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Using Particle Image Velocimetry to Measure the Wind in a Winnowing Chamber

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The array of vectors for the winnowing wind in the threshing unit was investigated using PIV in order to improve the winnowing accuracy. It is difficult to measure wind velocities at many points simultaneously using the anemometer. However, visualization of the winnowing wind was possible using the tracer and laser beam. Furthermore, the PIV method made it possible to measure an array of vectors for the winnowing wind. The results produced by PIV concurred with the results of conventional method. The wind map obtained in this method is expected to provide essential data for understanding of the characteristics of trajectories of grain and chaff.

INTRODUCTION

Head–feeding combines utilize the wind from a winnower to separate grain from chaff and other materials. In order to improve the accuracy of the winnower, it is important to investigate the characteristics of the trajectories of grain and other materials, as well as the array of vectors that represent the wind in the winnowing chamber.

A hot–wire anemometer is conventionally used to examine the wind speed in the winnowing chamber (Tani, 1977). Although the time resolution of a hot–wire anemometer is high, which is an advantage, it is difficult to determine the wind direction and wind speeds for all areas of the winnowing chamber because an anemometer takes measurements at a single point. Furthermore the probe itself causes turbulence in the wind field. In fact, it is impossible to measure all wind vectors in the winnowing chamber using a hot–wire anemometer. In recent years, improvements in computers and image–processing technology have facilitated the use of Particle Image Velocimetory (PIV) to measure vectors for liquids and soil (Raffel, 2000, Okayasu, 2002). It is possible to measure vectors in the wind field by means of PIV. In this study, we aimed to investigate the array of wind vectors in the winnowing chamber by means of PIV, and examine the feasibility and problems associated with this method.

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MATERIAL AND METHOD

Particle image velocimetry method

The objective of this study was to measure the array of vectors for a wind that ranges from 0 to 10 m/s in a winnowing chamber. Particularly important ranges were from 2 to 10 m/s because they were influenced to drag and lift force of the grains. This study used the gray level difference (GD) and successive abandonment (SA) method as the density correlation method (The Visualization Society of Japan, 2002, Kaga, 1994, Library Inc., Flow Vec32).

The sequence for measuring vectors is as follows (Figure 1):

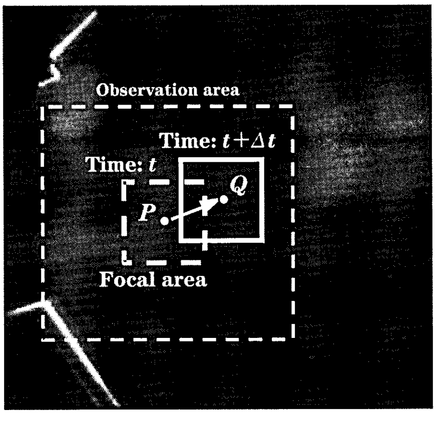

Fig. 1. PIV method: gray level difference (GD) and successive abandonment (SA) methods as pattern tracking algorithms

(1) Ascertain the brightness of various points within a small field around a point P in the image at time t.
(2) Designate the surrounding area of the small field as the observation field. From the image at $t+\Delta t$, compare the brightness of the field around point P with those of the field around point Q. And search for the point of minimum contrast while eliminate points whose contrast values are significantly larger than the minimum contrast value.
(3) Use the movement of a point during a specified period to calculate the mean distance that the tracer has moved.
(4) Repeat the operation for the entire examination field, and obtain an array of vectors for the movement of the tracer.

Experimental equipments

Tested winnower

Figure 2 shows the winnower that we used in this study. The fan was 240 mm in diameter and 180 mm width with 3 blades. The separation chamber was 200 mm wide, and the open far end of the separation chamber was 650 mm from the shaft of the fan. A

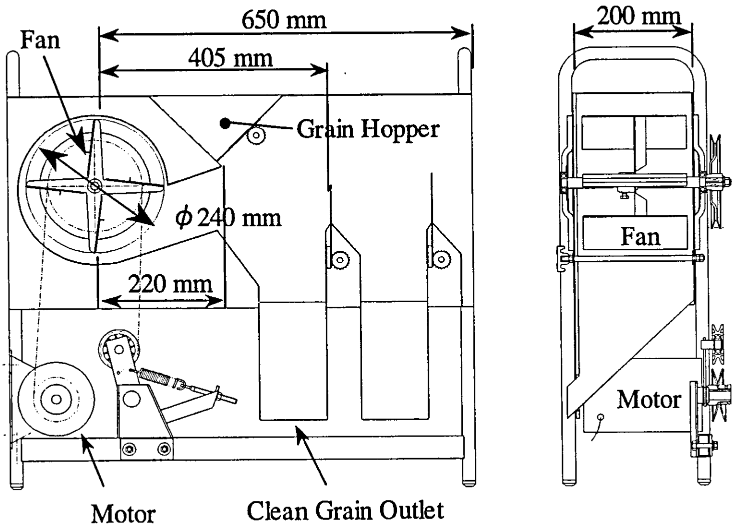

Fig. 2. Test winnower

hopper was located over the separation chamber to feed the grain. There were 2 outlets under the wind route. The fan was driven by an electric motor, and the fan speed was adjustable from 0 to 900 rpm by means of an inverter.

PIV system

In PIV systems, solids, smoke or liquids are used as tracers for measuring airflows (Table 1), and the mean diameters of their particles are different. It is necessary for scattered light from a tracer particle to be bright in order to obtain good PIV images. The brightness of a particle is proportional to its size. However, it is also necessary to consider that the following to the air and the sedimentation velocity of the tracer. The sedimentation velocity of 10μm in diameter of mist water was 3 mm/s, and 2μm or less of mist water and smoke were 0.13 m/s in maximum (The Visualization Society of Japan, 2002). Therefore, mist water and smoke was sufficient to use for the tracer because of

Table 1. Various types of tracer

Condition	Material	Mean diameter [μm]
Solid	Polystyrene	0.5–10
	Alminium	2–7
	Magnesium	2–5
	Hollow glass	30–100
	Coding particle	10–50
	Di-octyl-pasalete	1–10
Smoke		<1
Liquid	Various types of oil	0.5–10
	Water mist	2–35

that the fundamental objective of this study was measuring the winnowing wind from 2 to 10 m/s. Furthermore, it is necessary to mix the right amounts of tracer in the air of measuring space. In these reasons, water mist was used in the low wind speed and smoke was used in high. Natural light would illuminate the tracer, but it is not suitable because its multiple wavelengths cause color aberrations. And it is difficult to produce a thin sheet of light. As such, an Ar^+ laser was used to illuminate the tracer (Table 2).

Figure 3 shows the construction of the measuring system for the winnowing wind. The mist generated by an ultrasonic humidifier was used as a tracer. And the smoke generated by the fog machine. An Ar^+ laser was used as the light source. With the winnower in the center, the mist and smoke from the tracer generator were released into the separating chamber from the direction of the fan. The laser beam traveled in the same direction as the tracer and illuminated a vertical plane through the center of the separating chamber. The tracer and reflected light were then photographed from the side by means of a high-speed camera. Figure 4 shows how the tracer was photographed. The field of the photograph was between the entrance for the winnowing wind and a point near the farthest side of the first clean grain outlet. Figure 4 shows the probe's laser beam reflecting from the tracer (mist). Photographs were taken at 250 frames/sec. and with a resolution of approximately 250,000 (512 × 480) pixels.

Table 2. Light source for PIV

Type		Wavelength
Laser	Helium–Neon laser	633 nm
	Cu–Vapor laser	510,578 nm
	Ar–ion laser	514,488 nm
	Ruby laser	694 nm
	Nd: YAG laser	532 nm
Conventional light	Xenon lamp	
	Flash light	

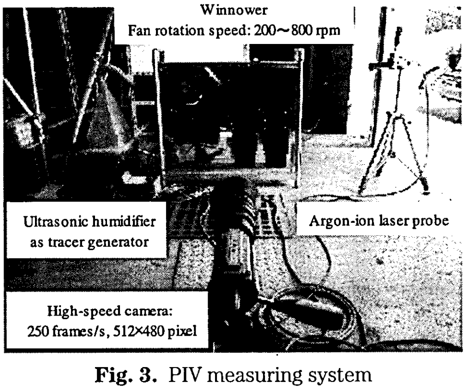

Fig. 3. PIV measuring system

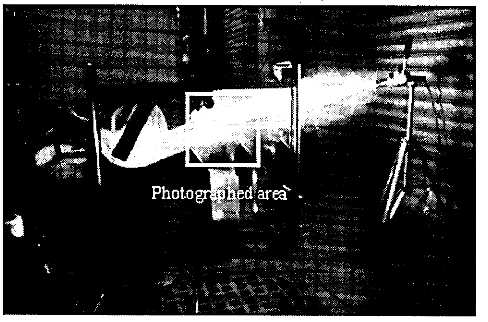

Fig. 4. Test states of PIV measuring

Determining the status of the tracer in PIV

In determining the position of the tracer, the measured points were arranged on a grid of 15–pixel intervals in both the X and Y directions. As it was thought that the observation field moved around 3 cm (at most) in 0.004 seconds. The observation field was designated as a square of 131 pixels (approximately 66 mm). The small field was designated as a square of 47 pixels (approximately 24 mm). In order to eliminate noise from the image, the lower limit of significant brightness was set at 20 within the total range of brightness from 0 to 256. Analysis was carried out on 50 frames (0.2 sec. each) because it was considered that 50 frames would provide sufficient information and was a convenient size for data transfer. Incorrect vectors were eliminated by twice conducting Neural–Network analysis (Kimura, 1994).

RESULTS AND DISCUSSION

Figure 5 shows the results of PIV for a fan speed of 800 rpm. Vectors were obtained for approximately 500 points; however, data is missing in areas where the tracer rarely passed. The area of high color intensity, extending from bottom–left to upper–right in Fig. 5, indicates that the wind speed is high (7 m/s), and the area of low color intensity indicates that the wind speed is low (2.5 m/s). It was considered that the results were reasonable in almost all areas. The direction of the winnowing wind was also obtained at the measuring points.

As mentioned above, there were various velocities in the direction of flow. This is because each image in the sequence examined a 0.2 second period and the flow of air was not uniform, and there was some lateral movement (i.e. flow in the Z direction). It is therefore considered that more precise results could be obtained by analyzing data that covers a longer period and increasing the frequency of frames for analysis.

Point P in figure 5 shows the measuring point of the anemometer; it is in the same position as in the previous PIV study. The mean velocity that was obtained from the examination was 4.9 m/s; however, X and Y components were not indicated. The wind velocities at P were measured by means of PIV and the anemometer every 200 rpm from 200 rpm to 800 rpm (Figure 6). The results obtained by PIV concurred with the results obtained by the conventional anemometer method. This proves that the wind speed in the winnowing chamber can be measured by means of a high-speed camera and the PIV method. It was considered that PIV is quite accurate because this method produced results that were the same as the results obtained by the conventional method. On the other hand, when the tracer is too dense or too weak, it is difficult to obtain satisfactory results because there is insufficient contrast. Moreover, when the tracer is weak and

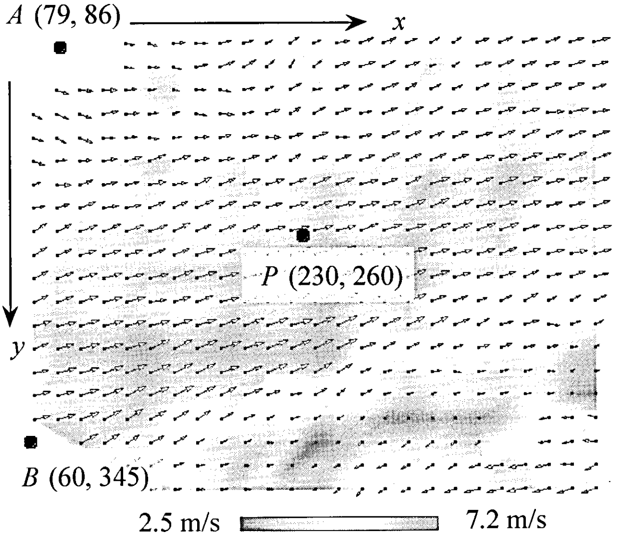

Fig. 5. Result of PIV in 800 rpm fan rotation speed

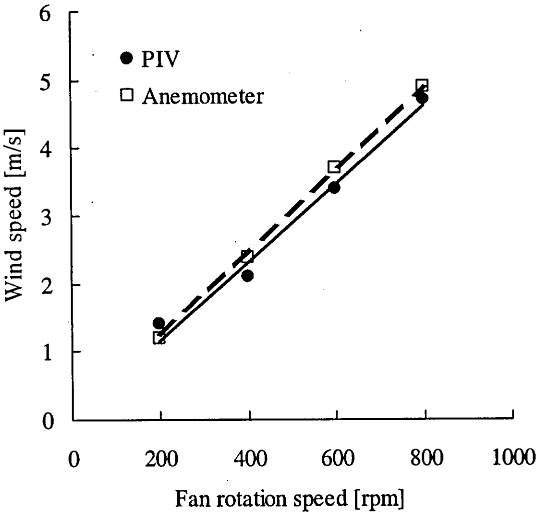

Fig. 6. Comparison of anemometer and PIV

there is insufficient scattered light, incorrect vectors could be generated due to noise caused by increasing the sensitivity of the camera.

CONCLUSION

The array of vectors for the wind in the winnowing chamber of the threshing unit of a combine harvester was investigated using PIV in order to improve the winnowing accuracy. It is difficult to measure wind velocities at many points simultaneously by means of the conventional method. However, visualization of the winnowing wind was possible using mist water or smoke and laser beam. In addition, the PIV method made it possible to measure an array of vectors for the winnowing wind. The results produced by PIV concurred with the results produced by the conventional method, and it can be said that a momentary array of wind vectors can be measured by PIV. The wind map obtained in this method is expected to provide essential data for understanding of the characteristics of trajectories of grain and chaff.

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