Real-Time Image Enhancement of Meteorological and Maritime Processes

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ABSTRACT

The spatial and spectral luminance properties of a cloud's surface are being studied to gather more information about the microphysical processes occurring within the cloud. A real-time, field-implementable image processing system has been developed by the authors to sense and display this luminance information, and is described in this paper. Applications, including the investigation of "crown flash" phenomena, are described.

1. Introduction

An effective technique used in the various sciences to study both the composition and structure of objects is the observation of the reflectance and emission properties in the various ranges of the electromagnetic spectrum. This technique has unfortunately been limited in most instances to laboratory experiments, due to the instrumentation involved, and has seldom been applied to large-scale meteorological processes. In this paper, a system capable of qualitative and quantitative spatial and spectral analysis of visible and infrared luminance properties with applications to meteorological phenomena is described.

The observation of a cloud's luminance properties provides data which can be correlated with the microphysical processes of the cloud. An excellent illustration of the importance of these data is a phenomenon known as crown flash, described by Gall *et al.* (1971). Crown flash is a sudden brightening effect which is sometimes observed near the top of a cumulonimbus cloud concurrent with a lightning discharge. A primary motivation for the development of the system to be described has been to record this phenomenon and, especially, to examine the validity of an explanation suggested by Vonnegut (1965).

Vonnegut's theory suggests the following explanation for the crown flash phenomenon. Above the melting band, the cloud is composed chiefly of ice crystals, often in the form of hexagonal platelets, needles or columns. In the absence of a strong electrostatic field, the orientation of the ice crystals is governed chiefly by gravity and aerodynamic forces within the cloud mass. During a storm, charge begins to separate within the cloud. In the influence of the electrostatic field thus formed, the ice crystals accept an induced dipole moment. This effect has been demonstrated experimentally in a Schaefer cold box (Vonnegut, 1965). As the field strength increases, the ice crystals slowly tend toward an orientation in which the axis of the dipole moment is aligned with the electric field. Field strength is generally strongest when a lightning discharge is imminent. When the discharge occurs, the flow of currents tends to relax the fields in the clouds rapidly, with a subsequent drastic realignment of the ice crystals. A change in the luminance distribution over the cloud surface occurs as the ice crystals, acting as tiny mirrors, change their angle of reflectance of incident sunlight. An observer at the proper angle will perceive the effect as a flash of light.

The device to be described enhances the change of luminance characteristics by generating the isoluminance contours of the cloud continuously and in real time and displaying these contours in an easily interpreted format—by color encoding. Other instrumentation at the test site generated a permanent record of lightning occurrences which could be cross-checked against the color-encoded display. The system about to be described performs this contour mapping together with other processing functions which extend the flexibility and scope of the device.

2. Real-time spatial and spectral processing system

Some past methods of generating isoluminance contour maps of visual imagery relied on photographic methods. Here a photograph or transparency of the scene of interest was scanned with a scanning densitometer either by hand or under machine control. This was a laborious procedure at best which usually required from 1 hour to 2 days. The data would then still have to be plotted and interpreted. Thus, on-line interaction with the display system was totally out of the question. Recently, electronic scanning systems have become available which scan and color encode the isoluminance contours in color in real time on a TV color monitor. These systems generally suffer from high cost, size, weight and power consumption, and are usually for laboratory operation only.

Over the last two years, a field, portable, color-image-enhancement system which overcomes these deficiencies has been designed, built and tested at Rensselaer Polytechnic Institute. The present enhancement system utilizes a television camera [equipped with both narrowband (visible) and wideband (visible plus IR) image tubes] for real-time video input to the enhancement system. The digital and analog processing electronics fit in a ruggedized 6 inch×11 inch×13 inch cabinet which weighs only 10 lb, and can be field-powered from batteries. At present a 19-inch color TV monitor serves as the output display. This system is a real-time, on-line, all-electronic digital/analog system which provides, among other functions, for the encoding of visible and/or infrared scenes into isoluminance color contour images. [It has been found that gray scale differences in an image are more readily understood by human operators if the gray scale is encoded into contrasting colors. Thus, by contouring (quantizing) the brightness range of an image into perhaps 4, 8 or 16 levels and then encoding these into dissimilar colors, the luminance structure of the image is more readily seen.] A photograph of the complete system appears in Fig. 1.

Thus, operator interactive use in the field is possible. Obviously, field use and interactive ability are of prime importance for meteorological application. Output of the system can be recorded either by motion pictures off the monitor or on video tape. Also camera output can be video-taped for instant playback. Other features of the system that throw new light on meteorological phenomena are circuitry to differentiate or edge-enhance the scene and circuitry to measure the percentage of a scene spanned by a particular range of density (area measurement). Two useful features are (i) the system's ability to display a vertical "cross section" of the isoluminance contoured scene at any point the operator chooses, in the form of a graph superimposed on the color-enhanced display, and (ii) the use of an enhancement "window" for selectively enhancing any size rectangular area of the screen.

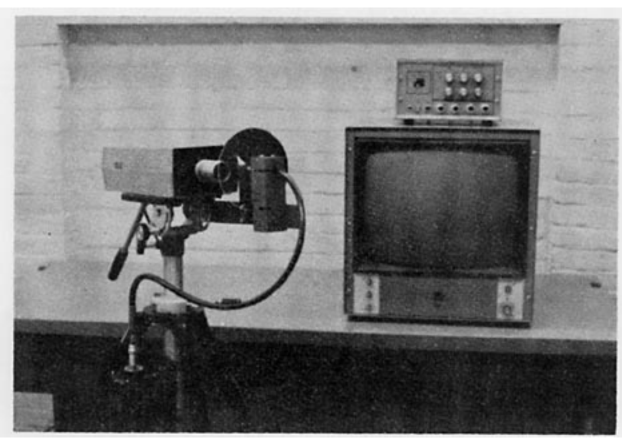

FIG. 1. Complete color-image-enhancement system.

Spectral processing capability, as well as spatial processing ability, has been added by the design and construction of a frame-synchronized sequential filtering attachment. This addition allows various spectral bands to be enhanced, color encoded, and displayed simultaneously on the color display, thus allowing the user to correlate visually and in real time, processes of interest in the various spectral bands.

3. System characteristics and features

The image processing system consists of four major sections: the camera, the analog preprocessing circuits, the thresholding and encoding electronics, and the display. The system operates on the standard 525 line, 30 frame per second, 2:1 interlace format used in commercial broadcasting. The block diagram is shown in Fig. 2. All units shown, except the monitor, camera and counter, are contained in the processor cabinet.

The input to the system is a high-resolution closed-circuit television camera with two interchangeable image tubes: a vidicon sensitive only to visible light and a Texas Instruments Tivicon (silicon target vidicon) sensitive to both visible and near infrared light, a range from about 0.4 to 1.2 μm.

The preamplifier and quantizer perform the basic processing operations. The preamplifier allows for adjusting the amplitude and bias of the analog video signal. The quantizer consists of four electronic comparators with staggered reference voltages. These divide the luminance range of the image into five levels. The output of each comparator is used to disable the comparator corresponding to the preceding amplitude level. In this manner the number of comparators turned on at any time is limited to one.

a. *Spatial enhancement*

Three types of displays can be generated for the quantized image. The first of these generates a map of isoluminance contours on the color monitor. This display is generated by a quantizer/monitor interface called the color matrix. This is a 4×3 matrix of two-terminal jacks. The four inputs to the matrix are the quantizer outputs. The three outputs drive the color guns of the monitor's tricolor picture tube through chroma amplifiers. By inserting pin-mounted resistances into the matrix board, the operator selects a color corresponding to each quantizer level. These colors may be any combination of the three primary colors. The operation performed by the quantizer and color matrix is called color enhancement. An example is the color-encoded cloud image in Fig. 3.

A particular area of the screen that is of special interest can be enhanced by the use of the "window"

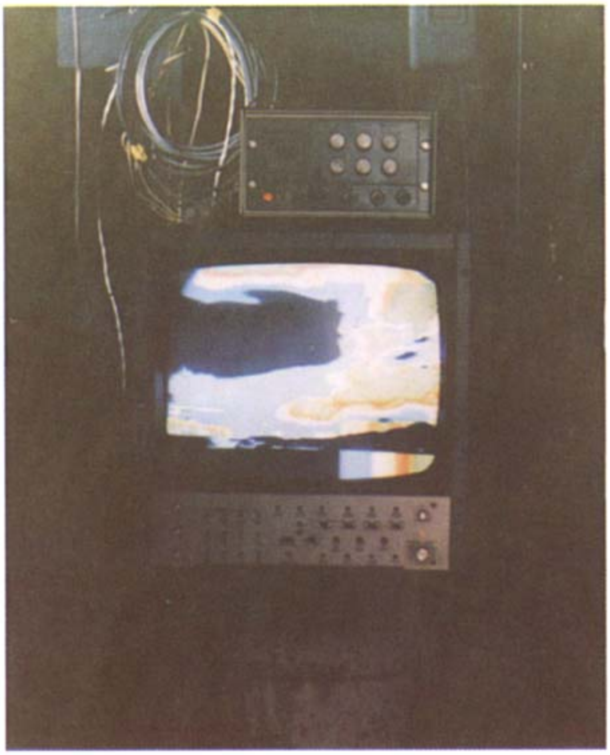

Fig. 3. Example of cloud enhancement.

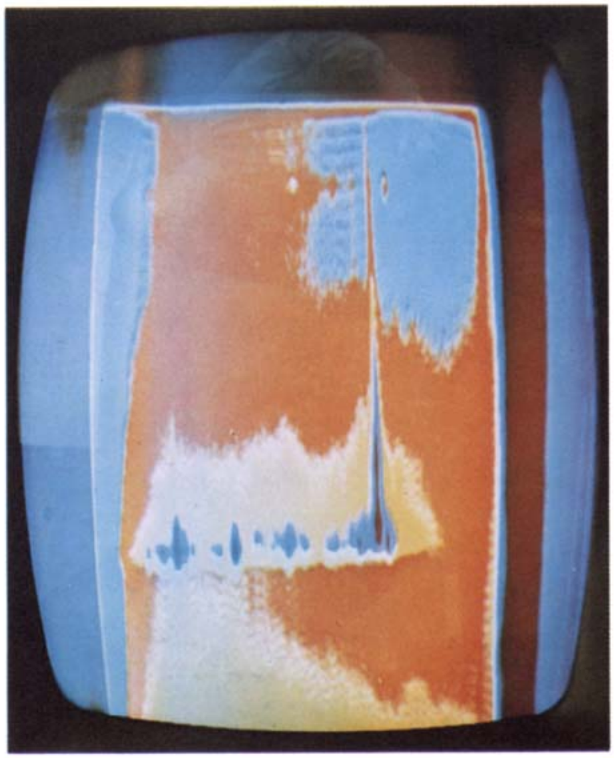

Fig. 5b. Enhanced version of Fig. 5a.

Fig. 6a. Original photo of a section of the Mississippi River delta.

Fig. 6b. Enhanced version of Fig. 6a, showing pollution monitoring capability.

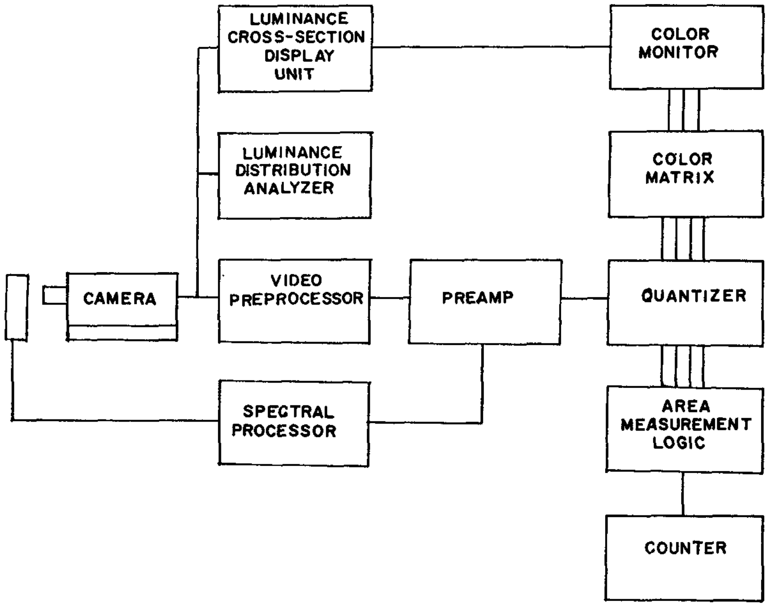

Fig. 2. System block diagram.

feature of the processor. A rectangle of any desired size and at any desired location is electronically generated and displayed. Only the area within the window is examined by the enhancement circuitry, so that local processing is possible.

A second display provided on the same color monitor is a plot of the luminance along a vertical line through the image. This vertical line is displayed on the screen with the enhanced image and is called a cursor. The cursor can be placed at any horizontal position on the screen by the user. The luminance along the cursor is then automatically plotted with respect to another fixed vertical axis on the screen, as illustrated in Fig. 4.

Finally, the area of an image for which the luminance falls between any two adjacent quantizer thresholds, i.e., the area covered by a given color, can be computed and displayed on an electronic counter. This computation can be repeated as the image changes, giving a continuously changing readout.

Additional enhancement of an image is achieved by preprocessing the camera signal prior to quantization. Among the possible types of preprocessing are inversion, nonlinear amplification, and differentiation. Differentiation is performed by electronically taking the derivative of the image line by line. This enhances the higher spatial frequencies corresponding to abrupt changes in luminance, such as edges, along the horizontal axis, while surpressing the features of lower spatial frequency.

Also available as a plug-in processing unit for use with the basic enhancement system is the Luminance Distribution Analyzer. This accessory generates a display in real time in the form of a histogram with shades of gray on the abscissa and on the ordinate, the percentage of the scene covered by that gray shade. The gray scale is quantized into ten discrete levels from black to white.

b. Spectral enhancement

Another type of preprocessing which can be performed by the system is spectral filtering. With the wideband Tivicon inserted in the camera, optical filters are placed in front of the camera lens to sensitize the imaging surface to a narrow segment of the visible or near-infrared band or to match certain spectral characteristics. By synchronously changing the filter with alternate camera fields, the luminance properties of an object in two different spectral ranges are displayed simultaneously. The highlights in each spectral range are encoded into different colors. In both cases, the settings of the color-encoded levels are displayed on the bottom of the enhanced display.

4. Applications

The system has been used primarily for two applications: investigation of crown flash and the enhancement of lightning phenomena. Regarding the first application, which has been described in the Introduction, the system was first extensively field tested in New Mexico during July and August, 1972, at the field facilities of the New Mexico Institute of Mining and Technology in Socorro by Dr. Bernard Vonnegut of the Department of Atmospheric Sciences, State University of New York at Albany, and the authors. During three weeks of eight hours a day continuous operation at the ground stations in the

Rio Grande Valley, no operational difficulties were encountered. During this time approximately 80 hr of time-lapse color, 16-mm motion pictures were recorded from the color display. A second set of tests was carried out at the same field facilities for three weeks in August 1973.

The nature of the work at Socorro is necessarily experimental. Large amounts of data are gathered and sifted in order to correlate the observations so that hypotheses can be proved. Currently, work is still proceeding to correlate our data with other data from the Socorro range.

During the tests at Socorro in 1972 and 1973, no instances of crown flash as dramatic as those reported by Gall *et al.* were observed. However, temporal changes in isoluminance contours did occur on the motion picture film record and at present work is still ongoing to determine the exact cause of these changes. The effect that we primarily sought, the slow temporal change of contouring indicative of charge buildup followed by rapid change during and after a lightning discharge, seems to exist on a smaller scale in the time-lapse movies. When the films are correlated with the test range data, it is hoped that the contour changes will correspond to those predicted by Vonnegut's theory. The actual enhancement work yielded valuable clues as to the proper operation and optimal control setting with regard to meteorological phenomena.

Qualitatively, several interesting new observations came out as a result of these trials. One of these is the increased visibility of the movements of the cloud structure which we called the "fine structure." This structure was revealed by the differentiation preprocessor. These movements were difficult, if not impossible, to see previously. The exact meaning of this fine structure is still under study. Of interest also are the further uses to which our system was put by personnel from the State University of New York at Albany.

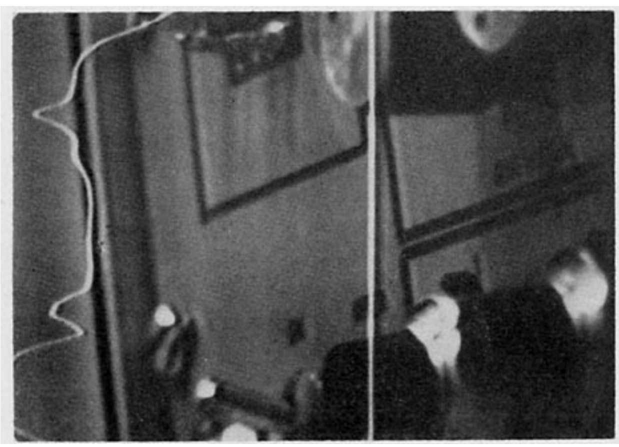

FIG. 4. Example of luminance cross-section analysis.

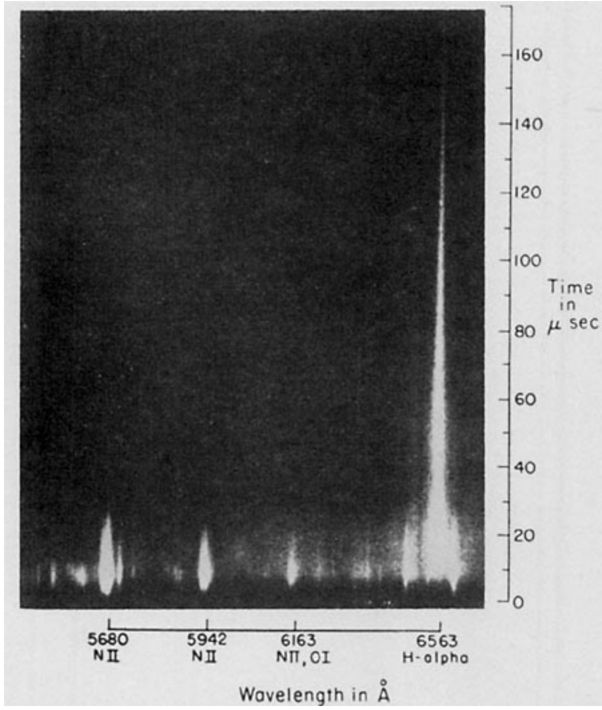

FIG. 5a. Original time-resolved spectrum of a 10 m section of a lightning discharge.

With respect to the second area, Prof. Richard E. Orville of the Department of Atmospheric Sciences has used the system to analyze the time-resolved spectrum of a 10 m section of a lighting discharge. The original black and white photo showed time on one axis with wavelength on the other. Brightness at any point was proportional to the strength of that wavelength component at that instant. The photo was first analyzed by standard densitometer during 1967, the results appearing in the September 1968 issue of the JOURNAL OF ATMOSPHERIC SCIENCES. The same photograph was analyzed by Prof. Orville using the R.P.I. facility and within an hour, structure and detail previously needing weeks of analysis rapidly became evident. The original photo, along with the enhanced version, are shown in Figs. 5a and 5b.

Another use revolved around the analysis of a much studied photograph purported to be of a ball lightning discharge. The photograph showed a building in the background with a weaving streak of light in the foreground that was supposed to be a time exposure of the ball lightning. Careful enhancement and analysis of the streak revealed a low-frequency sinusoidal pulsation in brightness that appeared to be near 60 Hz. Thus, it was concluded by the researchers that the photo showed a man-made electric light being moved past the field of view of the camera. This has resulted in a separate publication (Standler and Davis, 1972).

The system has also proved valuable in analyzing an infrared photgraph of the Mississippi River delta taken by high flying aircraft. The material was supplied to the researchers at R.P.I. by Dr. Hans Dolezak of the Office of Naval Research. The enhancement yielded contouring of the delta which was indicative of effluent discharge into the lower Mississippi. This contouring was due to changes in the reflectance properties in the infrared caused by turbulence at the point of discharge. Further contouring on the river surface itself indicated flow patterns of effluent due to changes in absorption and reflectance at the river's surface. Figs. 6a and 6b show the original and enhanced versions.

5. Conclusion

The image-enhancing system has been used successfully to analyze meteorological data, including lightning discharges and their spectra. Color film records have been made of the luminance properties of clouds which may contribute to an understanding of the crown flash phenomenon. Further work in the enhancement of meteorological data through various spatial and spectral windows will hopefully produce important data on the growth and structure of such processes as thunderstorms.

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