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Tomographic measurement of the vortex wind field based on the transmission and reception of the coded acoustic wave signals between parallel array elements

平行アレイ間符号変調音波送受信による渦風速場のトモグラフィ計測

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1. Introduction

We have been studied acoustic travel time tomography system for the monitoring of the vortex wind flow velocity profile by placing multi-channel acoustic transmitter/receiver pairs along the opposite sides of monitoring region.[1,2] For the simultaneous transmission and reception of the multi-channel signals, coded modulation was incorporated to realize the real time observation keeping up with the rapid change of the air flow field. The examinations were made under the condition assuming that position of the vortex field was located at the coordinate center.[3]

In this paper, reconstruction method was developed which can estimate the location of the vortex wind field, by using the propagated sound wave information between the oblique directional combination of transmitters and receivers. The experiment examinations were carried out to test the validity of the method to reconstruct the vortex wind fields locating at arbitrary positions.

2. Method

2.1 Wind flow velocity measurement using the travel time lag data

As shown in Fig.1, pairs of sound wave transmitter and receiver are arranged on both side of the target flow velocity field, with facing side distance L and element spacing d. The dual directional time lag data ΔT are measured along the path between the multiple combination of the facing transmitters and receivers. On this basis, tomographic problem is considered to reconstruct a vortex air flow velocity field $\mathbf{v}(x,y)$ in the sound transmitted horizontal (x,y) plane. To accomplish the collection of multi-channel data in a single sound wave excitation, transmitters are excited with sinusoid wave modulated with code sequences, where value {1,-1} of Kasami code is assigned to the phase {0, π}of the N_{sin} period of sine waves.

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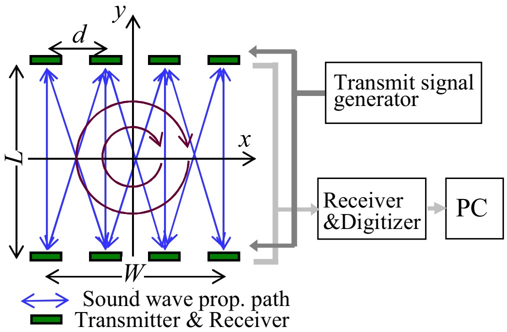

Fig.1 Multi-channel tomographic wind flow measurement system.

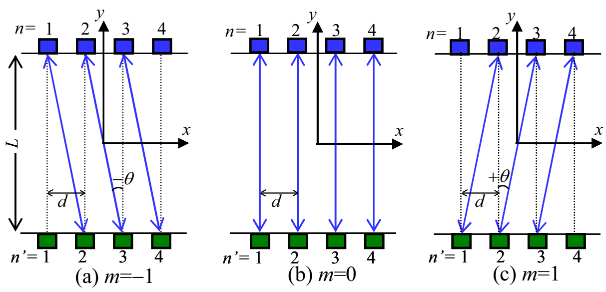

Fig.2 Transmitter/receiver arrangement and their combination of oblique sound propagation path.

After the reception of the signal transmitted through the air flow medium, the signal from the desired transmitter can be extracted by the correlation calculation with the selected excitation sequence.

2.2 Reconstruction of the vortex wind flow fields based on the oblique view observation data

As shown in Fig.2, travel time data ΔT_m are measured for the different sound wave propagation angle θ_m, where m is the index related with θ_m as

$$\theta_m = \tan^{-1}\left(\frac{md}{L}\right), \quad -M \le m \le M. \qquad (1)$$

We denote the rotated coordinate (x', y') with angle θ. From the travel time data ΔT_m for each propagation angle θ_m, vortex wind velocity field

$\mathbf{v}_m(x'-x'_c)$ can be reconstructed, where x'_c is the center position of the vortex in x' direction. It is noted that center position y_c' in y' direction is not determined at this point. To determine it, we pay attention to the following relation between the obtained $x'_c(\theta_m)$ and unknown center position (x_c, y_c) as,

$$x_c'(\theta_m) = x_c \cos\theta_m - y_c \sin\theta_m \qquad (2)$$

The collections of $x'_c(\theta_m)$ for different propagation angle θ_m provides a set of simultaneous equations. As a least squares solution of the simultaneous equations, vortex center position (x_c,y_c) can finally be obtained.

3. Test examination

3.1 Method of sound wave measurement

Four pairs of speakers (1.6-100 kHz) and condenser microphones (60-40 kHz) are placed with spacing d=70 mm along a pair of opposite sides of the two dimensional rectangular measurement region (W:210xL:500mm). Different {1,-1} sequences from n=8 bit Kasami code were assigned to the phase $\{0,\pi\}$ of the N_{sin}=2 period of sinusoidal waves with frequency f=20 kHz. The transmitter signals were generated by the home made digital arbitrary waveform generator (8 bit, 0.5 MPS DAC). They were emitted in twice from each side of 4 speakers as forward and reverse directional excitations. Sound waves passing through the medium were received by the facing receivers and demodulated to obtain the time lags along the propagation angels at θ_{-1}, θ_0, θ_{+1}. Finally, the collected data along 3 paths for m=-1, +1, and 4 paths for m=0 (10 paths in total) were used for the wind field tomographic calculation.

3.2 Test result

A fan with diameter 190 mm was used as a vortex air flow source, which was generated by sending the axial up flow wind from underneath the measurement plane. Center positions of the wind source were changed at (x_c, y_c)= (-35, 0), (+35,0), (0, -30), (0,+30)mm. Using the collected travel time lag data ΔT_m (m=-1,0,+1), wind flow fields were reconstructed as shown in Fig.3. In addition, the estimated center positions were summarized as shown in Table.3. We can see that there are large deviation errors in y-direction (range direction). This is mainly due to the ill-condition of the least square solution of the equation, caused by that observation aperture width was very small and there were errors in the time lag data for the case when the sound path intersecting just through the vortex center. To resolve the problems, examinations should be made under the wider observation width conditions. To this end, we are planning to reform the system using increased number of transmitter/receiver elements.

References

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3. H.Li, S.Takata and A.Yamada, Jpn. J.Appl. Phys., 50, 7, 07HC09 1-5 (2011).

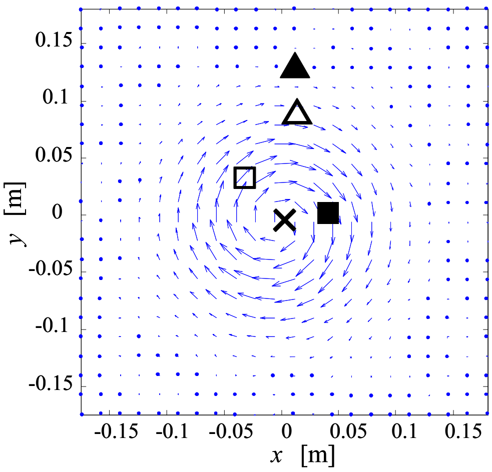

Fig.3 Reconstructed vortex air flow field when the source was positioned at center positions. The marks show the estimated center positions when the source was set at the positions, × :(0,0)mm, ■ :(35,0)mm, □:(-35,0)mm, ▲:(0,30)mm, △:(0,-30)mm.

Table 1 Estimated center position (x_c, y_c) mm of the vortex wind field.

Set-up	Exp.	Sym.
(-35,0)	(-34,39)	(-31,0)
(35,0)	(39,4)	(28,0)
(0,-30)	(16,94)	(-4,-55)
(0,30)	(9,134)	(-4,55)