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Tomographic measurement of the vortex air flow field using the multi-channel transmission and reception of the coded acoustic wave signals

符号変調音波の多チャンネル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

Acoustic travel time tomography system for the monitoring of the vortex wind flow velocity profile has been studied[1,2], where multi-channel acoustic transmitter/receiver pairs are placed along the opposite sides of monitoring region. So far, for the avoidance of the crosstalk between the elements, travel time collections must be made successively for every single transducer element. Hence, it was difficult to achieve the real time observation in keeping with the temporal variation of the air flow field. As a solution to the problem, the coded modulation method using Kasami sequence was introduced[3]. In this paper, to elucidate the feasibility of the method, measurement precision of the time lag yielded by the vortex wind flow field is tested through the simulation and experiment examinations.

2. Method

2.1 Wind flow velocity measurement using the travel time lag data

Pairs of sound wave transmitter and receiver are arranged on both side of the target flow velocity field. Measurement of travel time T_{ab} between transmitter a and receiver b in normal direction is considered, in addition, T_{ba} between transmitter b and receiver in reverse direction. Dual directional travel time lag is assigned as $\Delta T=T_{ab}-T_{ba}$. The time lag ΔT along the straight line path between a and b is described by the path integration of the wind velocity vector field $v(x,y)$. On this basis, tomographic problem is considered to reconstruct a flow velocity field from the observation of the dual directional travel time lag data along the paths between the multiple combination of the transmitters and receivers.

2.2 Simultaneous transmission and reception using code modulation sound wave

To accomplish the collection of multi-channel data in a single sound wave excitation without cross-talk interference, transmitters are simultaneously excited with code modulation signals. After the reception of the signal propagated

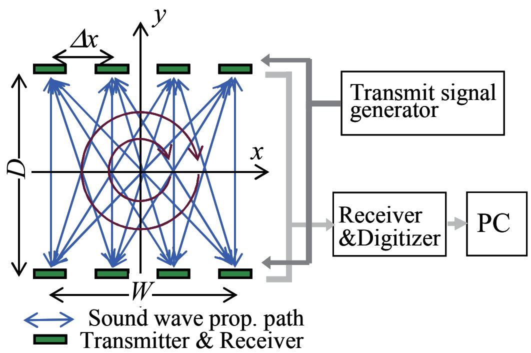

Fig.1 Multi-channel tomographic wind flow measurement system.

through the air flow medium from the multi-channel transmitters, the signal from the desired transmitter can be extracted by the correlation with the selected excitation sequence.

2.3 Kasami sequence

Kasami sequences are a set of pseudo-random binary sequences that have optimal cross-correlation values approaching the Welch lower bound. A m-th order (m is an even integer) set of sequence consists of M ($=2^{m/2}$) different ones with period n ($=2^m-1$)). Then, autocorrelation of a sequence is n for zero-lag, and takes on values -1, $-1-2^{m/2}$ $-1+2^{m/2}$ for all other lags. Moreover, the cross correlation between any pair of sequences takes on values -1, $-1-2^{m/2}$ $-1+2^{m/2}$. Consequently, the cross correlation values are small compared to the auto correlation peak by a factor of $1/2^{m/2}$. From the cross correlation between the received signal and any arbitrary transmitter signal, the time lag can be extracted which is propagated along the path between the selected transmitter and receiver.

2.4 PSK modulation of sound wave signal

In this study, sinusoid sound wave with frequency f is modulated with the set of Kasami sequences with order m, where value {1,-1} of Kasami code is assigned to the phase {0, π}of the N_{sin} period of sine waves according to the phase shift keying (PSK).

3. Test examination

3.1 Method of sound wave measurement

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In the experiment described below, four pairs of speakers and microphones are placed with spacing Δ*x*=50 mm along a pair of opposite sides of the two dimensional rectangular measurement region (*W*:150 x *D*:500mm) as shown in Fig.1. Modulated sound waves with different sequences are emitted from every 8 speakers at the same instant. Sound waves passing through the medium are received by the facing pairs of receivers and are demodulated to obtain the time lags along the propagation paths with the every combination of transmitters and receivers.

3.2 Simulation test

Sine wave signals was assumed with *f*=20 kHz and N_{sin}=1. The vortex wind field in the medium was considered with diameter D_W=190 mm and maximum flow velocity *v*=5 m/s. Based on the condition described above, received signals transmitted through the medium were synthesized. Demodulation correlation calculations were made and dual directional travel time lags were estimated for the entire different 16 (=4 speakers × 4 microphones) propagation paths. Estimated time lags Δ*T* for the case when the order of Kasami sequence *m*=8 as a function of distance from the center of vortex wind field were as shown in **Fig.2**. In addition, time estimation errors (standard deviation) as a function of order *m* are shown in **Fig.3**. The results demonstrate that the precision in the order of 0.1 μs is achieved by selecting *m* greater than *m*=8.

3.3 Experiment test

A fan (190 mm diameter) to be a source of wind for vortex was installed below the measurement plane. When the wind from the fan flows up to the target region, vortex air flow field generated on the horizontal cross section is measured. Four pairs speakers (Clarion:SRH293, 1.6-100 kHz) and coded sine wave generators were prepared. Since, only a single channel microphones (Aco:7012, 10Hz-40 kHz) were available at the time of writing, the transmission and reception collections are iterated

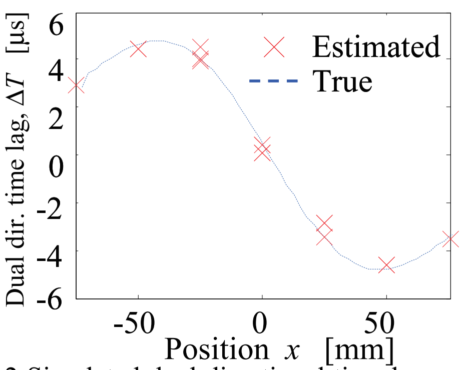

Fig.2 Simulated dual directional time lag as a function of position of transmitter and receiver pairs.

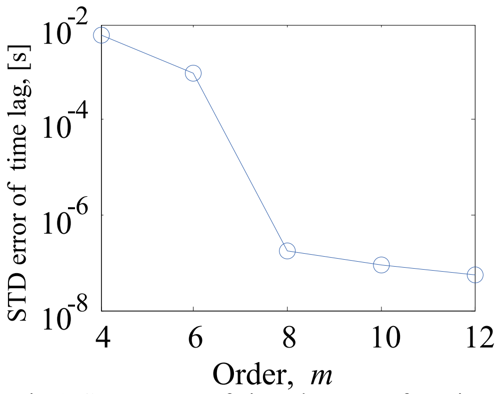

Fig.3 STD error of time lag as a function of order of modulation sequence.

by moving the single channel microphones to the four different transmitter positions. The coded signals were sent with the condition N_{sin}=6, *m*=4, other parameters were same as in the simulation. Resultant dual directional time lags along the four normal directional paths were as shown in **Fig.4.** The results demonstrate that the spatial variations of the time lag were as expected and in proportion to the preset flow velocities v_s.

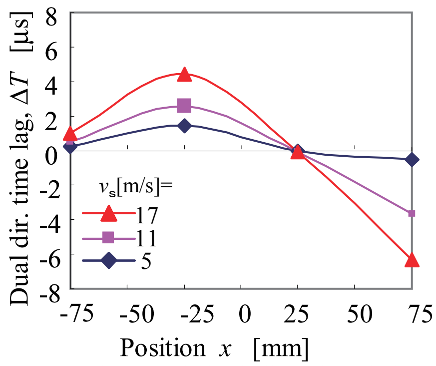

Fig.4 Experimented dual directional time lag as a function of position of transmitter and receiver.

4. Conclusion

Simultaneous multi-channel travel time collection technique for use in the air flow tomographic measurement using the coded modulation signal was investigated. As a result of the test examinations, fundamental feasibility of the method was confirmed.

References

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