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A practical method for quickly determining electrode positions in high-density EEG studies

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HIGHLIGHTS

► Measuring electrode position using a Polhemus digitizer.
► A method for reducing the number of channels to be measured.
► The method predicts the positions of channels that are not measured.
► The error in predicted position is comparable with the residual uncertainty.

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ABSTRACT

This report describes a simple and practical method for determining electrode positions in high-density EEG studies. This method reduces the number of electrodes for which accurate three-dimensional location must be measured, thus minimizing experimental set-up time and the possibility of digitization error. For each electrode cap, a reference data set is first established by placing the cap on a reference head and digitizing the 3-D position of each channel. A set of control channels are pre-selected that should be adequately distributed over the cap. A simple choice could be the standard 19 channels of the International 10–20 system or their closest substitutes. In a real experiment, only the 3-D positions of these control channels need to be measured and the position of each of the remaining channels are calculated from the position data of the same channels in the reference data set using a local transformation determined by the nearest three or four pairs of control channels. Six BioSemi ActiveTwo caps of different size and channel numbers were used to evaluate the method. Results show that the mean prediction error is about 2 mm and is comparable with the residual uncertainty in direct position measurement using a Polhemus digitizer.

1. Introduction

In multi-channel electroencephalogram (EEG) studies, information about the three-dimensional (3-D) position of each electrode on a subject's head is often required for correlating EEG data with the underlying brain activities [11]. Such information is also needed for accurate registration of EEG data with anatomical images from MR or CT scans [6,10], and for employing spatial enhancement techniques such as deblurring [7] and source localization [4,12]. Traditionally, clinical EEG is recorded by placing 19 electrodes on the scalp at locations specified by the International 10–20 system [5]. In recent years many new electrode systems have been developed and used for high-density EEG studies. Some of these new systems maintain the basic principle of standardizing electrode placement employed by the 10–20 system but insert more sites between the original 19 electrodes. One example is the 10–10 system which extends the number of electrodes (channels) to 74 [3]. Another example is the 10–5 system (also called the 5% system) which can contain up to 345 electrodes [9]. Manufactures have also developed electrode caps which do not follow the above principle of standardizing electrode placement. For example, the ActiveTwo 128-channel, 160-channel, and 256-channel caps manufactured by BioSemi (Amsterdam, Netherlands) have electrode positions that are radially equidistant from Cz. The (32, 64, 128, 256-channel) Geodesic Sensor Net (GSN) manufactured by Electrical Geodesics, Inc. (EGI; Eugene, OR, USA) is another example. For those systems, the 3-D position of each electrode (or channel) with reference to the subject's head has to be actually measured in each experiment. This process is often called sensor or channel registration.

A popular device for sensor registration is a magnetic digitizer manufactured by Polhemus (Colchester, VT, USA). The Polhemus digitizer uses a stationary transmitter to form a fixed 3-D

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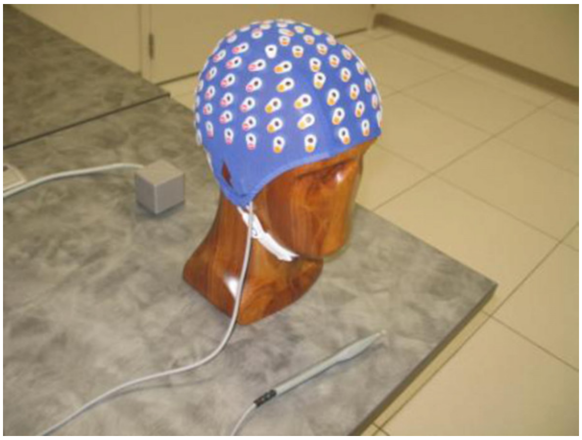

Fig. 1. A 128-channel BioSemi ActiveTwo electrode cap is placed over a wooden head model in order to generate the reference electrode position data.

coordinate system and a stylus probe to be placed at the measurement site. To determine the 3-D position of each electrode relative to the subject's head, the absolute positions of three fiducial points (nasion, left and right pre-auricular points) in the fixed 3-D coordinate system are first measured to establish a head coordinate system. The directly measured (absolute) position of each channel is then transformed to obtain the 3-D coordinates in the head system. To correct for the effects of head movement during the measurement, one or several reference receivers are attached to the subject's head. In the actual measurement the user moves the stylus to each electrode for digitizing. When the number of channels is large, the process can be tedious and time consuming, and the chance of human-induced inconsistency and fallibility increases.

To reduce the time for sensor registration, Le et al. [8] proposed a method that only requires measuring 14 distances between 11 electrodes. A limitation of the method is that it can only be applied to the standard 10–10 system. For fast sensor registration, EGI developed a Geodesic Photogrammetry System that uses a precision geodesic dome of 11 cameras to photograph the GSN. The system is bulky and expensive, and can only be applied to an EGI GSN. In this report we describe a simple and practical method that is aimed to facilitate and improve sensor registration using a Polhemus digitizer and can be applied to any electrode system.

The proposed method consists of three components or steps. (1) Establish a reference data set that consists of 3-D positions of all channels. This data set is obtained by placing the electrode cap on a reference head, which can be a head model (as shown in Fig. 1) or a human head that matches the size of the cap and has an average/normal shape, and digitizing the 3-D position of each channel. (2) Define a set of control channels that are adequately distributed over the entire cap. A simple choice is the standard 19 channels of the 10–20 system, or their closest substitutes. In a real measurement on a subject's head (target head), only the positions of these control channels are measured, and the positions of the remaining channels are calculated (predicted) using the algorithm described in the next step. (3) For each target channel whose position needs to be calculated, find a subset of nearest control channels (our results show that a subset consisting of three or four nearest control channels results in the least prediction error). From these control channels, a local mapping from the reference head to the target head is established, and the position of the target channel is then calculated from position of the corresponding channel in the reference set using local mapping.

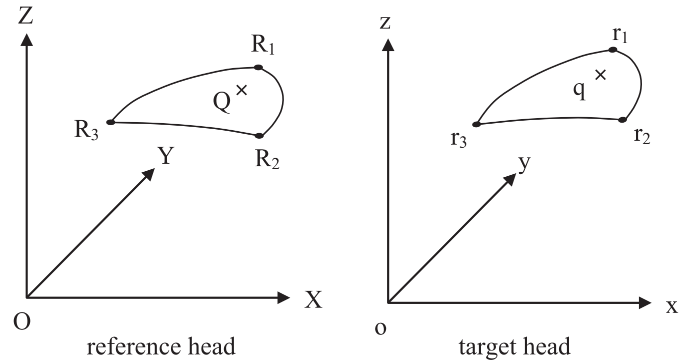

Fig. 2. Mapping of an arbitrary channel Q on the reference head to the corresponding channel q on the target head. R_1, R_2 and R_3 are the three nearest control channels to Q and r_1, r_2 and r_3 are corresponding control channels on the target head.

2. Method

2.1. Theory

The theory of local mapping using three control channels is described with the help of Fig. 2. The left side of the figure shows the head coordinate system of the reference head (O-XYZ) and the right side shows that of the target head (o-xyz). Point q represents a non-control channel on the target head and Q represents the corresponding channel on the reference head. The goal is to find a transformation that maps the (known) 3-D coordinates of Q to that of q.

R_1, R_2 and R_3 are the three nearest control channels to Q on the reference head and r_1, r_2 and r_3 are the corresponding control channels on the target head. Since the exact relationship between the shapes of the reference head and the target head is unknown, the algorithm is based on a local approximation: the triangular plane on the target head formed by r_1, r_2 and r_3 are transformed from the triangular plane on the reference head formed by R_1, R_2 and R_3 by a combination of rotation, scaling and skewing specified by a 3×3 matrix M [2]:

$$(x\,y\,z) = (X\,Y\,Z) \cdot M = (X\,Y\,Z) \cdot \begin{pmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{pmatrix} \tag{1}$$

where $(X\ Y\ Z)$ represent the 3-D coordinates of an arbitrary point on the reference surface bounded by R_1, R_2 and R_3 and $(x\ y\ z)$ are the 3-D coordinates of the corresponding point on the target surface bounded by r_1, r_2 and r_3. M can be solved by the known coordinates of the three sets of control channels. If we use matrix A to represent the 3-D coordinates of R_1, R_2 and R_3, and matrix B to represent the 3-D coordinates of r_1, r_2, and r_3,

$$A = \begin{pmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_2 \\ X_3 & Y_3 & Z_3 \end{pmatrix}, \quad B = \begin{pmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \end{pmatrix}$$

we have the following matrix equation:

$$B = A \cdot M \tag{2}$$

M can be solved as:

$$M = A^{-1}B \tag{3}$$

where A^{-1} is the inverse of A. The coordinates of the point q can then be obtained from the coordinates of point Q by using Eq. (1).

Our results show that the accuracy of the method can generally be improved by using four nearest control channels instead of three, especially for the peripheral channels (most distant from Cz).