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MEASUREMENT OF FALLING MOTION OF SNOWFLAKES USING CCD CAMERA

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Abstract: The horizontal and vertical falling motions of snowflakes were imaged by two CCD cameras. These images were analyzed by an image processor and a computer. The size and position of each snowflake were measured every 1/30 s from their two images. There were three patterns in falling motion of snowflakes: rotational motion, swing motion and straight motion. The angular velocity of smaller radii of rotational motion was faster than that of larger ones. On the other hand, the radius of rotational motion didn't depend on snowflake size.

1. Introduction

The falling motion of snowflakes is important in the investigation of their growth by collision and adhesion during their fall (PASSARELLI, 1978, 1979; ROGERS, 1974; SASYO, 1977). Although a number of methods for measuring the falling motion of snowflakes have been developed (JAYAWEERA and MASON, 1965, 1966; KAJIKAWA, 1976, 1982; SASYO, 1971, 1977), automatically measuring equipment has not yet been developed.

In this paper, we propose a new system which automatically measures simultaneously the size and falling motion of snowflakes using an image processor and a computer. From the analyzed data, the relationship between the size and falling motion of snowflakes was investigated. The advantage of this system is that all data are stored on disk and make up a data base, and any kind of relationship involving size and motion can be examined easily.

The observation of snowflakes was carried out during winters of 1988 and 1989 at the Toyama National College of Technology.

2. Measuring System

In order to measure the size and falling motion of snowflakes, two CCD cameras were arranged as shown in Fig. 1. Since the measuring system is the same as the previous one for falling attitude of snowflakes (MURAMOTO *et al.*,

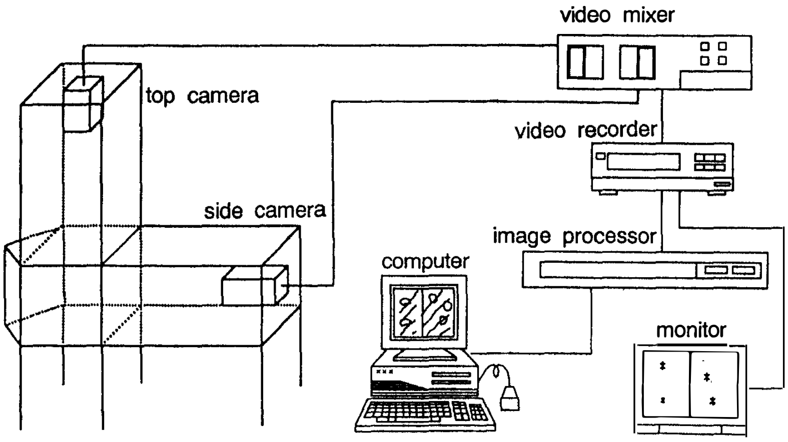

Fig. 1. System configuration for measuring falling motion of snowflakes.

1990), the equipment will be described briefly. Two images, taken from each of two cameras, of the same snowflake were recombined into a single pair of images by a video mixer, in order to synchronize timing, and input into an image processor.

3. Method of Analysis

To separate the snowflakes from the background, the images were binarized by a suitable threshold level. Figure 2a shows a snowflake model; this image was converted into the digital form shown in Fig. 2b. Using this digital image, the area and center of gravity of the region filled with pixels were calculated. The area of the snowflake cross section was obtained from the number of pixels inside the region. On the other hand, the trajectory in falling motion was obtained by tracing the positions of the center of gravity in serial order. Figure 3 shows three typical examples of falling snowflake images from both the top and side directions computed with the time interval of 1/30 s. Falling velocity was calculated from the vertical distance which the image of a snowflake seen from the side fell during sampling intervals (1/30 s). Trajectory on the horizontal plane

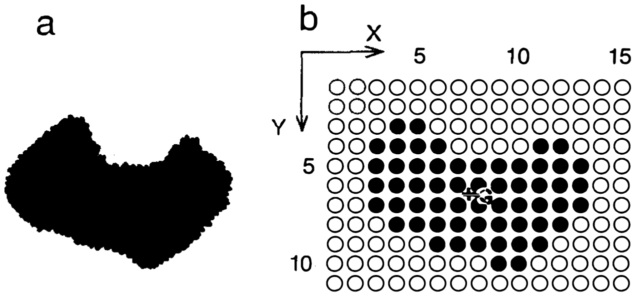

Fig. 2. A snowflake model (a) and reconstructed image after sampling with pixels (b). The center of gravity position of this model was point G (7.7, 6.4) indicated in the orthogonal coordinate system.

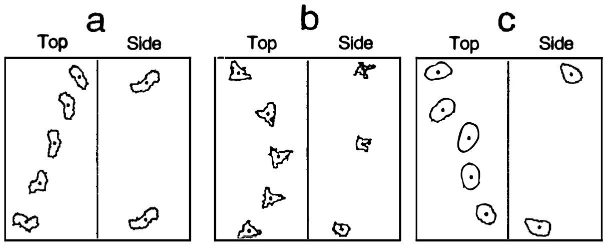

Fig. 3. *Three typical examples of the falling motion of snowflakes. Each small solid circle indicates the center of gravity position. a: Straight type. b: Rotation type. c: Swing type.*

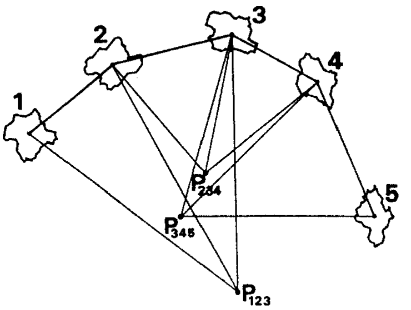

Fig. 4. *Center and radius of rotational motions in horizontal plane.*

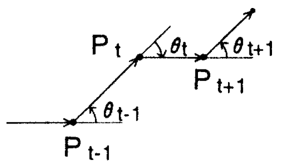

Fig. 5. *Vector diagram indicating the angle of motion calculated as the difference between two vectors. Each point indicates the position of every 1/30 s.*

was calculated from images from the top direction. According to the horizontal movement in Fig. 3, the falling motion pattern was classified into three types, namely, straight (Fig. 3a), rotation (Fig. 3b), and swing (Fig. 3c). Swing motion occurred when a snowflake oscillated horizontally during fall. In the case of rotational motion, it is possible to obtain a turning radius using three serial positions of the snowflake center of gravity shown in Fig. 4. To find the center and radius of the rotational motion, the point of intersection of the perpendicular bisector of the straight line between two positions was calculated. Figure 4 shows an example of five snowflake positions; in this case, the radius was obtained as the average of three values. Angular velocity was determined by the change in direction from 3 serial positions as shown in Fig. 5.

4. Experimental Results

Figure 6 shows the relationship between falling velocity and snowflake area. These data indicate that the velocity increases slowly with increasing area. This result agrees with previous reports (JIUSTO and BOSWORTH, 1971; MAGONO and NAKAMURA, 1965), though they measured diameter instead of area. Forty trajectories of snowflake center on the horizontal plane were traced as shown in Fig. 7. In this figure, each trajectory is shown by a solid square at the first snowflake position followed by solid circles at intervals of 1/30 s. There was no relationship between the direction of movement and size. To determine the

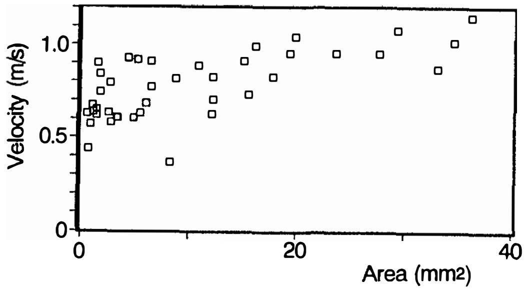

Fig. 6. Relationship between the falling velocity and the area of snowflakes.

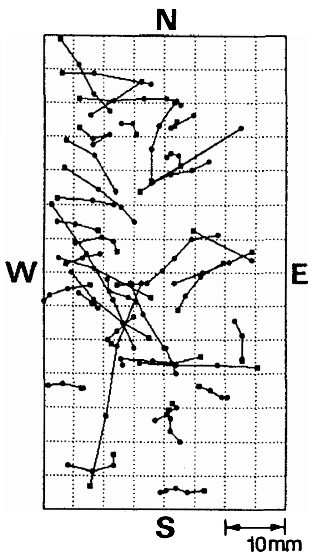

Fig. 7. Forty trajectories found by tracing snowflake centers on the horizontal plane. Each trajectory consists of a solid square at the first snowflake position followed by solid circles at intervals of 1/30 s.

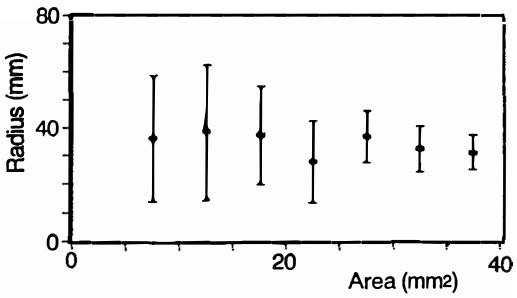

Fig. 8. Relationship between snowflake areas and mean radii of rotational motion. Each point represents a mean of radii. Bars indicate standard deviations.

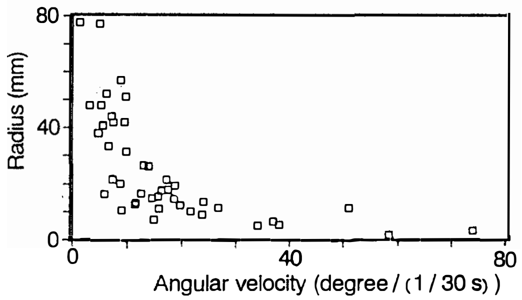

Fig. 9. Relationship between the radius of rotational motion and the angular velocity of snowflakes.

rotational motion quantitatively, relations between radius and area, and angular velocity were plotted in Figs. 8 and 9. Figure 8 indicates relations between snowflake areas and mean radii of rotational motion. Although the standard deviation gradually became smaller as the area increased, the mean values of radii were nearly same. Figure 9 shows that the turning radius is in inverse proportion to the angular velocity. This result shows that the angular velocities of smaller radii were faster than those of larger ones. As might be suspected, smaller radii show rotational motion more clearly than larger ones. The boundary radius between the rotational movement and straight movement was estimated as

60 mm by visual observation of snowflake trajectories as shown in Fig. 7. Therefore, the angular velocity of rotational movement was faster than 150°/s. KAJIKAWA (1976, 1982) observed the falling motions of early snowflakes composed of two to six crystals. Since we measured larger snowflakes, the relation between these snowflakes couldn't be compared directly. In order to examine these relations in detail, lots of snowflakes have to be measured.

5. Conclusions

We have proposed a new system which automatically measures simultaneously the size and falling motion of snowflakes using two CCD cameras from horizontal and vertical directions. The snowflake images were automatically analyzed by an image processor and a computer. The present results indicate that there were three patterns in the falling motion of snowflakes, that is, rotational motion, swing motion and straight motion. And there was a tendency for the angular velocity of smaller radius of rotational motions to be faster than that of larger ones. On the other hand, the radius of rotational motion didn't depend on snowflake size.

Acknowledgments

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