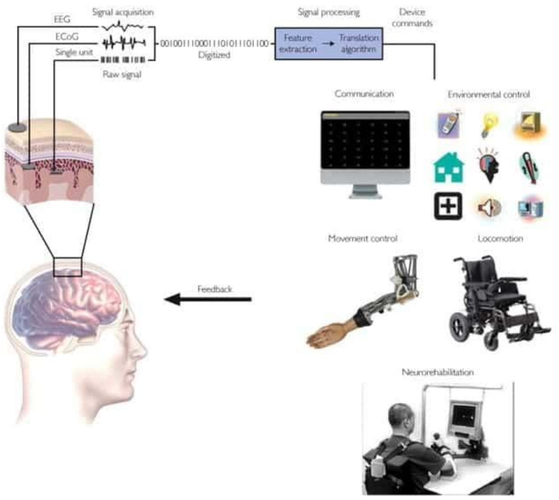
PhD Project:

Brain-Computer Interface & their Applications: Challenges and Future Directions

Project Description:

An electroencephalography (EEG)-based brain–computer interface (BCI) is a system that provides a pathway between the brain and external devices by interpreting EEG. EEG-based BCI applications have initially been developed for medical purposes, to facilitate the return of patients to normal life. In addition to the initial aim, EEG-based BCI applications have also gained increasing significance in the non-medical domain, improving the lives of healthy people, for instance, by making it more efficient, and collaborative and helping them develop themselves.



Components of a typical BCI system and its communication methods—simplified scheme [4]

There are many challenges in EEG-based BCI development and research as the cross-subject classification of motor imagery data. Due to the highly individualized nature of EEG signals, it has been difficult to develop a cross-subject classification method that achieves sufficiently high accuracy when predicting the subject's intention. In 2020, we proposed a multi-branch 2D convolutional neural network (CNN) that utilizes different hyperparameter values for each branch and is more flexible to data from different subjects. Our model, EEGNet Fusion, achieves 84.1% and 83.8% accuracy when tested on the 103-subject *eegmmidb* dataset for executed and imagined motor actions, respectively. The model achieved statistically significantly higher results compared with three state-of-the-art CNN classifiers: EEGNet, ShallowConvNet, and DeepConvNet. However, the computational cost of the proposed model is up to four times higher than the model with the lowest computational cost used for comparison.

In our recent studies, we further improved the model with a 5-branches 2D CNN that employs several hyperparameters for every branch and this network is more adaptable to data from various subjects. The proposed model achieved promising results on three publicly available datasets, the EEG Motor Movement/Imagery, the BCI Competition IV 2a, and the BCI Competition IV 2b dataset. The *eegmmidb* dataset is used for testing for actual and imagined motor activity and our newly proposed model, EEGNet Fusion V2, achieves 89.6% and 87.8% accuracy, respectively.

Moreover, the proposed model outperforms on the BCI Competition IV-2a and 2b datasets with an accuracy of 74.3% and 84.1% for the cross-subject classifications, respectively. Compared with the EEGNet, ShallowConvNet, DeepConvNet, and EEGNet Fusion, the proposed model's accuracy is higher. However, the proposed model has a bit higher computational cost, i.e., it takes around 3.5 times more computational time per sample than the EEGNet Fusion.

There may be further opportunities to explore more multi-branch designs. As EEG data is non-stationary, which has implications for the feature extraction process, different approaches can be explored to address the issue of non-stationarity. Transfer learning approaches can be implemented to resolve the issue of less data per subject and inter-subject variations of the EEG-based dataset.

Although the models were tested only on motor movement and imagery data, the underlying architecture is known to be well-suited for different EEG-based tasks. In the future, more testing of the model(s) should be done to validate its performance on a wider range of EEG-related areas, such as sleep stage and disorder detection or driver fatigue evaluation. Furthermore, the multi-branch architecture is not limited to three or five branches, and architectures with a higher number of branches could be explored.

Contact:
Dr Yar Muhammad: Y.Muhammad@herts.ac.uk
Profile: https://go.herts.ac.uk/yar_muhammad

References:

[1] Chowdhury, Radia Rayan, Yar Muhammad, and Usman Adeel. 2023. "Enhancing Cross-Subject Motor Imagery Classification in EEG-Based Brain–Computer Interfaces by Using Multi-Branch CNN" *Sensors* 23, no. 18: 7908. https://doi.org/10.3390/s23187908

[2] Roots, Karel, Yar Muhammad, and Naveed Muhammad. 2020. "Fusion Convolutional Neural Network for Cross-Subject EEG Motor Imagery Classification" *Computers* 9, no. 3: 72. https://doi.org/10.3390/computers9030072

[3] Värbu, Kaido, Naveed Muhammad, and Yar Muhammad. 2022. "Past, Present, and Future of EEG-Based BCI Applications" *Sensors* 22, no. 9: 3331. https://doi.org/10.3390/s22093331

[4] Kawala-Sterniuk, Aleksandra, Natalia Browarska, Amir Al-Bakri, Mariusz Pelc, Jaroslaw Zygarlicki, Michaela Sidikova, Radek Martinek, and Edward Jacek Gorzelanczyk. 2021. "Summary of over Fifty Years with Brain-Computer Interfaces—A Review" Brain Sciences 11, no. 1: 43. https://doi.org/10.3390/brainsci11010043