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Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 245-246
18-20 November, 2009

Parallel Simultaneous Transmission Air Flow Tomograpy Using Code Modulation Signal

符号変調波を用いた並列同時送受信風速トモグラフィ

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1. Introduction

Acoustic travel time tomography system for the monitoring of the vortex wind flow velocity profile has been studied by the present author[1,2], where multi-channel parallel 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. To realize the simultaneous multi-channel travel time collections, coded modulation method is introduced using Kasami sequence. To verify the validity of the method, basic examinations both in simulation and experiment data are made.

2. Method

2.1 Wind flow velocity measurement using the travel time difference

We consider a problem to measure the wind flow velocity $\mathbf{v}(x,y)$ in the (x,y) two-dimensional plane. To this end, acoustic wave transmitter and receiver facing pairs are placed around the target medium. Travel time between transmitter a and receiver b is denoted as T_{ab}, and transmitter b and receiver a as T_{ab}. The travel time difference ΔT of them is related with $\boldsymbol{v}(x,y)$ as

$$\Delta T = \frac{T_{ab} - T_{ba}}{2} \approx -\int_a^b \frac{\mathbf{v} \cdot d\mathbf{l}}{c^2}$$

where c is the sound velocity and $d\mathbf{l}$ is the line element vector along sound path. Equation (1) shows that the travel time difference ΔT represents the accumulation of cosine component of flow velocity $\boldsymbol{v}$ along sound propagation path.

As shown in Fig.1, multi-channel ultrasonic transmitter/receiver elements are arrayed on a pair of opposite sides of measurement region. From the observation of the travel time difference data along the multi-channel paths between the parallel facing array elements, reconstruction of the vortex wind velocity field in the medium is considered. For this purpose, set of multi-channel data must be collected

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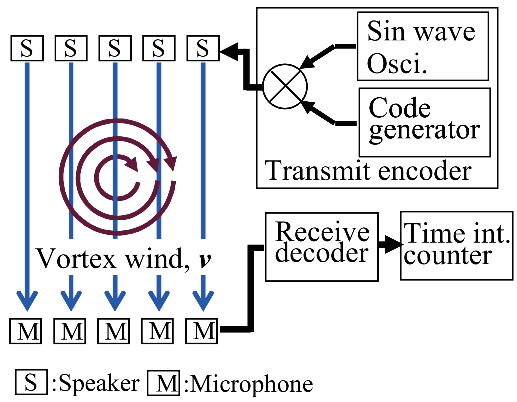

Fig.1 Multi-channel tomographic wind flow measurement system.

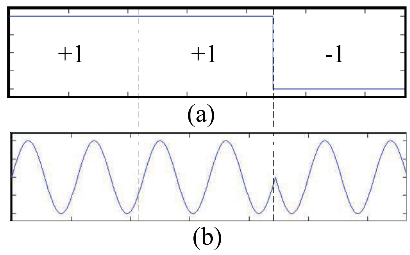

Fig.2 Phase coded modulation, (a)example of sequence (+1,+1,-1), (b) phase coded signal of sine wave.

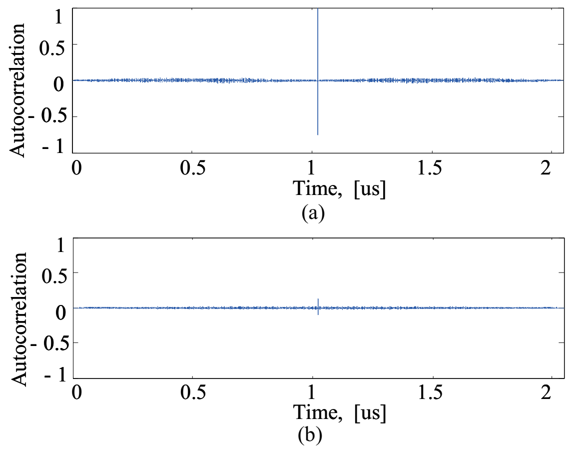

Fig.3 Decoded pulse signal (a) single channel excitation, (b) 10 channel simultaneous excitation.

in short period of time to keep up with the rapid variation of the wind fields.

2.2 Data collection using coded sequence excitation

To accomplish the collection of multi-channel data at one time, the transmitter arrays are simultaneously excited with coded sequences. Subsequently, the received signals are decoded by the own excitation sequence. In that case, if the compatibility of large auto-correlation and small cross-correlation between the sequences for different channels are satisfied, cross-talk signals from different channels are negligibly small and only a signal from own channel can be detected. In order to achieve the requirement described above, Kasami sequence code is used, since it is optimized to have smallest cross-correlation between the different channel sequences.

3. Test examination

3.1 Encode and decode property

Kasami sequences used in this study are binary sequences (taking value of +1 or -1) with order n and length 2^n-1. Using Kasami sequences with n=10 (for use in 10 channel air flow measurement system), phase coded sine pulse signals (with center frequency: f=20 kHz and duration T_s=2/f=100 μs) were synthesized as shown in Fig.2. It was assumed that ten different sequence signals were emitted from each channel and mixed received signals were simulated. Gaussian white noise with S/N=8 dB was added to the signals. Decoded pulse signals (cross-correlation between the received signals and the encoded transmit signal) are as shown in Fig.3, where (a) is the result for single channel excitation and (b) for parallel 10 channel excitations. We can see that decoded pulse in single channel excitation (a) is clearly detectable. On the other hand, in 10 channel excitation (b), amplitude of pulse peak becomes much lower. However, it is yet higher than the side-lobe noise level, arrival time of the pulse is detectable under the 10 channel simultaneous excitation condition.

3.2 Precision estimation of travel time difference

As a basic examination, a pair of speaker (Clarion: SRH293, 1.6-100 kHz) and microphone (Aco: 7012, 10-40 kHz) is placed with the separation L=500-510 mm. Encoded signal described above was sent from the speaker and the received signal by the microphone was decoded with the cross-correlation calculation between the received and excitation signals. Finally, the arrival time of the signal were estimated from the pulse position in the correlation function. The measured arrival times for the change of set-up distance L were summarized as shown in Fig.4, where experimented results are shown with circles, simulated ones with rectangles and true value with straight line. As a whole, the measured travel times are roughly in proportional to the set-up distance. However, errors around 5 μs can be seen in the measured travel time. This is mainly due to the distortion of the modulated sine pulse signals caused by the frequency characteristics of the speaker and microphone. The requirement of the measurement precision depends on the size of the airflow fields and the required precision of the air flow velocity. These elaborations were remained in the future work.

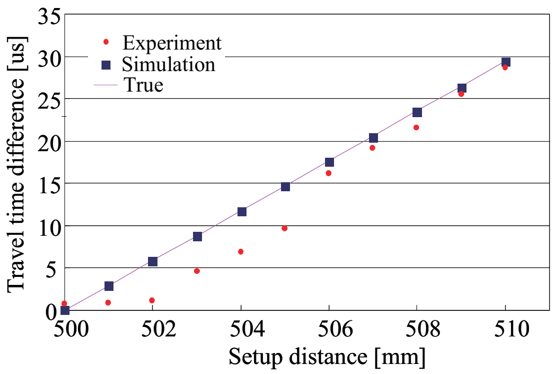

Fig.4 Measured travel time as a function of setup distance between transmitter and receiver.

4. Conclusions

Simultaneous multi-channel travel time collection technique for use in the air flow tomographic measurement system was proposed. To this end, basic examinations were made and fundamental feasibility was confirmed. Actual indoor air flow measurement examination is ongoing (where the dimension of the target is around several meters) and will be reported in near future.

References

1. Haiyue Li,et.al, Acoustical Imaging, 29, pp.347-352, Springer-Verlag (2008).
2. H.Li, T.Ueki and A.Yamada, Jpn J.Appl. Phys.,47,5,pp.3940-3945(2008).