Signal processing by a neural system and its application to location of multiple events

Yumi Takizawa and Atsushi Fukasawa

Abstract**—**This paper describes a neural system to minimize errors between observation and estimation. This scheme is different to the principle of conventional learning methods. The proposed neural system is applied to the problem of time-space analysis of multiple sound source locations on 2D plane and in 3D space. The number of sources is assumed 16 sounds with a time-frame of 15 sec, and number and size of sensors are 6 and 20 cm cubic. Sound sources are located at 20m with mutual distance 20cm cubic. The proposed scheme is confirmed with well coincidence of generation times and locations. The proposed neural system shows that the algorithm is enough to solve both of 2D and 3D time-space random data problems.

Keywords**—** Neural signal processing, Brain mapping, location estimation, time-space analysis.

I. Introduction

SIGNAL processing in brain is much interesting at wide areas including psychology, medical science, education, and social matters.

The authors have studied behavior of living system of neurons. The method of recognition of time and space by brain is first concerned by the authors. When the generation times of events are known, locations of space are decided by introducing wave velocity.

When events happen at only one place, the location and time are easily known..

In the cased that multiple events happened within a certain time and location spans, it is too hard to discriminate time and locations of multiple events by numerical methods. Because huge calculation times are needed corresponding to increasing time and space division numbers. But brain can perceive almost all events whenever they include some errors.

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Yumi Takizawa is with the Institute of Statistical Mathematics, Tachikawa , Tokyo 190-8562, Japan (phone: 81-50-5533-8539; fax: 81-42-526-4335; e-mail: takizawa@ism.ac.jp).

Atsushi Fukasawa was a professor, Chiba University, Yayoi-cho Inage-ku Chiba, 263-8522 Japan (e-mail: takizawa@ism.ac.jp).

Brain can solve variety of problems including sensing, motion, unification, and emotion. But the configuration, operation, and dynamics are little known until today.

The authors have taken a view point of essential function of brain to sense generation time, location, and number of events within a time and space span by research of experimentally known function of brain mapping of location in animals[1]-[6].

II. Neural Network

A. Configuration of neural network

Three sensors are used to compose a physical sensor system. The related neural network is built in 3D space corresponding to the three sensors. The coordinate of a neuron assigns a set of combination of pulse signals. For an example, the coordinate (3, 1, 3) corresponds to the combination pulses (3rd pulse of sensor 1, first pulse of sensor 2, 3rd pulse of sensor 3) in Fig. 1.

B. Operation of neural network

The operation of a neural network is induced into solving following equation whose solutions are given by the operation of convergence.

$$E = AF_1 + \frac{1}{2}BF_2 + \frac{1}{2}BF_3 \quad (1)$$

F1: Normalized Error of observed and estimated impulse arrival times [no dimension],

F2: Degree of super-positions of wave-fronts from source locations [no dimension],

F3: Difference of calculated and assumed number of effective solutions [no dimension].

A NN is composed to solve equation (1).

$$E = -\sum_{i'j'k'} W_{ijk,i'j'k'} \cdot V_{ijk} \cdot V_{i'j'k'} / 2 + \sum_{i} U_i \cdot V_i \quad (2)$$

$$V_{ijk} = u(I_{ijk}) \quad (3)$$

$$I_{ijk} = \sum_{i'j'k'} W_{ijk,i'j'k'} \cdot V_{i'j'k'} - U_{ijk} \quad (4)$$

Vi : output voltage of i-th neuron [V],
Ui : threshold current of i-th neuron [A],
Wij : conductance of i-th to j-th neuron [S].

A physical problem to find locations for time-space sequence data is expressed as a mathematical problem to solve equation (1), which corresponds to convergence problem of electric energy written by equation (2).

The solutions of analysis by a novel configuration of NN are shown in Fig. 1 as an example. It is sufficiently shown that newly proposed scheme and NN modeling are twice useful and effective to solve problems which are impossible to express by mathematical equation for software for Neumann computers.

III. Physical Configuration of Sensor system

A. *Location for a single sound source*

Position of a sound source is decided using 3 sensors minimally. A pulse signal is used to define the generation and reception times of a sound source. When wave form signal is used, the time is referred to the maximum amplitude of wave form as an example.

Three sensors are allocated at the positions with rectangular plane and equal length of distance. Three sensors receive a pulse from a source at different time points. Only one pulse is observed at time axis by each sensor.

Arriving time difference corresponds to the difference of distance from the source. The possible locations of source exist on hyperbolic curve. By the other, two hyperbolic curve can draw by 3 sensors. The position of the source is calculated on the cross point of two curves.

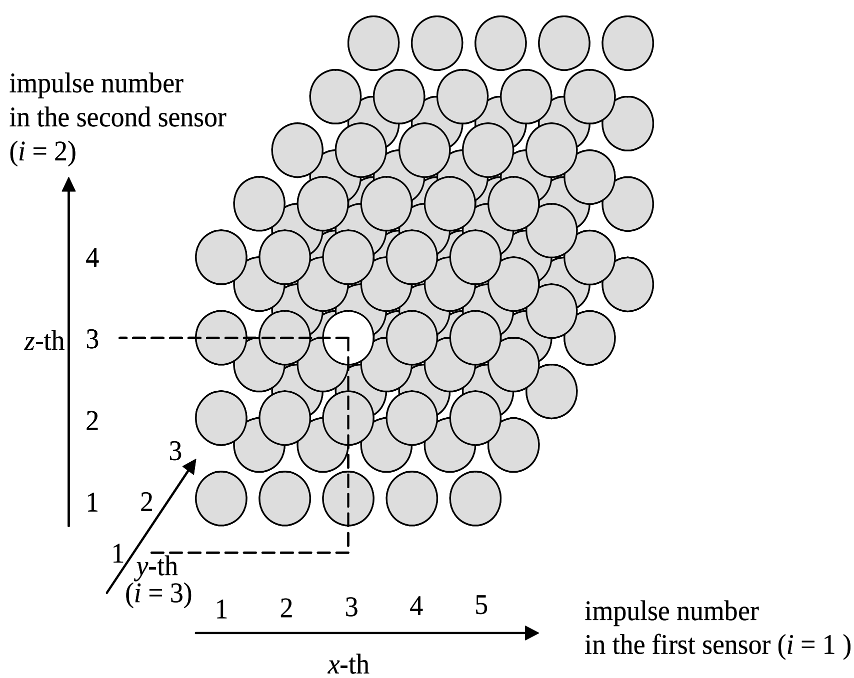


Fig. 1 A coordinate of point of neuron corresponds to the set of (*x*, *y*, *z*).

B. Location for multiple sound sources

When numbers of sources are two, two pulses are observed by each sensor. The combination of pulsed among sensors depend on the location and the time of source. If a location is close to a sensor, the time is short for arrival. But, if the generation time of the source is late the arrival might be delayed compared to the receiving time from a sensor at far point.

Therefore combinations of pulse number do not correspond to the number of source. Namely combination of pulse number vs. source number is not uniquely defined. This reduces to one of error minimization problems.

IV. ESTIMATION ON 2D PLANE

The location of objective point is the solution of the following equations, which exists on elliptical hyperboloid plane.

$$\left.\begin{aligned} \frac{X^2}{a_X^2} - \frac{Y^2}{\left(d_n^2 - a_X^2\right)} = 1 \\ -\frac{X^2}{\left(d_n^2 - a_Y^2\right)} + \frac{Y^2}{a_Y^2} = 1 \end{aligned}\right\} \quad (5)$$

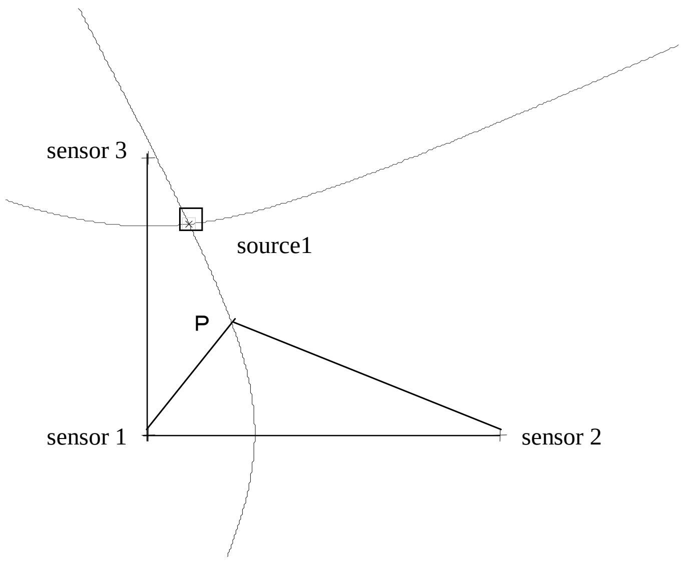


Fig. 2 Principle of the Hyperbolic Method.

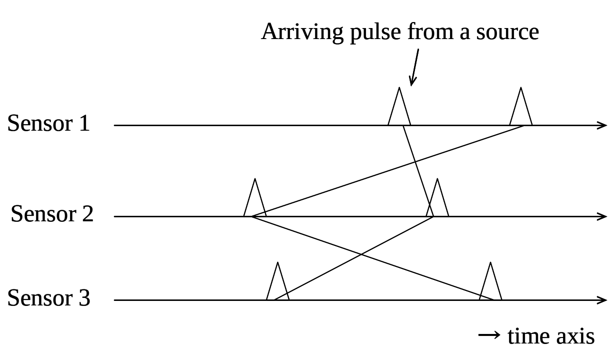


Fig.3 Relation among observed times of arriving pulses from two sound sources.

where,
X and Y are axes on a plane, d_n is distances of sensors.
$2a_X$ and $2a_Y$ are difference of distance from objective point to sensors on each axis.

The examples of location estimation are shown in Fig. 5 showing the case of source existing inside (a) and outside (b) of sensors.

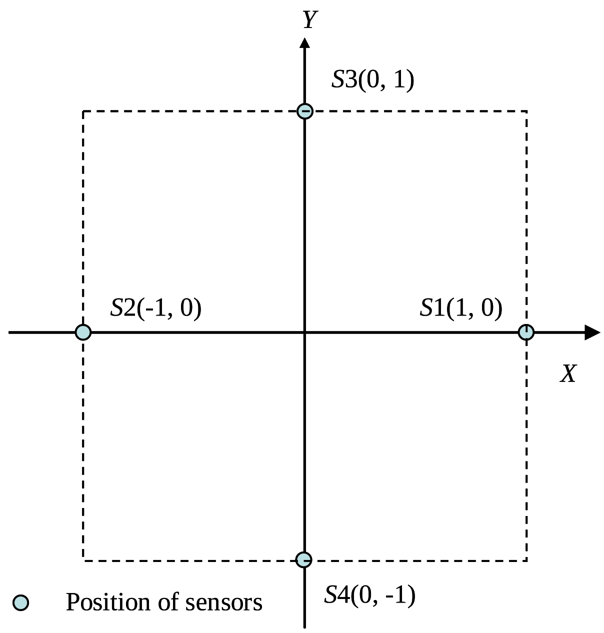
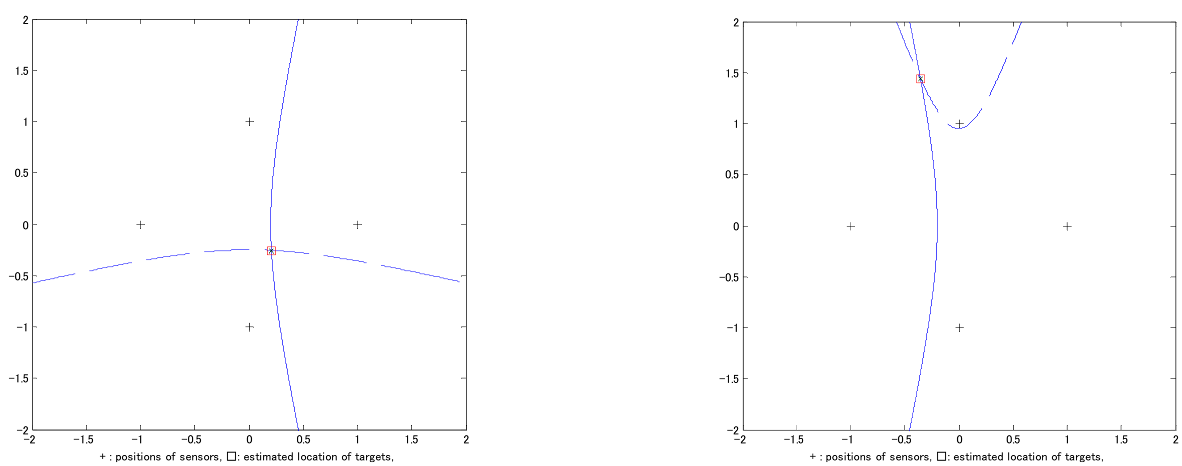


Fig. 4 Sensor system configuration.



(a) A sound source inside sensor system.

(b) A sound source outside sensor system

Fig. 5 Principle of th hyperbolic method for single sound source.

V. Result of Estimation on 2D Plane

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 2~18,

Transmission time of pulse 1～10 sec

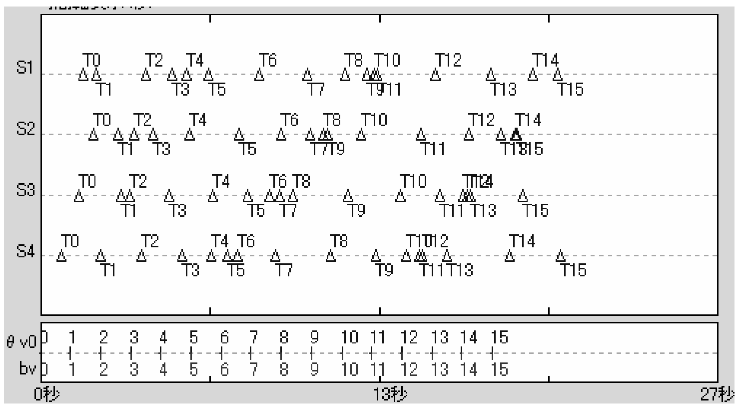
Time window for analysis ＝ 15 sec

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.

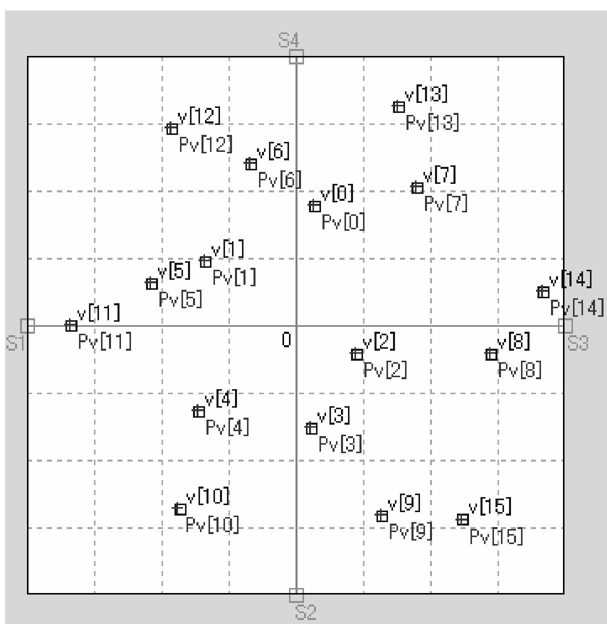
The computer simulation in Fig. 6 shows following points;

The resolution of location of points is 20 cm for multiple sounds located in 1 km square.

It was proved that multiple sound sources on real 2D plane were projected correctly onto 4 dimensional hyper plane composed of the neural system.



(a) Received time of impulse into each sensor (above), Generated time of sounds (below), real (upper) and estimated (lower).



(b) Point of sound generation on a plane,

□ : estimated

＋ : real

Fig. 6 Result of estimation points group in space.

VI. Estimation in 3D space

The location of single objective source is calculated by the following equations, which exists on elliptical hyperboloid plane.

$$\begin{cases} \frac{X^2}{a_X{}^2} - \frac{Y^2}{\left(d_n{}^2 - a_X{}^2\right)} - \frac{Z^2}{\left(d_n{}^2 - a_X{}^2\right)} = 1 \\ -\frac{X^2}{\left(d_n{}^2 - a_Y{}^2\right)} + \frac{Y^2}{a_Y{}^2} - \frac{Z^2}{\left(d_n{}^2 - a_Y{}^2\right)} = 1 \\ -\frac{X^2}{\left(d_n{}^2 - a_Z{}^2\right)} - \frac{Y^2}{\left(d_n{}^2 - a_Z{}^2\right)} + \frac{Z^2}{a_Z{}^2} = 1 \end{cases} \quad (6)$$

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.

VII. Result of estimation in3D space

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.

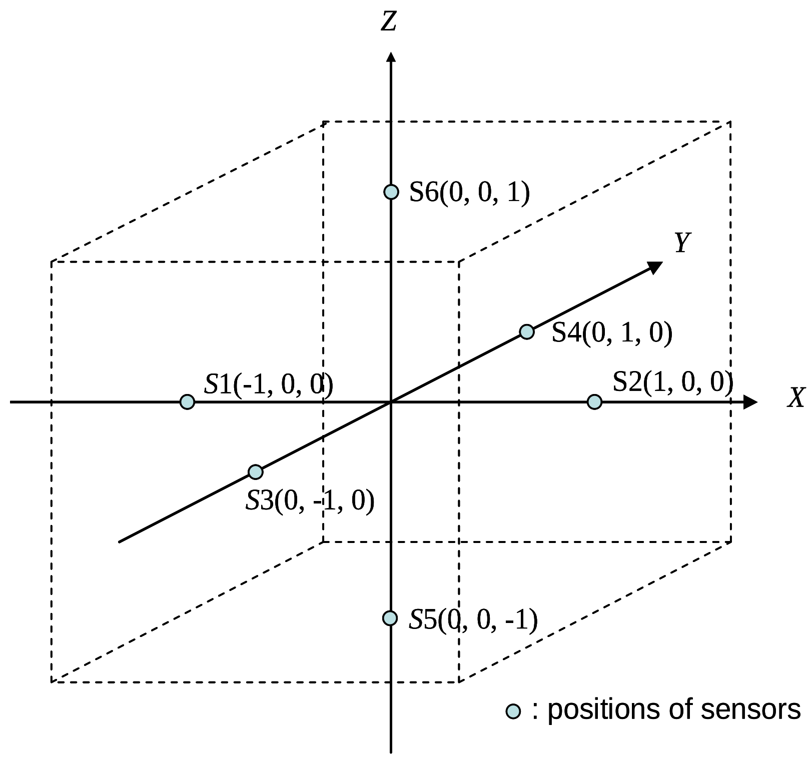


Fig. 7 Settlement of sensors in 3D space.

The computer simulation in Fig. 8 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.

It was proved that multiple sound sources on real 3D plane were projected correctly onto 6 dimensional hyper plane composed of the neural system.

It was proved that multiple sound sources on real 2D plane were projected correctly onto 4 dimensional hyper plane composed of the neural system.

VIII. Conclusion

Brain mapping was experimentally observed ever. In this paper, the authors intended to prove this effect by physical modeling with mathematical equation, and we were successful by the same configuration of neural system and operational algorithms for 2D plane and 3D space estimation problems. The operation of neural systems converged within several neuron steps. This results show that the proposed scheme exceed the conventional mathematical and numerical ways.

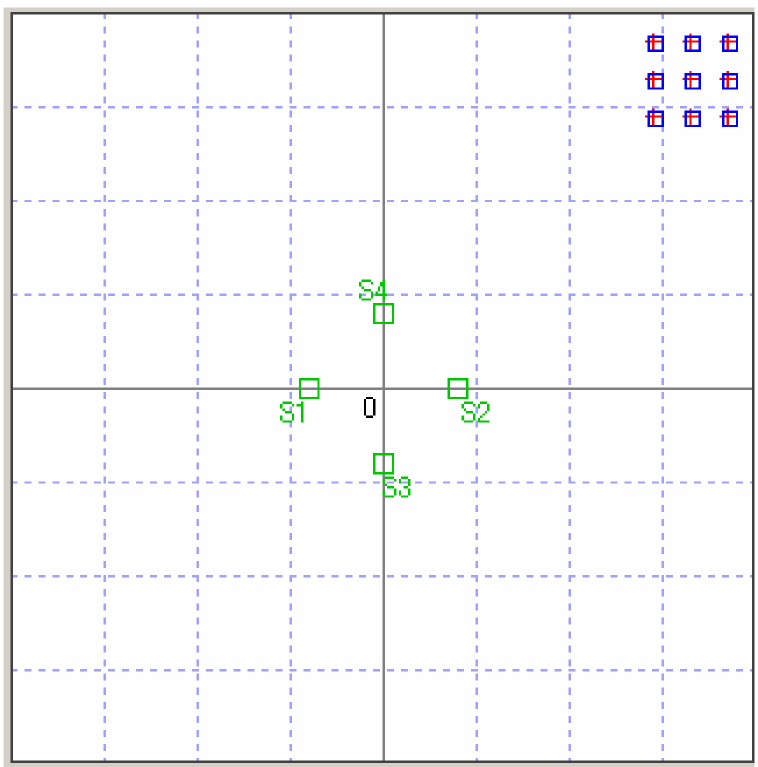


Fig. 8 Result of estimation points group in space.
Six sensors are at center with distance 20cm between sensors,
Sound sources are located at distance20 m from center, and
20 cm between source points.
□ : real position of 6 sensors,
\+ : estimation of 16 sources.

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Yumi Takizawa was born in Tokyo, Japan, Feb. 8th 1961. She received the B.S. degree in Physics from Shinshu University, Japan, in 1984, and the Ph.D. degree from the University of Tokyo in 1994. She was a research leader of signal processing for communication system Lab., OKI Elecric Industry Co. Ltd., Tokyo since 1984. She joined the Institute of Statistical Mathematics, Japan, in 1995.

She has been engaged nonstationary signal processing methods and its application to wide areas of industrial systems. She also has been engaged in digital mobile communication system of Wideband CDMA. Then she has been engaged in neuroethology of weakly electric fish as a visiting researcher at University of Virginia, 1997-1998 and 1999-2000. She continued research of biological signal processing including behavior of neural systems.

She received the Prize on Telecommunication System Technology from the Foundation of Telecommunication Association, Japan in 2004. She is an associate Professor.

Atsushi Fukasawa received the B.S. degree in Electric Engineering from Chiba Unversity, in 1962, and the Master of Arts degree in Electrical communication from Waseda University, Tokyo, in 1967 and the Ph.D. degree from Waseda University in 1983.

He joined Graduate University of Science and Technology, Chiba University as a professor in 1997. He received the Award of the Ministry if Science and Technology, and the Ohm Technology Prize in 1967 and 1994 respectively. He received also the Prize on Telecommunication System Technology from the Foundation of Telecommunication Association, Japan in 2004. He is a senior member of the IEEE. .