Wearable sensors and artificial intelligence for monitoring of Parkinson's disease

Summary

Parkinson's disease (PD) is the second most common neurodegenerative disorder, affecting more than 10 million people worldwide. Being a movement disorder, many motor symptoms manifest at different stages of the disease, including bradykinesia (slowness of movement), postural stability, gait impairment, and freezing of gait (FOG - a sudden motor block). PD represents a very complex disorder for several reasons, including the difficulty of early diagnosis, the heterogeneity in the manifestation of symptoms, their evolution, and their fluctuations throughout the day. For these reasons, the longitudinal monitoring of PD, possibly performed in daily life conditions, is fundamental for achieving a global picture of the disease and its evolution, allowing the planning of proper therapy adjustments. A large spectrum of technological solutions is available for the accurate and precise evaluation of motor impairment in PD. However, most of them are costly and can be used only in laboratory settings. In this context, wearable motion sensors represent a valuable and ecological solution for collecting and processing movement data, allowing to continuously monitor PD in free-living settings. Moreover, the combination of wearable sensors and machine learning (ML) methods provides great opportunities for an accurate and objective evaluation of motor impairment in PD.

This present thesis aims to provide new opportunities for monitoring PD using wearable sensors and ML. A wide range of sensor settings and signal processing, ML, and deep learning (DL) methods for PD assessment are described and discussed in this study. Indeed, their use for the evaluation and prediction of specific motor symptoms is described. Overall, motion data were recorded from more than 200 subjects with PD, using different experimental protocols for different objectives. Specifically, this thesis describes and discusses methods for the automatic evaluation of bradykinesia, estimation of postural stability and gait impairment, and detection and prediction of FOG. Both dedicated hardware and sensors embedded in commercial smartphones were used for data collection. Different signal processing, ML, and DL algorithms were designed to maximize performance while maintaining a low computation burden.

When evaluating lower-limb bradykinesia using a single smartphone, results demonstrated that the correlation between the computer scoring system and the average clinical score was larger than the best agreement among four independent raters. This suggests that, for specific tasks, computer methods may overcome inter-rater variability. When assessing postural stability using a smartphone during simple activities such as stance and turning, results suggested that it is possible to obtain a gross evaluation of the postural response in PD. This information may be important for predicting the risk of falls and taking proper countermeasures. The combination of a single inertial sensor and DL methods provided promising performance in FOG detection, even predicting FOG before its actual occurrence. The large number of participants involved in the analysis and the heterogeneity of activities executed by subjects strongly enforce the validity of the obtained results. Moreover, the high-speed and low-memory characteristics of the developed algorithm suggest a possible real-time implementation of the detection model in a stand-alone wearable device. The designed solution can be used for triggering some kind of auditory or tactile cue for reducing FOG or even preventing its occurrence. Overall, the results suggest that it is possible to use simple and non-invasive technology for monitoring several motor aspects of PD. The designed solutions can be used during the normal follow-up clinical visits for a more objective estimation of motor symptoms severity. Moreover, they can be used to remotely assess the disease, providing precise and continuous measures describing the presence, severity, and fluctuations of PD motor signs.

Future studies will make use of even less obtrusive wearable solutions (e.g., smart clothes), in order to maximize patient compliance, thus allowing long-term monitoring of PD. Moreover, data will be collected and analyzed in semi-supervised and non-supervised environments, in order to evaluate the robustness of the designed algorithms in heterogeneous and complex real-life scenarios.