

VERTICAL GROUND REACTION FORCE AND CENTER OF PRESSURE PREDICTION DURING LIFTING ACTIVITIES USING MACHINE LEARNING

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Introduction

Ground reaction forces (GRFs) and their center of pressure (CoP) are essential inputs in spine musculoskeletal models especially when investigating load-handling activities [1]. While GRFs and CoP are usually measured via force-plates or insole sensors, they can also be predicted based on body motion data, developed in AnyBody Modelling System (AMS) thus eliminating the need for costly laboratory equipment and measurements [2]. However, AMS itself is a hard-to-use and expensive software. This study, therefore, aims to develop easy-to-use yet accurate artificial neural networks (ANNs) based on AMS outputs to predict vertical GRF (GRFz) and CoP during various manual material handling (MMH) activities.

Methods

Ten healthy right-handed normal-weight ($20 < \text{BMI} < 25 \text{ kg/m}^2$) male individuals each performed a total of 204 one- and two-handed load reaching activities at, respectively, 15 and 7 different horizontal and vertical load locations while adapting four different lifting techniques: upright standing, stoop, semi-squat, and full-squat [3]. During these tasks, full-body motion data were collected via a ten-camera Vicon motion capture system and full-body plug-in gait marker standard [4,5]. Nine different loads in hands (between 0 and 30 kg) were modeled using a full-body AMS model resulting in total of 18360 MMH activities ($10 \text{ subjects} \times 204 \text{ tasks} \times 9 \text{ hand-loads}$) while assuming identical postures for different hand loads. GRFz and CoP were estimated for every MMH activity using the validated GRF prediction model of AMS [2,6]. Two ANNs were trained to predict GRFz and CoPs of both feet during different MMH activities considering eight simple input parameters including 3D hand-load coordinates, its mass, adapted lifting (upright standing, stoop, semi-squat, and full-squat) and handling (one- or two-handed) techniques and body height/weight magnitudes using the predicted GRFz and CoP dataset. Based on random hold-out validation method using 70-15-15% of the dataset for, respectively, training, validation, and testing, the ANNs architectures were designed by Optuna framework to achieve the least prediction error [7,8]. Moreover, the performance of the trained ANNs were evaluated via the leave-one-subject-out cross-validation method [3].

Results

Both developed GRFz and CoP ANNs had the same architecture including 3 hidden layers between input and

output layers with 50, 50, and 25 neurons in each of the hidden layers. The range of predicted GRF and CoP values from AMS modeling as well as root-mean-square-error, normalized-RMSE (to mean value of the data, nRMSE), and R^2 of the trained/validated/tested ANNs for GRFz and CoP are presented in Table 1.

Parameter	Range	RMSE	nRMSE (%)	R^2
Right GRFz (N)	0-1163	65 ± 17	5.6 ± 1.5	0.97
Left GRFz (N)	0-1040	64 ± 18	7.6 ± 2.2	
Right CoPx (mm)	26-509	38 ± 10	7.8 ± 2.1	0.77
Right CoPy (mm)	-60-300	31 ± 8	8.6 ± 2.3	
Left CoPx (mm)	-251-535	102 ± 19	13.1 ± 2.4	
Left CoPy (mm)	-50-305	39 ± 5	10.9 ± 1.6	

Table 1: The range of GRFz/CoP data predicted by AMS modeling as well as prediction errors of the developed ANNs. The values for CoP are based on a local coordinate system on the force-plate.

Discussion

Overall, the trained ANN for predicting GRFz was more accurate than the ANN for CoP prediction (Table 1). Using these new easy-to-use yet accurate GRF and CoP prediction ANNs, there will be no need to use hard-to-use models such as AMS or expensive measurement tools like force-plates to evaluate these biomechanical parameters. However, it should be noted that these ANNs are developed based on the predicted GRFz and CoP values of AMS thus the prediction errors are included in these new prediction ANNs. In addition, assuming no changes in the body posture while handling different hand-loads would compromise the accuracy of the model prediction performance [3]. Future studies, therefore, should be focused on evaluating the accuracy of these ANNs using laboratory collected GRF and CoP data for all hand-loads. Finally, similar machine learning-based models could be developed to predict joint/muscle forces during dynamics lifting activities.

References

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