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LASER DISCRIMINATION BETWEEN RAIN AND SNOW

By

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INTRODUCTION

Development of a remote-sensing gauge that can accurately distinguish between snow and rain would markedly benefit hydrometeorologic science. In many mountainous environments, rainfall or mixed rain and snow comprise major portions of the winter precipitation. Streamflow discharges from rain on snow can cause flooding, and the threat of rain on snow may reduce the efficiency of reservoir management. For these reasons, hydrologists need improved techniques for discriminating between snow and rain to aid in forecasting snow accumulation, melt, and streamflow.

Most simulation models providing such forecasts use air temperature indexes and lapse rates to differentiate between precipitation types. Temperature indexes are frequently in error, however, since storm origin, terrain effects, and orographic uplift confound simple temperature-precipitation type rules.

This paper describes a prototype gauge based on laser/photo-detection technology that discriminates between particle types and may be adaptable to remote sensing.

LASER/PHOTO-DETECTION TECHNOLOGY

The prototype gauge, which we call the laser weather identifier, is based on earlier systems developed by Schmidt (1977) and Wang et al. (1982). The unit consists of an assembly housing a helium-neon laser, an expander-collimator producing a 10-cm diameter laser beam, and a receiver assembly located 4 meters from the transmitter (Figure 1). The

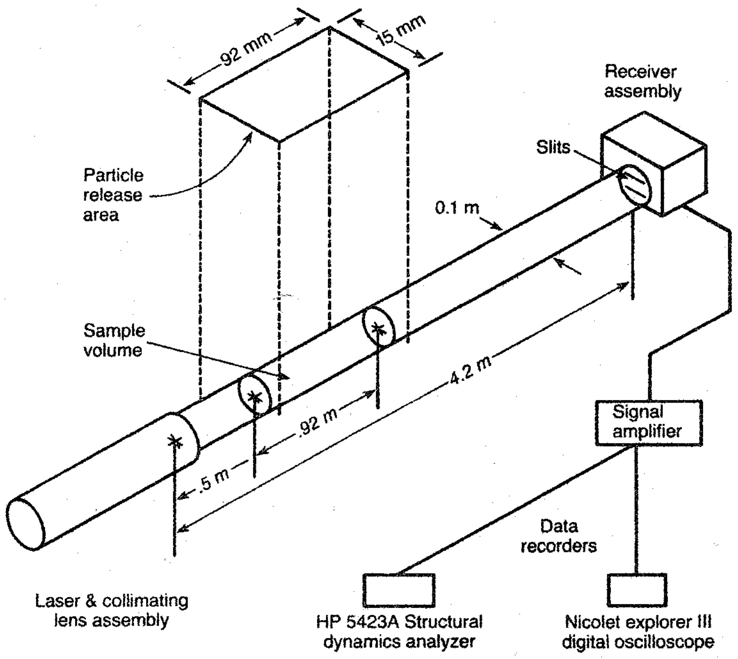

Figure 1. The laboratory prototype laser weather identifier consists of a drop former, helium-neon laser, expander-collimater, and receiver.

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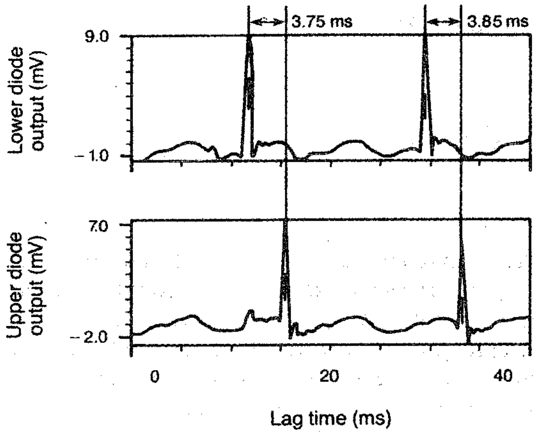

Figure 4. Photo-diode response to the passage of two water droplets from a height of 1.65 m.

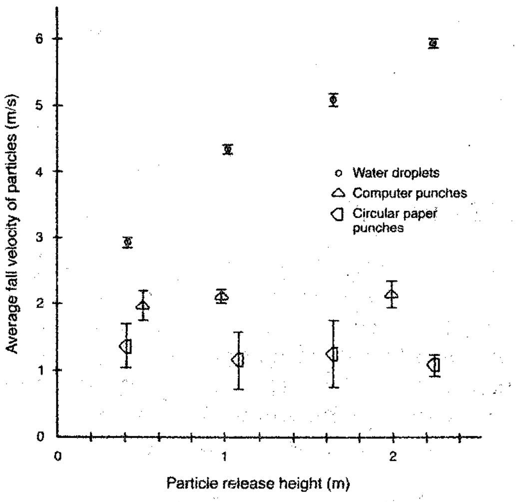

Figure 5. Range of measured fall velocities and deviations for three types of particles.

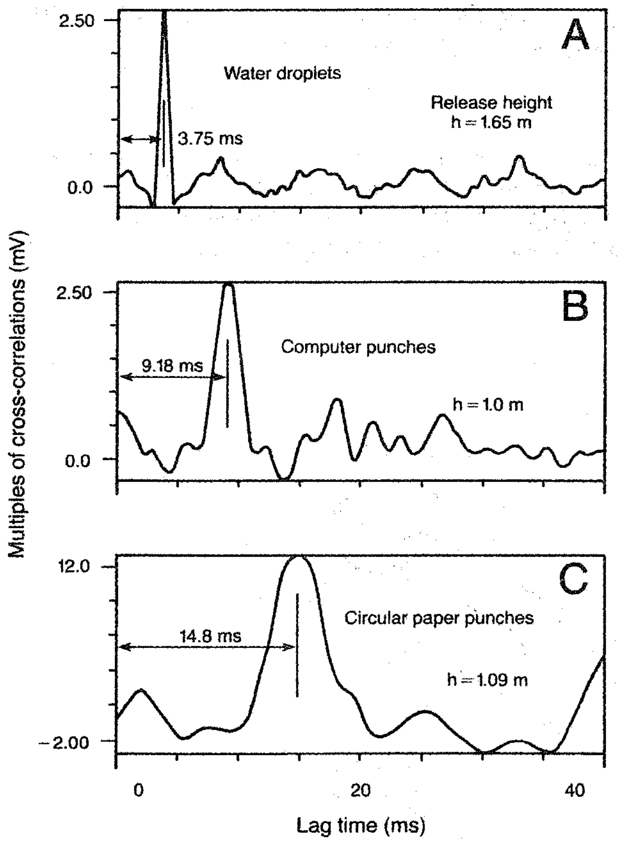

Figure 6. Cross-correlation of three types of particles released at various heights.

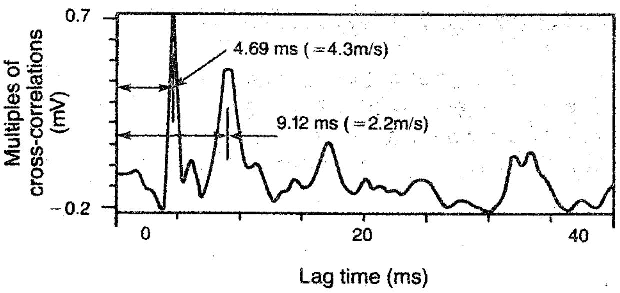

Figure 7. Cross-correlating of water droplets and computer punches released from a height of 1 m.

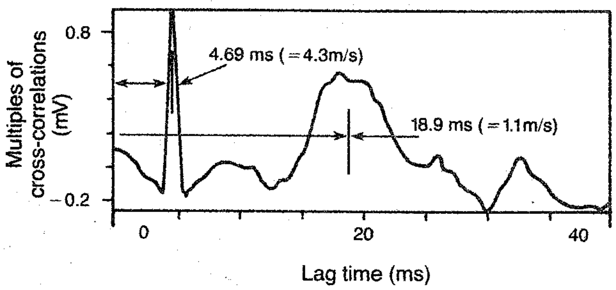

Figure 8. Cross-correlating of water droplets and circular paper punches released from a height of 1 m.

IMAGE RECONSTRUCTION FROM SIGNAL RESPONSES

The feasibility of reconstructing a two-dimensional projection of a particle from the diode responses was investigated by passing two-dimensional shapes through the laser beam. To reconstruct a particle, a vertical axis, corresponding to the established vertical length of the particle, was drawn to scale. At selected intervals along that axis the width of the particle was determined from the diode amplitude-particle diameter relationship (Figure 9). A line corresponding to that width was then constructed. Each line was centered on the axis and the end points of these lines were connected on each side of the axis to form the outline of the particle.

receiver face is masked so that two horizontal, parallel slits (10 cm x 1 mm), 2 cm apart, collimate and focus light onto photo-diodes (Figure 2). The diode output is processed for precipitation information (Figure 3). The passage of a precipitation particle falling vertically through the laser beam reduces the light reaching the photo-detectors and produces a significant increase in output voltage. A particle is identified by cross-correlating time delays of the two photo-detector signals as it passes through the light beam, and by analyzing the fall velocity and shape of the particle.

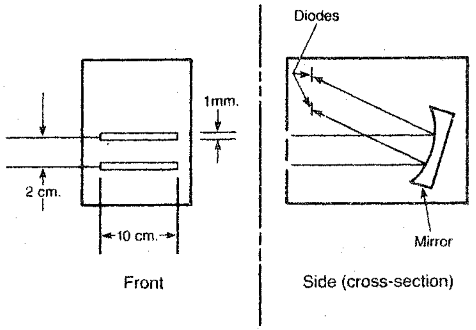

Figure 2. Detail of receiver assembly.

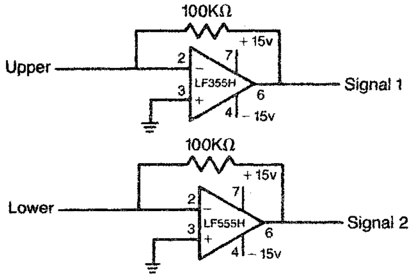

Figure 3. Diode amplifying circuit.

Particle velocities are determined by cross-correlating the diode outputs to obtain a peak correlation representing the average (mode) delay between the diode signals. This relationship can be expressed as:

$$r_{j,h}(k) = [\sum_{i=1}^{n-k} (x_{j,i}-\bar{x}_j)(x_{h,i+k}-\bar{x}_h)] \,/\, (n-k)\; S_{x,j}\; S_{x,h}$$

in which k = delay (lag) time between diode ouputs, n = total number of observations on diode outputs x_j and x_h, $x_{j,i}$ is the ith observation on x_j, $\bar{x}_j$ = mean of the observations on x_j, and $S_{x,j}$ = square root of the variance of x_j.

Average particle velocity is calculated directly from the delay as the quotient of the vertical distance between the slit and the delay time. Direct estimation of particle type may be possible through use of an algorithm suggested by Wang (1982) that attributes velocities under 3 m/s to falling snow, those between 3 and 8 m/s to rain, and above 8 m/s to hail.

FALL VELOCITIES OF SIMULATED RAIN AND SNOW PARTICLES

We tested the prototype gauge by using three kinds of particles to simulate rain and snow. In one test, velocities of water droplets (mean diameter 2.5 mm) were estimated by positioning a drop-former 1.65 m above the laser beam (Figure 4). The other two types of particles tested were falling circular paper punches (7-mm diameter) and rectangular (1.5 x 3 mm) computer punches. Water droplets are distinguishable from paper particles both by their average velocity and by the distribution of the particle velocities. They have greater mean fall velocity and lower velocity deviations than the paper particles (Figure 5). Measurement of the average particle velocity and velocity distribution by cross-correlation can distinguish the presence of particles with distinct velocities. Water droplets have the highest average velocities and smallest deviation. The less aerodynamic paper punches fell more slowly and with greater variation in velocity (Figure 6). When particle types were combined, cross-correlation clearly distinguished between the two types (Figures 7-8).

PARTICLE SIZE TESTS

The relationship between the amplitude and duration of the photo-diode output and the size and velocity of the falling particle was determined by releasing 11 opaque spheres, ranging in diameter from 2 to 8 mm, individually above the laser beam and recording the two photo-diode responses. The duration of each signal response was standardized by the corresponding delay time between slits to account for differing fall velocities. The average fall velocity was determined from the delay, and the amplitude and duration of the response of the lower diode can be expressed as a function of sphere diameter (Figure 9).

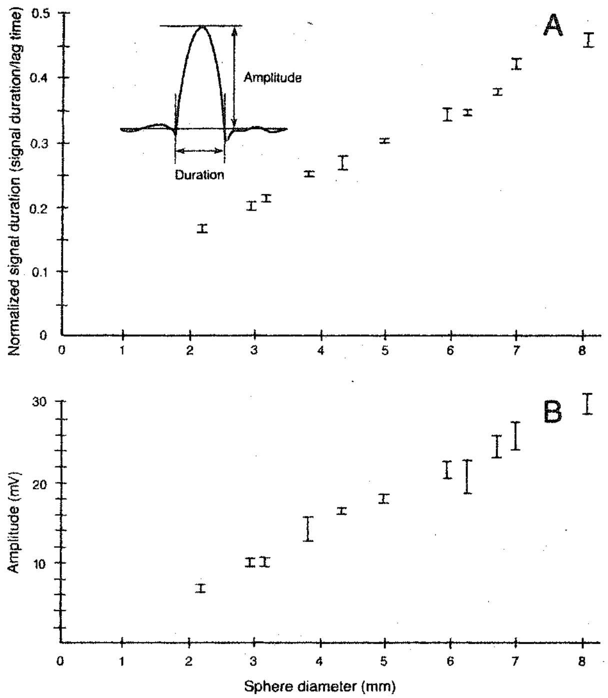

Figure 9. Response range of the lower diode to the passage of spherical particles of various diameters.

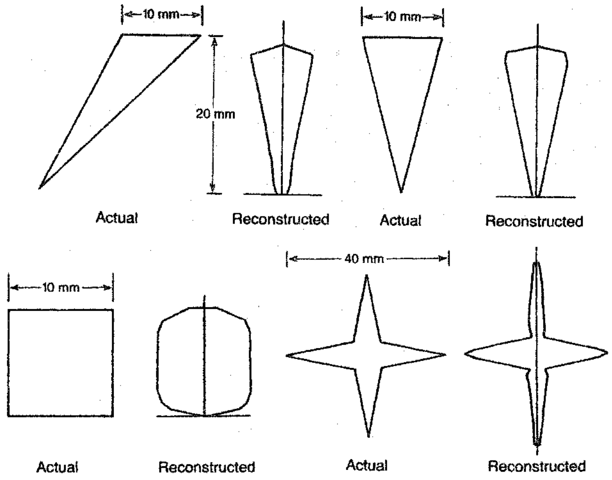

Figure 10. Reconstruction of particle images from signal response.

The reconstruction procedure was applied to a square, two triangles, and a four-cornered star. The resulting images were then compared to the true shapes (Figure 10). A reasonable degree of reproducibility seems possible, although symmetric shapes are not readily distinguishable from asymmetric ones.

DISCUSSION AND CONCLUSIONS

The prototype gauge has 1.0-mm slit openings. With this slit dimension the reconstruction of natural hydrometeors with projected vertical lengths on the order of several millimeters or less would be rather imprecise because too much of the particle is viewed at any given time through a slit. A smaller aperture size should be evaluated. If the aperture size were reduced, a higher intensity laser may be required. Increased beam intensity--probably most easily accomplished by reducing beam diameter--would also reduce the distortions in particle image reconstruction.

Further gauge development will also require assessment of the effects of wind. Wind will significantly influence particle fall velocities and will complicate the use of a simple fall velocity algorithm for discriminating among particle types. The image reconstruction procedure will also be wind-affected.

Results of tests with the laser identifier unit suggest that this approach of identifying precipitation by measuring fall velocity and determining particle shape shows promise. The velocity measurement approach is easier to implement but the shape determination approach offers the possibility of direct, though geometrically inaccurate, imaging of particles. Data are needed to confirm the usefulness of this algorithm under conditions of mixed snow and rain. Extensive laboratory and field testing using real hydrometeors is necessary to evaluate whether the determination of particle velocity alone is adequate. Further testing is also needed to assess other potential complicating factors such as the effects of non-vertical particle movement, particle impaction onto the detector slit surfaces, and the asymmetry of falling snow flakes.

REFERENCES

Schmidt, R.A., 1977: A System that Measures Blowing Snow, USDA Forest Service Research Paper RM-194, 80 pp.

Wang, T., D.C. Brinning, G.R. Ochs, and R.S. Lawrence, 1982, Optimization for the Algorithms of an Operational Laser Weather Identifier, NOAA Tech. Memo. ERL WPL-107, Oct., 1982.