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# Fabrication of 4-path remote outdoor wind velocity measurement system and its performance evaluation

屋外風速場の 4 経路遠隔音波計測システムの構築と性能評価

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## 1. Introduction

The wind gusts monitoring systems is demanded on the railway bridge and/or airport runway where high levels of safety is requested. Conventional methods cannot meet the problem, since non-uniform local vortex wind fields might be overlooked when using a conventional fixed-point observation anemometer. As a way to address the problem, sound wave transmitters and receivers were placed at the perimeter of the monitoring region. From the collections of the travel time data along the different observation paths, wind flow field over the entire monitoring region can be reconstructed[1,2]. So far, it has been investigated based on the single channel test experiment system[3]. It was restricted to measure the directional velocity component along the sound propagation path. Actual flow amplitude as well as flow direction was unknown. In the present study, to encounter the problem, it was extended to 4-path outdoor long distance travel time measurement system. Evaluation experiments were made to estimate the spatially averaged vector wind flow fields in the outdoor monitoring region.

## 2. Method

**2.1 Relationship between wind velocity and sound wave travel time** A facing pairs of speakers and microphones are separately placed in the target air flow medium with a distance $L$. For avoidance of reverberations and surrounding noise, as well as the improvement of receiving sensitivity, code modulation signals are emitted. From the correlation peak time between the transmitter and receiver signals, sound wave propagation time $T$ in the wind flow medium along the sound propagation path is measured. A bidirectional propagation time lag $\Delta T$ between normal and reverse direction is related to the spatially averaged wind velocity $\bar{v}$ along the line between the transmitter and the receiver:

$$\bar{v} = -c^2 \Delta T / 2L, \tag{1}$$

where $c$ is the sound velocity in the air medium.

**2.2 Estimation of wind velocity amplitude and direction** We assume that 4 transmitter and receiver pairs are placed at the corner of a rectangular-shaped target region (distance $L$, separation $d$) as shown in Fig.1.

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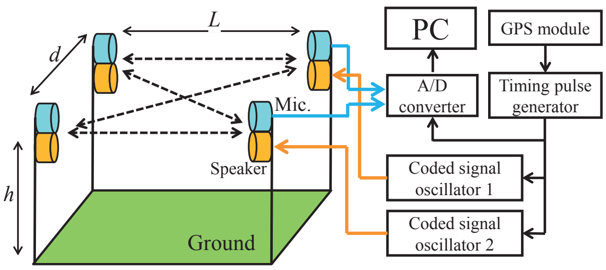


**Fig.1** Schematics of wind flow measurement system.

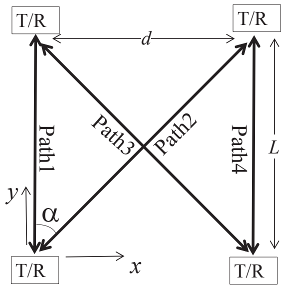


**Fig.2** Location of transmitter and receiver and sound wave propagation path assignment.

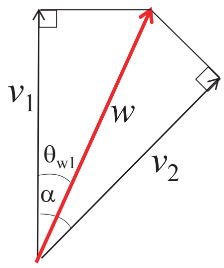


**Fig.3** Relationship between measured wind velocity and actual wind velocity vector.

As shown in Fig.2, we observe the travel time lag $\Delta T$ along 4 propagation paths (2 straight direction and 2 oblique direction paths). Where, $(x, y)$ coordinate axis is assigned as shown in the figure, crossing angle of oblique path is to be $\alpha$. Assume that wind velocity in the medium is constant with amplitude $w$ and direction $\theta_w$. Velocities $v_1$ and $v_2$ are measured along the straight directional path 1 and the oblique path 2, respectively. On this occasion, $\alpha$, $v_1$, $v_2$ are geometrically related with the unknown wind velocity vector as shown in Fig.3. From this, wind velocity amplitude $w$ can be obtained as a solution of the following quadratic equation:

$$\left(1-\cos^2\alpha\right)w^4 + [(v_1{}^2 + v_2{}^2)(\cos^2\alpha - 2) + 2v_1 v_2 \cos\alpha]w^2$$
$$+(v_1{}^2 + v_2{}^2 - v_1 v_2 \cos\alpha)^2 - v_1{}^2 v_2{}^2 \cos^2\alpha = 0. \tag{2}$$

Furthermore, wind direction $\theta_{w1}$ is obtained from the relation:

$$\theta_{w1} = \cos^{-1}(w / v_1). \tag{3}$$

Similar results are obtained for path 3 and path 4. There are 5 possible combinations of paths: (i)1&2, (ii)1&3, (iii)4&2, (iv)4&3, (v)2&3. Corresponding to the combinations of paths, 5 different wind velocity amplitudes and directions are estimated. Finally, (vi) average of them is calculated and determined as a final value.

## 3. Evaluation test

**3.1 Simulation** Measured velocities $v_n$ ($n$ = 1~4) along each 4 paths were simulated for constant wind velocities $w$ and different wind directions $\theta_{w1}$, which were changed over all-round angles. Noises were added to the data assuming 5% velocity measurement error. Using the simulated data, estimation errors of the wind velocities with respect to crossing angle $\alpha$ were evaluated, as shown in Fig.4. Where, results were compared for three different path data. We can see that crossing angle $\alpha$ should be selected greater than 20 deg. to achieve a high degree of accuracy.

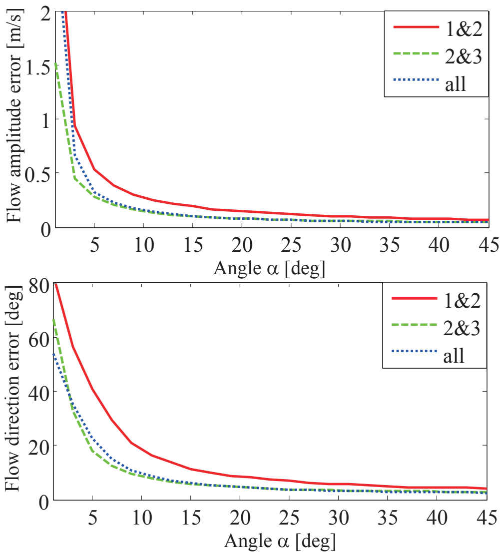


**Fig.4** Simulated wind velocity error as a function of crossing angle of sound propagation path (upper: amplitude error, lower: direction error).

**3.2 Outdoor experiment** As shown in Fig.1, 4-path sound wave measurement system was prepared for outdoor experiment. The speaker/microphone pairs were placed with distance $L$=10m, separation $d$=4 m and height $h$=1.4 m. 4-path simultaneous excitations and receptions were carried out by sending coded phase modulation sine signals with frequency $f$=20 kHz and duration 25.5ms. Travel time lag data were collected over 300 s at every 1s interval. Time variations of measured wind velocities are shown with red circles in Fig.5. For comparison, results measured by the fixed-point type 3D ultrasound anemometer were shown with blue lines, which was placed at the center of the rectangle measurement region. Note that both results are not necessarily same. Nevertheless, we can see that both results are in pretty good agreement.

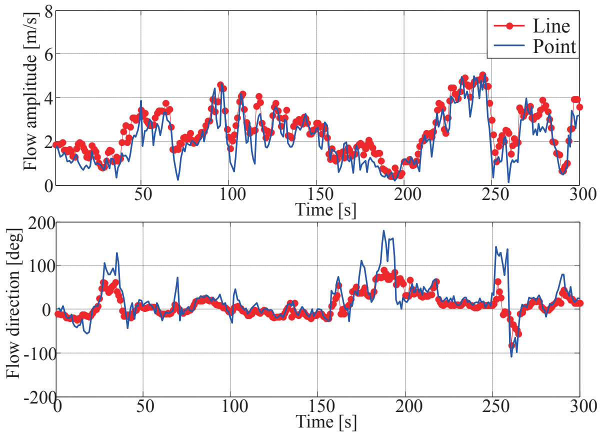


**Fig.5** Measured wind velocity amplitude (upper graph) and wind direction (lower graph), red circles show the results of the present method, blue lines results of point observation using 3D ultrasound anemometer.

Another evaluation tests were carried out changing separation $d$ (i.e. crossing angle $\alpha$). Measured errors between the results using the present line observation method and the point observation were summarized as shown Fig.6. As predicted in Fig.4, errors become lower with the increment of $d$. However, when it reached at $d$=5m, there are catastrophic errors. This is caused by the errors in travel time measurement which is relevant to the directivity of the speaker and sound attenuation (which are proportional to path angle and propagation distance). Hence, optimum results was obtained at separation $d$=4 m.

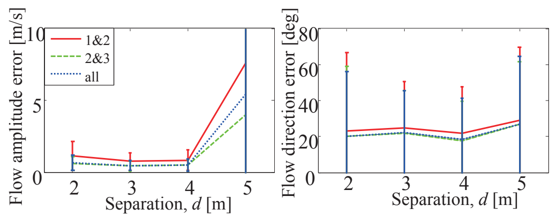


**Fig.7** Measured wind velocity error with respect to separation $d$ (left: amplitude error, right: direction error, connected lines show average errors over time interval of 300 s, error bars show their standard deviation.).

## 4. Conclusion

As mentioned above, 4-path long-distance remote outdoor wind velocity measurement system was developed. From test experiments, it was demonstrated that spatially averaged vector wind velocities over the distance 10 m were remotely measured at every 1 s interval with a high degree of accuracy.

### References


1. H.Li, S.Takata, and A.Yamada, Jpn. J. Appl. Phys., 50, 07HC09, pp.1-5 (2011).
2. H. Li, H.Terada, and A. Yamada, Jpn. J. Appl. Phys., 53, 07KC18, pp.1-7 (2014).
3. T. Hirasawa, N. Ogawa, H. Li and A. Yamada, 2012 Autumn meet. Acoustical Society of Japan, 2012, 1-6-7.