ASSESSING GAIT BIOMECHANICS FROM IMU SENSORS MIMICKING THE USE OF SMARTPHONES

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Abstract This study explores the feasibility of using a single inertial measurement unit (IMU) mimicking the use of smartphones to perform gait analysis. Fifty-two participants walked on a treadmill at three speeds while carrying a smartphone-sized IMU in the hand, trouser pocket, or jacket pocket, while feet kinematics were assessed using optical motion capture. A machine learning model predicted gait events for further estimation of stride, stance, swing, and double support time. The IMU-based features were compared to those from optical motion capture. The stride time, stance time and swing time predictions presented errors between 5 and 20%, while double support time had the highest errors (>20%). Moderate-to-strong correlations between predicted and experimental parameters preserved inter-subject trends. Our results show the potential of using data from smartphone's IMUs and machine learning to perform remote gait monitoring on a variety of motion contexts and speeds.

Introduction Healthcare systems face challenges from aging populations and workforce shortages, increasing the need for cheap and highly simple health monitoring. Gait analysis is useful to detect and track neurological and metabolic conditions, and inertial measurement units (IMUs) provide optimal technology to assess human movement. While gait parameters extracted from IMUs on the pelvis or shanks are accurate[1-3], tight fixation with tapes or straps is a burden to users. Recent studies have explored assessing data from smartphone's IMUs to evaluate gait, but accuracy varies by placement[4]. Therefore, the aim of this study was to determine the accuracy in extracting gait parameters from an IMUs mimicking a smartphone using neural networks.

Methods Fifty-two healthy adults (35 males 17 females were asked to walk on a treadmill at three speeds (1.0, 1.25, and 1.5 m/s) while carrying a smartphone-sized IMU in their hand, trouser pocket, or jacket pocket. Foot kinematics was acquired from optical motion capture for subsequent identification of ground truth gait events. IMU data was recorded at 1259 Hz and downsampled to 100 Hz to match the optical data. A long-short term memory convoluted neural network (CNN-LSTM) was trained to predict gait events from 200-ms data windows across different phone placements and walking speeds. A leave-one-out approach was used for model validation. Subsequently, the gait events were used to compute stride time, stance time, swing time, and double support time. The error between the optical (experimental) and predicted gait parameters was assessed using relative root-mean-square error (rRMSE). Moreover, the association between the experimental and predicted gait parameters was assessed using Pearson's correlation coefficient, the significance level was set at $p<0.05$.

Results and Discussion After removing incorrect predictions, an average of 67±23 valid stride cycles/condition were analysed. The rRSME for predicting the double support was generally high (>30%, Figure 1) whereas the rRMSE for stride and stance times were the lowest, reaching as low as 4% across all participants. The double support is the shortest variable extracted in the study, lasting apprximately the same length as the data window used for predictions. Therefore, the larger error is strictly related to the limitation of the prediction method. Gait parameters extracted from hand and trouser locations presented the lowest errors when compared to the jacket predictions, due to the looser placement of the IMU sensor in the jacket. Regarding the association between experimental and predicted data, the predictions from double support did not yield significant correlations ($p>0.05$), whereas stride time ($0.35>r>0.98$), stance time ($0.43>r>0.76$) and swing time ($0.45>r>0.54$) presented predominantly significant correlations with experimental data, regardless teh phone location or walking speed.

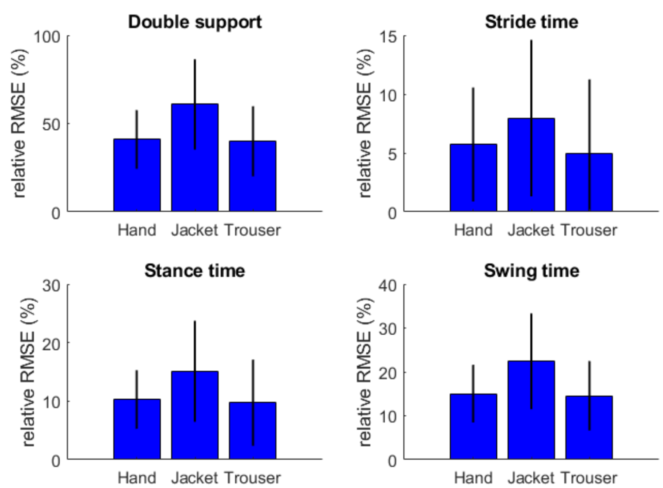

Figure 1. Mean(SD) relative RMSE of the prediction of gait parameters from IMUs located at the hand, jacket and trousers. All gait speeds are included in the averages.

Conclusion Our study demonstrated that estimations of gait parameters from a single IMU mimicking the use of a smartphone can generate stride time predictions with low errors (rRMSE <5%), while stance and swing times had moderate errors (6–20%). Double support time was not well predicted (>40%). Moreover, the overall moderate-to-strong correlations with experimental data suggest potential of using CNN-LSTM models to perform remote gait analysis regardless of smartphone placement or walking speeds.

References

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