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MEASUREMENT OF SNOWFLAKE SIZE AND FALLING VELOCITY BY IMAGE PROCESSING

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Abstract: To measure simultaneously the size and velocity of falling snowflakes quantitatively, images of snowflakes were put into an image processor continuously every 1/30 s with a video camera. The distributions of snowflake sizes were measured by these widths; the average velocity of all snowflakes and the velocity of a particular snowflake were calculated by a personal computer from the falling distance and the time interval taken for them to fall.

This system is capable of measuring the size distribution and falling velocity of snowflakes automatically over a long period of time.

1. Introduction

Although a number of methods for measuring the size and velocity of falling snowflakes have been developed (JIUSTO and BOSWORTH, 1971; LANGLEBEN, 1954; MAGONO and NAKAMURA, 1965), suitable equipment to automatically measure these has not yet been developed. We have now introduced a new system which automatically measures simultaneously the size and falling velocity of snowflakes using a personal computer and an image processor.

2. System for Measuring Snowflakes

The measuring system is shown in Fig. 1. Naturally falling snowflakes which were introduced into a tower [1.5 m(L)$\times$1.5 m(W)$\times$2 m(H)] to protect them from wind and sunlight were illuminated by two halogen lamps (500 W) from the two directions and photographed with a CCD video camera. To decrease the geometrical errors generated by the depth of field, the pictures of the falling snowflakes in this space [12–48 cm(L)$\times$13–51 cm(W)$\times$15–50 cm(D)] were taken by a zoom lens at a distance of 6 m.

In this way, the deviation in the snowflake diameter caused from the depth of field is less than 4.0%. We observed snowflakes during the winter months of 1985–

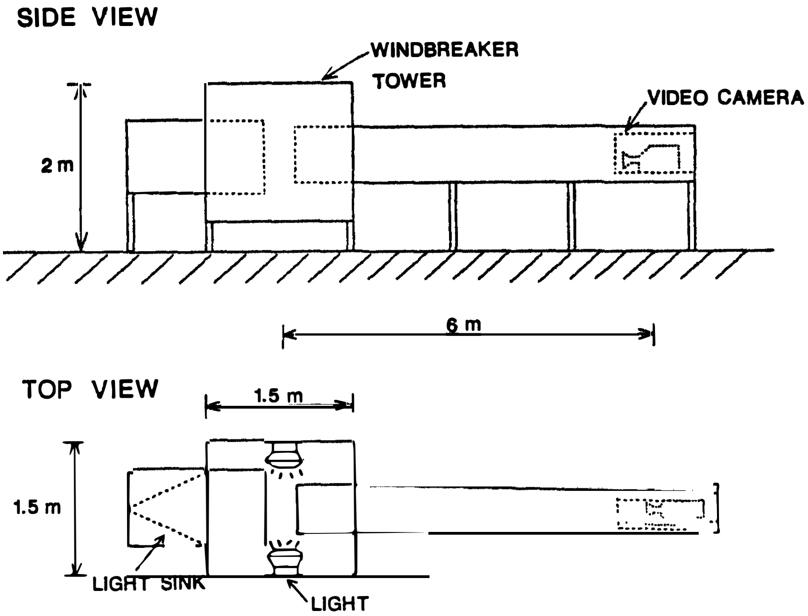

Fig. 1. System for measuring snowflakes.

1986, 1986–1987, and 1987–1988 on the rooftop of the 3rd Electrical Engineering Building of the Toyama National College of Technology.

3. Measuring Process

Using a video camera, snowflakes were put into four image memories of an image processor (resolution, 240×256 dots; level, 256 steps; speed of picture acquisition, 1/60 s) continuously every 1/30 s. The binarization, detection of the snowflakes, and the calculation of their sizes and falling velocities were processed within 30 s by a personal computer. These were determined in each image by the length of a dot given from the observed space and resolution. The measurements were made every 30 s and the average data measured during each 60 s were stored on a hard disk.

3.1. Binarization

To separate the snowflakes from the background, the images were binarized by suitable threshold level. Figure 2 shows the binary images of snowflakes consisting of dots (Image 2 is delayed 1/30 s from Image 1) and the sum of detected dots of each row.

3.2. Snowflake detection

Assuming that the shapes of snowflakes taken by a video camera are approximately ellipses, the following algorithm is given to search for snowflakes and to detect the positions of the highest dot, maximum width and length, and the sum of the dots. An image memory (240×256 dots) is shown in Fig. 3. Snowflakes are depicted by white dots.

a) Start from point A on the upper left side.

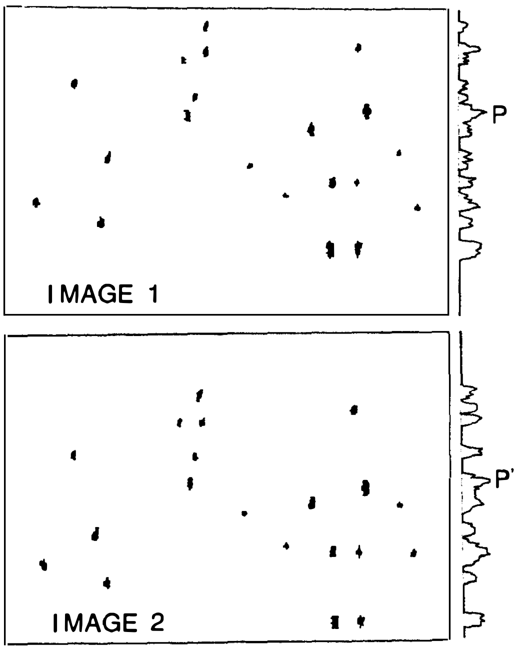

Fig. 2. *Examples of images of snowflakes and a method for measuring the average falling velocity of all snowflakes.*

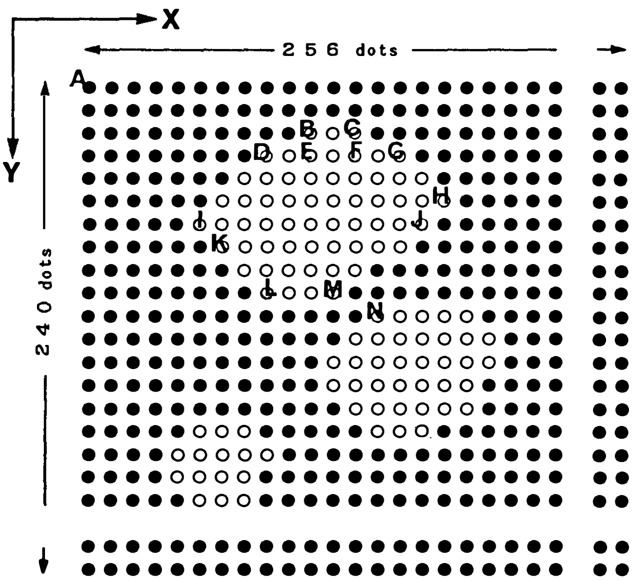

Fig. 3. *Images of snowflakes.*

b) Search a snowflake from the left end towards the right side.

c) If finished, search the next line from the left end towards the right side.

d) When the topmost dot (B) of a snowflake is detected, search from this point towards the right side (+x) and find the terminal (C) in the same line.

e) Calculate the width of this line from the detected starting point and terminal point.

f) Mark the detected dots so that they will not be mistakenly found again.

g) Examine the dot under the starting point.

1) When a dot is found (*i.e.*, E under point B), look for the starting point (D)

toward the left ($-x$).

2) When a dot is not found (*i.e.*, under point I), look for the starting point (K) toward the right.

If a dot is not found under the starting point and the position of the detected starting point is more to the right side than the terminal point in the last line (*i.e.*, position M vs. position N), the detected dots in this line belong to another snowflake. Finished for this search; go to step j).

h) Examine the dot under the terminal point.

1) When a dot is found (*i.e.*, F under point C), look for terminal point (G) from this point toward the right side ($+x$).

2) When a dot is not found (*i.e.*, under point H), look for the terminal point toward the left (J).

i) Go back to f) and continue the search for the same snowflake.

j) Calculate the maximum length of this snowflake from the difference between the first line detected and the last one.

k) Store the position of the snowflake (starting point), the maximum width and maximum length of the sum of dots on a hard disk.

l) Go back to d) and search for a new snowflake. The starting point of the snowflake just finished is regarded as the next starting point.

Above is the algorithm to detect snowflakes. This method is faster than a continuous search for all dots in a regular sequence. Since the depth of the observed space is limited to be from 15 to 50 cm, it seldom happens that snowflakes overlap each other throughout the observations.

3.3. *Size distribution of snowflakes*

Since the shutter speed is set at 1/60 s, the observed images of snowflakes introduced into the tower are seen as streaks which are longer than real ones. Therefore, the maximum width is adopted as the size of the snowflake and the size distribution of snowflakes are calculated by these widths.

3.4. *Falling velocity of snowflakes*

The average velocity of all snowflakes and velocity of a particular showflake were measured.

3.4.1. The average falling velocity of all snowflakes

The method to determine the average velocity of all snowflakes is as follows. After dot projections, which consist of the summation of each row in images, were calculated, an average falling velocity was obtained from the correlation function of the two projections (Fig. 2). In this system, velocities were calculated respectively and averaged by three pairs of data in which four images were continuously put into memories at 1/30 s intervals.

3.4.2. The falling velocity of a particular snowflake

1) One-image method: Since each falling snowflake produced a short streak during 1/60 s, its velocity was calculated from its vertical length (l). If the assumption was made that each snowflake is the shape of a ball, and that diameter (d) is as shown in Fig. 4, its falling distance is $l-d$ for 1/60 s. Using this method, it is possible to

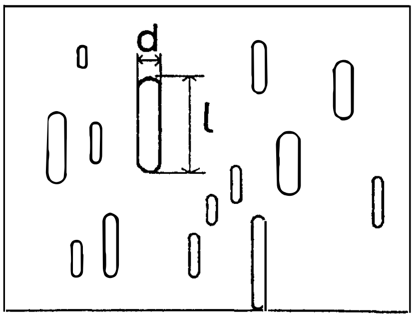

Fig. 4. One-image method for measuring falling velocity of a particular snowflake.

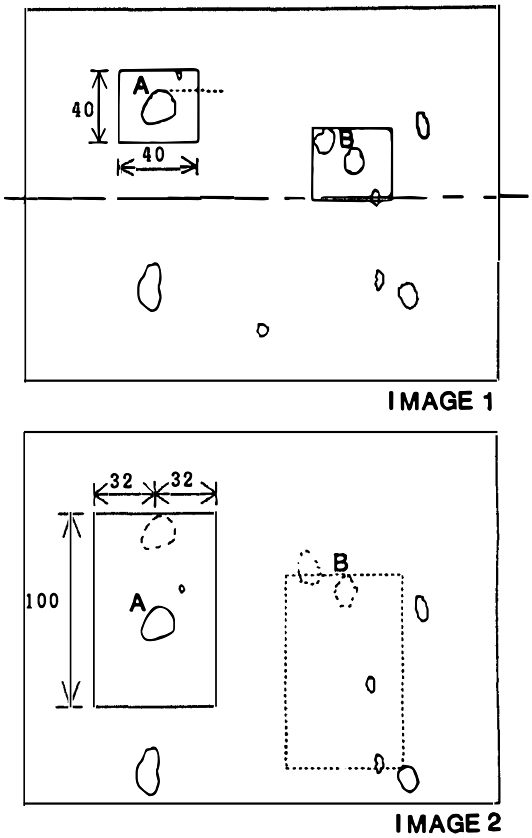

Fig. 5. Two-image method for measuring falling velocity of a particular snowflake.

quickly calculate the falling velocity of all snowflakes.

2) Two-image method: The process to calculate falling velocity by the two-image method is shown in Fig. 5. The falling velocity was measured from the vertical distance in which the snowflake fell down from one image (Image 1) to the next image (Image 2) during sampling intervals (1/30 s). After selecting a snowflake isolated from others of the same size (70–130% area) within a window 40×40 dots, its position and area were stored. If in the next image the same-size snowflake was found within a window 64×100 dots to downward from the position of snowflake in Image 1, we regarded it as the same flake in Image 1 and calculated the falling velocity by the distance and time that it fell during the 1/30 s sampling interval. Since there is no assumption about the shape of the snowflake, the falling velocities calculated by this method seemed to be more exact than the one-image method.

It sometimes happens that the same snowflake cannot be found in two images, but the same snowflake can be found in long-time observations and we can obtain relations between size and falling velocity of a snowflake.

4. Experimental Results

The time dependence of snowflake size distribution and the average falling velocity of all the falling snowflakes at the Toyama National College of Technology on Feb-

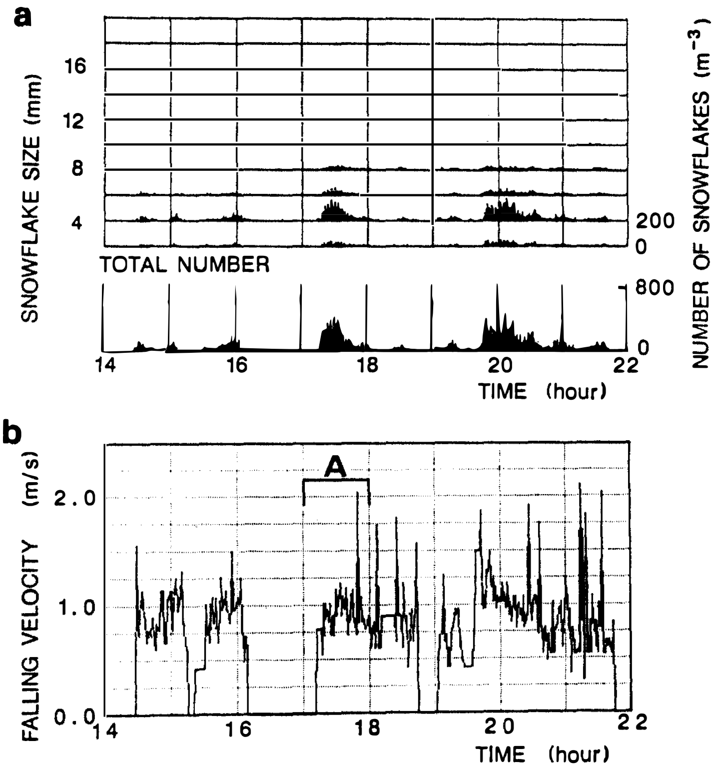

Fig. 6. The distributions of snowflakes and average falling velocity during 8 h.

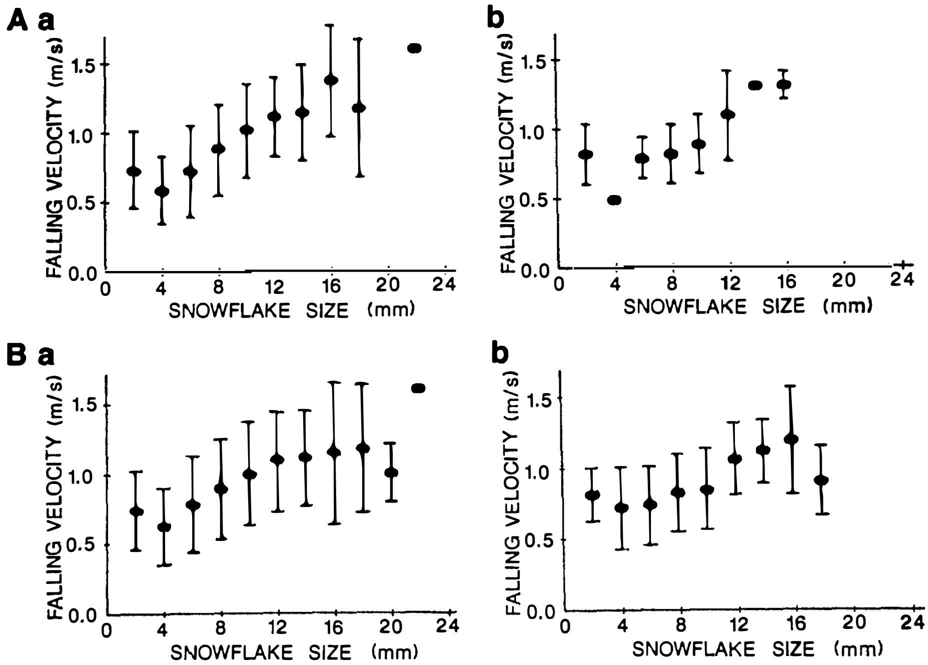

Fig. 7. The relations between snowflake size and the falling velocity of a particular snowflake.

Table 1. Detected numbers of the snowflakes by each method.

Snowflake size (mm)	1700–1800		1400–2200	
	One-image	Two-image	One-image	Two-image
2	712	6	2747	17
4	2802	1	10078	24
6	708	3	2686	40
8	479	11	1709	44
10	179	8	636	20
12	66	5	198	17
14	31	2	103	7
16	20	2	45	5
18	5	0	12	2
20	0	0	3	0
22	1	0	1	0
24	0	0	0	0

ruary 10, 1988 are shown in Fig. 6. These had a falling velocity of 0.5 to 2.0 m/s. Figure 7 shows the relations between snowflake size and falling velocity (Upper, computed at the time of A as shown in Fig. 6; Lower, computed during 8 h). Each point with error bars shows the mean $\pm$SD of falling velocities. Figure 7A and B are a comparison of data calculated by the one-image method and the two-image method. Table 1 shows detected numbers of snowflakes by each method. The falling velocities computed by the two-image method show the exact data, but the quantity of data is much less than that by the one-image method. These data indicate that the velocities show a tendency to be fast according to increasing diameter except for 2 mm in diameter. These observations agree with previous reports (JIUSTO and BOSWORTH, 1971; LANGLEBEN, 1954; MAGONO and NAKAMURA, 1965), though snowflakes under 3 mm in diameter were not observed by them.

5. Conclusion

We have introduced a new system which automatically measures simultaneously the size distribution and falling velocity of snowflakes over a long period of time. The average velocity of all snowflakes and the velocity of a particular snowflakes were calculated by the length of dots given from the observed space and resolution with a personal computer.

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