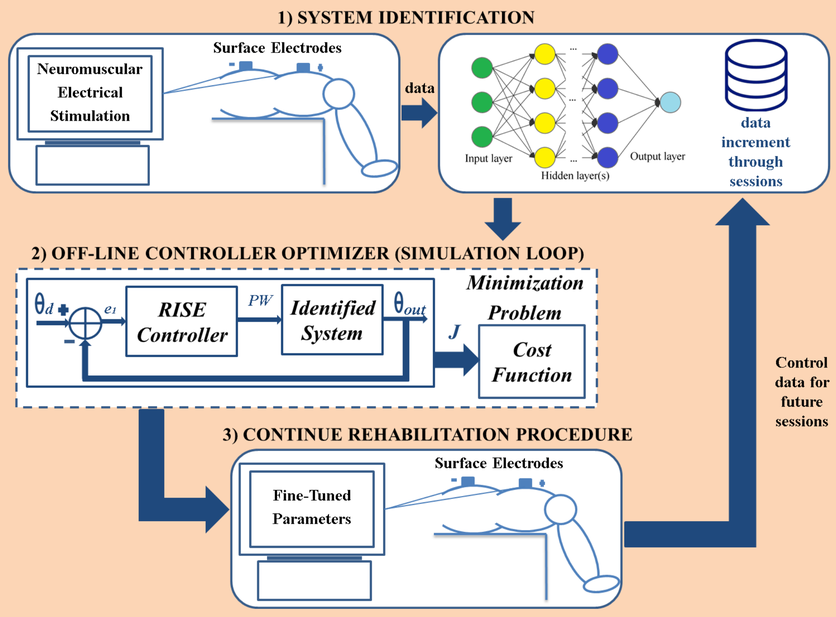
Neuromuscular Electrical Stimulation (NMES) has been applied in many treatments of spinal cord injured patients providing many social and health benefits. While commercial stimulators are designed in open-loop there are many studies on closed-loop NMES systems that require an adequate mapping over the delivered electric stimulus and achieved angular position (or torque). On the other hand, Recurrent Neural Networks (RNNs) offer a promising possibility for identifying and modeling dynamic nonlinear systems. One of the most popular and applicable RNN is the Long Short-Term Memory (LSTM) architecture. Hence, this paper investigates the effectiveness of the LSTM in the specific task of identifying the knee joint angular position under NMES using experimental data from three male healthy individuals. As shown in results, the LSTM model demonstrated to be an effective estimator for this application, proving to be a prospective method for deeper investigation on nonlinear system identification and modeling.

Material and Methods



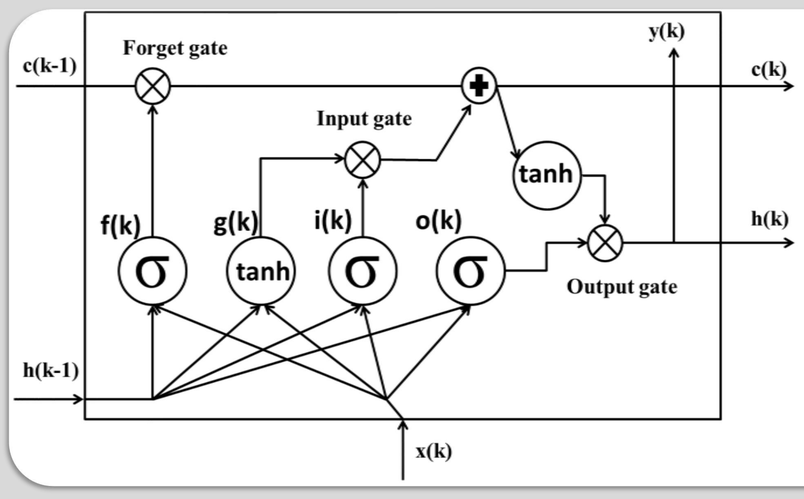
python

LabVIEW



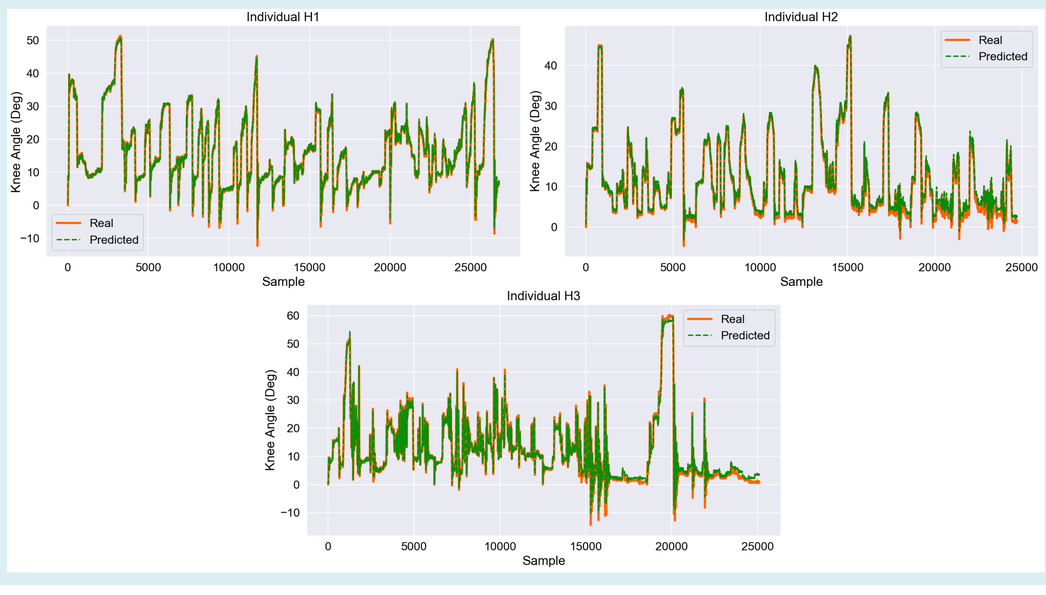
Theoretical Background

- **Long Short-Term Memory (LSTM)**
  - **The best architecture used for all individuals is composed of one single LSTM layer with 271 neurons and a fully connected layer as output.**
  - **The batch-learning mode was used with mini-batch size as 64.**
  - **The Adam opti-mizer was used with learning rate as 0.0003, and models have trained at most 5000 epochswith an "earlystopping" method of 15 epochs configured to check the Root Mean SquaredError (RMSE)**



$$i_{(k)} = \sigma(W_{xi}^T \cdot x_{(k)} + W_{hi}^T \cdot h_{(k-1)} + b_i)$$
$$f_{(k)} = \sigma(W_{xf}^T \cdot x_{(k)} + W_{hf}^T \cdot h_{(k-1)} + b_f)$$
$$o_{(k)} = \sigma(W_{xo}^T \cdot x_{(k)} + W_{ho}^T \cdot h_{(k-1)} + b_o)$$
$$g_{(k)} = \tanh(W_{xg}^T \cdot x_{(k)} + W_{hg}^T \cdot h_{(k-1)} + b_g)$$
$$c_{(k)} = f_{(k)} \otimes c_{(k-1)} + i_{(k)} \otimes g_{(k)}$$
$$y_{(k)} = h_{(k)} = o_{(k)} \otimes \tanh(c_{(k)})$$

Results



Conclusions

The identification of knee joint dynamics under the application of NMES has been addressed for three healthy male subjects using LSTM NNs in this paper. The behavior of a dynamic system can be described as special time-series problems, whereby using an RNN in which there is a self-feedback of neurons in the hidden layer(s) it provides the ability to use contextual information when mapping between input and output sequences. Therefore, using the series-parallel structure, the LSTM could identify highly accurately the knee angular position due to the electrical stimulus for all three individuals, proving to be a prospective method for deeper investigation on nonlinear system identification and modeling.

Main References

[1] H. H. Arcolezi, W. R. B. M. Nunes, S. L. C. Ñahuis, M. A. A. Sanches, M. C. M. Teixeira and A. A. de Carvalho. **A RISE-based Controller Fine-tuned by an Improved Genetic Algorithm for Human Lower Limb Rehabilitation via Neuromuscular Electrical Stimulation**, 6th International Conference on Control ... (CODIT), Paris, France, 2019.

[2] T. Anwar, Y. M. Aung and A. A. Jumaily. **The estimation of Knee Joint angle based on Generalized Regression Neural Network (GRNN).** IEEE International Symposium on Robotics and Intelligent Sensors (IRIS), 2015.

[3] Y. Wang, **A new concept using LSTM Neural Networks for dynamic system identification.** American Control Conference (ACC), 2017.

Acknowledgements

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