Estimating 3D Ground Reaction Forces during Running using 3 IMUs

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1 - Introduction

- Ground reaction force (GRF) can be used to quantify biomechanical load in running [1], which is important to monitor runners and get better insights in the development of running injuries. However, GRF measurements are restricted to a laboratory.
- Artificial Neural Networks (ANNs) can be used to estimate GRF from Inertial Measurement Units (IMUs). An ensemble of multiple ANNs can increase the performance [2].
- With GRF estimation models, the forces can be estimated in the runners' environment to get more insights into loading during running.

The main aim of this work is to predict GRF in 3D with 3 IMUs in an outdoors setting

3 –Validation and Ensemble

- Leave-one-subject-out cross validation
- Per subject, 7 different models with random splits in validation (n=4) and training (n=7) subjects, combining the 7 different models in one ensemble by taking the average (Fig. 1)

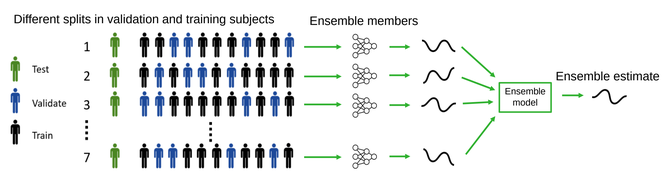


Fig. 1: An ensemble model is created by taking the average over the prediction of 7 different models.

5 – Discussion and Conclusion

This is the first study that uses generic ensemble models in to estimate 3D GRF in runners. The average accuracy of the ensembled model was higher than conventional models with a RMSE of 10.8%, 7,8 and 7,3 in the medio-lateral, anterior-posterior and vertical direction, respectively.

Ensemble models leads to higher accuracy of 3D GRF estimation in running than conventional models as typically reported in literature

2 - Methods

Protocol

- 12 heel strike subjects (4M/8F, 31.5y ± 11.7y), 9 trials
- 10, 12, 14km/h
- 90, 100 and 110% of preferred stride frequency, imposed
- 3 IMUs, 240Hz, at pelvis and tibias
- 3D Instrumented treadmill

Data Processing

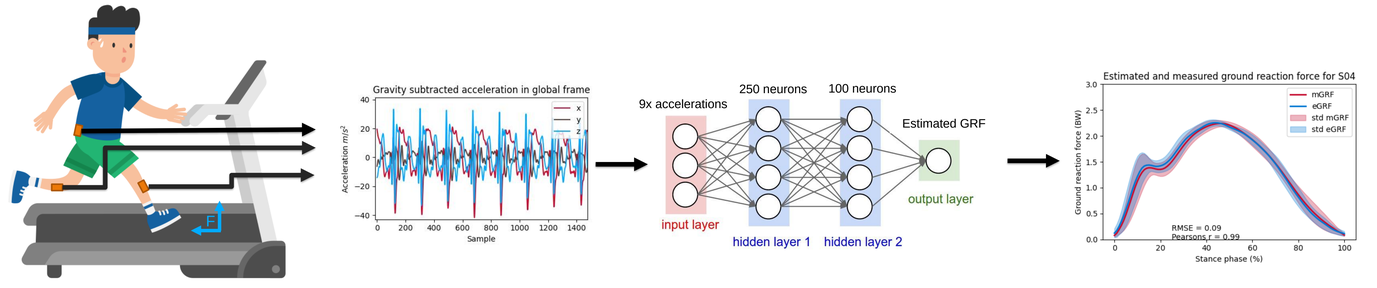
- Gravity subtracted acceleration in global frame
- Accelerations in x, y and z-direction, filtered at 10Hz, low pass filter
- Force plate data filtered at 30Hz, low pass filter

Neural Network

- 2 Layers with 100 neurons
- 9 Input layers
- ReLu activation profile
- Mean squared error as loss function

Outcome Measures

- Root Mean Squared Error between measured and estimated GRF, normalized over the full range (rRMSE)



4 - Results

- The ensemble models do have a lower rRMSE than most ensemble members in all directions (Fig. 2)
- The 3D GRF waveforms are shown in Fig. 3 for a representative subject, with estimated GRF (eGRF) in blue and measured (mGRF) in orange

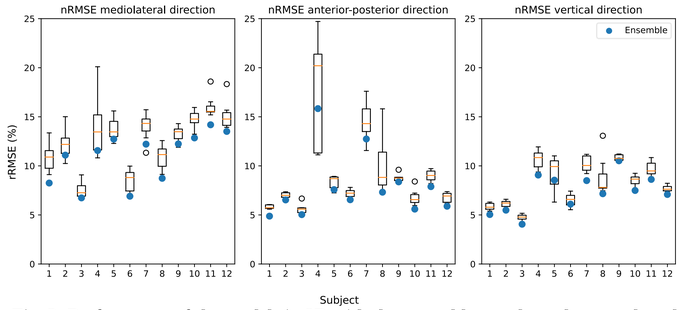


Fig. 2: Performance of the models in 3D with the ensemble members shown as boxplot and the ensemble model as blue markers

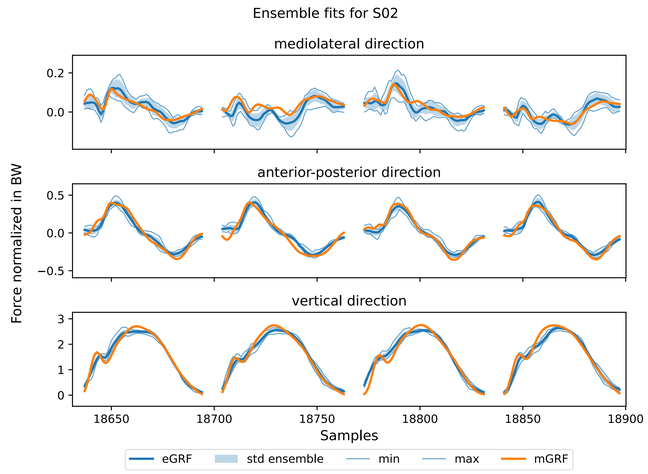


Fig. 3: Estimated GRF from ensemble model in three different directions for a representative subject

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[1] J. Verheul *et al. 2020*, Measuring biomechanical loads in team sports–from lab to field

[2] E. Grzesiak, *et al. 2022*, Predicting Ankle Moment Trajectory with Adaptive Weighted Ensemble of LSTM Networks