THE OBJECTIVE ANALYSIS OF HAILPADS USING A COMPUTERIZED VIDEO SCANNING SYSTEM

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Abstract. Data reduction and analysis of hailstone impacts on a variety of materials has always been a labor-intensive procedure. In both hail research and operational programs, questions of objectivity also arise from the interpretation of hail dents. A new method has been developed for reducing and analysing hail impacts using a computerized video scanning system. This new approach provides the user with a high speed analytical system which reduces human error and is objective, accurate, and reproducable. The system is discussed, data reduction methods are shown, and analysis examples are presented.

1. INTRODUCTION

Hail can produce extreme damage to property but, from an economic point of view, it is far more frequent and severe in terms of damage to crops. In the United States hail damage to agriculture is more than ten times the amount inflicted on property.

For more than 100 years, the surface characteristics of hailfall on the ground have been examined by casual observations, subjective accounts from farmers, and general reports from organisations and groups of individuals. During the past 30 years, many areas of the world have experienced a renewed and major interest in attempts to suppress hail damage through the application of modern cloud seeding technology. This technology continues as a high priority subject, particularly in those areas subject to annual and repeated hail damage.

A major ingredient for all hail suppresion projects is the collection of surface hail data that will allow a practical evaluation of this application technology in a minimum amount of time. The methods of obtaining surface hail information have been related to the objectives of the particular program. For example, in the agricultural community, commercial and governmental hail insurance companies have compiled a broad base of hail loss records (Changnon, 1966, 1972). Other investigators in the past have also used crop damage records in different ways as a measure of hail intensity (Henderson, 1970). However, some research work (Summers, 1960) has suggested that crop damage is not a very precise measure of hailfall because of the large number of crop variables unrelated to hail intensity.

Other programs have required the actual collection of hailstones (Douglas and Hitschfeld, 1958; List,1961; Carte, 1963). A few airborne radiometric studies (Roads, 1973) have been implemented to determine the areal extent of hail on the ground. Additionally, mobile vehicles have been used in attempts to deploy a variety of collection devices ahead of the storms immediately after hailfall (Summers, 1968; Morgan 1969; Renick, 1969, 1970).

A precise and complete description of hailfall would require an examination of each hailstone which fell inside a study area. Such a description would include the time and place of arrival, shapes and sizes, crystal structure and hardness, rotation, and velocity just to list a few of the more important characteristics. Although this may be a revealing and important undertaking within a hail research project, it is not practical within an operations program developed around funding at much lower levels.

On the other hand, many operations programs do require some measure of hail on the ground and, for many years, the total kinetic energy of hailstones integrated over an event period has been used as a measure of effect within these programs. The presumed relationship between kinetic energy and crop damage led some investigators (Schleusener and Jennings, 1960; Wilk, 1961;Decker and Calvin, 1961) to a development of a passive method (hailpad) of hailfall measurement.

The hailpad is a simple device composed of a flat horizontal surface of semi-resilient material such as styrofoam which, in its original configuration, was wrapped in aluminum foil. More recently, some specific types of styrofoam and other materials have been calibrated and used without the addition of aluminum foil. The impact of hailstones on such surfaces produces dents related to impact, size, and shape. Although a wide variety of hail sensors have been developed and used in the field, the hailpad remains the only hail-measuring instrument which has been used for a sufficient time to produce a significant sample of quantitative hailfall data.

2.0 REQUIREMENTS

Some of the difficulties encountered in surface hail measurements include:

- The extreme variability of hailfall parameters in time and space
- The wide variations in hailstone properties (hardness, size, sphericity, etc.)
- Abberations produced by wind and turbulence
- The hail occurence is a relatively rare event

All of these considerations have a strong bearing on the important requirements for the instruments. Because hail is a relatively rare but potentially devastating event, instrument dependability and the choice of rather large areas within which measurements will be made are two high priority considerations. The extreme space variations in hailfall produce restrictions on the required number of instruments within an operations area and the sensing area of a single instrument. The variations in hailstone property and abberations produced by wind across the sensing surface pose additional requirements on instrument design. Of course, it is not possible to design a practical and economical instrument which is totally responsive to all the desired requirements. However, the hailpad does meet a significant number of the requirements so its continued use has been a favored choice.

The advantages of the hailpad are numerous and some of the primary points can be summarised as follows:

- the hailpads do indicate a hailfall occurence
- they are inexpensive and many sites can be serviced in a short time period
- hailstone concentrations and sizes can be determined
- windspeed and direction can be estimated from the shape of the hail dents
- vertical kinetic energy and momentum imparted by the hailstones can be calculated given the measurement of dent sizes and some theoretical values of fall speeds

The disadvantages include such considerations as:

- large numbers of hailstones in short time periods can produce overlapping dents which are extremely difficult to analyze
- the hailpad does not produce information on time of fall, although coordinated radar information and nearby recorded rainfall records often help sort out the time problems
- hailstones falling under high wind conditions often produce impacts difficult to analyze
- the hailpad can usefully record only one hailfall incident without a required service visit
- the subsequent analysis of each hailpad can be tedious and time-consuming

It has been common to note a requirement of at least 35 minutes for one person to measure (length and width) every hailstone impact on a single hailpad and manually record the information in a format useful for subsequent analysis. Longer times are required when total impacts are numerous and the hailfall patterns are complex. When several hundred hailpads require analysis, the time requirement can total several months.

Any system of hailpad analysis should contain at least these three elements:

- it must provide a high degree of objectivity
- the system must produce accurate and repeatable information
- it must substantially reduce the labor intensive aspect of this task

A recent development and subsequent applications have produced a much improved method for basic data reduction and compilation.

3.0 SYSTEM DESCRIPTION

The hailpad Computerized Video Scanning System (CVSS) is an adaptation of existing video scanning components which provide a capability for extracting both qualitative and quantitative information from all types of visual images (Henderson, 1985). The qualitative information can aid in comprehension and interpretation of the imagery. The quantita-tive information can define the size, contrast, brightness, shape, concentration, and spatial relationships (distances and positions) of selected features with the visual imagery.

The basic system components described in this paper were originally developed as a bacteria colony counter for use in the medical profession and later expanded for use in the analysis of aerial photo-graphs, agricultural maps, and certain landsat applications. Video imagery analysis systems are becoming standard "shelf items" from several manufacturers within this industry. In this particular system, two video cameras are used; one for imaging the hailpad and the other for hailpad image editing. By overlaying the images from the two cameras on a monitor, a light pen can be utilized with the second camera to edit out abberations on the hailpad image. The CVSS components also include a color printer so multi-colored hard copies can be produced for any select data or image.

The "heart" of the CVSS is an image processor which uses simple controls with digital precision to divide an image (ie. the hailpad) into 49,152 pixels (picture elements) and to select the resolution (pixels per unit area) required to define the image with sufficient accuracy and resolution. Each image element defined by a pixel can be further defined by its brightness for up to 256 different brightness (density) values. This is a particularly useful feature in hailpad data reduction because it allows the operator to rapidly and objectively edit a hailpad for minor scratches, imperfections in the material, and indentations or other markings not related to hail impacts. Another editing tool is the light pen which can be used to erase the more extensive and severe non-hail imperfections. The image processor is connected to a micro-computer which ultimately receives the image data and places it in a format defined by the user. These data can then be analysed using programs selected by the user. The hailpad images can also be stored on disk for later analysis.

A block diagram of the CVSS is shown in Figure 1.

4.0 HAILPAD ANALYSIS

When the hailpad is removed from the field site, the surface is rolled with a soft rubber roller coated with black printer's ink. This covers the total surface except for those areas where hail impacts or extraneous marks are present, thus providing a high-contrast viewing area. The hailpad is then placed on one of the light tables or viewing areas and the hail impact images are examined on the monitor. Editing of obvious scratches, bird pecks, or other non-hail marks can proceed via the light pen, adjustments in image density values, or black felt tip pen. The hail dent information is then ready for scale

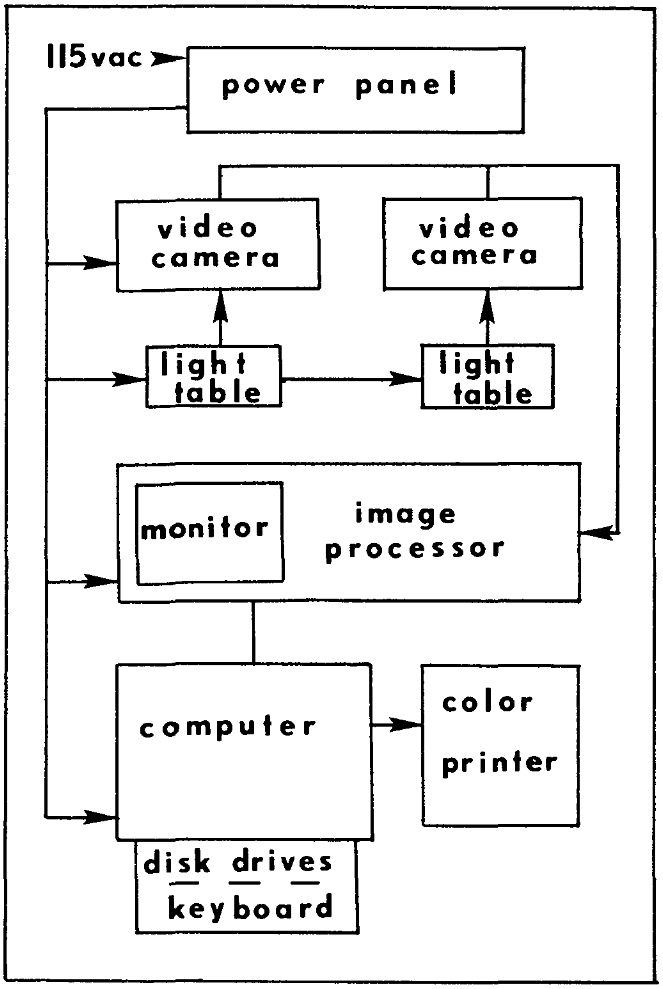


Figure 1. Block diagram of the computerized video scanning system

calibration and final video camera scanning.

The image processor will operate on any information displayed on the video monitor. As the hailpad is scanned, each piece of information stored in the graphic memory has a numeric (digital) horizontal and vertical position value. The screen is divided into 192 rows and 256 columns, and the hail dents are displayed at various locations related to the memory's rows and columns. The intersection of a row and column defines a point with a specific X and Y coordinate value; the smallest graphic overlay element being the pixel.

In order to measure the information which has been extracted from the video display appearing on the monitor, the number of pixels for each hail impact are automatically counted and multiplied by an established constant referencing the size of each pixel. All pixels are square and equal in size. The image processor assumes that the input video signals represent flat, rectified, geometrically correct, two-dimensional presentations.

Once the video scanning and digitizing task is complete within the image processor component, the final image is then transferred to the memory of the microcomputer (IBM XT, Apple IIe, etc.) and is then available for printout and further processing. A computer printout of an actual hailpad display of 85 hail impacts is shown in Figure 2b.

The various software as developed by the user is now ready for a variety of hailpad statistics calculations. Some general statistics covering the hailpad display noted in Figure 2b are presented in Figure 2a. This table includes such information as the individual pixel size, the number of hailstones, their total and mean area, the range of areas from smallest to largest hailstone, and the standard deviation of the mean.

The software is organized to produce other types of displays as well. For example, the data graph presented in Figure 2d is a plot of the numbers of hailstones of various sizes from 0.051 cm2 to 1.299 cm2 for all 85 hail impacts. Mode, median, and mean values are calculated and plotted. The shortest single vertical line in Figure 2d denotes one hail impact. Another type of software output categorizes the hail impacts in various ranges of sizes (bins). Up to ten separate ranges are available. An example of this capability for the same hailpad is presented as a computer-generated bargraph shown in Figure 2c. The percentages of hail impacts within each of the eight ranges are plotted for the 85 hail impacts.

Basic information used in the range bargraph plot is also available for computer printout. These data are presented below the bargraph in Figure 2c. Here we note the values for each of the eight ranges, the number of hail impacts within each range and their total areas, and the actual percentage of the total hail impacts within each range. Not presented in this paper is the capability to print out in different colors on the hailpad display (Figure 2b) the images of the actual hail impacts which are included within each range.

A final output is the ability to print out the raw data values as obtained from the hailpad image. These data are reported to the resolution of the CVSS and are presented in Figure 2e. These data, when stored on disk, are useful for further data processing at some later point in time.

A few comments about the hailpads and surface impressions which occur between site visitations are useful to observers and field technicians. First, an experienced field technician can almost always distinguish between hail impacts and extraneous marks and impressions. For example, heavy rain leaves very smooth and very shallow spherical impressions in the surface of the styrofoam material. With the proper choice of inking material, these rainfall impacts are blacked-out when each hailpad is treated following removal from the field site.

Indentations caused by birds pecking on the hailpad surfaces are easily identified and the images can be quickly removed in the editing process. In most cases, the occurrence of bird pecks are far less numerous when the styrofoam is not covered with aluminum foil.

Inquisitive residents throughout a hailpad area will occasionally leave fingerprints in the hailpad surface, or mark the surface with other objects such as sticks, nails, or stones. Most of these non-hail impressions are obvious because it is rare to find anyone who can make an impression on the hailpad surface that looks exactly like a hail impact. Very rare exceptions are those cases when a person takes the time to

FIGURE 2
COMPUTERIZED HAILPAD ANALYSIS PRINTOUT
12 MAY 1985 (#018)

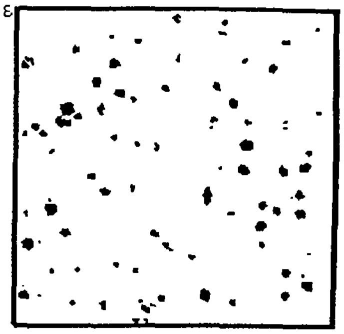
2a. G120585018

SCALE DATA:
1 PIXEL= .0254640109 SQ CM IN AREA
= .159574468 CM IN LENGTH

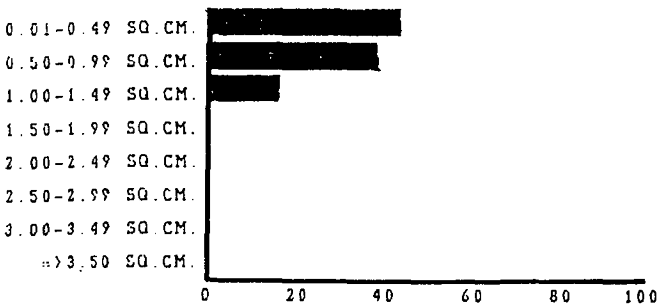
AREA DATA:
TOTAL IMPACTED AREA: 33.74
NUMBER OF HAIL IMPACTS: 85
AVERAGE AREA: .4
RANGE .05 TO 1.3

STD.DEV. .292

2b. G120585018
*000
300485
1147
150585
1900



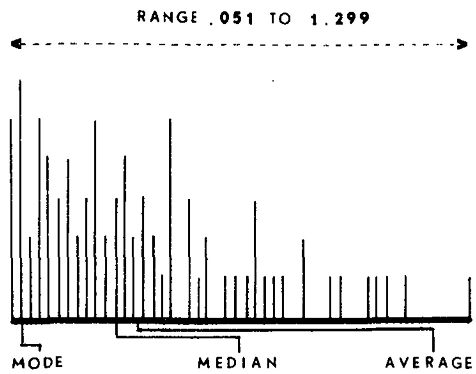
2c.



-- 0.01-0.49 : 61 IMPACT(S) TOTALING
14.89 SQ CM = 44.2% TOTAL IMPACTED AREA
-- 0.50-0.99 : 19 IMPACT(S) TOTALING
13.29 SQ CM = 39.4% TOTAL IMPACTED AREA
-- 1.00-1.49 : 5 IMPACT(S) TOTALING
5.55 SQ CM = 16.5% TOTAL IMPACTED AREA
-- 1.50-1.99 : 0 IMPACT(S) TOTALING
0 SQ CM = 0% TOTAL IMPACTED AREA
-- 2.00-2.49 : 0 IMPACT(S) TOTALING
0 SQ CM = 0% TOTAL IMPACTED AREA
-- 2.50-2.99 : 0 IMPACT(S) TOTALING
0 SQ CM = 0% TOTAL IMPACTED AREA
-- 3.00-3.49 : 0 IMPACT(S) TOTALING
0 SQ CM = 0% TOTAL IMPACTED AREA
-- =>3.50 : 0 IMPACT(S) TOTALING
0 SQ CM = 0% TOTAL IMPACTED AREA

FIGURE 2 (Continued)

2d. **G 1 2 0 5 8 5 0 1 8**



MODE .08
MEDIAN .33
AVERAGE .4

2e.

G120585018

SIZE(SQ.CM.)	NUMBER
.0636600218	5
.0891240327	6
.114588044	7
.140052055	4
.190980076	3
.216444087	4
.241908098	5
.267372109	5
.318300131	2
.343764142	3
.369228153	6
.394692164	3
.445620185	2
.471084196	1
.496548207	5
.522012218	3
.57294024	1
.598404251	2
.623868262	1
.649332273	1
.700260295	1
.725724306	4
.751188317	1
.776652327	1
.85304436	2
.903972382	1
.954900404	1
1.00582843	1
1.03129244	1
1.08222046	1
1.10768447	1
1.28593255	1

MEAN .399223529
MODE .114588044
TOTAL NUMBER OF IMPACTS : 85

actually make some ice balls, or collects and refrigerates some actual hailstones, then impacts these on the hailpad surface.

The relationship between hail and crop damage is extremely complex and, in a large measure, depends upon wind which accompanies the hailfall. The CVSS analyses on hail impacts which are produced during strong wind conditions can be simplified by the objective analysis approach itself. This is particularly true for randomized programs where it might be assumed that wind effects will equalize between random choices. It is sometimes difficult to differentiate between the impact produced by an oblong hailstone without wind and an impact produced by a spherical hailstone driven by high winds.

In any case, when analyzing hailpads, it must be understood that wind effects will increase the number of stones having potential for crop damage, increase the impact energy of the hailstones, and increase the calculated hailstone volumes as derived from the volume of each hailstone impact. Further, calibration curves which relate hailstone and impact diameters must be adjusted for wind, noting the laboratory tests which have shown that the minor impact axis is an excellent predictor of hailstone diameter.

5.0 CONCLUSION

After three years of applying the CVSS to (1) hailpads obtained from laboratory tests of falling spheres on a variety of resilient impact materials, and (2) hailpads obtained from a randomized hail suppression operations program, the following tentative conclusions can be stated:

- The CVSS produces good correspondence when data from manually reduced hailpad measurements are compared with the measurements produced by the CVSS. In fact, the evidence suggests a much higher level of repeatability from the CVSS.

- A high degree of objectivity is associated with the CVSS. Although there may be minimal measurement errors associated with the CVSS, these errors are constant and not specific to any group of hailpads, nor do possible error sources change during an analysis period. Therefore, analysis of hailpads from seeded and nonseeded areas could be expected to yield measurements of equal quality.

- Normally the manual analysis of a hailpad with 75-100 impacts will occupy some 30-40 minutes, not including graphics presentations and analysis. The CVSS allows a complete data compilation, reduction and information printout in 5-10 minutes, including a variety of linegraphs and bargraphs.

- Another bonus has emerged from the use of the CVSS system. Once the hail impact images are completely edited, the original hailpads can be discarded because the CVSS can reanalyze the hail impact images stored on disk or reanalyze the actual hailpad display printout just as accurately as it does from the original hailpad.

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