Iowa Initiative for Artificial Intelligence

Final Report

Project title:	Discovery of the Spinal Musculoskeletal Mechanism for the Lumbar Stabilization using Bayesian Graph Convolutional Neural Networks
Principal Investigator:	Tae-Hong Lim (Professor, BME) & Stephen Baek (Assistant Professor, ISE)
Prepared by (IIAI):	Yanan Liu
Other investigators:	
Date:	
Were specific aims fulfilled:	Y
Readiness for extramural proposal?	N
If yes … Planned submission date	Late 2022
Funding agency	NIH
Grant mechanism	R21
If no … Why not? What went wrong?	The result needs to be further validated on a larger number of samples.

Brief summary of accomplished results:

We have developed and validated a long short-term memory networks (LSTM) model to accurately predict bone displacements in lumbar system. Small values of root-mean-square errors (RMSE) were achieved between LSTM predictions and ground truth.

Research report:

Aims (provided by PI):

The overall goal of this pilot project is to obtain preliminary evidence supporting our scientific premise that artificial neural networks should be able to discover the hidden control mechanism of the CNS for the lumbar stabilization.

As the project progressed, the team decided to focus on predicting lumbar system displacement from a given spinal position and muscle forces.

Data:

To accomplish the above aims, a simulation software, called LS-Dyna, was used to generate data. Muscle forces, force directions Ux,Uy,Uz, bone displacements and positions were exported from the simulation software, for each time step during the simulation. Initial conditions varied to have diverse training data. 1500 sets of data points for this pilot project were generated. Each contained 300 timesteps. For each timestep, 20 muscles and 7 bones were simulated.

AI/ML Approach:

In this study, supervised machine learning algorithm was implemented for lumbar system displacement prediction using LSTM in Python. Motion of individual body regions was separately modeled and motion prediction was evaluated vs. ground truth. Motion of the following body regions/landmarks was learned and predicted: Upper body center of gravity (CG), geometrical center(GC) of 1 thoracic and 5 lumbar vertebral bodies (GC_T12, GC_L1, GC_L2, GC_L3, GC_L4, and GC_L5). As large numbers of timesteps were involved, LSTM was selected to predict displacement. Training: validation split was 1200/300 cases for each body region.

Experimental methods, validation approach:

Data preparation

Data preparation or pre-processing is an essential step in any machine learning study. In this project, we combined all our 1500 csv files in a Python .npy file. Due to different ranges of different cases, we normalized the input and output data to [-1,1] using minmaxscaler in Python.

<u>LSTM model</u>

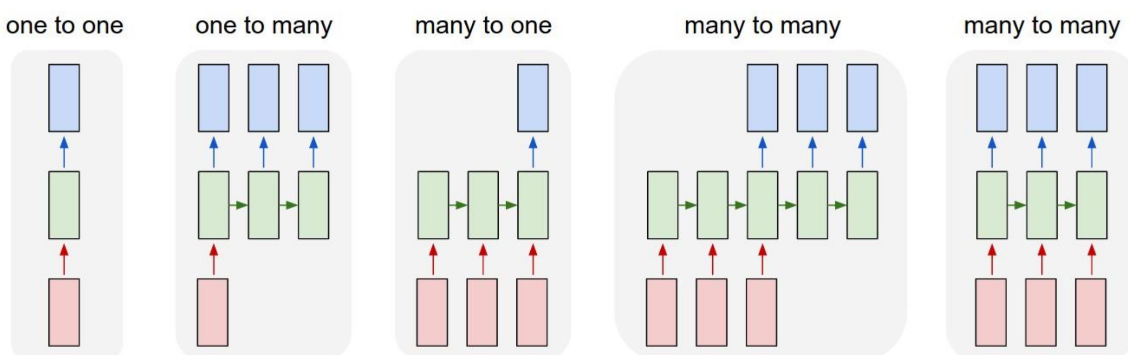

Figure 1. LSTM models [1]

Long short-term memory (LSTM) uses an artificial recurrent neural network (RNN) architecture [2], frequently used in deep learning. The common models are showed in Figure 1. We used many to many models for this project. Mean square error was used for loss function. Since the target was displacement in (x,y,z) direction, we treated each bone separately. In that case, the loss function had strong correlation with 3D distance.

Results:

Figures 2-4 show examples of typical results obtained by LSTM model, demonstrating an excellent agreement between our prediction results and the ground truth.

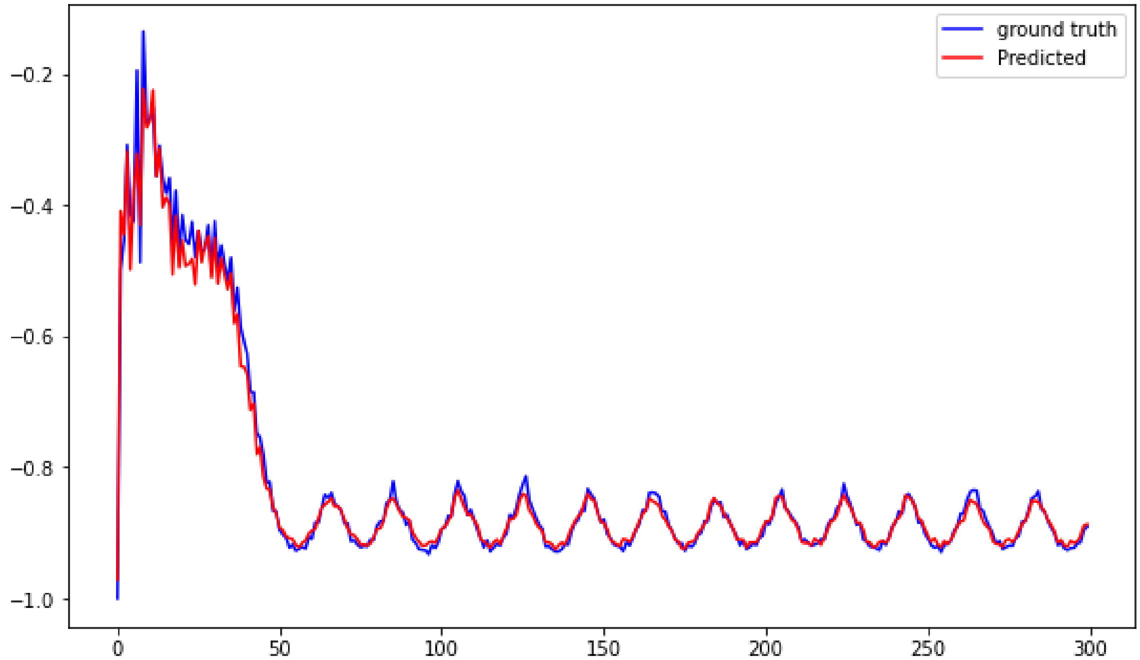

Figure 2. Results comparison for Bone displacement at X direction

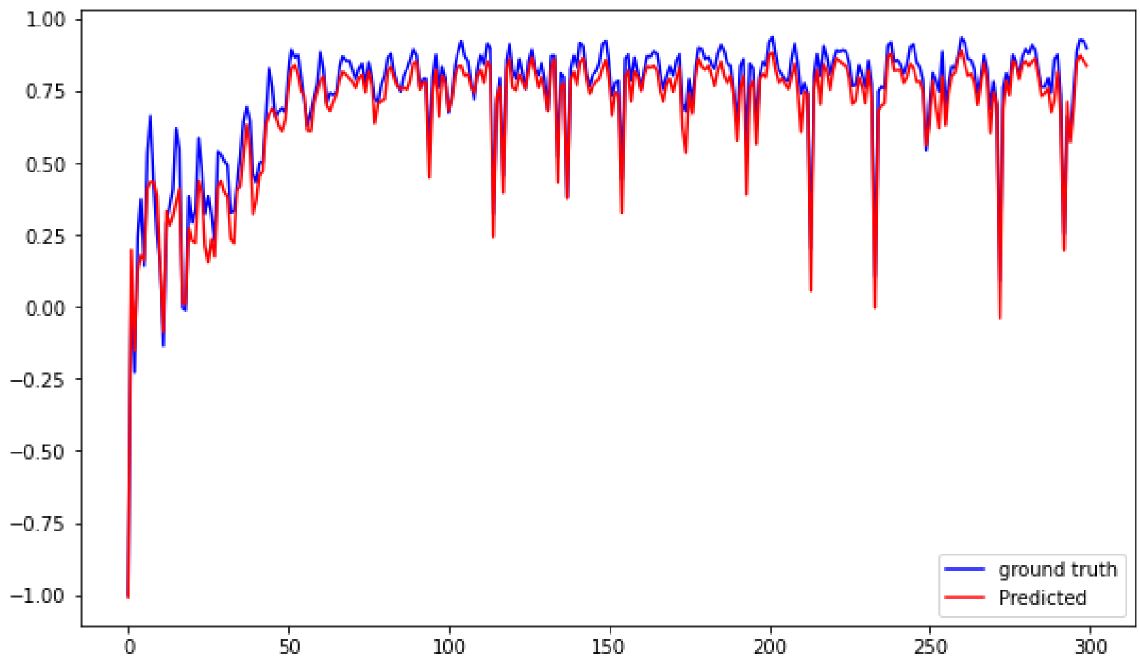

Figure 3. Results comparison for Bone displacement at Y direction

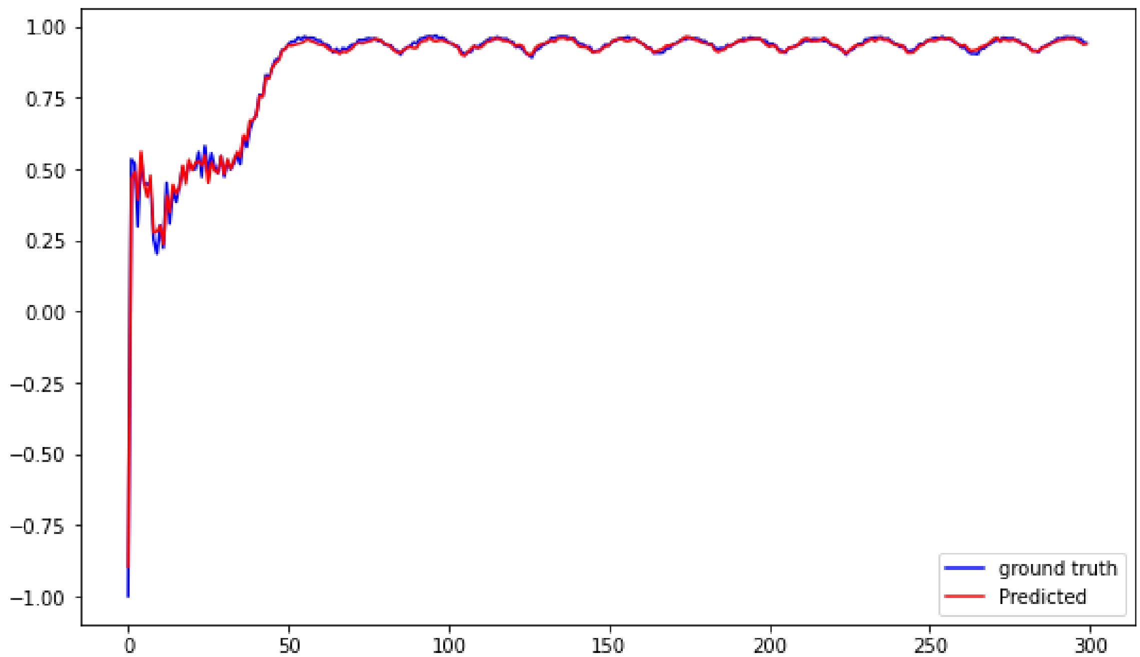

Figure 4. Results comparison for Bone displacement at Z direction.

The root-mean-square error (RMSE) was used to measure of the differences between LSTM prediction and ground truth in validation group. The RMSE for each bone is shown in Table 1.

Lumbar system	RMSE (mm)
Upper body CG	0.58
GC_T12	1.20
GC_L1	1.02
GC_L2	0.32
GC_L3	0.16
GC_L4	0.11
GC_L5	0.05

Ideas/aims for future extramural project:

Building upon the LSTM model, the team will expand the scope of analysis and test the hypothesis on a larger variations of initial posture and different stabilization mechanisms (different force combinations). The aims for our future project will include (1) developing a physics-aware ML model to assimilate the mechanical response of the lumbar system; (2) develop a reinforcement learning algorithm to discover different force combinations for stabilization; and (3) validating the model through in-vivo experiments.

Publications resulting from project:

No publications resulted from this project.

References

1.Andrej Karpathy blog. http://karpathy.github.io/2015/05/21/rnn-effectiveness/

2. Sepp Hochreiter, Jurgen Schmidhuber (1991). “Long short-term memory”. Neural Computation. 9(8): 1735-1780