Nonlinear Phenomena in Electromagnetic Fields
T. Furuhashi and Y. Uchikawa (Editors)

AN ESTIMATION OF THE NEURAL BEHAVIOR IN THE HUMAN BRAIN BY THE CORRELATIVE ANALYSIS

K.Kitsuta, H.Saotome, S.Hayano and Y.Saito

College of Engineering, Hosei University, Koganei, Tokyo 184, Japan

Abstract

This paper proposes a modified correlative approach to estimate the current flows from the local magnetic field distributions. This new method is now applied to estimate the current flows in the human brain. As a result, a sequential current flow in the human brain is clarified when the median nerve of the right wrist is stimulated electrically.

1. INTRODUCTION

One of the most important and interesting investigations concerned with the biological systems is to clarify the neural behavior in the human brain. With the developments of modern high sensitive SQUID magnetometer, it is possible to measure the magnetic field distributions on the human brain surface (magnetoencephalogram, MEG) [1]. This fact suggests that the functional as well as physiological operations in the human brain may be elucidated by the analysis of magnetic field distribution on the brain surface. This analysis is essentially reduced to evaluating the signal/current flow in the brain. Namely, we have to solve an inverse problem in magnetostatic fields.

This paper proposes a modified correlative approach to estimate the current flows from the local magnetic field distributions. This new method is now applied to estimate the current flows in the human brain. As a result, a sequential current flow in the human brain reveals the functional behavior of the brain when the median nerve of the right wrist is stimulated electrically.

2. A MODIFIED CORRELATIVE ANALYSIS

2.1 Fundamental equations

Most of the magnetostatic field problems are reduced to solving a following equation assuming the Coulomb gauge $\nabla \cdot A = 0$:

$$(1/\mu)\nabla^2 A = -J, \tag{1}$$

where μ, A and J are the permeability, vector potential and current density, respectively. The magnetic field H is related with the magnetic flux B as well as vector potential A by

$$H = (1/\mu)B = (1/\mu)\nabla \times A = \nabla \times \int [J/(4\pi|r|)]dv, \tag{2}$$

where r is a distance between the field H and source J points. In (2), the volume V containing the current density J is subdivided into a large number of subdivisions V_i, i=1~m, also the number of field points is denoted by n, then (2) reduces into

$$U = \sum_{i=1}^{m} \alpha_i d_i \tag{3}$$

where

$$U = [H_1, H_2, \cdots, H_n]^T, \tag{4}$$

$$d_i = \{1/(4\pi)\}[n_i \times a_{1i}/r_{1i}^2, n_i \times a_{2i}/r_{2i}^2, \cdots, n_i \times a_{ni}/r_{ni}^2]^T, \tag{5}$$

$$\alpha_i = J_i V_i,\quad i=1\sim m,\quad m>>n. \tag{6}$$

In (5), n_i is a unit vector in the direction of J_i; $a_{1i}, a_{2i}, \cdots, a_{ni}$ are the unit vectors from the source point i to the field points 1,2,···,n; $r_{1i}, r_{2i}, \cdots, r_{ni}$ are the distances from the source point i to the field points 1,2,···,n, respectively. Further in (6), α_i, i=1~m, is a magnitude of the current dipole P_i, also the condition m>>n is always satisfied because the field H can be measured in the limited points. Equation (3) is a system equation [2].

2.2 Modified correlative method

According to the condition m>>n, it is obviously difficult to obtain a unique solution of (3). Namely, the number of equations n is smaller than the number of unknowns m. Thus, we apply a correlative analysis to estimating the current distribution pattern from (3) [3].

Let the vector U in (4) decompose into the space variable component U' and mean component U_0. Similarly, the vector d_i (i=1~m) in (5) is decomposed into the space variable component d_i' and mean component d_{i0}. By means of these decompositions, (3) is also decomposed into

$$U' = \sum_{i=1}^{m} \alpha_i d_i', \tag{7a}$$

$$U_0 = \sum_{i=1}^{m} \alpha_i d_{i0}. \tag{7b}$$

Equation (7a) is rewritten by

$$U' = \sum_{i=1}^{m}\{\beta_i d_i' + \sum_{j\neq i}^{m}\{\beta_{ij}(d_i'+d_j') + \sum_{k\neq i,\,k\neq j}^{m}\{\beta_{ijk}(d_i'+d_j'+d_k') + \cdots\}\}\}. \tag{8}$$

Physically, each of the terms in (7b) has no field pattern, i.e. DC magnetic field, but each of the terms in (7a) has its distinct field pattern whose average takes zero. Namely, the 1st, 2nd and 3rd groups on the right hand in (8) give the one, two and three pairs of the north (N) and south (S) magnetic poles normal to a plane surface, respectively. This means that the correlative analysis should be applied not only to the 1st solution group but also to the other remaining solution groups. After carrying out this modified correlative analysis to all of the groups in (8), summation of their results will yield a general correlative coefficient pattern. In order to evaluate a particular correlative coefficient distribution, the practical modified correlative

analysis is carried out in the following way.
At first, we calculate

$$\gamma_i = [U'/|U'|]^T[d_i'/|d_i'|], \ i=1\sim m, \tag{9a}$$

then we can get the 1st correlative coefficient distribution. If the γ_h takes the maximum value in the 1st correlative coefficient distribution, then the 2nd correlative coefficient distribution taking d_h' as a pilot pattern is calculated by

$$\gamma_{ih} = [U'/|U'|]^T[(d_h'+d_i')/|d_h'+d_i'|], \ i=1\sim m, \ i\neq h. \tag{9b}$$

Similar process is continued up to the peak value of γ. Thereby, the modified correlative coefficient distribution γ_i', $i=1\sim m$, of (3) becomes

$$\gamma_1' \simeq [\gamma_1 + \gamma_{1h} + \cdots], \tag{10a}$$
$$\gamma_2' \simeq [\gamma_2 + \gamma_{2h} + \cdots], \tag{10b}$$
....
$$\gamma_h' \simeq [\gamma_h + 1 + 1 + \cdots], \tag{10c}$$
....
$$\gamma_m' \simeq [\gamma_m + \gamma_{mh} + \cdots]. \tag{10d}$$

This gives a particular correlative coefficient distribution depending on the field vector U in (4), and corresponds to the normalized current distributions [4-6].

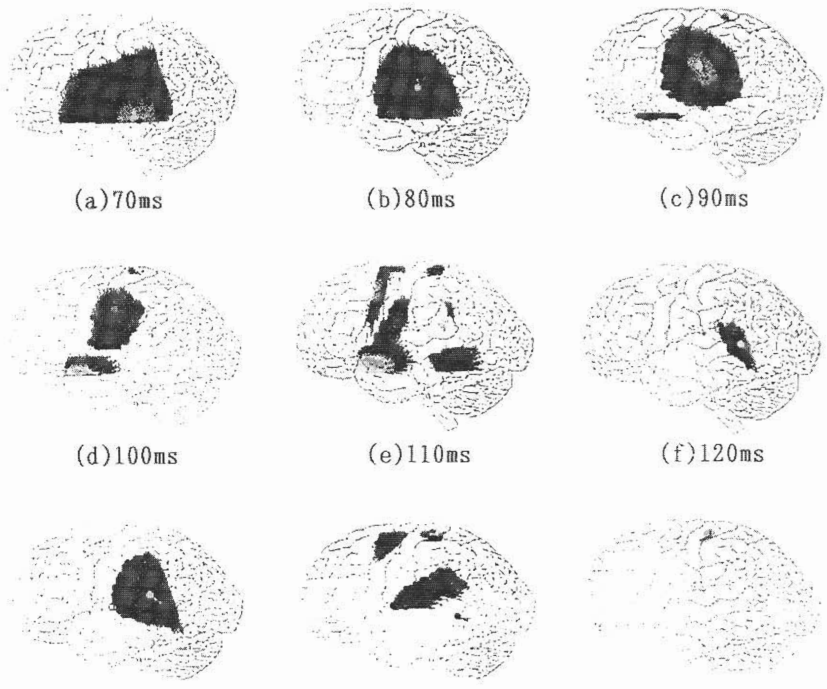
2.3 Examples

The modified correlative analysis is applied to estimating the current flows in the human brain. As a result, a sequential current flow in the human brain reveals the functional behavior of the brain when the median nerve of the right wrist is stimulated electrically [2].

Figure 1 shows the most dominant parts of the correlative coefficient distributions at each of the times. The stimulated electrical pulse is a square wave having the period 0.5s.

After 70ms past the pulse impressed at the median nerve of the right wrist, Fig.1(a) shows that the signal reaches the brain via a vertebra. Similarly,Fig.1(b) shows that the signal reaches the hand sensory cortex after 80ms. After 90ms in Fig.1(c), signal focuses on the hand sensory cortex and starting the recognition or memorization of the electrical pulse stimulation. After 100ms in Fig. 1(d), signal stays at the hand sensory cortex but strong recognition and memorization are carried out. After 110ms in Fig.1(e), the strongest signal stays at the recognition and memorization region but small signals are arising at the motor and vertebra regions. After 120ms in Fig.1(f) signal flows to the vertebra region. After 150ms in Fig.1(g), the signal at the vertebra becomes the strongest. After 175ms in Fig.(h), the signal at the vertebra becomes weak but the motor and hand sensory cortex are gradually activated. Finally at 200ms in Fig.1(c), the sensory cortex feels hot.

Thus, it is revealed that the electrically stimulated signal is initially transmitted to the brain through the vertebra. After that the brain identifies and recognizes the stimulated position. To avoid the stimulation, the brain transmits the signal to move the hand, but hand could not move and feels hot.



(a)70ms (b)80ms (c)90ms

(d)100ms (e)110ms (f)120ms

(g)150ms (h)175ms (i)200ms

Fig.1. The modified correlation coefficient distributions in a human brain when the median nerve of the right wrist is stimulated electrically.

3. CONCLUSION

As shown above, we have successfully estimated the current distribution patterns in human brain by the modified correlative analysis with MEG. Thus, our new method makes it possible to investigate the human brain's functional operations.

4. REFERENCES

1 T.Ohmori, Editor, Sensor-Jitsuyou-Jiten (Fuji Techno System, Nov. 1986, Tokyo, in Japanese) pp.1365-1394.
2 Y. Uchikawa et al., Journal of Japan Applied Magnetics, Vol.13, No.3, (1989)pp.508-512.
3 T.H.Wonnacot et al., Introductory Statistics (John Wiley & Sons, 1990)
4 K.Kitsuta et al., Paper on Technical Meeting of IEEJ, Vol. MAG-91-220, (1991) pp.75-84.
5 Y. Saito et al., J.Appl. Phys., Vol.67, No.9, May 1990, pp.5830-5832.
6 H.Saotome et al., JIEE Part A, April 1992, in Printing.