Applications of artificial neural networks: Detections of the location of a sound-source

Koji Oobayashi*, Yan Yuan, and Tomoo Aoyama

*The Faculty of Engineering, Miyazaki University, Japan
(Fax: +81-985-58-7411, E-mail: tgb311u@student.miyazaki-u.ac.jp)

Abstract: Non-destruction examinations are required in medical sciences and various engineering now. We wish to emulate the examinations in very simplified experiments. It is an educational program. We show a neural network analysis to predict the locations of a sound-source or a body irradiated by sound-waves in audio-region. The sound is an interest flux, and it enables to clear local-structures in a non-transparent space. However, the sound-propagation equations are not solved easily, therefore, we consider to adopt multi-layer neural-networks instead of the direct solutions. We used detected intensities and coordinates for input data and teaching data. A neural network learned them. The neural-network analysis decomposed the distance of 50cm. The resolution is rather rough; however, it is caused by the limitation of our equipments. Since there is no problem in the neural network processing, if we could revise experiments, then, progress of the resolution would be got. Thus, the proposed method functioned as an educational and simplified non-destruction examination.

Keywords: neural networks, non-destruction examinations, educational programs, sound waves, sonic-waves, acoustic analysis, and location predictors.

1. INTRODUCTION

1.1 Non-destruction examination

Non-destruction examinations are required in medical sciences and various engineering now. If there were low-cost means to find inner structures of a space, they would be applied to many fields. To realize it, we must adopt a flux that transmits the space and interacts with the inner bodies. The interactions are reflects on the surfaces or absorptions by the bodies.

It is an important problem. Usually, X-ray and ultra-sound wave are used [1]. The interacted flux are detected and digitized, and observation values are got. The observations have a fragment of information for the inner structures. If we knew equations that emulated the observations, we could estimate the inner structures of the space.

Or, in a local region of the space, if we were able to represent numerical expressions for the emulations of the flux, we would trace the flux-propagation by using computers. Thus, we can forecast the inner structures approximately.

Modern non-destruction examinations are based on knowledge of the flux-propagation. If the knowledge had a bit of uncertain part, we couldn't do the examinations in high precision. On the viewpoint, X-ray and ultra-sound fluxes are effective physical properties.

1.2 Functions of multi-layer neural networks

Techniques of artificial neural networks are remarkably developed; and now, the networks are used for various application fields. Multi-layer neural networks have a function to classify observation data. The function is obtained by a process of learning automatically. After the learning process is completed, the networks have also a function that interprets non-linear relations between observations and the consequences [2].

On the neural networks, even if the flux propagation equations were unknown, if we can observe typical examples of interactions between the flux and bodies, thus, we use the observations as the learning data for the neural networks, and we can construct an implicit propagation equation approximately in the neural networks.

The fact represents a possibility that there is no longer necessary to solve the flux equations.

To confirm the idea, we select sound-wave in audio-region as the flux. Observing and learning interactions between the sound and bodies, we researched a means that detects the location of bodies. In the audio region, we can use microphones as a detector of sound-intensity, which do not require special specifications. Thus, we can construct experimental equipments in low-costs.

However, the audio-sound is diffractive, and its propagation/refractive equation would be complex.

Under the complex conditions, sound-intensity is not linearly decreased for the distance between a source and detector. Prediction of the intensity is not a simple process; therefore, we cannot do it a priori. On such a difficult situation, the neural network analysis may be an effective means.

If we could build up the means, it is an effective and practical method to check inner structures of the space.

2. TRADITIONAL RESEARCHES OF ACOUSTICS

Some researches are known until now, which detect bodies in a space by using sound-waves in audio region. Following researches give us important information.

(1) By observing incidence angles, the paper proposed a predictor for the locations of sound-sources [3]. The sound-field is overlapped by plural low-frequency waves.
(2) The paper evaluates the locations and sizes of sound-sources on observations of acoustic signals detected by four microphones that are arranged in a plain [4]. The research is done for designs of concert-halls or churches.
(3) The paper proposes an estimator to indicate a talker's location, which is implemented on an autonomous-transportation robot [5].
(4) Using transmitting and receiving detectors array, and processing MUSIC method [6], the paper predicts the location of a sound-source [7].

These researches adopted direct evaluations of a propagation equation. They didn't generate implicit propagation functions in neural networks.

3. EQUIPMENTS AND NEURAL NETWORKS

3.1 Acoustic equipments

We used following acoustic equipments.
(1) Sound source: non-directivity speaker produced by Sugiyama Electron Co. Ltd. (in Japan), the specification number is SEP-01.
(2) Measuring instrument: dynamic microphone produced by Audio-Technica Co. Ltd. (in Japan), the specification number is AT-VD5. The sound-intensity is measured by [-dB].
(3) Measurement frequency: 100Hz and 12.5KHz, those are two terminal frequencies of AT-VD5.
(4) Lattice: square by 2[m]*2[m] and 50[cm] intervals (figure 1).
(5) Positions of sound-source and body: On all lattice points (25 points)
(6) Position of detectors: Terminal points on corners (in figure 1)

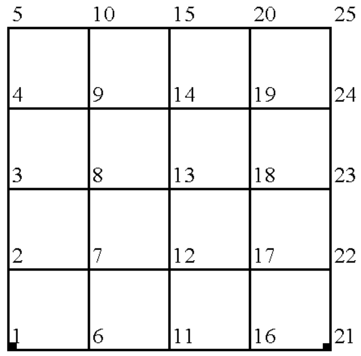

Fig.1 Lattice and numbering of the points, for prediction of sound-source

Two detectors are set on the points 1 and 21, and a sound-source is put on other points. One observation is to detect sound-intensity from a point of 2-25 (except 21). The number of observations is 25.

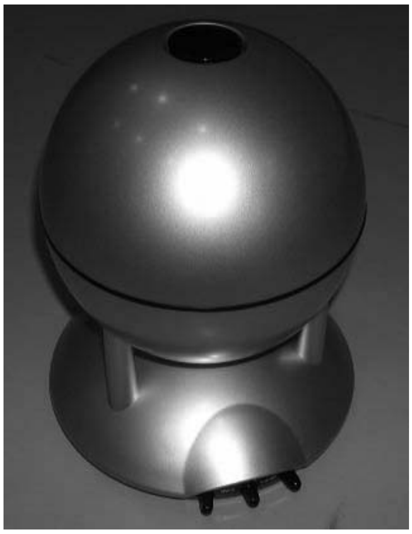

Fig.2 Photography of non-directivity speaker SEP-01, by Sugiyama Electron Co. Ltd. (in Japan).

3.2 Neural network structures

(1) Three-layer neural network.
(2) Operation function of neuron on hidden-layer: sigmoid function, $f(x)=1/\{1+\exp(-x)\}$.
The learning coefficient is 0.15.
(3) Operation function of neuron on output-layer: linear function, $f(x)=x$.
The learning coefficient is 0.1. This type is often called "analogue type neural network."
The characters are rapid learning and suitable to analogue outputs.

(4) Number of neurons: 3, 12, 2 for input, hidden, output-layers.

One neuron on input-layer is the bias-neuron. Other two neurons on the layer correspond to two detectors. Two neurons on output-layer indicate x-and y-coordinates.

(5) Number of learning: 100K.

4. EXPERIMENT 1: DETECTIONS OF THE LOCATION OF A SOUND-SOURCE

4.1 Abstracts of the experiment

This experiment is to detect the location of a sound-source in a space. The space is surround with many sound-reflecting walls; therefore, the acoustic-field is complex. Appropriate expression for the field is unknown. Under the wrong conditions, we try to predict the sound-location by using neural networks. We observed the sound-intensities from a sound-source that were located on each lattice points in figure 1. The intensities were used as input data of the neural networks, and the coordinates of the source were used as teaching data. By low-resolution property of audio-sound-waves, we couldn't set so many lattice points. Then, we used standard deviations of leave-1-out method, as an index to examine the prediction ability.

4.2 Examinations of prediction ability of neural networks

The number of observations is rather small, which is not sufficient to make statistical processing. In such a case, as an examination of predictor, leave-1-out method is proposed. Principle of leave-1-out method is simple; that is followings.

(1) One datum is left from the examination assemble.
(2) The remains are learned by a network.
(3) The exclude datum is inputted to the network, and the difference between the output and excluded observation is calculated.
(4) The above scheme is repeated on every numbers of data.

We used the leave-1-out method, calculated standard deviations of the differences, and made them an index of the judgment.

4.3 Convergence of back-propagation equation.

We calculated the back-propagation (BP) equation by using observation data for sound-intensities and coordinates of the source, where the former is used as input data and the later is used as teaching data. Where the learning iterations are 100K, and learning coefficients are 0.15 and 0.1 for a hidden-layer and output-layer. When we adopt intensities observed by one frequency wave, the BP-equation was not completed. We tested various coefficients, but didn't convergences. It was caused by two equivalent input data and the corresponding different teaching values. We call it contradiction. Figure 3 shows a contour map of the input data. Each curves in figure 3 are plotted on x- and y-Cartesian coordinates. Therefore, the existence of same values in the contour map means the contradiction.

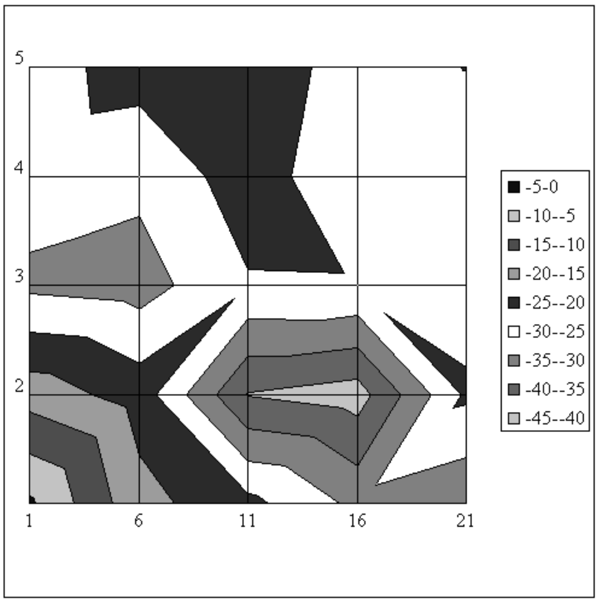

Fig.3 Contour map of detected sound-intensities

The numbers on vertical and horizontal axes are same that of figure 1. Classifications of sound-intensities [dB] are shown in small right box. The map is got by connecting equivalent [dB] value points. The observations are done by a left-side microphone and about a frequency. That is, there are other four kinds maps. A contour line is almost a circle. It means that there are plural points observing the same [dB] value. Those are a contradiction data for neural networks.

On such an un-convergent network, prediction of the locations couldn't be executed. To avoid the defect, we re-observed the sound-intensities by two kinds of frequencies, that is, 100Hz and 12.5KHz. When the re-observations are used as input data, the

BP-equations are completed normally.

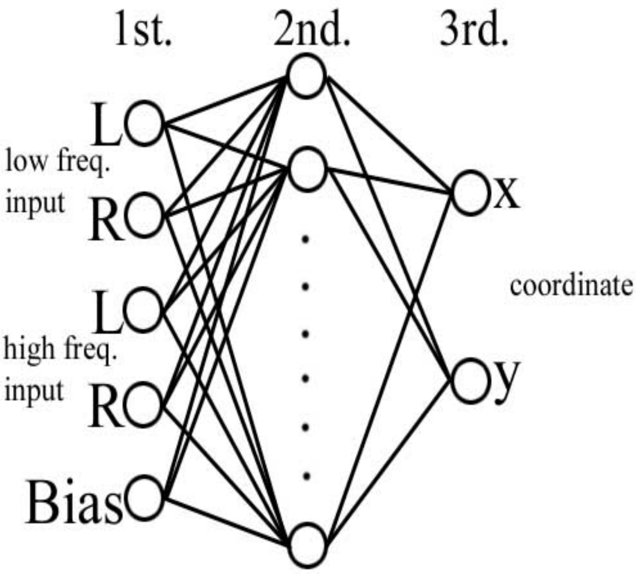

Fig.4 Neural network structure and the learning data.

The network has 3-layers, the first receives two kinds data that are observed by 100Hz and 12.5KHz. The neuron number of second-layer is 12. The third receives coordinates for BP-learning.

4.4 Learning precision of leave-1-out method

We calculated the leave-1-out method for those observations and coordinates. On each calculation, we calculated the average standard deviation among all outputs and teaching data. It indicates a learning convergence of each leave-1-out calculation. The standard deviations are shown in figure 5, which are plotted on the coordinate of excluded datum.

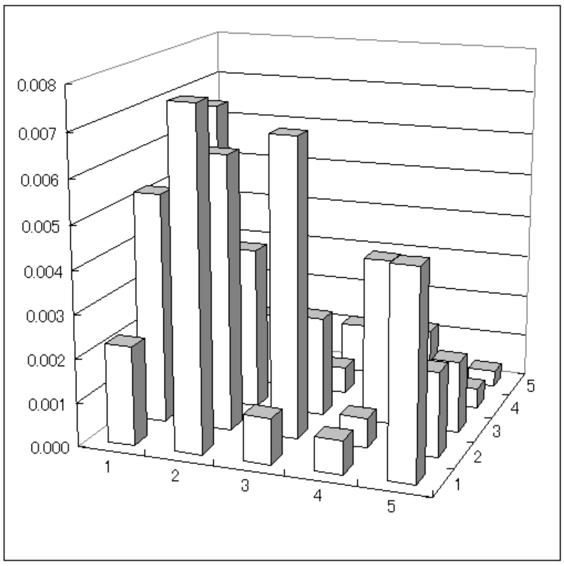

Fig.5 Average standard deviations calculated by plural leave-1-out method, which are ordered by the coordinate of excluded datum.

The numbers 1-5 on horizontal axis correspond to 5-1 of figure 1. The numbers 1-5 on depth axis corresponds to 1, 6, 11, 16, 21 of figure 1. The scales of vertical axis are values of standard deviations.

Finding the scales, there are O(-2) errors, and it means precision of the learning level of leave-1-out method. Judging the figure, we believe the learning is completed normally.

4.5 Prediction of locations of sound-source

As for each converged networks, we inputted the excluded datum to the network, and got one output. The output datum was compared with excluded teaching datum, and the standard deviation was calculated. We repeated the procedures for the number of all data. The standard deviations are listed in figure 6.

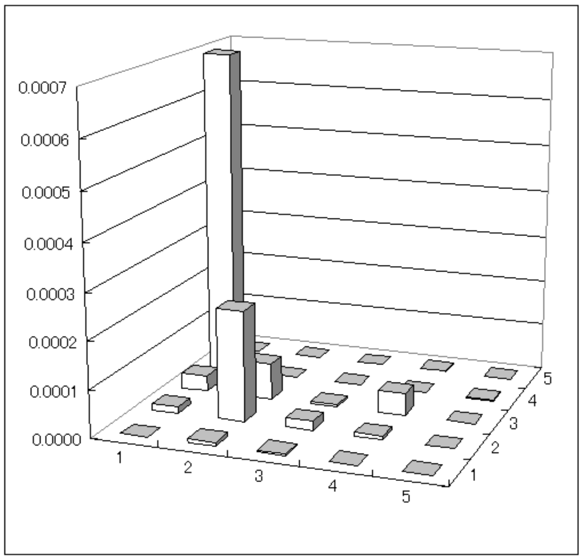

Fig.6 Standard deviations of leave-1-out method

The numbers 1-5 on horizontal axis correspond to 5-1 of figure 1. The numbers 1-5 on depth axis corresponds to 1, 6, 11, 16, 21 of figure 1. The scales of vertical axis are values of standard deviations.

Errors of the deviations are O(-3)~O(-5); that is, they are less than 0.1%. That means the prediction ability of a method introduced by idea in section 1.2.

Thus, the locations of sound-source are predicted in extremely high precision.

5. EXPERIMENT 2: DETECTIONS OF THE LOCATION OF A BODY

5.1 Abstracts of the experiment

The objective is to detect the location of a body in a space. The space is surround with many sound-reflecting walls.

The space is meshed by a square lattice, where a sound-source is fixed at a terminal point, and two detectors are set at other terminal points. The object body is located at various lattice points.

They are shown in figure 7.

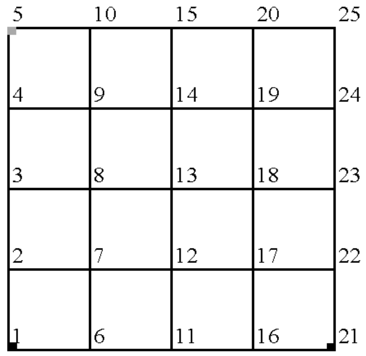

Fig.7 Relative positioning of a source, detectors, and the body,

Two detectors are set on the points 1 and 21, and a sound-source is fixed at point 5. One observation is to detect sound-intensity when a body is put on the point of 1-25. The number of observations is 25.

The acoustic-field is complex. Appropriate expression for the field is unknown; however, we try to predict the body-location by using neural networks. We observed the intensities of sound interacted with the body that were located on each lattice points. The intensities were used as input data of the neural networks, and the coordinates of the body were used as teaching data. As well as section 4, we used standard deviations calculated by leave-1-out method, as an index to examine the prediction ability.

5.2 Convergence of back-propagation equation.

We calculated the back-propagation (BP) equation by using observation data for sound-intensities and coordinates of the source, where the former is used as input data and the later is used as teaching data. Where the learning iterations are 100K, and learning coefficients are 0.15 and 0.1 for a hidden-layer and output-layer. We used two frequency waves; then, the BP-equation was completed normally.

5.3 Prediction ability examined by leave-1-out method

For each converged networks, we inputted the excluded datum to the network, and got one output.

The output datum was compared with excluded teaching datum, and the standard deviation was calculated. We repeated the procedures for the number of all data. The standard deviations are listed in figure 8 and 9, which show the prediction ability for body-locations.

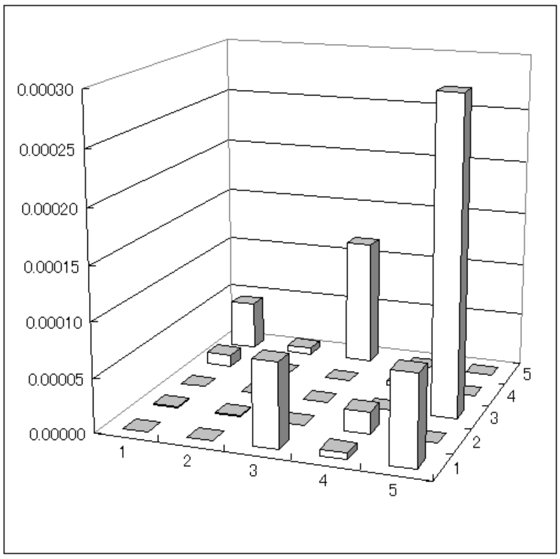

Fig.8 Standard deviations of location-predictions of reflecting body.

The drawing schemes are same as figure 6.Errors of the deviations are O(-3.3)~O(-6); that is, they are less than 0.1%. That means the prediction ability of a method introduced by idea in section 1.2.

Thus, the locations of sound-reflecting body are predicted in extremely high precision.

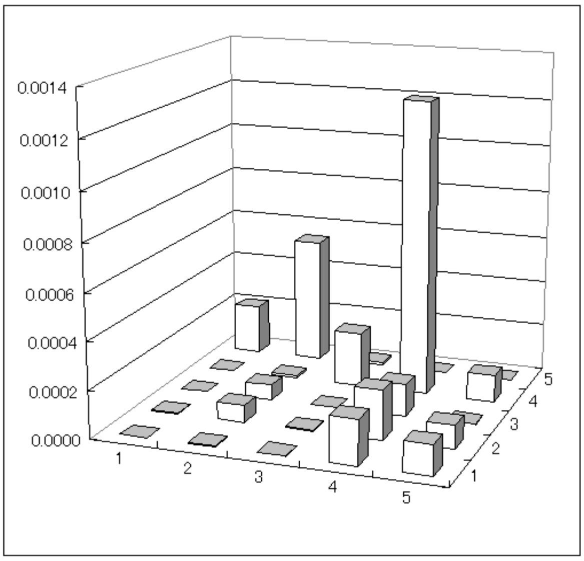

Fig.9 Average standard deviations of absorption body.

The drawing schemes are same as figure 6. Errors of the deviations are O(-3)~O(-5); that is, they are less than 0.12%. That means the prediction ability of a method introduced by idea in section 1.2.

Thus, the locations of sound-reflecting body are predicted in extremely high precision.

CONCLUSIONS

A flux propagates through the space, and interacts the inner bodies. By detecting the variation of flux and analyzing the variations, we can predict locations or characters of the bodies. If the flux propagation equation is unknown, and even if the variations are non-linear, by using the learning function of a multi-layer neural network, we can predict them. It is a kind of non-destruction examinations, and it is an important technique.

In this work, we used sound-waves in audio-region as the flux. They are diffractive, and the propagation/refractive equation is complex. The sound-intensity is not linearly decreased for distances between a source and detectors. Prediction of locations of sound-sources is not simple. Even such a difficult case, we could expect that the neural network analysis was effective. We planned two kinds experiments, which were;

1) That is to determine the location of a sound-source in the space surrounded by complex walls.

2) That is to determine the location of a body under the fixed a sound-source and detectors. Where, we provided two bodies that have reflecting and absorption surfaces.

Someone may feel these experiments are rather rough. However, under unknown propagation-equation and complex interactions, it is kept the problem's essence to predict the body's location or other information. Another essence, a multi-layer neural network, is also used as an analyzer. The usage makes flux propagation-equation be unnecessary. By means of them, we can predict the locations of sound-source and the bodies within the precision of 0.1-0.12% errors. Thus, our proposed method is proved. However, it is a step; so, we should make next steps that are more detail and less observed-points. We are planning a new experiment, which is to observe irradiating sound-wave to a body, and to determine its location. The mesh is 5x5 now, that is rather rough. We should make it be fine mesh.

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