Topographical Mapping by a Synchronous Neural System with Physical Measures of Time, Space, and Motion

Yumi Takizawa and Atsushi Fukasawa

***Abstract*—**This paper presents topographical mapping in brain by synchronous neural system. This model is based on function of recognition of events in physical measures, time, space, and motion. This effect is realized by a neural system with synchronization established by unique configuration with recurrent connections and mutual pulse injections among all neurons. Topographical mapping in brain has been proved on this system with autonomous convergence algorithm. This algorithm was proved in convergence of calculation for estimation of time and position of events with adaptation less than 3 or 5 times for 20 sounds within 2 sec time frame.

***Keywords*—Recognition of time, space, and motion, topographical mapping in brain, multiple random sources, recurrent connection, synchronous neural system**.

I. Introduction

VARIETIES of functions are integrated in small quantity of mass in a brain. Most of conventional researches have been performed by electro sensory equipments. Against external stimuli, activated parts and paths in brain are almost known now a day. The principle of operations and actual processing schemes in ganglions and nucleus are still unknown.

Conventional themes of studies are about advanced and complicated capabilities such as recognition of target, learning of language, and so on.

This paper presents recent results of studies about the capability of knowledge on events in the physical measures of time, spaces, and motions of events. Capability of knowledge on acoustic events has been taken up in this research. Multiple sound sources are generated in unknown points of time and space domain[1]-[7].

A neural system in this research is composed by a great number of neurons. Each neuron generates pulse with individual timing. Timings of pulses must be common among neurons.

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II. Physical Scheme for Knowledge of Events in 3D Space

A. Hyperboloid Method in 3D for Single Event

The position of a wave source in 2D is given by the principle of the Hyperbolic method. Signals from one source are received by a pair of sensors. The time differences given the difference of distances from the source to each sensor. A hyperbolic curve is drawn by tracing the constant difference of the distances. 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.

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 $s1$ – $s6$ 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 $s1$ and $s2$. 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 $s3$ and $s4$, and $s5$ and $s6$. The coordinate (X, Y, Z) is solution as the cross point of three hyperbolic curves.

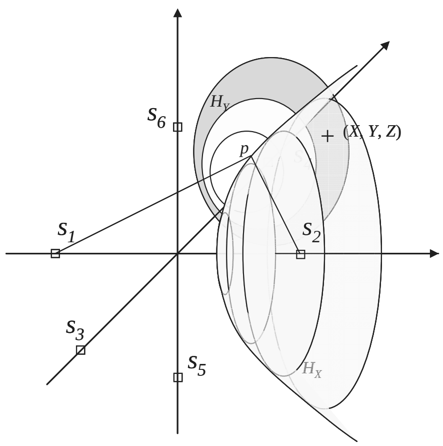

Fig. 1 Principle of the Hyperboloid Method in 3D space. The third hyperboloid is abbreviated.

The solution is given by the following equations.

$$\begin{cases} \dfrac{X^2}{a_X{}^2} - \dfrac{Y^2}{\left(d_n{}^2 - a_X{}^2\right)} - \dfrac{Z^2}{\left(d_n{}^2 - a_X{}^2\right)} = 1 \\ -\dfrac{X^2}{\left(d_n{}^2 - a_Y{}^2\right)} + \dfrac{Y^2}{a_Y{}^2} - \dfrac{Z^2}{\left(d_n{}^2 - a_Y{}^2\right)} = 1 \\ -\dfrac{X^2}{\left(d_n{}^2 - a_Z{}^2\right)} - \dfrac{Y^2}{\left(d_n{}^2 - a_Z{}^2\right)} + \dfrac{Z^2}{a_Z{}^2} = 1 \end{cases} \qquad (1)$$

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

$2aX$, $2aY$, 2aZ are difference of distance from sensor to objective point on each axis.

III. Biological Action for 3D Acoustic Sensing

A. 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.

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

B. 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.

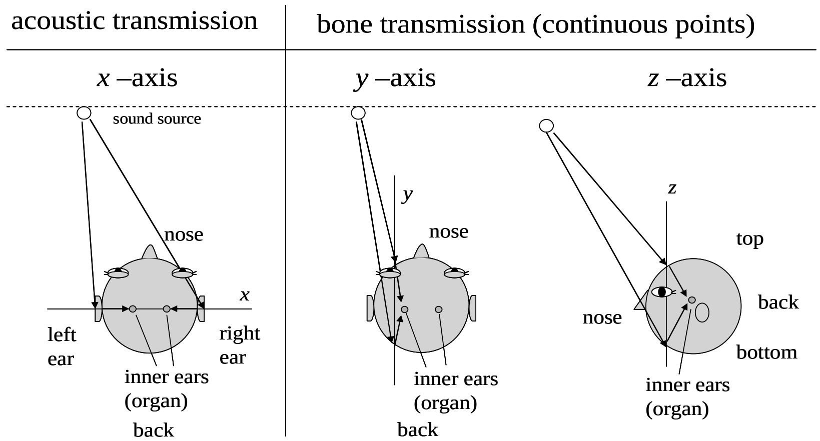

Fig. 2 Reception of sound signals in 3D space by phase delay defined along x, y, z axes.

IV. Formulation of Operation by the Proposed Neural System

A. Formulation of a 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 dawn partially.

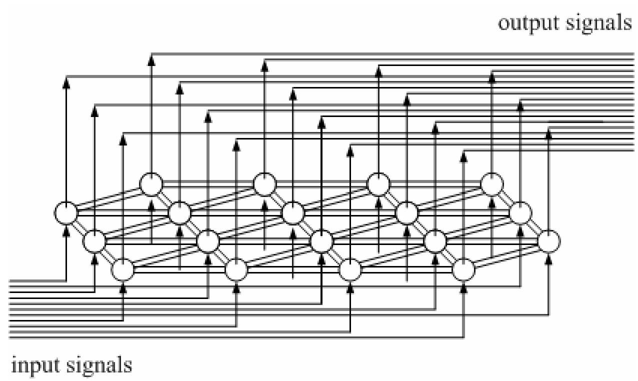

Fig. 3 Formulation of a neural system with mutual connections. Circle shows a neuron. Double solid lines denote mutual connections.

Operation of a neural system is given as follows;

$$I_i = \sum_{i \neq j} W_{ij} V_j - U_i \tag{2}$$

$$V_i = u(I_i) \tag{3}$$

$$u(I_i) = \begin{cases} 1 & ; \quad I_i \geq 0 \\ 0 & ; \quad I_i < 0 \end{cases} \tag{4}$$

$$W_{ij} = \begin{cases} W_{ij} & ; \quad i \neq j \\ 0 & ; \quad i = j \end{cases} \tag{5}$$

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. $u(\,.\,)$ 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;

$$E = -\sum_{i,j} W_{i,j} V_i V_j / 2 + \sum_i U_i V_i \tag{6}$$

B. Performance and Scale of a Neural System

The minimum number of neurons is defined by the maximum number of unknown events by this system. Three axes in brain are considered for sensing events in 3D space. A pair of receiving sensors is then assumed along each axis. A receiving system is composed of six (6) sensors in 3D space. The minimum number of neurons is given in Fig. 4 by Eq. (2) for number of acoustic events in 3D space.

(1) Biological neural system

Scale is taken as number of neurons in neural system.

Number of neurons is known as order of 104 for ganglion in peripheral neural system, and order of 105 for nucleus in central neural system.

It is found that number of events will be less than 7 for a nucleus and less than for 4.

(2) Ideal system

An ideal neural system could also be assumed. This system is derived as extension of biological system as shown at the area larger number of neurons $10^6 \sim 10^8$ in Fig. 4.

All events are included in a time frame which is defined by time length between the earliest and the latest arriving times.

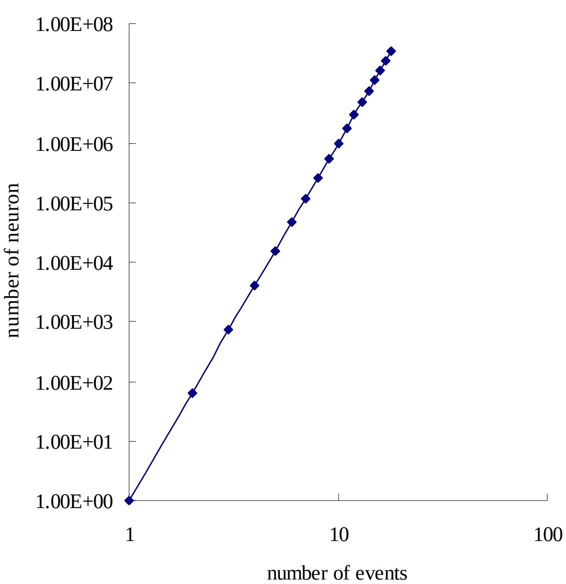

Fig.4 Scale of a neuron system for number of targets.

V. Algorithm and Evaluation

A. 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;

$$E = AF_1 + \frac{1}{2}\left(BF_2 + CF_3 \right) \qquad (7)$$

where, $F1$ is defined by difference of input time among sensors (receptors). $F2$ is defined by degree of super position of wavefront of multiple sources. $F3$ 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.(7) is an inversion of entropy for estimation (prediction). This system is defined as driven by the principle of the maximum entropy in physics [12].

N_0 is number of solutions.

$$N_0 = \min N; \quad \partial \log E(N) / \partial N = 0 \qquad (8)$$

B. Algorithm

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

$$W_{ijklmn,i'j'k'l'm'n'}$$

$$= -\frac{B}{2}\left\{ \delta_{ii'}(1-\delta_{jj'}\delta_{kk'}\delta_{ll'}\delta_{mm'}\delta_{nn'}) \right.$$

$$+ \delta_{jj'}(1-\delta_{ii'}\delta_{kk'}\delta_{ll'}\delta_{mm'}\delta_{nn'})$$

$$+ \delta_{kk'}(1-\delta_{ii'}\delta_{jj'}\delta_{ll'}\delta_{mm'}\delta_{nn'})$$

$$+\delta_{ll'}(1-\delta_{ii'}\delta_{jj'}\delta_{kk'}\delta_{mm'}\delta_{nn'}$$

$$+\delta_{mm'}(1-\delta_{ii'}\delta_{jj'}\delta_{kk'}\delta_{ll'}\delta_{nn'})$$

$$+\delta_{nn'}(1-\delta_{ii'}\delta_{jj'}\delta_{kk'}\delta_{ll'}\delta_{mm'})\Big\}-\frac{C}{2} \qquad (9)$$

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

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

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.

C. 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. 5 and 6 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.

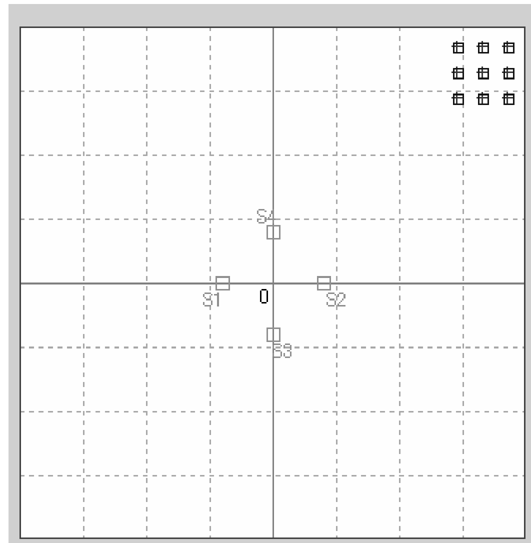

Fig. 5 Result of estimation points group in space. Observed time of pulses at sensors s_1–s_6.

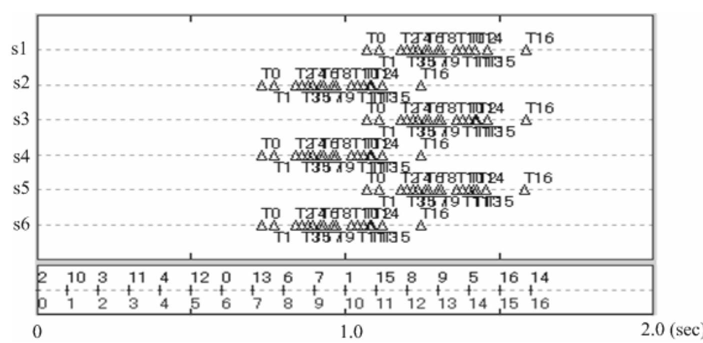

Fig. 6 Estimated and actual generation times.
Upper: sequences of arrival pulse times at each sensor.
Below : Actual(upper) and estimated(lower) time of pulse generations.

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.

VI. 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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