Analysis Method for Time-Space Sequences
by a Novel Neural Network

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Abstract: - Multiple data sources are received from arbitrary positions in space and at arbitrary times. Received impulse signals are provided through 4 sensors allocated at each corner of square field. Neural network (NN) has essentially time-space structure. 4 dimensional hyper space is composed corresponding to 4 sensors. A novel modeling is given for neuron to provide efficient capability of processing thorough forward and reverse couplings with positive and negative signs. The number of elemental neurons is assumed around $10^7$. A novel data processing algorithm is derived for separation and identification of impulse sound sources based on above the neuron model.

Key-Words: - time-space data processing, neuron network, separation of time-space signals, identification of source location

1 Introduction

Effective methods are essentially requested for analysis of data to extract useful information. The authors have been engaged in research and development of acoustic ocean tomography, passive and active sonar, and acoustic location finding[1][2]. They are all regarded as time-space data processing.

For the processing of time-space data, large amount of data must be treated. For practical procession, drastic reduction of data amount is needed. Decimation on time axis and rough digitization on space are needed for numerical operation. Smoothing is essentially needed for visual understanding. This paper is concerned for an advanced method of time-space data analysis based on a novel neural network.

As said above, data attributed to time-space hyper space. A novel neural network is proposed as a system to create a hyper space with time-space axes. According to this perception, data and a neural network as a processor correspond well with each other. This newly proposed configuration of a neural network is given to meet the studies of biological approach of neuroanatomy, neuroethology[3][4], and artificial approach of electrical engineering and mathematics.
2 System Configuration

2.1 System Configuration
A useful method is studied for signal processing of time-space sequences based on novel neural networks. This algorithm was used for discrimination of impulse signals received from spatially distributed multiple sound sources.

Generation of impulse signals are at random temporally and spatially, vibration sensors are set at each quarter of a square space.

A system is considered with the following configuration. Impulse sound signals are received from multiple sound sources located at arbitrary points in space. Impulse signal is generated at arbitrary time for each sound source. These received data are treated as time-space sequences.

2.2 Sensor System
Sensor system is settled shown in Fig. 1. Multiple Sources exist on arbitrary position in a plane. Four sensors are put in the corner of the plane. Impulse signals from sources reached to sensors with time difference. The locations of the sources are calculated using the time difference of reached impulse signals.

When the impulse intervals are enough long, it is easy to decide the set of impulse from same source and to estimate the position of sound sources. However, actually a sensor receives the impulse signals from different sources mixed on time axis.

Time-space data analysis for location of multiple sources was not available without decision of combination of impulse received in sensors. But this procedure requires huge number of calculation to evaluate all combinations of impulses. In the case of 10 sources, the multiple sources location system requires 10000 times calculations comparing to single source system.

A novel neuron network is proposed to derive data processing algorithm for separation and identification of impulse from multiple sound sources.

Modeling of neuron network is referred by accompanied paper[5].

![Fig. 1 Source and sensor allocations.](image1)

![Fig. 2 Impulses arrive to each sensor. A line shows a set of impulse belong to a wave front from a same source.](image2)
3 Neural Network Configuration

3.1 Clustering of Received Impulse Signals

A neural network (NN) is composed of neurons with mutual coupling among all neurons. Electric signals with discrete time wave form are used for operation of NN. Namely, NN is essentially composed of time-space. A 4 dimensional super-plane is composed for the NN corresponding to 4 sensors allocated each corner of square plane.

3.2 Minimization Function

If a time occurrence of an impulse is determinable, the spatial location is determined by the determinate number of the signal sources with hyperbolic method on the case of constant time. On the other hand, if a time occurrence of an impulse is not determinable, it is difficult on the conventional way. In this study, we construct a novel configuration of NN, and study a novel data processing method based on it.

\[ E = W_1 F_1 + W_2 F_2 + W_3 F_3 \]  

(1)

Where, \( E \) is Lyapunov / Energy function, and \( W_1, W_2, W_3 \) are weighting factors.

3.3 Modeling of Neural Network

The coupling among neurons takes the value of negative and positive near zero in both directions. The response of \( i \)-th neuron is modeled by the following.

\[ I_i = \sum_i W_{ij} V_j - U_i \]  

(2)

\[ V_i = \{1 + \tanh(I_i / \mu)\} / 2 \]  

(3)

\( I_i \) : input current of \( i \)-th neuron [A]  
\( V_i \) : output voltage of \( i \)-th neuron [V]  
\( W_{ij} \) : conductance of \( i \)-th to \( j \)-th neuron [S]  
\( U_i \) : threshold current of \( i \)-th neuron [A]  
\( \mu \) : a constant corresponding to sigmoid function

The minimization function of this neuron network is considered as follows.

\[ E_n = -\sum_{i,j} W_{ij} V_j / 2 + \sum_i U_i V_i \]  

(4)

4 Algorithm

4.1 Evaluation of Impulse Arrival Times

The first term of minimization function corresponds to difference of observed and estimation values.

\[ F_1 = \sum_{x,y,z,w} D_{xyzw} V_{xyzw} \]  

(5)

Where,

\[ \sum_{x,y,z,w} := \sum_x \sum_y \sum_z \sum_w \]

\( D_{xyzw} \) is normalized error of observed and estimated arrival time by the impulse combination \((x, y, z, w)\) selected by neuron network. \( V_{xyzw} \) is output of firing neuron at coordinate \((x, y, z, w)\) in neuron network space.

\[ D_{xyzw} = \min_{b_v} \left[ \sum_{i=1}^4 (\tau_i - b_v)^2 \right] / \tau_0^2 \]  

(6)

\[ = \left( \sum_{i=1}^4 \tau_i^2 - \frac{1}{4} \sum_{i=1}^4 \sum_{j=1}^4 \tau_i \tau_j \right) / \tau_0^2 \]  

(7)

\[ \tau_i = T_{(xyzw)i} - T_{mi} \]  

(8)

\[ \tau_0 = \frac{d_0}{V_s} \]  

(9)

where, \( b_v \) is estimated occurring time of impulse from the \( v \)-th source. \( T_{mi} \) is estimated arrival time into the \( i \)-th sensor and \( T_{(xyzw)i} \) indicates observed time of the \( x \)-th impulse in the case of first sensor, the \( y \)-th impulse in the case of the second sensor, ... This combination is written in Table 1.

<table>
<thead>
<tr>
<th>No. of sensors</th>
<th>( i )</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set of impulse no.</td>
<td>((xyzw))</td>
<td>(x)</td>
<td>(y)</td>
<td>(z)</td>
<td>(w)</td>
</tr>
</tbody>
</table>

Table 1: Set of impulse in the sensors.
\(d_0\) is distance of sensors, \(v_s\) is sound velocity, \(\tau_0\) is wave propagation time between sensors. The output neuron \(V_{xyzw}\) indicates that \(x, y, z, w\)-th impulses are combined as same wave front from a source.

**Fig. 3** A coordinate of flashing neuron corresponds to the impulse numbers from same sound source. In the figure, \((3, 1, 3)\) indicates a set of impulse numbers, \(x = 3, y = 1, z = 3\) in the case of 3-D neuron network for easy understanding.

### 4.2 Evaluation of Superposition of Solutions

The second term of minimization function corresponds to control super-positions of impulse from the different sources. The following equation means super-positions are allowed up to two pulses. (Refer to Fig. 2.) In this study, the degree of super-position is selectable to match applications.

\[
F_2 = \sum_{x,y,z,w} \sum_{p,q,r,s} V_{xyzw} V_{pqrs} - \left( \sum_{x,y,z,w} V_{xyzw} \right)^2 \\
+ \sum_{x,y,z,w} V_{xyzw} V_{pzw} + \sum_{x,y,z,w} V_{xyzw} V_{qzw} \\
+ \sum_{x,y,z,w} V_{xyzw} V_{xyrw} + \sum_{x,y,z,w} V_{xyzw} V_{xyzs}
\]

(10)

### 4.3 Evaluation of Number of Effective Solutions

The third term of minimization function corresponds to control the effective number of solutions. Difference of obtained and assumed number of effective solutions is evaluated in the following.

\[
F_3 = \left( \sum_{x,y,z,w} V_{xyzw} - N_0 \right)^2 
\]

(11)

\[
N_0 = \min N; \quad \partial \log E(N)/\partial N = 0
\]

(12)

### 4.4 Parameters calculation of NN

The minimization function is written by Eq.(1), (5), (10), (11) as follows.

\[
E = AF_1 + \frac{1}{2} BF_2 + \frac{1}{2} CF_3
\]

(13)

\[
= \left[ \frac{B}{2} \left( 1 - \left( \delta_{x\delta_{qp}} \delta_{x\delta_{ws}} + \delta_{y\delta_{pq}} \delta_{y\delta_{ws}} + \delta_{z\delta_{pr}} \delta_{z\delta_{ws}} + \delta_{w\delta_{pq}} \delta_{w\delta_{pr}} \delta_{w\delta_{qs}} \delta_{w\delta_{rs}} \right) \right) + \frac{C}{2} \right] V_{xyzw} V_{pqrs}
\]

\[
+ (AD_{xyzw} - CN_0) V_{xyzw}
\]

(14)

Correspondence of the expression (1) and (14) brings the following formulation of \(W_g\) and \(T_r\).

\[
W_{xyzw,pqrs} = -\frac{B}{2} \left( 1 - \left( \delta_{x\delta_{pq}} \delta_{x\delta_{ws}} + \delta_{y\delta_{pq}} \delta_{y\delta_{ws}} + \delta_{z\delta_{pq}} \delta_{z\delta_{ws}} + \delta_{w\delta_{pq}} \delta_{w\delta_{qs}} \delta_{w\delta_{rs}} \right) \right) - \frac{C}{2}
\]

(14)

\[
U_{xyzw} = AD_{xyzw} - CN_0
\]

(15)

The solution of combinatorial problem is given by the coordinate value of exciting neuron on 4-th dimensional space. Location of sound sources is specified by this solution.
5 Data Processing and its Flow

Figure 3 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 ($V_{xyzw} \geq \theta$) are selected. One excited neuron assigns a set of impulses for location calculation of one source.

As initial value, $(x_{i}, y_{i}, z_{i}, w_{i}) = (1,1,1,1), (2,2,2,2), \ldots, (N, N, N, N)$ 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 $D_{xyzw}$
   The coincidences are calculated using the estimated and observed time of impulse signals.

(6) Convergence Decision
   Coincidence $D_{xyzw}$ is the index of convergence. In the case of $D_{xyzw} < \varepsilon$, go to end. Otherwise, go to the next step.

(7) Calculate parameters of NN
   Neuron network parameters $W_{xyzw}, p_{qrs}, T_{xyzw}$ are calculated using coincidence $D_{xyzw}$ in Eq.(7).

(8) Activate neuron network
   Calculate the output $V_{xyzw}$ of neuron networks.

(9) Detect excited neurons.

(10) go to step (2).

6 Conclusions

A novel modeling was described for a neuron and a neural network. The proposed algorithm of neural network is given in this paper. It was made clear that efficient capability of processing is realized thorough forward and reverse permittivity with positive and negative signs. The number of elemental neurons is assumed around 10^7 or more packed in a hyper space with four axes. The size of new NN exceeds so high compared with that by Hopfield.

A novel data processing scheme was applied for separation and identification of impulse sound sources. Advanced modeling and result of applications are under the study.
References:


