論 文 の 内 容 の 要 旨

論文題目　**A Method for the Estimation of Muscle　Activation Pattern from sEMG and MRI using　Electrical Network Graph Theory**（電気回路網のグラフ理論にもとづく表面筋電位と **MRI** からの筋活動パターン推定）

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The estimation of muscles' activities is an important topic that has recently gained a lot of interests for many fields in which that information could be applied. At the state of the art different methods were proposed with diverse approaches and using different type of input information.

The most common approach is to calculate an estimation of muscles' activation using the surface electromyography (sEMG), which records the muscles' electrical activity from electrodes positioned at skin level over the targeted muscle groups. In order to overcome the low spatial resolution of traditional sEMG methods, the high density sEMG (HD-sEMG) was recently introduced. It utilizes a matrix of dense electrodes to collect information from multiple points over the target muscle. Even though HD-sEMG allowed a better investigation of the neural control on muscles, several limitations were highlighted. In fact the increase of electrodes came with an increase of the information collected in the unit of time, with a higher processing time as a consequence. Furthermore, one important limitation of this approach is the inability to estimate the information coming from deep muscles. This information could be accessed with the use of imaging methods. Among these category of methods the golden standard is the magnetic resonance imaging (MRI) which allows to obtain detailed images of anatomical structures. The use of MRI is not only limited to the

acquisition of static images, but it can also be applied for the visualization of metabolic physiological processes. In that case it goes under the name of functional MRI(fMRI). Even though the fMRI is mainly known for its application on brain science, there is another form of fMRI called muscle fMRI (mfMRI) which exploits a different contrast level on T2-weighted images to assess the activation of all muscles, including deep ones. Furthermore, due to how the mfMRI images are created, it does not suffer noise problems that are usually corrupting the EMG information. However, despite its ability to access all muscles, mfMRI provides information at a very low time resolution and it is very expensive.
Alternative methodologies were proposed with different type of information processed for the estimation of muscles activities, such as electric impedance myography (EIM), elastography or EMG computed tomography (EMG-CT). However important limitations are identifiable in these methods too, such as models that are too complex or that require time consuming optimizations and the use of cumbersome instruments or external perturbations for the estimation.

With my thesis I wanted to introduce a novel method for the estimation of muscle pattern activation of forearm muscles using a simple and intuitive modeling based on circuit theory. The model aims to overcome the limitations that could be identified in the state of the art methods using electromyography (EMG), magnetic resonance imaging (MRI) and other alternative technique that were proposed. In particular the proposed method wants to provide a solution for the impossibility of obtaining an estimation of deep muscles activities with a time resolution comparable with that of the electromyography. Furthermore, in the past methodologies, often the morphology of the body parts studied was ignored, rather basing the processing on reasonable, yet abstract assumptions.
The method I proposed in this thesis utilizes single rows of EMG wrapped around the forearm and construct a purely resistive electrical network to describe the volume conductor morphology using visual information that could be directly extracted from an MRI slice. A set of intuitive rules to describe the information in the MRI as a resistive network is presented. The resulting network of resistances could be conveniently described using a graph where muscles and electrodes are the nodes of the graph, the edges are represented by the different connections created and the weights of the edges is given by the resistance values. The resulting graph relate the voltages on the electrodes' nodes and the currents on the muscles' nodes in the electrical network in a linear manner. Furthermore, due to the criteria followed to construct the model, the resulting description is strongly subject-dependent. The currents on the muscles' nodes were then estimated solving an inverse problem exploiting the matrix description of the electrical network obtained from the graph theory. The

validation of the resulting muscle activation patterns needs to be indirect and is based on criteria on the electrodes space and based on information from anatomical literature. The results shows that the method applied on isometric contractions could provide estimation explaining over 90% of the input information and that have a correspondence with the literature information.

To better understand the relation between the electrodes in specific position and the method's performance for different motor tasks, a study on the influence of the electrodes removal was performed. The issue is approached with the removal of 1 to 3 electrodes and assessing the influence on both the electrode and muscle space. The findings suggests that some of the electrodes could be removed without affecting the results significantly, while parts of the forearm surface are fundamental for the exploitation of the EMG input information. Furthermore, the influence of the position of the electrodes on the estimation of muscles mainly involved on each task was studied. Results showed that electrodes not directly over the activated muscles might have an influence on the muscle currents estimation, indicating the presence of underlying path in the electrical network.

Finally, the method is extended to the dynamic cases, with a study on non-isometric movements and estimation over the time dimension. The extension to the time dimension is approached with a windowing of the EMG input signal. The method described is then applied on each window to estimate the currents during simple wrist movements. The results show that the input EMG information could still be mostly reconstructed and the resulting activation are valid solutions from an anatomical point of view. In particular for flex-extension movements of the wrist, confirming the results obtained for the isometric case. Given the simplicity of the proposed model, the calculation time was well under the electro-mechanical delay, proving that its potential application in real time situations.

I believe that this type of new approach, where the morphological information of the anatomy is directly utilized could provide a way to extract additional information from the EMG, with important potential application in the fields of prosthetic and rehabilitation therapy.