Fast Brain Strain Evaluation in Head Impact

Video: https://youtu.be/I_a1aUi0L9I

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Abstract

Conventional methods of evaluating brain deformation caused by head impacts: **Finite Element Analysis (FEA)** can be both time-consuming and difficult to model efficiently. In this work, a novel method of **characterizing brain deformation** in the head impact with **deep neural network** trained on **mouthguard kinematics** signals is proposed. To model the brain as an entity, our model gives comparable results to previous publications. To show the element-wise brain strain, our models show similar results to those of FEA but with **a significant speed increase** (on the order of 3,500x faster). This project could potentially help those engaging in contact sports **better detect brain injury**.

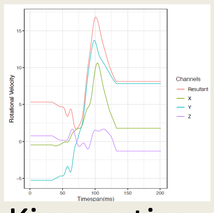
Data Source

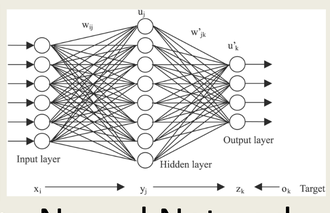
1. 79 Mixed Martial Arts head impacts
2. 517 American Football head impacts

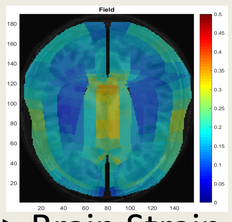
- Kinematics signal recorded by Stanford Instrumented Mouthguard.
- 6 degrees of freedom

Method

Flow Chart







Kinematics -> Neural Network -> Brain Strain

Input: Kinematics signals:

$$a_x, a_y, a_z, \omega_x, \omega_y, \omega_z$$

Output: 1. Single-metric for whole brain strain. (95% MPS)

2. Strain for every brain element(MPS)

Data Preprocessing

1. Label Reference: Calculated by KTH modelling.
2. Signal Padding: Length 200ms, Peak at 100ms.
3. Dimensionality Reduction: PCA(Label data, 10 PC)
4. Feature Extraction: Maximum Value; Minimum Value; Integral of Signal; Integral of Absolute Value of Signal; Exponential Moving Average of Signal Derivative(Max & Min)

Neural Network Modeling

1. Single-metric prediction

DNN (engineered features): 36-60-30-1

2. Strain for every brain element

DNN (engineered features): 36-120-480-4124

DNN (padded signals):600-200-50-4124

DNN+PCA (padded signals): 600-200-50-10

LSTM+PCA (padded signals):201×3-LSTM(100)-FC(50)-FC(10)

3. Modified Loss Function

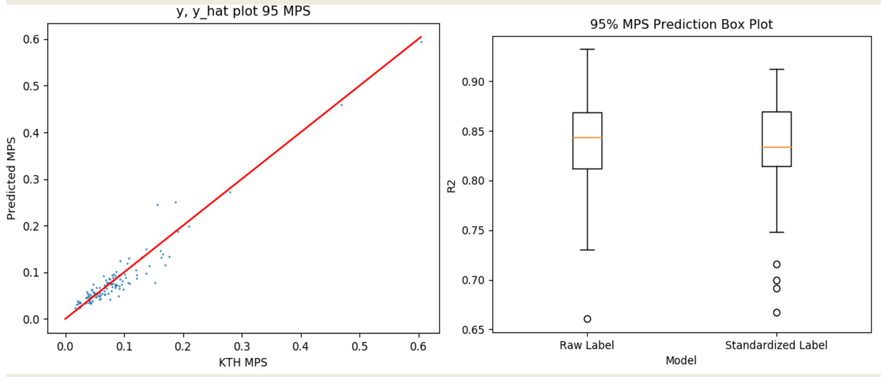
$$L(Y_{PCA}, f(X)) = Var \times ESS \times (Y_{PCA} - f(X))^2$$

Result

1. Time cost for one impact

   Deep Learning: ~0.5 s KTH Model: ~30 min

2. Single-metric prediction

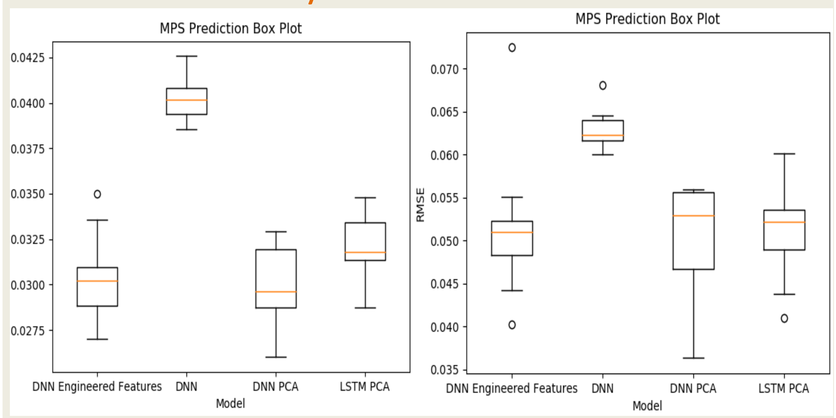


Example y-y plot R^2 Box plot (50 tests)

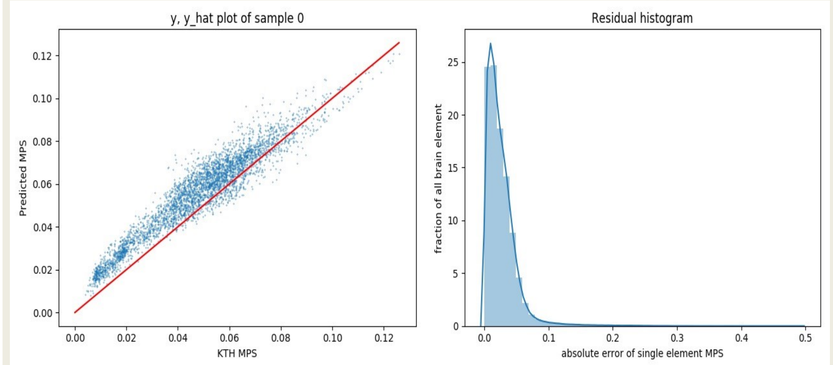
Comparison with paper published[1]

	Previous Publication	Our Result
R^2	0.6-0.9	0.85
RMSE	0.03-0.06	0.3

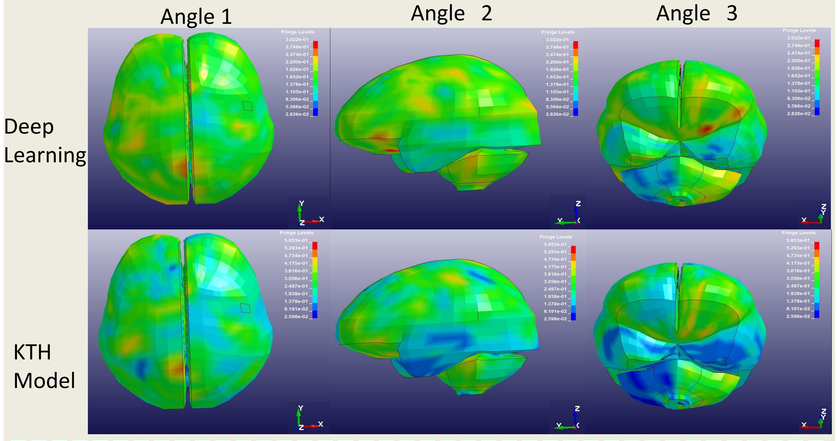
3. Strain for every brain element



Mean Absolute Error Root Mean Squared Error



Example y-y plot Error Histogram



Conclusion

The neural-net-based method is much faster (by a factor of approximately 3,500x) and able to give similar brain deformation profiles, making it easy to interpret brain damage for players.

Reference

[1] Wu S. et al, Sci. Rep., 9:1-11, 2019

[2] O'Keeffe E et al, J Neurotrauma, 2019.

[3] Hernandez F et al, Ann. Biomed. Eng., 43:1918-1934, 2015.

[4] Wu L et al, Ann. Biomed. Eng., 44:1234-1245, 2016.