

Formulation of Topographical Mapping in Brain With a Synchronous Neural System

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Abstract: - Formulation of a neural system is presented for topographical mapping in brain. Composition of a system is first given to receive and analyze random pulse sequences with sensors set at corner points of a cube. An algorithm is obtained to discriminate multiple sound sources by minimizing evaluation function between observed and estimated set of received signals. An evaluation function is defined by time errors of arriving pulses, and solutions are given as coordinates in space and time domain.

A synchronous neural system is then given organized by mutual pulse injections among neurons. A model of 3D reception by two ears (x axis) and bone transmissions (y - and z -axes) to correct 3D data. Then a configuration of the neural system is given based on the result of another study by authors. Synchronous signal processing is performed for topographical mapping in brain. The error of estimation is found enough by computer simulation.

Key-Words: - Topographical mapping in brain, discrimination of multiple sound sources, recurrent connection among neurons, synchronous neural system

1 Introduction

Real time perception of events in time and space domain is essential for animals living in changing environments. These capabilities provided by neural systems mainly in brain.

Visual perception of pictures has ever been much taken up including stereo-optics. Input stimuli are specified by space information and not related to time structure.

In this study, acoustic perception is taken up, where input stimulus is specified by both of time and space. Basic information is related to acoustic phase difference via two ears and bone conductions. Measuring of time and phase is essentially required for perception of events generated randomly in time and space domain[1].

Topographical mapping in brain are found in experimental biology[2]. Parts in brain are almost known for signal processing of sound. However principles and operations of processing are less known nowadays.

Formulation of a neural system is given with mutual connections among neurons. Modelling of the topographical mapping is presented by physical and neural frameworks in time and space domain. Operational equation is defined to minimize energy

in a neural system. Neural system synchronization is provided the proposed neural network[3]. An algorithm is introduced for topographical mapping of the multiple random events in 2D plane and 3D space. As an example of evaluation, the numbers of sound sources up to 17 generated within 2sec are set at the distance of 20m. All events were drawn topographically on assumed hyper plane of cortex in brain.

The subject and theories of this research are related not to unique area but to multiple areas of neurology, electro-physics of solid, physical and chemical biology, and circuit theories.

2 Physical Scheme for Sensing of Events in 3D Space

2.1 Hyperboloid method in 3D for single event

The position of a wave source is given by the principle of the Hyperbolic method. A hyperbolic curve is drawn by tracing the constant difference of distance between two sensors. Another hyperbolic curve is also drawn by another pair of sensors. The cross point between two hyperbolic curves gives the position of a wave source on a plane.

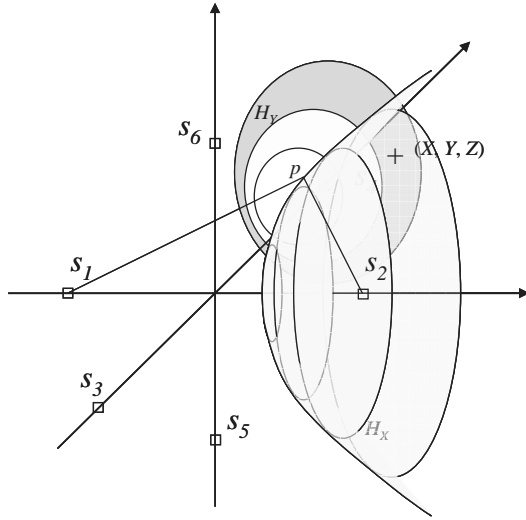


Fig. 1 Principle of the Hyperboloid Method in 3D space. The third hyperboloid is abbreviated.

In the case of 3D, the estimation is achieved by the cross point of curved surfaces of three hyperboloids. Minimum four (4), preferably six (6) sensors enable to define three hyperboloids.

In this paper, a 3D sensor system was prepared by six (6) sensor elements, which are allocated on orthogonal three axes.

Fig. 1 shows the Hyperbolic method in 3D space. Six sensors $s_1 - s_6$ are set on each axis. The distance along X , Y , and Z axes are shown normalized by the length between sensors 1 and 2.

p denotes a point on a hyperbolic curve defined by the time difference between s_1 and s_2 . p is a point in Hyperboloid H_x . The second and the third hyperboloids H_y , H_z are drawn as the same way with pairs of s_3 and s_4 , and s_5 and s_6 . The coordinate (X, Y, Z) is solution as the cross point of three hyperbolic curves.

The solution is given by the following equations.

$$\begin{cases} \frac{X^2}{a_X^2} - \frac{Y^2}{(d_n^2 - a_X^2)} - \frac{Z^2}{(d_n^2 - a_X^2)} = 1 \\ -\frac{X^2}{(d_n^2 - a_Y^2)} + \frac{Y^2}{a_Y^2} - \frac{Z^2}{(d_n^2 - a_Y^2)} = 1 \\ -\frac{X^2}{(d_n^2 - a_Z^2)} - \frac{Y^2}{(d_n^2 - a_Z^2)} + \frac{Z^2}{a_Z^2} = 1 \end{cases} \quad (1)$$

where, X , Y , Z are space axes, d_n is distances of sensors.

$2a_X$, $2a_Y$, $2a_Z$ are difference of distance from sensor to objective point on each axis.

2.2 Algorithm for sensing of positions of multiple wave sources

The velocity of waves depends on the wave of sound, microwave, etc. The estimated arrival time from sensor to generation point is calculated by the estimated position. Evaluation for single wave source is defined by the error between estimation and observation of receiving times.

Evaluation for multiple wave sources is defined by sum of the errors between estimation and observation of receiving times together with physical factors. The following evaluation function is introduced as;

$$E = AF_1 + \frac{1}{2} (BF_2 + CF_3) \quad (2)$$

where, F_1 is defined by difference of input time among sensors (receptors). F_2 is defined by degree of super position of wavefront of multiple sources. F_3 is defined by the difference of number of sources between observation and estimation.

A , B , and C are weighting coefficients to define the effect of each factor to the final error E . They are defined to provide the system with harmonization of operation conditions.

Logarithm of E in Eq.(2) is an inversion of entropy for estimation (prediction). This system is defined as driven by the principle of the maximum entropy in physics [4,5].

N_0 is number of solutions.

$$N_0 = \min N; \quad \partial \log E(N) / \partial N = 0 \quad (3)$$

3 Biological Action for 3D Acoustic Sensing

3.1 Reception of auditory signals of events in 3D space

This system estimates each position and time of multiple random sound generations in time and 3D space domain.

For biological sensing of position in 3D space, followings are suggested conventionally.

- i) 3D sensor is made of two ears which have the capability for sensing phase difference along 3 axes using complex shape of ears, and
- ii) 3D sensor is made of one axis (1D) by two ears and also made of 2 axes (2D) through bone transmissions.

Scheme of biological reception of sound signals in 3D space is shown in Fig. 2. Time sequences data

sets are gathered by two ears along x -axis, and bone transmission along y - and z -axes.

Estimation of points of events are calculated by the proposed neural system based on phase delay between each pair of sensors along axis.

3.2 Organization of a Neural System

A large number of dendrites belonging to a neuron are found in experimental observation.

Operational capability of a system depends on way of neural connections for limited number of neurons. Recurrent connection contributes to reduce the required number of neurons.

In this paper, all neurons are assumed to be connected mutually reflecting the above knowledge. Connection is defined with value, sign (positive and negative), and directivity (bilateral). Self connection between output to input of a neuron itself is inhibited.

This networking is neither serial nor parallel connection, and is not available in practical systems.

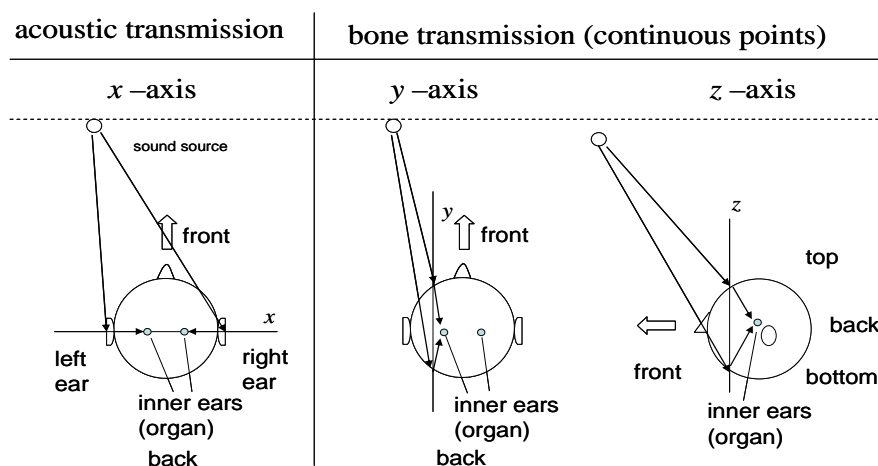


Fig. 2 Reception of sound signals in 3D space by phase delay defined along x , y , z axes.

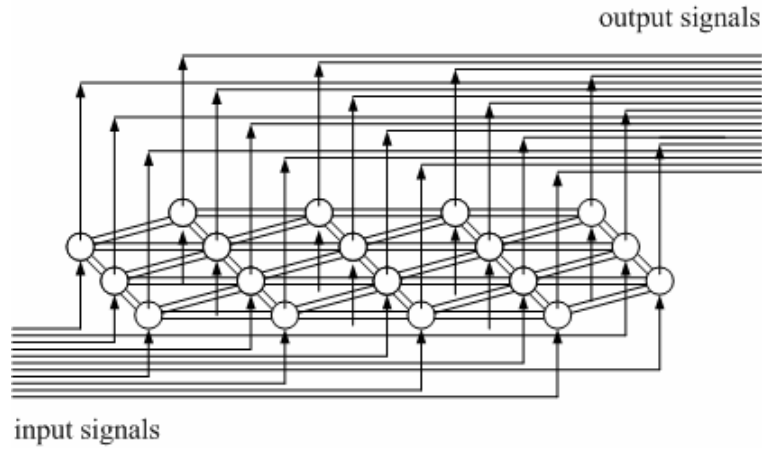


Fig. 3 Formulation of a neural network with mutual connections.
Circle shows a neuron. Double solid lines denote mutual connections.

4 Formulation of Operation by the Proposed Neural System

A neural system with mutual connections is shown by the following equations and Fig. 3. In the figure, circle shows a neuron. Double solid lines denote mutual connections. The inputs of all neurons are error between observed and estimated signals. The outputs of all neurons are digital signals with zero or one. The values of inputs and mutual connections are bilateral (positive and negative connections). The mutual connections among neurons are davn partially.

Operation of a neural system is given as follows;

$$I_i = \sum_{j \neq i} W_{ij} V_j - U_i \quad (4)$$

$$V_i = u(I_i) \quad (5)$$

$$u(I_i) = \begin{cases} 1 & ; I_i \geq 0 \\ 0 & ; I_i < 0 \end{cases} \quad (6)$$

$$W_{ij} = \begin{cases} W_{ij} & ; i \neq j \\ 0 & ; i = j \end{cases} \quad (7)$$

where, I_i [A], V_i [V] are input current, output voltage with bias of i -th neuron. U_i [A] is defined by factors of input signal and threshold value. $u(\cdot)$ stands for normalized amplitude of pulse waveform. W_{ij} is mutual conductance of i -th to j -th neuron.

A neural system is specified by Eq.(4). The output voltage V_i is the function written in Eq.(5). The input current I_i is sum of currents from other neuron j to neuron i with bias current U_i .

A neural system takes error signal between estimation and observation as its input.

The error power E is given as;

$$E = -\sum_{i,j} W_{i,j} V_i V_j / 2 + \sum_i U_i V_i \quad (8)$$

5 Algorithm and Evaluation

5.1 Algorithm

Operational parameters of the neural system are given by minimization of error energy of Eq. (2);

$$\begin{aligned} W_{ijklmn,i'j'k'l'm'n'} &= -\frac{B}{2} \left\{ \delta_{ii'}(1 - \delta_{jj'}\delta_{kk'}\delta_{ll'}\delta_{mm'}\delta_{nn'}) \right. \\ &+ \delta_{jj'}(1 - \delta_{ii'}\delta_{kk'}\delta_{ll'}\delta_{mm'}\delta_{nn'}) \\ &+ \delta_{kk'}(1 - \delta_{ii'}\delta_{jj'}\delta_{ll'}\delta_{mm'}\delta_{nn'}) \\ &+ \delta_{ll'}(1 - \delta_{ii'}\delta_{jj'}\delta_{kk'}\delta_{mm'}\delta_{nn'}) \\ &+ \delta_{mm'}(1 - \delta_{ii'}\delta_{jj'}\delta_{kk'}\delta_{ll'}\delta_{nn'}) \\ &+ \delta_{nn'}(1 - \delta_{ii'}\delta_{jj'}\delta_{kk'}\delta_{ll'}\delta_{mm'}) \left. \right\} - \frac{C}{2} \end{aligned} \quad (9)$$

$$U_{ijklmn} = AD_{ijklmn} - CN_0 \quad (10)$$

$$\delta_{ij} = \begin{cases} 1 & ; i \neq j \\ 0 & ; i = j \end{cases} \quad (11)$$

where, W_{ijklmn} is connection coefficient between neurons, δ_{ij} is Kronecker's delta, and D_{ijklmn} is the error between estimation and observation defined in time domain. It corresponds to the input current to neuron at a point $ijklmn$. N_0 is estimation of number of sources.

5.2 Results of evaluation

The proposed scheme of time-space analysis is proved useful for the case of multiple sound location identification. Multiple sound pulse sources are randomly generated on time and space.

Evaluation condition is as follows;

Number of sound sources 2~17,

Transmission time of pulse 1~10 sec

Time window for analysis = 15 sec

The sound locations are shown for the correct and calculated locations with square and cross marks. The error of estimation was proved small enough practically.

The computer simulation in Fig. 4 and 5 shows following points;

The resolution of location of points is 20(cm) for multiple sounds located at 20(m) from sensors. The capability of separation is equal to distance of two ears of animals at the point of 100 times of sensor distance.

This study suggest that proposed formulation of neural system and principle of proposed algorithm will be used in wide area of signal processing in brain.

Some relationship is pointed between entity of estimation and configuration of a neural system.

The physical error is dependent on mutual relation among wavefronts of multiple sources. All factors of errors depend on interaction among wavefronts of multiple sources.

This fact suggests that interactive processing is realized by mutual connection among neurons.

The system operates autonomously toward conversion as minimizing electric power defined by error between observation and estimation of time and space in 3D space

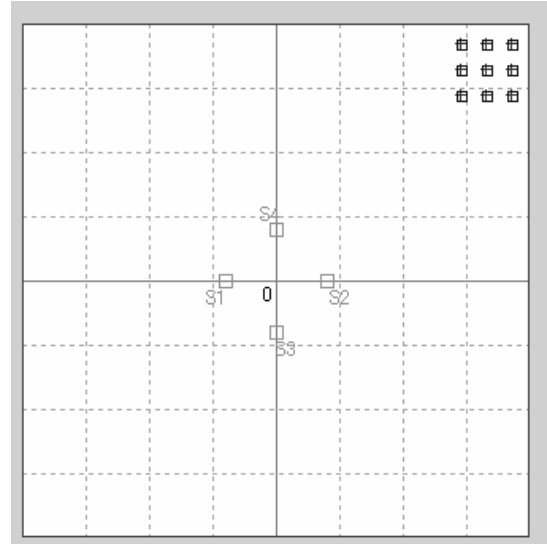


Fig. 4 Result of estimation points group in space. Observed time of pulses at sensors s_1 – s_6 .

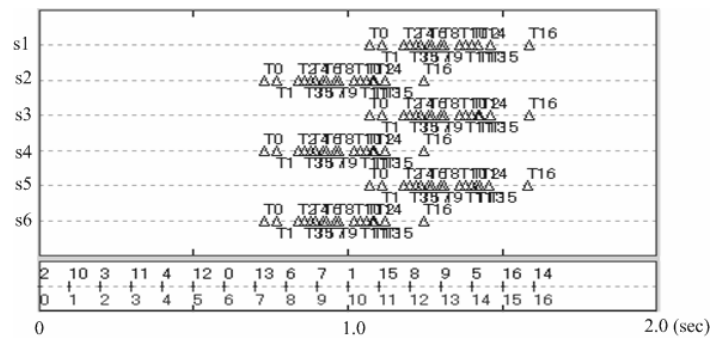


Fig. 5 Estimated and actual generation times. Upper: sequences of arrival pulse times at each sensor. Below : Actual(upper) and estimated(lower) time of pulse generations.

6 Conclusion

By establishing system synchronization, all of the neurons in a system hold the time in common, the system operates according to the common clock. The system could perceive time, space, and motion of observed events. The system also could bring a rhythm of motion. These functions are essential to maintain lives of animals.

A neural system is composed by mutual connections among neurons. This configuration suggests that intellectual signal processing is brought in brain by interactive processing among neurons.

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