Machine Learning approaches applied to the analysis of muscle activation patterns

Summary

Gait analysis is the study of human locomotion and is widely used to assess normal and pathological functions of human walking. Particularly, the instrumented gait analysis allows for collecting signals from several sensors (i.e. basographic and electromyographic sensors) placed on the subject body, and to obtain a fully and completely operator-independent statistical analysis of the gait. However, the aggregation and the correct interpretation of data collected is a crucial point to provide an objective and correct assessment of the characteristics of human walking, usable for clinical practice.

In a previous work, a method based on a fuzzy logic classifier, named GAITSCORE, was developed to aggregate data collected from basographic sensors: the result of the system is a gait impairment score, that provide an objective and quantitative measurement of gait impairment. A further improvement of this system would be the integration of the information related to the timing of muscular activation during gait. However, human locomotion is characterized by a large intra-subject variability in muscle activation patterns: muscle activation onsets and offsets markedly vary from stride-to-stride also in individuals without neurological or orthopedic disorders. Therefore, before being able to correctly use the information extracted from the EMG signals, it is necessary to develop strategies to identify the variability in the muscle activation patterns and to provide tools for a correct interpretation of the acquired data. Particularly, for a correct interpretation of EMG data, a promising strategy consists in grouping strides characterized by similar EMG activation patterns.

The CIMAP (Clustering for Identification of Muscle Activation Patterns) is the method, based on machine learning techniques, that has been developed for this purpose: it allows to group strides in clusters sharing similar EMG activation patterns. Once the clusters are obtained, an element that is characteristic of each cluster

is defined. This element is the prototype and it represents all the elements of a specific cluster.

The first part of the thesis presents the CIMAP method, its optimization and the final validation. The CIMAP is applied to EMG signals acquired from different muscles of lower limb of both healthy and pathological subjects. The results obtained have proved that this method definitively improves the correct interpretation of the acquired signals. At first the method provides an organized representation of the most common type of muscle activation patterns of the individual, that may be useful to clinicians to simply identify possible criticism in subject walking. Then, the characterization of the all the strides belonging to a specific cluster with a single element (the prototype) allows for introducing the concept of principal activation. From the biomechanical point of view, the principal activations represent those activations necessary for accomplishing a specific motor task and they describe the essential contributions of a specific muscle to the movement. In practice, the principal activations of each muscle are extracted as the intersection of the corresponding cluster prototypes, obtained using CIMAP. The introduction of the concept of principal activations allows characterizing a subject with a single muscle activation pattern, representative of the specific muscle. This characterization allows for performing complex analysis of entire group of subjects.

To illustrate the potentialities of the principal activation concept, a first study is performed on a population of 100 school-age children. The results show that, analysing gait data using principal activations only, it is possible to clearly understand the biomechanical contribution of the analyzed muscles to the movement and to describe muscle activity in an simple form that may be useful in clinical practice, for a correct interpretation of gait data. As an example, in this study, it is possible to identify and describe phenomena related to gait maturation.

It is followed by two studies aimed to compare muscle activation in healthy and pathological subjects, using principal activations. In the first study gait data acquired from a group of patients effected by normal pressure idrocephalus are compared with gait data acquired from a group of age-matched healthy subjects (controls). In the second study, gait data acquired from 20 patients with Total Hip Arthroplasty at 3, 6 and 12 months after surgery and 20 age-matched controls are analysed and compared. The dataset comparison has always been a very challenging problem due to the EMG intra-subject variability. The results obtained in these studies highlight how the application of the CIMAP algorithm and the principal activation extraction may be powerful tools for the aggregation of EMG results of huge dataset, and they may allow a clear comparison between different datasets.

Then, two studies are presented in order to introduce tools, based on muscle principal activations, for the quantification and interpretation of specific aspects of gait. In the first study an EMG asymmetry index, for assessing muscle-activation asymmetry in cyclic movements, is introduced and validated over o population of 114 subjects consisting of healthy subjects and both neurological and orthopaedic patients. Different asymmetry levels are expected to be found on each group, considering the different disorders and treatments which patients underwent. The value obtained for the asymmetry index are consistent with the expected asymmetry level of each specific group and this suggests that the index can be successfully used in clinics for an objective assessment of the asymmetry of muscle activation patterns during locomotion.

In the second study, two indices are presented. The first one is a muscle-specific functionality index that quantifies the similarity of the activation pattern of a specific muscle of a subject with that of the corresponding muscle of a healthy population. The second one, considering a pool of muscles, is a global index to quantify the distance between the functionality of a specific subject and that of a reference population. The effectiveness of the muscle-specific and global indices is validated by applying these indices to a group of 25 healthy children and to a group of 25 hemiplegic children to measure the distance of specific subjects and of the entire populations from a reference population of 55 healthy children. The results obtained show that these indices may be useful in clinics: it may be used for providing an overall evaluation of muscle functionality during both the first instrumental examination of a subject and when a subject is evaluated successively, along a rehabilitation program.

A brief introduction to the application of principal activation extraction to muscle synergy analysis is then provided. The results suggest that this kind of processing provide a more interpretable assessment of the modular organization of the central nervous system during a walking task without any loss of information.

In conclusion, this thesis describes several tools that have been developed and validated to analyse the muscle activation characteristics during gait. They may be useful in clinical practice (to help clinicians in the interpretation of data of single individuals or to assess patient improvement during a rehabilitation protocol) and in clinical studies (to characterize gait anomalies correlated to a specific pathology). Moreover, they may be used in research studies as demonstrated by the muscle synergies application.

Finally, a future work will be the integration of the indices in GAITSCORE to construct an initial dashboard for analysing the gait of a subject.