Basic research in surface electromyography

The Italian-South African research collaboration project, entitled *Neuromuscular system assessment by surface EMG: finite element modelling – Part II*, between the Bioengineering Centre LISiN at the Politecnico di Torino, Torino, Italy and the Bioengineering Group at the University of Pretoria, has been running since 2004. The project is funded within the framework of the Italian-South African Research Collaboration Programme. Both the South African government, via the National Research Foundation (NRF), and the Italian ministry contribute toward the expenses of the project. On the South African side the project is headed by Prof Tania Hanekom, a member of the Bioengineering Group within the Department of Electrical, Electronic and Computer Engineering at the University of Pretoria. Prof Roberto Merletti, head of the Bioengineering Centre LISiN at the Politecnico di Torino and an international leader in the field of modelling of muscle physiology, is the overseas partner.

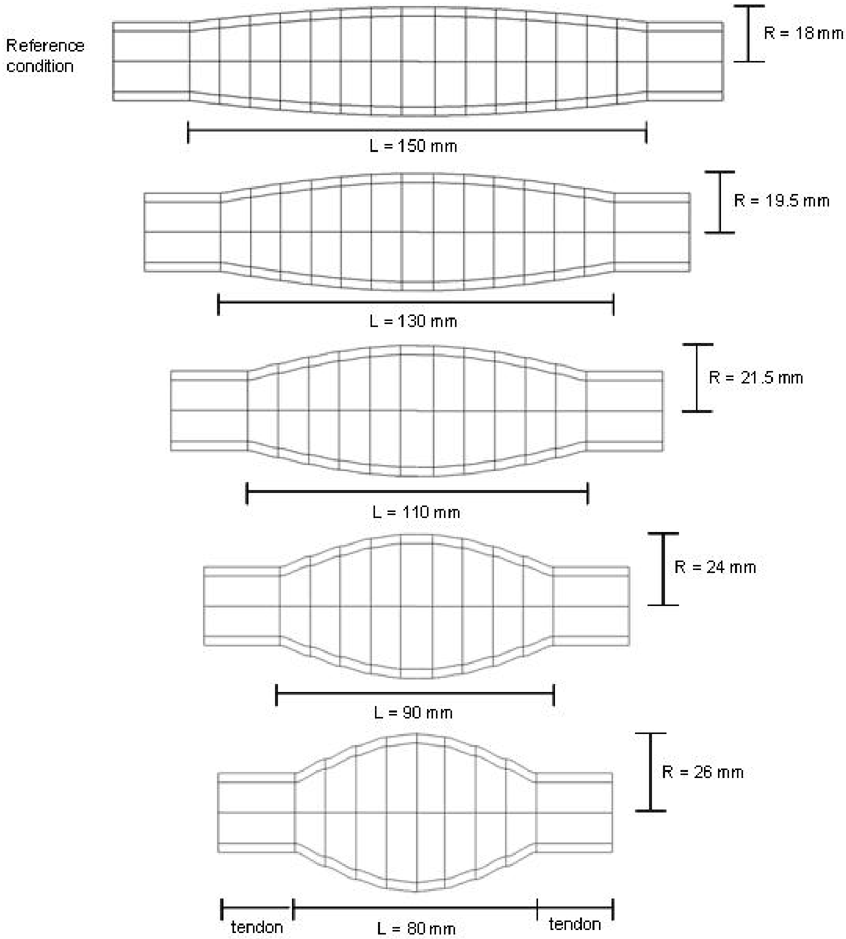
In the three month period of May to August 2007 Ms Suzanne Hugo and Mr Stuart Smith, both postgraduate students of the Bioengineering Group paid a research visit to the Politecnico di Torino in Italy. The objective of the visit was two-fold: to equip postgraduate students with research experience in an international biomedical engineering environment and to contribute towards the newest developments in mathematical modelling of surface electromyography.

→ 1. From left to right, Stuart Smith (UP), Prof Roberto Merletti (Politecnico di Torino) and Suzanne Hugo (UP) at the Bioengineering Centre LISiN at the Politecnico di Torino, Torino, Italy.

Surface electromyography (sEMG) is the term used for non-invasive (i.e. on the skin surface) recordings of the electrical activity that is generated by muscle contraction. A muscle consists of hundreds to thousands of muscle fibres depending on the size of the muscle. The muscle fibres are grouped together in motor units where each motor unit is innervated by a single motor nerve fibre. Consequently, when a signal is conducted via the nerve fibre servicing a motor unit, all the muscle fibres comprising the motor unit contract simultaneously. The body uses selective activation of different motor units as a means to control the strength of muscle contraction and also the spatial precision of movements. Larger motor units would typically be used for strong contractions requiring less precise control (such as walking) while small motor units would typically be used for low-force, accurate spatial control functions such as eye movement or writing. During muscle contractions, the electrical activity of the active motor units may be detected by electrodes placed on the skin. The resultant surface electromyography (EMG) signal reflects the contributions of all the motor units that are within the detection volume of the electrode system. Numerous difficulties arise when one wants to use the sEMG signal to obtain information regarding the underlying physiology of muscles and subsequently for diagnostic and other applications. In the first place the tissues located between the signal sources (i.e. the motor units) and the detection electrodes act as low-pass filters, causing a blurring effect on the surface potentials. The electrical potential generated by a motor unit is thus spread over a large skin region. Secondly, the territories of motor units intersect within a muscle, i.e. motor units are intertwined causing many motor units to contribute to the signal measured at a specific electrode location. The contribution of each individual motor unit is hence difficult to isolate within the measured sEMG. Thirdly, in the case of different muscles in close proximity to one another, the electrical activity of one muscle may be detected over another non-active one (crosstalk signals). Apart from these important issues, factors such as interpersonal variability in muscle anatomy and the influence of muscle contraction on model parameters (which are frequently difficult to quantify) add to the challenges that researchers face in this field.

Surface EMG signal modelling is fundamental for interpreting EMG recordings, designing and testing algorithms for information extraction, and for didactic purposes. In the last decades, many surface EMG generation models have been proposed. Both numerical and analytical approaches were used to describe the electrical properties of the tissues separating the muscle fibres and the detecting electrodes. In the current project two types of models were focused on. The first model was developed to simulate the generation of the interference surface EMG signal, i.e. the objective was to simulate a signal that contains all the components that a measured sEMG signal would contain. Previous models simulated the effect of simple components of the sEMG signal at the skin surface, e.g. by using the activity of single muscle fibres instead of complete motor units and multiple motor units within one muscle. The specific aim of the study was to investigate crosstalk signals and how they are affected by 1) the anatomy of the limb, 2) the conductivities of the tissues, and 3) the electrode system for signal detection (i.e. the way in which the electrodes are placed to detect the signal). Since this model was an analytical model, the complexity of the geometry that could be used was limited. For this reason a cylindrical approximation of the muscle was implemented. The study demonstrated under which circumstances specific electrode systems are effective to reduce crosstalk from neighbouring muscles. It also underlined the effect of fat layer thickness, fibre length, inter-electrode distance, and skin conductivity on crosstalk reduction. These results are particularly important for the selection of electrode systems in practical applications.

The second model addressed the issue of muscle contraction. During muscle contraction a number of additional factors have to be accounted for such as the changing geometry of the muscle and sliding of the muscle under the electrode system. A more accurate representation of the anatomy was required to enable an accurate assessment of the effects of the abovementioned factors on the sEMG. One needs to know how much of, for example, a decrease in signal amplitude is due to the attenuation caused by a superficial fat layer or, alternatively, by an increase in the electrode to motor unit distance resulting from the change in the muscle geometry during contraction. A finite element model of a muscle for different stages of contraction was developed (Figure 2). One of the novelties of the model is the inclusion of space-variant tissue properties, i.e. instead of using the customary assumption that the muscle's electrical properties are the same in all the directions, the model was created to reflect the natural occurring directional tissue properties in muscle tissue. During



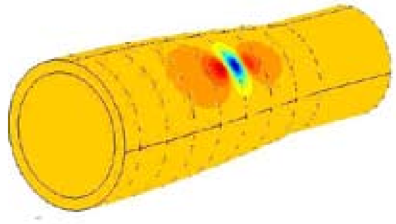
→ 2. Model geometries for five stages of muscle contraction.

the first part of the project the model was created to represent a fusiform muscle without any superficial layers such as fat and skin. During the recent visit the model was expanded to include a superficial fat layer. A typical result obtained with the model is shown in Figure 3 where the instantaneous distribution of the electrical potential, generated by a single muscle fibre, is shown on the surface of the fat layer.

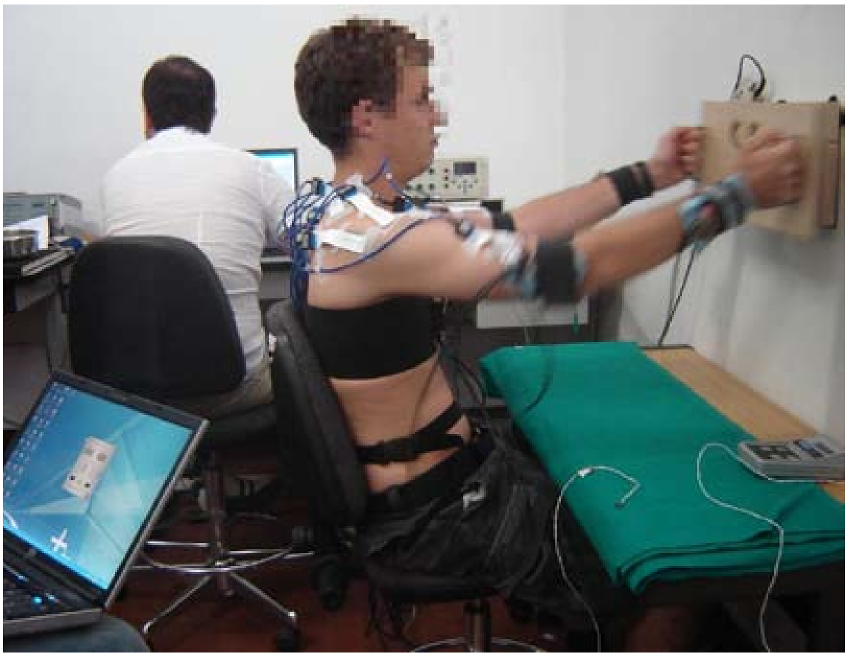
Applications of the model at this stage mainly lie in quantification of the effects of a number of variables on the sEMG so that accurate diagnostic and experimental tools may be developed. These in turn find major application in sports research and medicine, rehabilitation and geriatric medicine.

Lastly the work at LISiN involved experimental work to obtain measured results against which the models may be validated and to obtain parameters that are required for the construction of the models. Validation is done by comparing sEMG results predicted by the models and experimental results recorded under controlled conditions that should reflect the conditions for which the models were developed. To obtain experimental data for the muscle contraction model, measurements were taken for the biceps brachii (upper arm) muscle. The experiment was performed for five elbow joint angles, representing the five different stages of contraction in the model. Preliminary results indicated good correspondence between experimental and simulated results with regard to the magnitude changes of the sEMG signal with propagation and the localisation of the tendon regions and innervation zone.

Research performed under the project has been published both locally and internationally and a number of journal publications are expected to result from the current collaboration effort. Once again it is clear that the education provided by the University of Pretoria lives up to the standards of the international research community and that staff and students are competent to play a vital role in the expansion of the global bioengineering knowledge base.



→ 3. The potential distribution on the surface of one half of the muscle model caused by the electrical activity of a single motor unit. Since the model is symmetric, the solution may be calculated over one half of the muscle. Blue represents the most negative electric potential while red represents the most positive electric potential with colour gradients in-between to represent intermediate potential values.



→ 4. A subject performing specified muscle contractions. The experimental results are used to measure parameters that are required for the models and to verify results that were simulated using the muscle models.