Electrode position optimization for facial EMG measurements for human-computer interface

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Abstract— **The aim of this work was to model facial electromyography (fEMG) to find optimal electrode positions for wearable human-computer interface system. The system is a head cap developed in our institute and with it we can measure fEMG and electro-oculogram (EOG). The signals can be used to control the computer interface: gaze directions move the cursor and muscle activations correspond to clicking. In this work a very accurate 3D model of the human head was developed and it was used in the modeling of fEMG. The optimal positions of four electrodes on the forehead measuring the activations of frontalis and corrugator muscles were defined. It resulted that the electrode pairs used in frontalis and corrugator measurements should be placed orthogonally by comparison with each other to get a signal that enables the separation of those two different activations.**

Keywords - fEMG; volume conductor model; FDM; modeling

I. INTRODUCTION

We have constructed a wireless head cap that enables the measurements of facial muscle activations and the movements of the eyes. Our ultimate goal is to develop a measurement system that would suit in the control of a computer interface: the gaze direction could move the cursor with some facial expressions to correspond clicking. The radio circuit used in the wireless data transmission enables the use of six measurement channels. To be able to get a good signal quality with only a few measurement electrodes the electrode positions on the forehead should be planned carefully.

In this work a very accurate 3D head model is developed and used to model the fEMG. Modeled signal is used to optimize the electrode positions for fEMG measurements. Modeling of EMG is important also in other research areas: fEMG could be used in human-computer interfaces to control the cursor [3], but the use of the facial muscle activation measurements will probably increase also in medicine as the level of sedation or anesthesia is controlled with those measurements.

Modeling of EMG parameters has been in focus also earlier, and there exist several studies that model for example the motor unit potentials and the effects of changing different motor unit parameters on the surface EMG [1,2]. Most of the existing studies use mathematical models instead of anatomical. Also there is a lack of models that cover the whole activation feature of a muscle, not only the surface EMG produced from a few motor units. Our anatomic accurate 3D model allows us to obtain precise results for the purposes of the muscle activation modeling and we use a source that models the activation of a whole muscle.

II. MATERIALS AND METHODS

A. Head model

The volume data of the head used was of the Visible Human Female project consisting of anatomical cryosection images and CT slices. The initial segmentation of major tissues was performed employing 3D methods with flexible propagation restraints e.g, 3D active contour and level set methods. The resulting raw segmentations were further fine tuned where necessary using 3D morphological and 2D methods. In some cases when there were very complex structures or almost invisible tissue borders, manual segmentation was the only option.

For tissues within the skin and the eyes, synthetic tissue layers were produced using morphological methods due to their low visibility resulting from poor image contrast. For example the forehead muscles like corrugator and frontalis muscles could not be seen in every CT and cryosection image, but in the segmentation phase those two muscle types were approximated to exist at the positions where they should be according to the correlated CT and MR images in the book named Basic Atlas of Sectional Anatomy [4].

The volume conductor model included seven different tissue types: scalp, muscle, eye, skull, cerebrospinal fluid (CSF), grey matter, and white matter. The tissue resistivity values that were applied in the volume conductor model are shown in Table I.

TABLE I. TISSUE RESISTIVITY VALUES

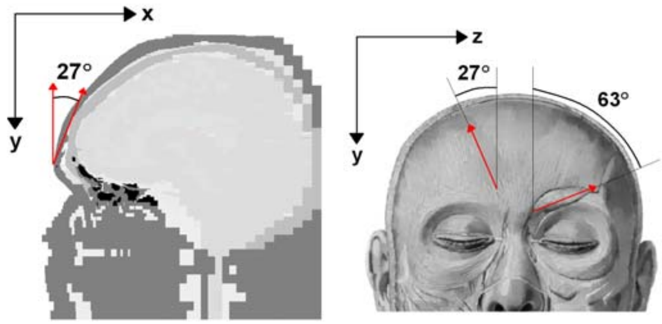
Tissue	*Resistivity / Ωcm*	*Reference*
Scalp	351	Latikka, Kuurne, Eskola [5] (the same resistivity than the grey matter has)
Muscle	250	Duck [6]
Eye (vitreous humour)	67	Gabriel & Gabriel [7]
Skull	5265	Oostendorp et al. [8] (value of white matter multiplied by 15)
CSF	55	Duck [6]
Grey matter	351	Latikka, Kuurne, Eskola [5]
White matter	391	[5]

Originally the segmented realistically shaped volume conductor model had a resolution of 0.33 mm x 0.33 mm x 0.33 mm. Anyhow the resolution had to be decreased in some parts of the model so that the calculation capacity of the computer and the calculation program were able to solve the forward and inverse problems. The best resolution was kept unchanged at the forehead parts, because the muscles whose activity the modeling concerned located there. A sagittal view of the original model and the model with the decreased resolution can be seen in Fig 1.

B. Simulated fEMG

Reciprocity theorem and lead field concept were used to calculate the surface potentials [9]. An iterative FDM solver developed in our institute was used to construct a finite difference method -model (FDM) of the segmented anatomical model. Lead vectors were calculated for all the 16 804030 nodes in the volume conductor model, and those lead fields were calculated with 33 different surface electrodes, one being all the time a reference. The lead vectors and source vectors in the muscles were used in calculations of the surface potentials.

The source configuration used to simulate the surface potentials consisted of dipoles in every node point of an activated muscle: In corrugator muscles (left and right) there were 17773 and 13123 source dipoles and in frontalis muscles 102470 and 91641. The whole muscle can be treated as a source, because muscles in a face always contract so, that every muscle cell in an activated muscle contracts despite the force needed. In facial muscles the gradation of tension force is carried out via variation in the firing rates. Source dipoles were unit vectors that were aligned approximately parallel to the realistic muscle cells. In the frontalis muscles dipoles were unit vectors directing 27° back and left or right depending on the side of the muscle. In the corrugator muscles dipoles were unit vectors directing upwards and 63° left or right. Fig 2. clarifies the directions of the source dipoles.



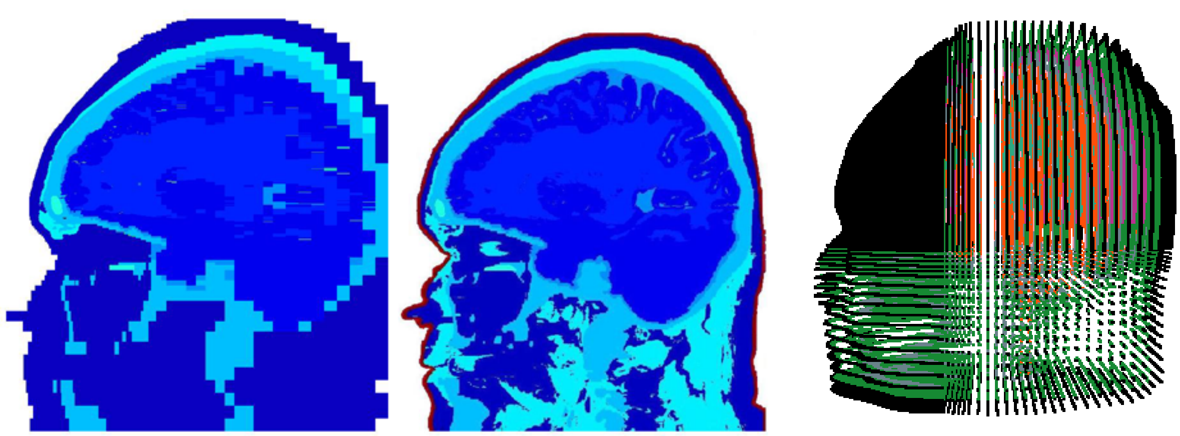
a) b)

Figure 2. a) Source dipoles in frontalis muscles were aligned 27 degrees backward. That was an approximation for the direction of the forehead and thus for the direction of the muscle cells in frontalis muscles. In the corrugator muscles dipoles were aligned on a (z,y)-plane the x component being zero. b) The direction of source dipoles in frontalis and corrugator muscles in (z,y)-direction. In frontalis muscles dipoles were aligned 27 degrees left and right, and in corrugator muscles 63 degrees left and right. Fig. b) modified from [10].

C. Optimal electrode positions

The positions of four electrodes measuring the activations of frontalis and corrugator muscles were defined in this work. Radio transmitter system has a limited data rate and the wireless data transmission in the current head cap enables the data transmission of six measurement channels with the sampling frequency of 1 kHz. Channels are reserved for bipolar measurements of fEMG (2), EOG (2), and the last two channels for later use e.g., for the measurement of brain activity. More detailed information of the radio transmitter in the head cap can be found in [11].

Optimal positions for muscle activation measurements were defined so that one of the source muscles at a time was chosen to be active and the surface potentials produced by that muscle were calculated. The surface potentials at the forehead were considered on 33 different electrodes. The electrode pair which produced the biggest potential difference was the most sensitive for the measurement and was selected to be the optimal electrode pair for measuring the activity of that specific muscle.



a) b) c)

Figure 1. The resolution of the original head model was decreased in posterior and lowest part of the head. a) Sagittal view of the model with the decreased resolution. b) Sagittal view of the original model. c) 3D view of the model with the decreased resolution.

III. RESULTS

We segmented Visible Human Female head from 855 cryosection images along with data from the CT images. The model comprised of seven different tissue types. The original model consisted of altogether over 160 million voxels and the model with decreased resolution of 16 million voxels. Voxel resolution was 0.33 mm in all dimensions in the region of interest. Within the eyes and skin we created more detailed synthetic segmentations based on anatomical data from literature. The lead field calculations with the model for 33 electrodes took almost five days, but those had to be calculated only once.

Optimal electrode positions obtained by comparing the simulated surface potential values on the forehead are shown in Fig 3. It can be seen, that the positions of the measurement electrodes for corrugator and frontalis are partly overlapping. That causes the signal of corrugator or frontalis muscle activation to be measured with both measurement electrode pairs, what means that we do not know whether the corrugator of frontalis is activated. It can also be seen, that for the frontalis muscles the electrode positions are not symmetrically placed on the forehead. This might result from the asymmetry of the muscles – those are by hand separated from the homogenous muscle tissue – and muscles can also be naturally asymmetric since the facial expressions are unique.

Obtained electrode positions were improved so that they have better separating capability for different sources. The 20 electrode pairs, which gave the biggest potential values for both right corrugator and right frontalis muscle, were selected for a test, in which the separating capability of the measurement electrode was studied - the electrode positions were tried to tune so that the electrode pair sensitive to the corrugator would not be sensitive to the frontalis. This way we attempted to avoid the overlapping problem. In Fig 4. there are potential values of the surface electrode pairs due to active corrugator (gray bars) and active frontalis (black bars). The electrode pairs which were the most sensitive for the corrugator are the ten first from the left and the ten last are the electrode pairs which were the most sensitive for the frontalis. In every electrode pair the ratio of the potentials resulting from the wanted source (corrugator or frontalis) and from the other (frontalis or corrugator) was calculated. The electrode pair which gave the biggest ratio was selected to be the electrode pair which measures the activation of the wanted source best without measuring the activation of the other source.

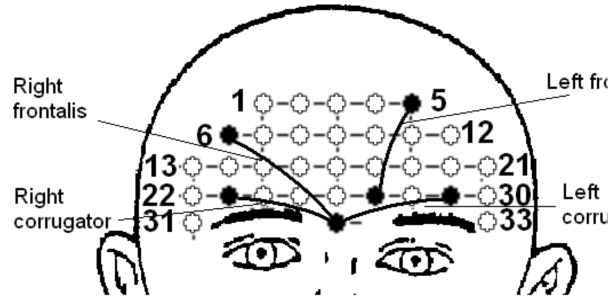


Figure 3. The most sensitive electrode pairs for right and left corrugator measurements are (32, 23) and (32, 29), and for right and left frontalis (32, 6) and (27, 5). The numbering of single electrodes goes from left and up to right and down.

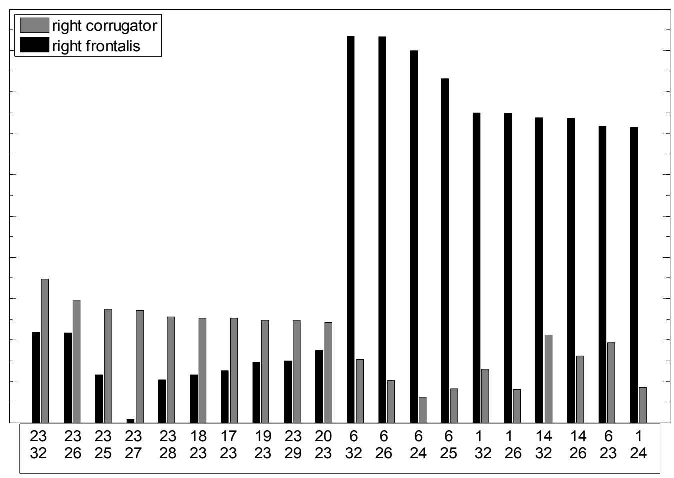


Figure 4. Black bars show the potential value difference due to right frontalis muscle activation and gray bars due to right corrugator muscle activation on each electrode pair. Electrode pairs are named underneath the bar pairs. The ten electrode pairs from left are selected, because, they showed the biggest sensitivity for corrugator muscle activation, and the ten electrode pairs on the right, because they were the most sensitive for the frontalis activation.

When the best measurement electrode pair for the corrugator activation was searched, the best potential ratio (32.6) was given by the electrode pair (23, 27). The ratios of other pairs were below 2. For the frontalis activation the electrode pair (6, 24) gave the best potential ratio (14.6). Also the electrode pairs (6, 26), (6, 25), (1, 26) and (1, 24) gave good ratios (about 10). The final optimal electrode positions for frontalis and corrugator measurements are shown in Fig 5. Because the left and right corrugator and frontalis muscles activate normally in tandem it is enough to measure only the other side.

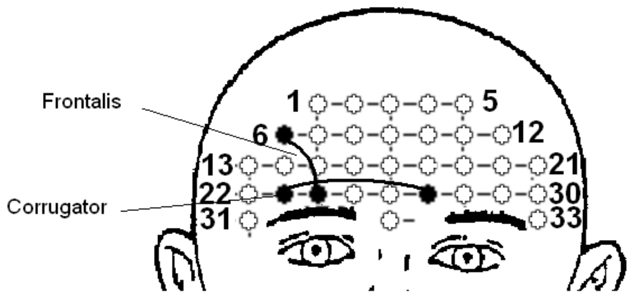


Figure 5. The optimal electrode positions for the measurements of frontalis and corrugator muscle activations.

Comparing the electrode positions in Fig 3. and Fig 5. shows that better separating capability for frontalis and corrugator muscle activation measurements is achieved by placing the electrode pairs more orthogonally. Our result of the optimal electrode positions is particularly applicable to the person used as a model. The anatomy of the head, facial muscles and eyes is highly individual and thus, the strict optimal electrode positions can vary from person to another. Still the main result holds: the positions of the electrode pairs should lie orthogonally on the forehead to be able to separate the signals from corrugator and frontalis sources. That is based on the directions of the muscle fibers: those are quite alike from person to person despite the fact that the thickness or the places of the muscles can vary.

IV. CONCLUSIONS

A new accurate model is now available for modelling purposes such as bioelectric field problems. It has high spatial accuracy and number of inhomogeneities providing good platform for various simulations. For bioelectric simulation with FEM or FDM methods the number of elements in the resulting model exceeds the standard computer resources. The model used in this study had seven but the latest version has already 23 different tissue types.

In this work the used source model for facial muscle activation was the whole muscle full of unit vectors all directed to same direction parallel to real muscle cells. In the future the activation of the frontalis and corrugator muscles could be measured and different source configurations inserted into the model to see what kind of source configuration produces the most realistic surface potential distribution. Real measurements should also be done to make certain that the obtained electrode positions provide better signal quality than those used in the current head cap.

With the current measurement system the movements of eyes and the activations of two different facial muscles can be measured, and measured information can be used to control the computer. We will develop our system further, and modeling of both fEMG and EOG will be used in the development.

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