Formulation of a Neural System and Analysis of Topographical Mapping in Brain

Yumi Takizawa, Atsushi Fukasawa

Abstract— Formulation of a neural system is presented, and analysis of Topographical mapping in brain is presented with system synchronization. Synchronization is first taken up as an essential and important function of operation. The measures of time, space, and motion are given based on a common time by all neurons of a system. Topographical mapping by a neural system is presented based on the measures given above. This function was taken up as a fundamental operation of complex and supreme brain function. Mapping is applied for topologies on 2D. 3D space is also analyzed. Operation with this modeling and algorithm are evaluated by computer simulation using sound signals received by physical sensors. Results of simulation show that the modeling and algorithm are effective and reliable with least error of generation times and positions in space.

Keywords— Formulation of a neural system, analysis of a neural system, system synchronization, topographical mapping in brain, multiple sound sources.

I. Introduction

RESEARCHERS are much attracted in complex and supreme functions of brain.

Subject of this research is to study fundamental design of neural systems in brain for high-performance signal processing.

Our research is focused on activity of a neuron and its group.

Fundamental designs of neural systems are made clear by analyzing dynamics in operation, and the analysis is achieved on the time-space domain [1].

In this paper, formulation of a neural system is first given based on mutual injection among neurons. This system is used for system synchronization among neurons. Physical measures of time, space, and motion are given by holding time in common by the system synchronization [2].

This system is then applied to topographical mapping in brain for events on 2D plane and also in 3D space[3]. Validation of modeling and algorithm is conducted for detection of multiple sound sources generated randomly on time-space domains [4-8].

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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)

II. Fundamentals for Modeling

A. A neural system with mutual injection

For the analysis of operations and functions of a neural system, operational modeling is used for systematic description.

Feed-forward neurons and a limited number of feedback loops outside these neurons are popularly used for conventional modeling. Serial and parallel connections are used to compose a system in conventional system.

A concept of mutual injection is first given here for an effective modeling of living neurons. Mutual injection is realized by forward and reverse currents between neurons. The values of forward and reverse currents are independent each other. A reverse current plays an essential role in modeling of a neural system given by the authors.

A novel networking of multiple neurons is then given mutual injection. This networking is presented by neither serial nor parallel connections (refer III. *B*). This configuration is not utilized for practical communication, control, and computer systems.

B. System synchronization

Timing is an essential requirement to achieve reliable operation. External clock signals are provided for practical systems to secure efficiency and reliability of data processing. External clock signal maintain enough stability. Considering living neural system, these stable synchronous operations are impossible except the following.

The effect of mutual injection between two multivibrators is shown. The timing of output of an oscillator is adjusted by the other. As number of oscillators increased, the timing of total system gets sufficient stability.

C. Physical measures of time, space, and motion by system synchronization

Neural systems process input signals for useful solution. If all of the neurons in a system hold the time in common, the system perceives time, space, and motion of observed events. The system also could bring a rhythm of motion.

Topographical mapping is shown in Section IV and V for perception of time and space of random events as an example.

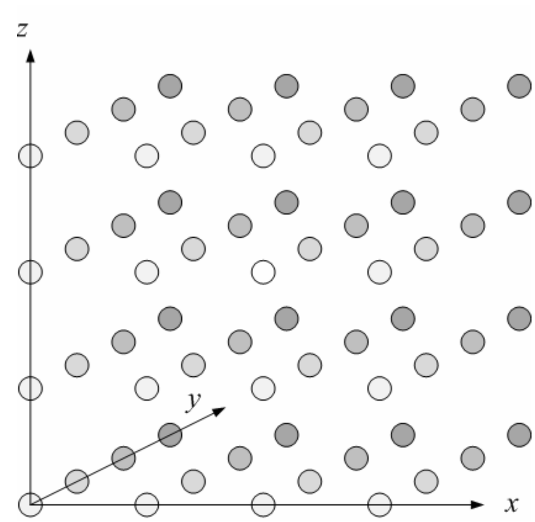


Fig. 1 Allocationa of neurons in compound in 3D for an example.

III. Composition of a Neural System with Mutual Injection

A. Modeling of a neural system

Operation of a neural system is presented as follows;

$$I_i = \sum_{i \neq j} W_{ij} V_j - U_i \tag{1}$$

$$V_i = u(I_i) \tag{2}$$

$$u(I_i) = \begin{cases} 1 & ; \quad I_i \geq 0 \\ 0 & ; \quad I_i < 0 \end{cases} \tag{3}$$

$$W_{ij} = \begin{cases} W_{ij} & ; \quad i \neq j \\ 0 & ; \quad i = j \end{cases} \tag{4}$$

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 takes error signal between estimation and observation as its input.

The error power E is given as;

$$E = -\sum_{i,j} W_{i,j} V_i V_j / 2 + \sum_i U_i V_i \tag{5}$$

The allocations of neurons in compound is shown in Fig. 1

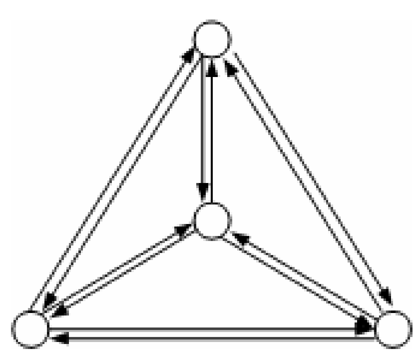


Fig. 2 Mutual injection for synchronization and signal processing. ○ shows a neuron. Connection between two neurons is bilateral with input (the dendrites) and output (the axon terminal).

B. Operation by mutual injection

A neural system is specified by Eq.(1). The output voltage V_i is the function written in Eq.(2). The input current I_i is sum of currents from other neuron *j* to neuron *i* with bias current U_i.

This system is built up by mutual injection among neurons. Mutual injection is permitted among different neurons, and inhibited between same neuron.

Way of mutual injection among four neurons in Fig.2. Small circles stand for neurons. Arrow shows input to dendrite and output from axon. The oscillator becomes more stable as more neurons. Symmetry is not always needed [4].

This system is composed of neurons which are not parallel but also not serial. But this system includes element of parallel and serial connections among part of neurons.

IV. Configuration of Position Estimation System

A. Hyperbolic method for single event

(1) Hyperbolic method in graphics

The position of a wave source is given by the principle of the Hyperbolic method. Each sensor exists in different distance to a source. a hyperbolic curve defined by the difference of distance against a pair of sensors. Another hyperbolic curve is also drawn by another pair of sensors. A solution of position on 2D plane is specified at the cross point of two hyperbolic curves. Minimum number of sensors is three (3).

Fig. 3 shows the principle of Hyperbolic method. Three sensors *s*1, *s*2, *s*3 are set shown in Fig. 3. The distance along horizontal and vertical axes is shown distance 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. Another hyperbolic curve is drawn by *s*2 and *s*3.

The following matters are concern to utilize hyperbolic method in practice; (i) reduction of estimation error of position, and (ii) existence of singular points on 2D plane.

For reduction of error, the number of sensors can be selected preferably four (4) or more to reduce error estimation than less number of sensors. Existence of singular point is studied and are shown in Fig. 4 (a) and (b) for the case of four sensors.

In Fig. 4 (a), the position of sound source is located anywhere inside the sensor system. In Fig. 4 (b), the position of sound source is located anywhere outside the sensor system. Any singular point are not found except point at a the origin of the coordinate. By an additive processes, this point can be avoided by check of condition. The condition is shown as the point with equal distance to each sensor.

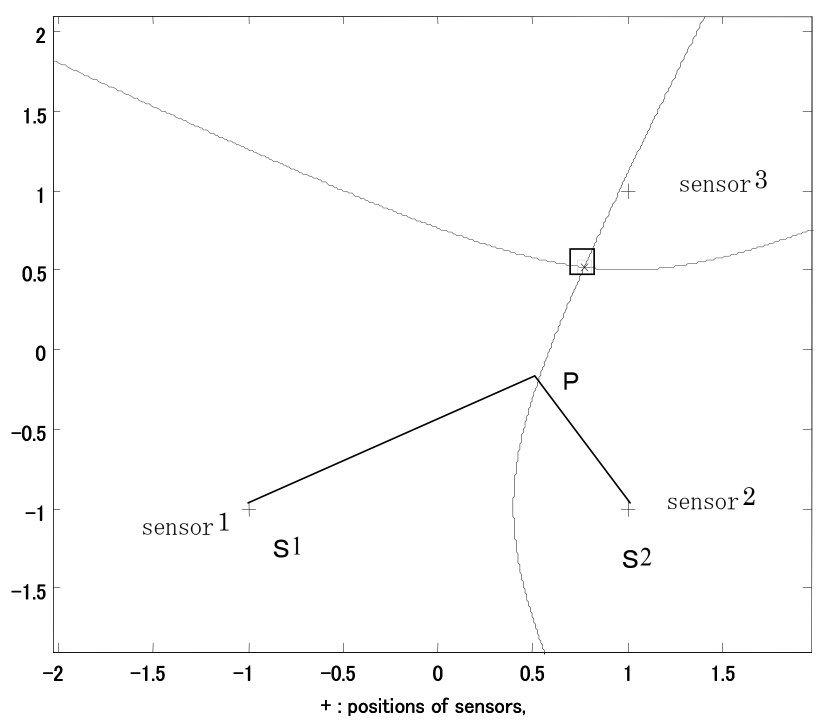


Fig. 3 Principle of the Hyperbolic Method.

(2) Hyperbolic method in Equations

The hyperbolic method is also shown in equations.

The position of a wave source is solved analytically or obtained by numerical operations.

The hyperbolic method in equation is shown as follows.

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

where,
X, Y are coordinate of the position, dn is distances of sensors.
$2aX$, $2aY$ are difference of distance from sensor to a target source on each axis.

B. Physical Algorithm for estimation 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 wavesource is defined by the error between estimation and observation of receiving times.

Evaluation for multiple wavesources 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;

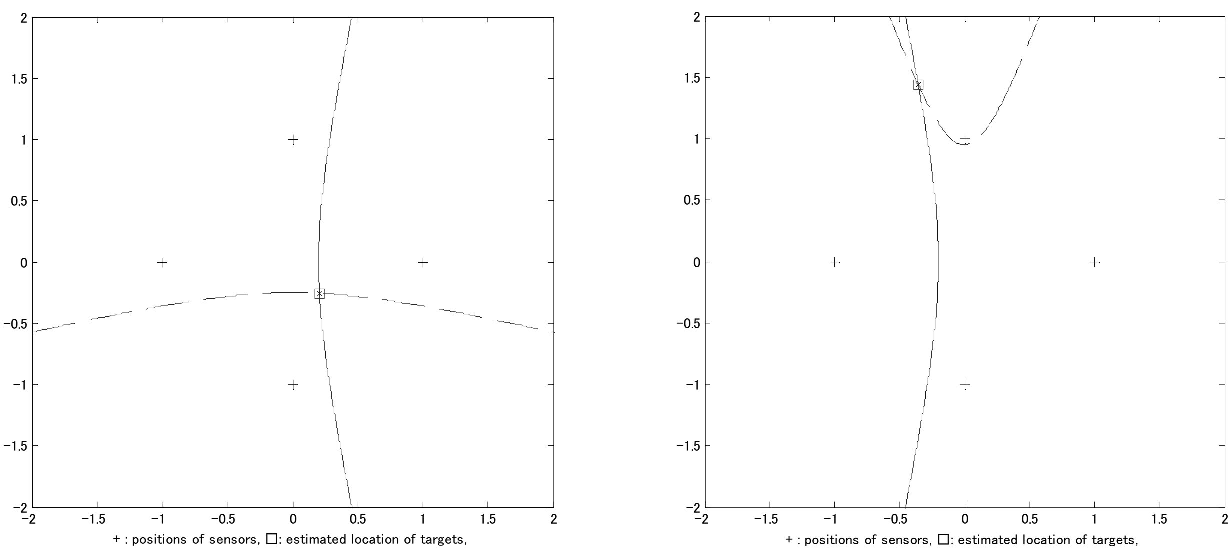
$$E = AF_1 + \frac{1}{2} \cdot \left(BF_2 + CF_3 \right) \quad (7)$$

where, $F1$, $F2$, $F3$ are mathematical error factors reflecting characteristics of biological and physical 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 [9, 10].

N_0 is number of solutions.

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



(a) A sound source inside sensor system.
(b) A sound source outside sensor system

Fig. 4 Possible positions of estimation by the hyperbolic method.

C. Neural Algorithm for mapping

The followings are given by Eq.(5) and (7);

$$E = [\frac{1}{2}\{1-(\delta_{xp}\delta_{yq}\delta_{zr}\delta_{ws} + \delta_{yq}\delta_{zr}\delta_{ws} + \delta_{xp}\delta_{zr}\delta_{ws} + \delta_{xp}\delta_{yq}\delta_{ws} + \delta_{xp}\delta_{yq}\delta_{zr}) + \frac{C}{2}\}] \cdot V_{xyzw}V_{pqrs} + (AD_{xyzw} - CN_0)V_{xyzw} \tag{9}$$

$$W_{xyzw,pqrs} = -\frac{B}{2}\{1-(\delta_{xp}\delta_{yq}\delta_{zr}\delta_{ws} + \delta_{yq}\delta_{zr}\delta_{ws} + \delta_{xp}\delta_{zr}\delta_{ws} + \delta_{xp}\delta_{yq}\delta_{ws} + \delta_{xp}\delta_{yq}\delta_{zr})\} - \frac{C}{2}. \tag{10}$$

$$U_{xyzw} = AD_{xyzw} - CN_0. \tag{11}$$

$$\delta_{ij} = \begin{cases} 1 & ; \quad i \neq j \\ 0 & ; \quad i = j \end{cases} \tag{12}$$

Where, *Dxyzw* is the input current to neuron defined by point *xyzw*. N_0 is estimation of number of sources.

V. System Evaluation

A. Eight sources on 2D space

Factors $F1$ 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.

Physical signal is used for evaluation of a neural system. Receiving system is composed with four sensors on 2D plane.

The estimated and real locations and generation times are shown in Fig. 5 and 6 for eight (8) sound sources being generated randomly in time and space domain. The result of simulation was found reliable sufficiently.

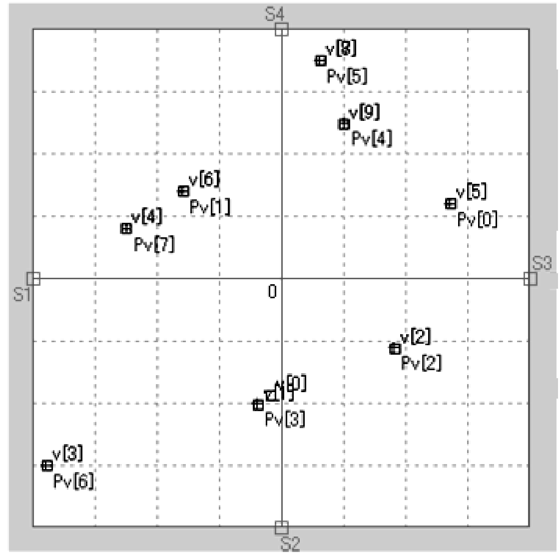
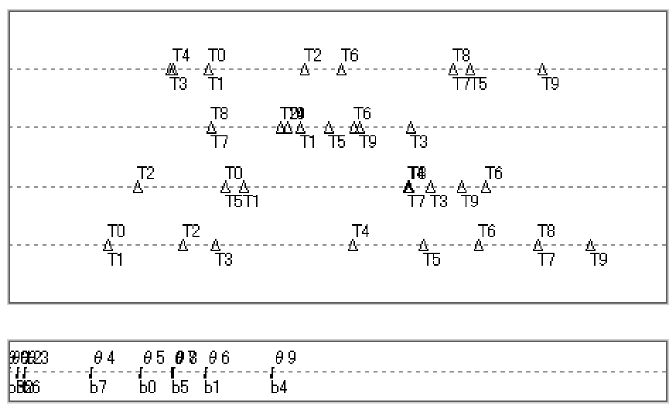


Fig. 5 True and estimated generation points for the case of eight sound sources.
+ : true
□ : estimated



→ time (sec)

Fig. 6 True and estimated generation times for the case of eight sound sources.
Above : Observed time of pulses at sensors s_1–s_4.
Below : True(upper) and estimated(lower) time of pulse generations.

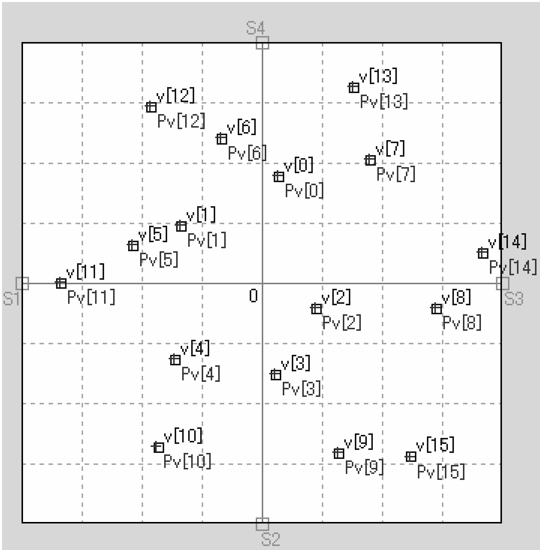
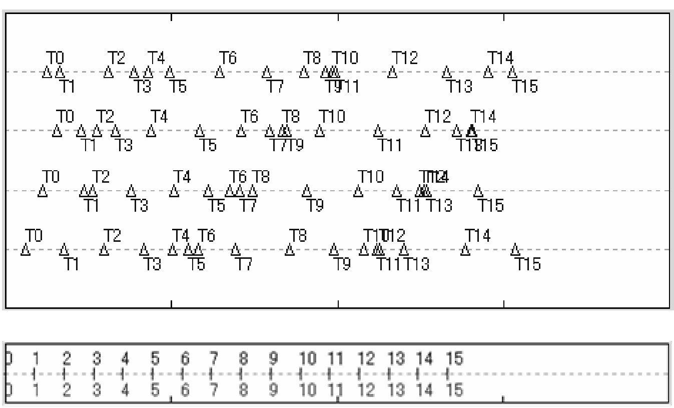


Fig. 7 True and estimated generation points on a plane for the case of 16 sound sources.

+ : true

□ : estimated



→ time (sec)

Fig. 8 True and estimated generation times for the case of 16 sound sources.

Above : Observed time of pulses at sensors s_1–s_4.

Below : True(upper) and estimated(lower) time (sec) of pulse generations.

Some relationship is pointed between entity of estimation and configuration of 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.

Artificial 2D sensor was used to prepare test signals. The system operates autonomously toward conversion as minimizing electric power defined by error between observation and estimation of time and space in 2D plane.

B. 16 sources on 2D space

The estimated and real locations and generation times are shown in Fig. 7 and 8 for sixteen (16) sound sources being generated randomly in time and space domain.

C. Mapping in 3D space

The principle of mapping algorithm is common for 2D and 3D. The same operation is used reduction of error power in Eq. (7).

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 following points are found by computer simulations.

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.

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 injection among neurons. This configuration suggests that intellectual signal processing is brought in brain by interactive processing based on mutual injection among neurons.

APPENDIX

A. Data Processing and its Flow

Figure A1 shows a flowchart of the proposed method.

(1) Detect impulse time

Impulses are detected from signal waveforms in each sensor by a threshold.

(2) Select sets of impulse time

Excited neurons (*Vxyzw* ≥ th) are selected. One excited neuron assigns a set of impulses for location calculation of one source.

As initial value, (*xyzw*) = (1,1,1,1), (2,2,2,2), …, (*N*, *N*, *N*, *N*) are selected in this study.

(3) Estimate position in space with hyperbolic method

Source locations are calculated using hyperbolic method applied to the time difference of the set of impulses.

(4) Estimate propagation times

Propagation times in the sensors are estimated with spherical wave model from source location calculated in step (3).

(5) Calculate coincidence *Dxyzw*

The coincidences are calculated using the estimated and observed time of impulse signals.

(6) Convergence Decision

Coincidence *Dxyzw* is the index of convergence. In the case of *Dxyzw* < ε, go to end. Otherwise, go to the next step.

(7) Calculate parameters of NN

Neuron network parameters *Wxyzw*, *pqrs*, *Txyzw* are calculated using coincidence *Dxyzw* in Eq.(7).

(8) Activate neuron network

Calculate the output *Vxyzw* of neuron networks.

(9) Detect excited neurons.

(10) go to step (2).

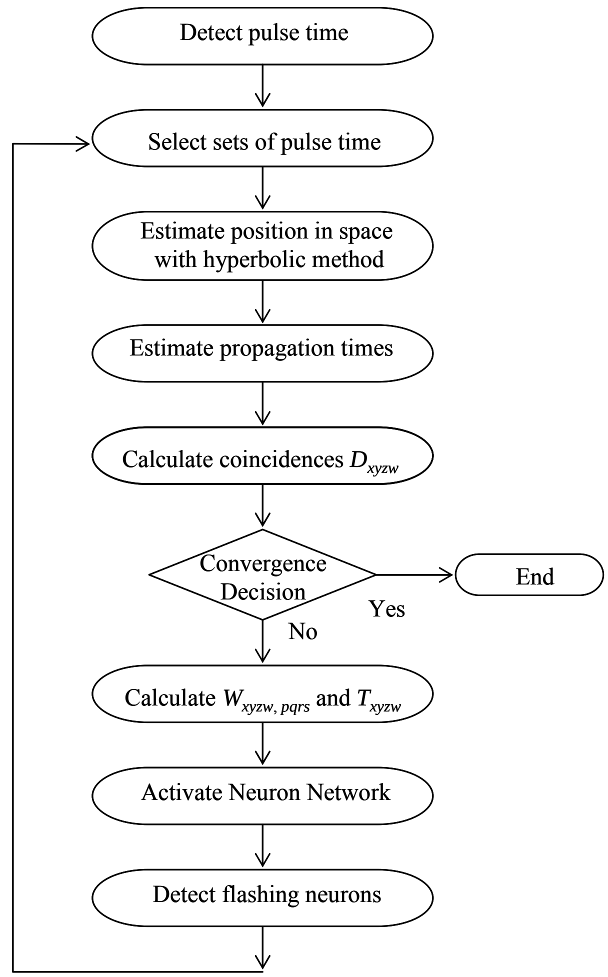


Fig. A1 Calculation Flow.

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Yumi Takizawa 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 as an associate professor 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 Electrical Engineering from Chiba Unversity in 1962. He received 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 joined the department of Electrical and Electronics Engineering, faculty of Engineering, Chiba University in 1998, and the department of Urban Environmental and System Engineering, Chiba University in 1999. He joined Transdisciplinary Research Integration Center, Research Organization of Information and Systems as a project professor in 2004.

He received the Award of the Ministry if Science and Technology, Japan in 1967, and received the Ohm Science and Technology Prize from Ohmsha in 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.