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# The Visualization of the flowfield Using Lidar's Range Detection and Digital Image Correlation

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## 1. Introduction

Flow visualization is a method for observation and monitoring of the fluid flow structures in which flow structures are made visible by adding a pollutant such as a dye or a smoke to the fluid, unless the structures are already visible by themselves. Main advantage of flow visualization methods is their very low impact on the flow dynamics as they are mostly non-contact methods. Such methods are also advantageous in processes with harsh measurement conditions (hot or corrosive fluids, etc.) where the choice of conventional measurement methods is very limited. There are many principles of flow visualization and a number of flow properties that can be assessed. In this paper however we focused on flow velocity, visualization measurement. Using cameras one is able to collect large amount of spatial flow structure data in a very short time. Image data is further processed to determine velocity fields and other flow properties.[1] Therefore, we tried to find a way to measure change of image and to apply it to the lidar technique, which is a powerful technique in the field of climate study and we have an interest in the digital image correlation (DIC). Among the DIC algorithms, the sum of squared differences (SSD) method is a way to track the sub-set image in different images. We used this algorithm for tracking the same point in different moving smoke images. In this paper, we present a method for the measurement of smoke velocity, and visualization of flow field using lidar's range detection and DIC (Digital Image Correlation) system. The lidar system acquires the distance to the smoke, and the smoke images are tracked using the developed fast correlation algorithm of DIC. We acquired the velocities of smoke using the calculated distance and DIC algorithm.

## 2. Experimental setup

As shown in Fig. 1, our experimental set-up is divided into two major parts. One is the transmitter, which is an injection seeded Nd:YAG laser. The laser beam is split into two paths by a beam splitter (BS1). The transmitted beam passes through the beam expander (L4), and the expanded beam is sent to an elliptical mirror. The beam reflected at the elliptical mirror is sent into the air using a 2-axis scanner with two rotatable mirrors. We use this scanner to find the target cloud and transmit a pulsed laser beam to the clouds. The other is the acquisition part, which is separated into two systems. The scattered laser beam on the target smoke is collected by a telescope and passes through the beam splitter (BS2). The transmitted laser beam is focused on a pinhole by lens (L2). At this time, the pinhole blocks the background signal. After the pinhole, the expanded beam is colliminated by lens (L3) and the colliminated beam is line-filtered by a band pass filter (532 nm). The filtered beam is focused on PMT (Hamamatsu, R9880U) by lens (L4) and the lidar signal is acquired. We used lidar signals to measure the distance of L. As shown in Fig. 2, lidar signals show the laser light traveling time from the light source to the smoke. We can acquire the length of L easily by multiplying the traveling time with the light speed. In addition, the height of the smoke can be acquired by using the distance of L and a laser illuminating angle of θ. If the distance is acquired once, we can calculate the actual area of the telescope's field of view at the position of the smoke. Then the ratio ($R=Csize/L_{CCD}$) of the imaged cloud pixel size ($L_{CCD}$) of CCD to the actual size (Csize) of the smoke within the field of view is acquired. Thus, the moving distance of the smoke image in the monitor is converted into the actual moving distance per unit time by the application of this ratio. We intended to configure the smoke monitoring system as mentioned above, and the following are the configurations of the optical and DIC systems.

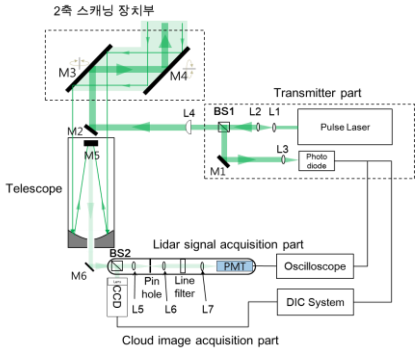

Fig. 1. Schematic diagram of the optical system configuration.

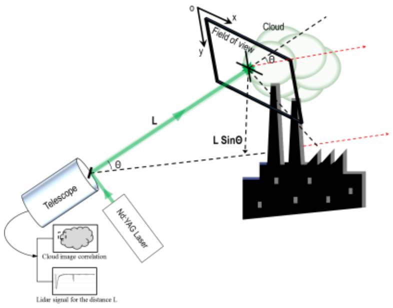

Fig. 2. Schematic diagram of the system configuration.

### *2.1 DIC System Configuration*

Figure 3 shows the algorithm for a high-speed correlation comparison. The first image ('Before' image in Fig. 3) is set up as the reference image among images that the CCD records. We select a point of the reference image to be tracked, then the coordinates of the selected point are set up by algorithm. We separate the subset image from the reference image by unit of (2n+1) x (2n+1) pixels which is based on the coordinates of the point. In the second image ('After' image in Fig. 3), an initial estimation area is set up which is to be compared and the subset images are separated from the initial estimation area. And then the digital image correlation algorithm calculates the correlation coefficient by using SSD (Sum of Squared Difference) between the subset image of reference and the subset images of the second image. The subset image which has the least value is found among the subset images of the second image and the coordinates of the subset are acquired. We can track the cloud image to record the coordinates of the subset images.

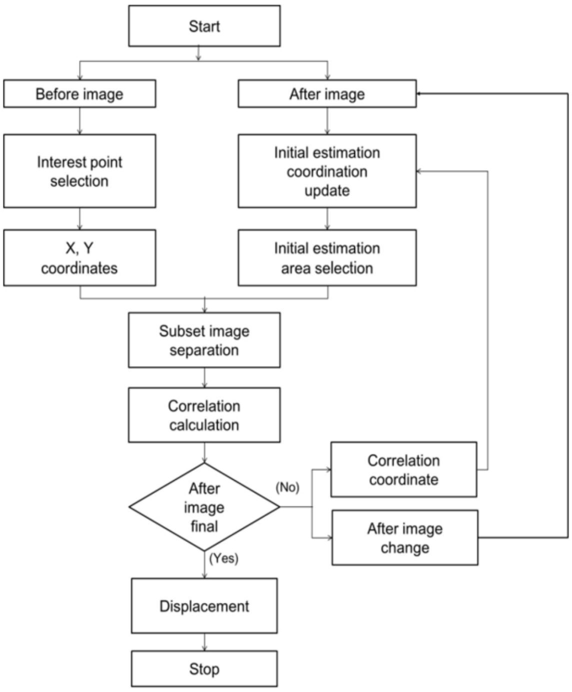

Fig. 3. Fast correlation algorithm of DIC.

Table I: CCD specifications

| Parameter | Specification |
|---|---|
| Resolution (H × V pixels) | 1296 px × 966 px |
| Pixel Size horizontal/vertical | 3.75 ㎛ × 3.75 ㎛ |
| Mono/Color | Mono |
| Maximum Frame Rate | 30 fps |
| Pixel Bit Depth | 12 bits |
| Sensor Size (mm) | 4.68mm × 3.62 mm |

## 3. Experimental results

As shown in figure 4, we acquired the velocity of smoke at each point and the arrows are velocity vector. Table 2 shows the velocity values (m/s) of the first line vectors.

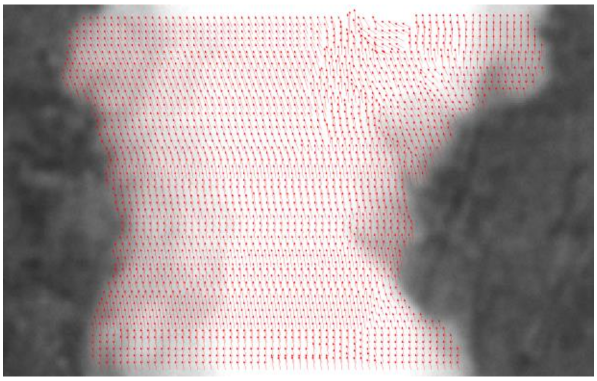

Fig. 4. The velocity of smoke at each point

Table I I : The velocity values of the first line vectors

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1.128594 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 |
| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.161532 |
| 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| 1.161532 | 1.161532 | 1.161532 | 1.161532 | 1.174534 | 1.174534 | 1.153441 | 1.145734 | 1.356733 | 1.805055 |
| 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 |
| 1.190801 | 1.223512 | 1.181196 | 1.09859 | 1.062038 | 1.048848 | 0.977909 | 0.955919 | 1.311964 | 1.339648 |
| 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
| 1.339648 | 1.339648 | 1.339648 | 1.339648 | 1.336811 | 1.317355 | 1.351686 | 1.305776 | 1.305776 | 1.305776 |
| 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| 1.305776 | 1.305776 | 1.305776 | 1.305776 | 1.305776 | 1.305776 | 0 | 0 | 0 | 0 |

## 4. Conclusion

In this paper, we presented a method for the measurement of the smoke velocity and the visualization of flow field using lidar's range detection and the DIC system. For the lidar system, we used an injection-seeded pulsed Nd:YAG laser as the transmitter and an photon multiplier tube (PMT) as the laser light sensor to measure the distance to the target clouds. We used the DIC system to track the smoke image and calculate the actual displacement per unit time. The configured lidar system acquired the lidar signal of smoke at a distance of about 150m. The developed fast correlation algorithm of the DIC, which is used to track the fast moving smoke relatively, was efficient to measure the smoke velocity in real time. We acquired the velocities of the smoke at each point and visualized the smoke flow field.

## REFERENCES

[1] Horn BKR,SchunckBG.Determiningoptical flow. ArtifIntell1981;17:185–204.