Sensors Fusion for Cognitive Load Analysis using Gait Data

Introduction

Gait (see fig. 1) is the manner of walking in people and one of the basic functions for humans to move purposefully from one position to another. The quality of life can be affected by gait abnormality and result in morbidity and mortality. This effect is a consequence of neuronal dysfunction, and accurate analysis of gait can assist for the prediction of the development of diseases (even years before they are clinically diagnosed) such as dementia, Parkinson disease. A detailed review **[1]** reveals the existing achievements and gaps in the current knowledge in gait analysis. Following from the review, sensors under the foot are identified as a suitable method to study gait deterioration due to cognitive load in this research. Deep learning models are implemented to fuse sensors under the foot and deliver automatic feature extraction of gait patterns and perform classification in the following sections (**I,II,III**).

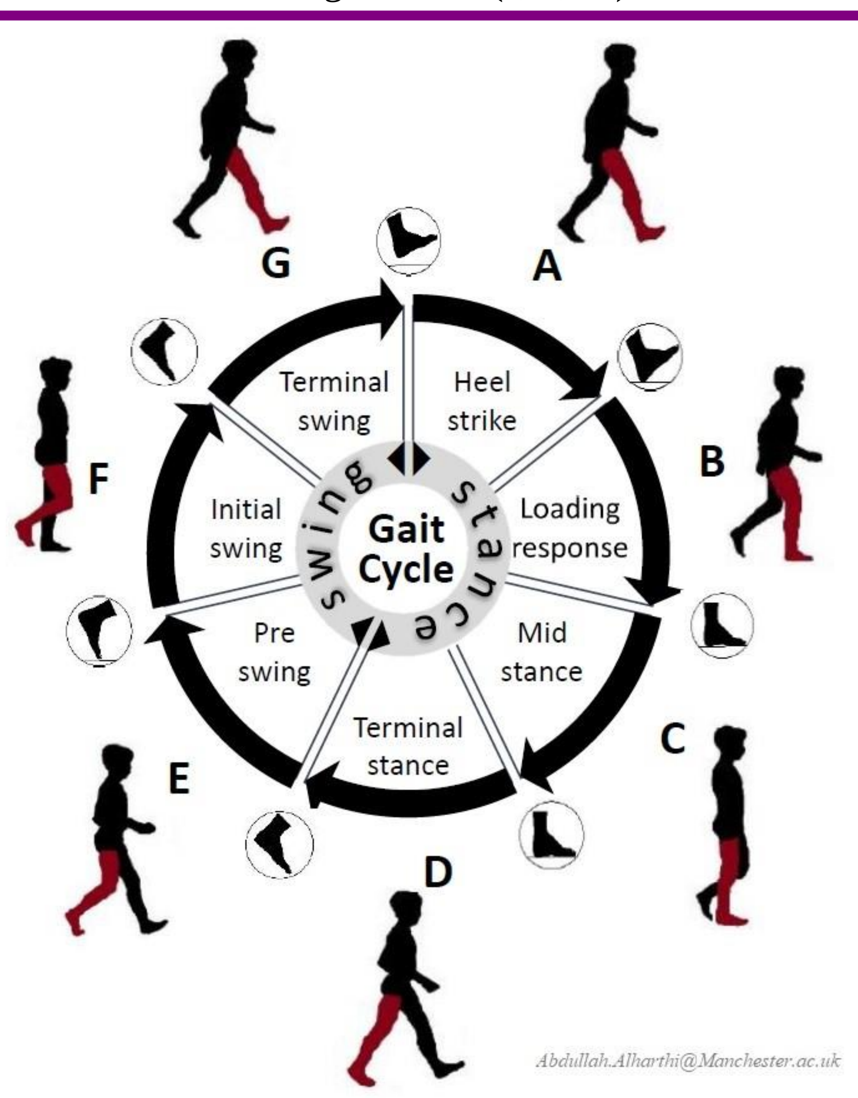

Fig. 1. Important gait events and intervals in a normal gait cycle **[1]**.

I) Deep Learning and Sensor Fusion Methods for Studying Gait Changes Under Cognitive Load in Males and Females

Objective) The gender difference in the response to cognitive load is a focus in this study, based on observing the impact on males and females of a cognitively demanding tasks while walking. In the longer term, this approach could contribute to improving the quantification of gait decline in studies of cognitive changes (under e.g. comparable stage of Alzheimer's disease) manifested in men and women **[2]**.

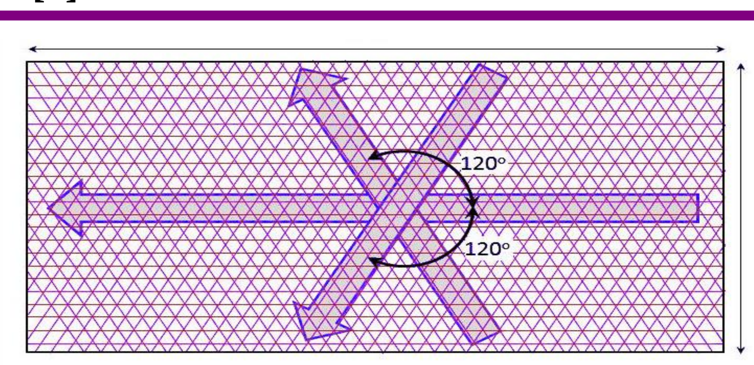

Fig. 2. iMAGiMAT system

System and Data Acquisition) A photonic guided-path tomography sensor head (the iMAGiMAT fig.2 footstep imaging system), is utilized in this experimental work. Three gait experiments reordered for 5 subjects (3 males and 2 females) as the following.

Class 0, Normal Gait: walking at normal self-selected gait speed.

Class 1, gait with serial 7 subtractions: normal gait speed, while at the same time performing serial 7 subtractions (count backwards from 100 by sevens e.g. (93, 86, 79…72, 65,) or by count from given random number, stop after completing the task).

Class 2, gait while texting: normal gait attempted self-selected gait speed while typing in text on a smartphone.

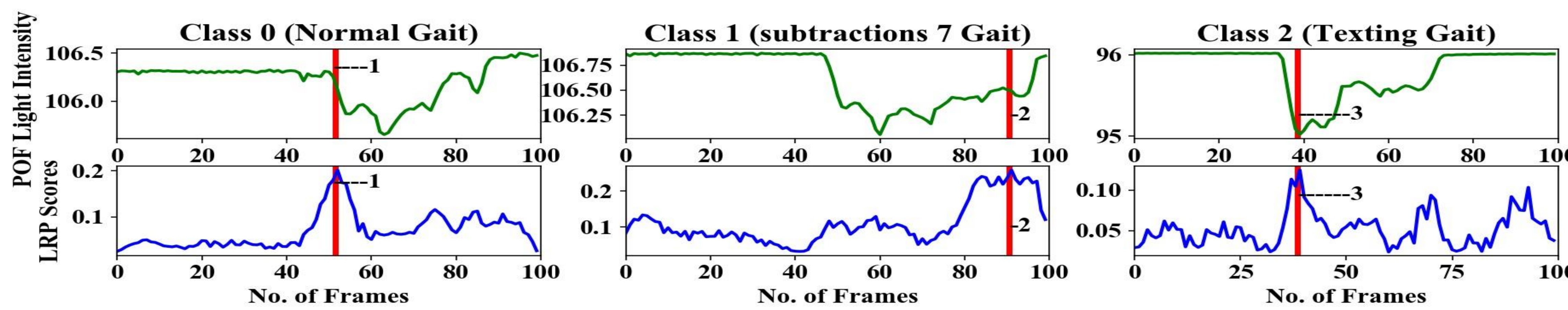

Fig. 4. LRP methods is applied on testing data, to identify gait events relevant for the CNN prediction to classify the cognitive load impact on gait. Spatial average of gait spatiotemporal signals: green; spatial average for LRP relevance signals over gait temporal period: blue. Vertical red bars with numbers display consistency with gait events as per fig. 1**[2]**.

Classifier and Results) A parallel Convolutional Neural Network CNN model (see architecture in fig. 3) is engineered using Keras libraries. The model hyper-parameters are selected based on extensive trial way. The CNN classifies gait for both genders identification by 95% yet they share the same cognitive load by 93%.

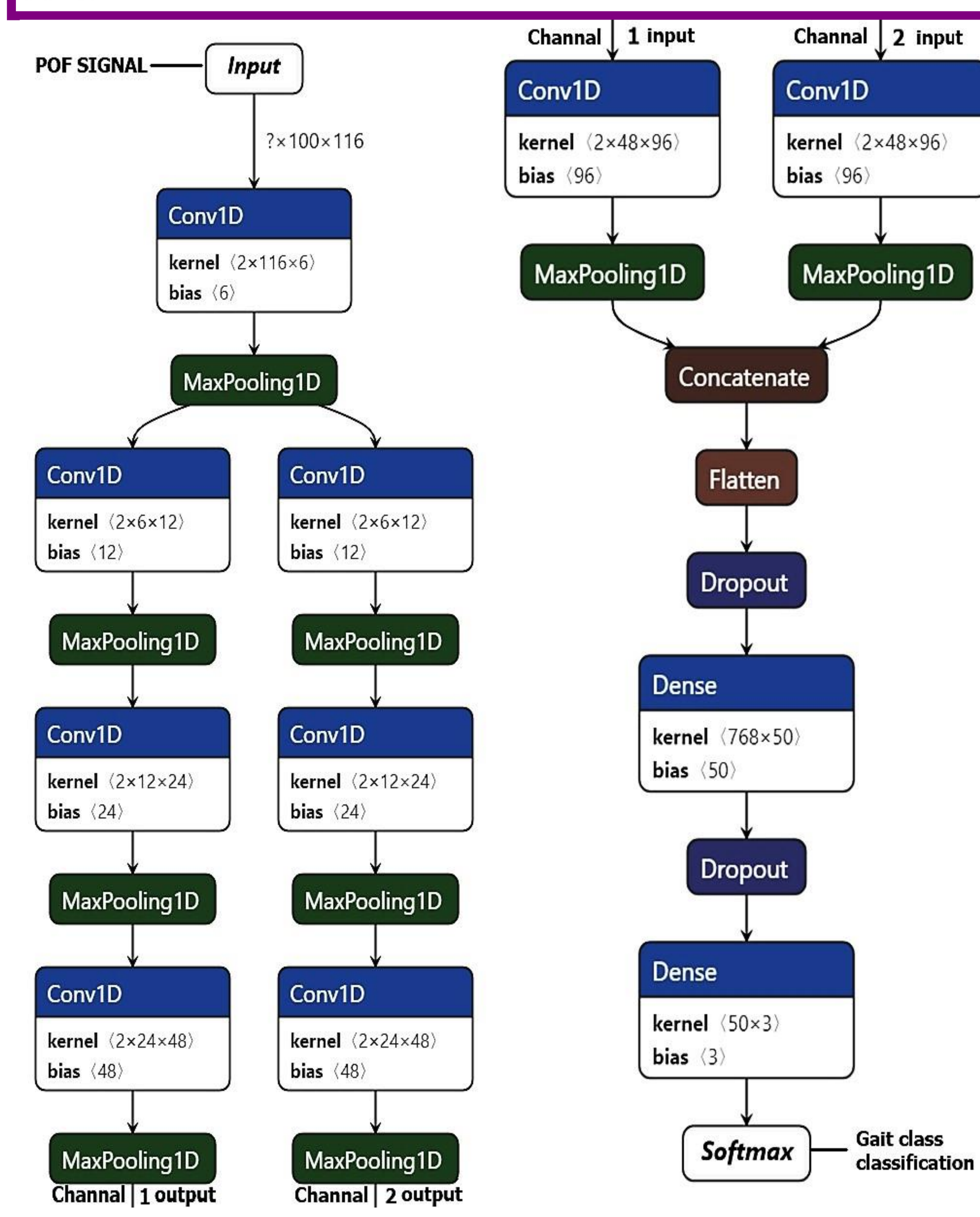

Fig. 3. CNN classifier for males and females classification **[2]**.

II) Sensor Fusion for Analysis of Gait under Cognitive Load: Deep Learning Approach

Objective) Firstly, Categorizing gait parameters for 15 healthy adults while performing cognitive demanding tasks, using deep CNN; secondly, interpreting the model performance on unseen spatiotemporal signals by applying the technique of Layer-Wise Relevance Propagation (LRP) to attempt linking key known events in the gait cycle to cognitive deterioration. The data acquisition and system in section I is used in this study **[3]**.

Classifier and Results) Gait class prediction is redistributed to each intermediate node via backpropagation until the input layer. The LRP outputs a heat map over the original signal to highlight the signal sections of highest contributions to the model prediction.

i. Normal gait: the signals most influential for the CNN to identify this class are after the heel strike and before the foot-flattening (figure 4, event numbers 1). **ii.** Walking while performing 7s subtraction: the CNN classification of this gait is based strongly on the transition between foot-flattening and opposite toe-off (figure 3, event numbers 2). **iii.** Walking while writing a text in smartphone: LRP scores for this event, are based on the transition between foot flattening and double or single support (figure 3, event numbers 3).

III) Deep Learning for Ground Reaction Force Data Analysis: Application to Wide-Area Floor Sensing

Objective) Parkinson's disease staging based on postural imbalance caused by gait deterioration. Ground reaction force data is classified using several models to find the best model.

Classifier and Results) Parkinson's disease data acquired from *PhysioNet* to test several models as shown in fig 5. The deep learning models outperformed the shallow learning and LSTM models as shown in confusion Metrix in fig 6.

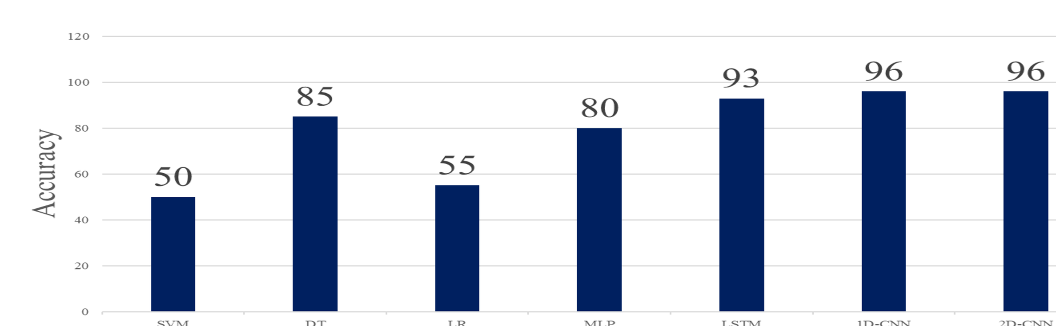

Fig. 5. Proposed Algorithms Accuracy

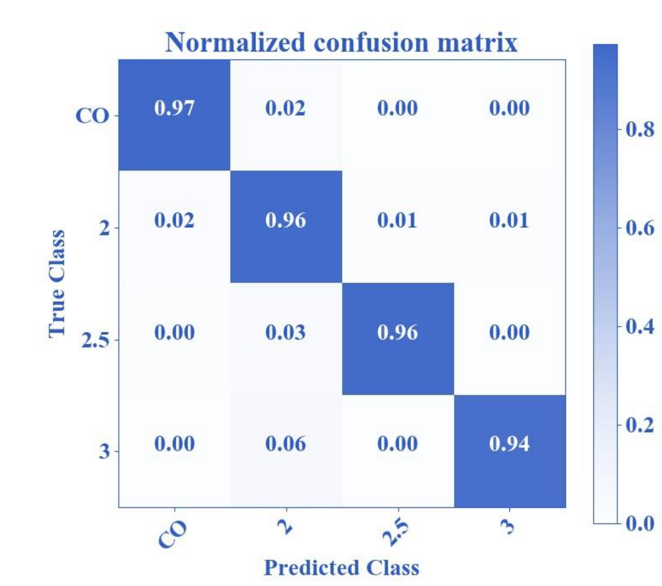

Fig. 6. 2D-CNN confusion Metrix

Conclusion

The research findings present valuable insight for gait spatiotemporal signals analysis for the effect of cognitive load on gait, with other potential spin-offs are in the areas of biometrics and security.

References

1. Abdullah S. Alharthi, Syed U. Yunas and Krikor B. Ozanyan, 'Deep Learning for Monitoring of Human Gait: A Review,' IEEE Sensors Journal. 19 (2019), 9575-9591. DOI: 10.1109/JSEN.2019.2928777
2. Abdullah S. Alharthi, Krikor B. Ozanyan, 'Deep Learning for Ground Reaction Force Data Analysis: Application to Wide-Area Floor Sensing,' 28th International Symposium on Industrial Electronics (ISIE). (2019) 1401-1406. DOI: 10.1109/ISIE.2019.8781511
3. Abdullah S. Alharthi, Krikor B. Ozanyan, 'Deep learning and Sensor Fusion Methods for Cognitive Load Gait Difference in Males and Females,' 20th International Conference on Intelligent Data Engineering and Automated Learning. (2019) 229-237. DOI: 10.1007/978-3-030-33607-3_25. Best student paper award IDEAL 2019.
4. Abdullah S. Alharthi, Krikor B. Ozanyan, 'Sensor Fusion for Analysis of Gait under Cognitive Load Deep Learning Approach,' IEEE Sensors Applications Symposium (2020) (Accepted and pending for presentation). (Available online): https://www.research.manchester.ac.uk/portal/en/publications/sensor-fusion-for-analysis-of-gait-under-cognitive-load(baedaf75-bc59-47ad-adb0-20b554f6b986).html

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