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Real-Time Color Display Techniques for High-Resolution Acoustic Sounder Echoes

P. G. Papageorgas [1], **C. G. Helmis** [1], **A. T. Soilemes** [1], **D. N. Asimakopoulos** [1], **Ch. Metaxaki-Kossionides** [2]

[1] Department of Applied Physics, University of Athens, Ippokrates Str. 23, GR-10680 Athens, Greece (Fax: +30-1/360-5080)
[2] Department of Informatics, University of Athens, TVPA Buildings, Panepistimiopolis, GR-15771 Athens, Greece

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Abstract. A description of two real-time color display techniques for high-frequency acoustic sounders is presented. The on-line false-color display techniques presented are those produced by a color ink-jet printer and a color video graphics array. These techniques are thoroughly described using data obtained from a recent experiment. It seems that the relatively low cost of the required instrumentation combined with the definite advantages of the method, makes these techniques feasible for all users.

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Acoustic sounding has already proved its usefulness in the identification of the thermal structure of the Atmospheric Boundary Layer (ABL), vertical mixing processes and features such as waves, temperature inversions, etc. [1,2]. The interpretation of these phenomena is essential for a better understanding of the inner structure of the ABL. Conventional Acoustic Sounders (AS), however, can not always give the necessary information as they are limited by their time and space resolution as well as their data recording capabilities.

Recently developed acoustic minisounder systems have improved the recording dynamic range by a factor of 10 dB [3], thus allowing for higher resolution, assuming that an ap propriate recording system is used.

The classical method for displaying the backscattered signal acoustic echo intensity as a function of height and time, incorporates analog facsimile recorders, which have a dynamic range of about 12 dB, while the received AS signal has a dynamic range of the order of 40 dB. Thus, a significant compression of the signal is required to avoid saturation, especially at low ranges. Another disadvantage of this method is that the modification of the facsimile recorder to maximize performance (e.g. by changing pulse repetition frequency, or range), is not always possible because of mechanical restrictions.

The use of a digital processing method and a display system is one solution to the above mentioned problems. In this respect, computer controlled dot-matrix printers or digital storage scopes have been used to display or plot the acoustic echoe intensity,using different techniques [4–7]. The primary limitation of these methods is poor resolution. In practice, a color display system could provide a better dynamic range than those mentioned above, by employing a large number of colors. In this respect, combining lightness, brightness and hue of colors, the human eye can create contours concerning areas with different levels of signal intensity. The use of "false-color techniques" to increase the information that the human eye can compile, is used for the enhancement of sattelite and weather radar images [8]. Thomson et al. [9] used a dedicated sattelite color display system, to off-line display AS measurements with low resolution. More recently, research laboratories and commercial companies used the color display technique to depict the thermal structure of the ABL. It is worth noting here that these techniques can be expensive and require a good knowledge of the lower atmospheric boundary-layer physics to avoid data distortion.

This paper presents a method for interpreting high-resolution AS echoes in real time using a simple color-display system or an ink-jet printer. The process for the signal-level estimation from digitized data using averaged values and the suppression technique of the environmental noise by statistical methods is also given. Finally, detailed examples for potential users of ink-jet printer and color display generated AS signals are presented and discussed.

1 System Description and Data Processing

The system used is a monostatic AS operating at 4.3 kHz. The acoustic antenna is a 5 × 5 element array of piezo-electric tweeters (Motorola KSN 1005A), with corner elements removed. The transmitted frequency and the control signals are produced by an IBM-AT PC which is also used for the digitization of the receiver output, the processing of the backscattered signal and the driving of the display devices. The received signal processed by the computer is the envelope amplitude of the backscattered echoes, which are caused by atmospheric scatterers and follow the Rayleigh distribution function. Thus, if Z is the output voltage of the AS, its probability density function is given by:

$$P(Z) = (Z/\sigma^2)\exp(-Z^2/2\sigma^2)\,, \tag{1}$$

where σ^2 is the variance of the random variable Z.

The background (electronic) noise is low compared with environmental noise, which follows the same distribution function. Its probability density function is fully defined, provided the mean-noise level is known. The environmental mean-noise level can be determined by sampling the received signal over a number of succesive pulses, at ranges where acoustic returns are not present. Thus, a noise-voltage threshold is defined, which should be exceeded by the signals in order to be printed and/or displayed. This noise voltage threshold is given by the relation:

$$V_n = N[-4\ln(P_e)/n]^{1/2}, \tag{2}$$

where P_e is the noise error probability,

$$1 - P_e = \int_0^{V_n} P(Z)\,dZ$$

and N is the mean value of the environmental noise. According to the available display device, the sample is then categorized into one of the available levels and then displayed and stored to the hard disk for further processing.

2 On-line False-Color Display

2.1 Color Ink-Jet Printer

An ink-jet printer can be used to obtain a color hardcopy of the AS echoes with different intensity regions. For the application described below, the AS signal intensities are categorized into eight 3 dB spaced succesive levels. Each level is represented by a discrete color, produced by the combination of yellow, magenta and cyan, which are provided by the printer. This arrangement gives the system a total dynamic range of 24 dB. The lower and the higher amplitude signals are represented by the darker and the brighter colors, respectively, while the noise level is represented by white. The size of the ink drops is so small, that a resolution of 300 dots per inch (dpi) is achieved. Considering the effective range of the AS used in the present application, the signal intensity was only displayed up to 250 m, incorporating 480 dots, (i.e. 0.5 m per dot). This performance is almost ideal for high-frequency AS systems that operate on short pulse lengths to achieve high-resolution records. The time resolution of the system was set to 26 cm per hour. A Tektronix 4696 printer was interfaced to the computer via the centronics parallel port. The printer was programmed through special escape sequences that control the color of the printed dot, and operated in real-time.

A typical example of a high-resolution AS ink-jet printer record is shown in Fig. 1. This was recorded during the 1st of November 1990 Athens experiment between 0400 to 0430 LST. As can be seen from Fig. 1, a strong ground-based inversion is present at 0400 LST which extends up to about 80 m with a weaker elevated layer aloft. In less than 10 min the structure changes to an elevated wave-like activity just above the ground-based inversion which remained until the end of the record. This figure shows clearly the potential capability of the color display to visualize such a fine scale atmospheric structure that is not available by other conventional displays. Similar records, although not of the same quality, were obtained using a color dot-matrix printer (Mannesmann Tally MT-222, 24-pin), with the same color code dynamic range and signal processing.

2.2 Color VGA Monitor

Today, most personal computers, are equipped with low-cost Video Graphics Array (VGA) color monitors. The resolution of such a display system is 640 (horizontally) by 480 (vertically) pixels, while colors are produced by programming the intensity of three beams (red, green and blue) in 64 steps. Although it is possible to display 256 K colors, only 4 bits correspond to a pixel, leaving 16 colors to be displayed on-screen simultaneously.

The colors used here were chosen in a way that their brightness was analogous to the signal strength, thus, the

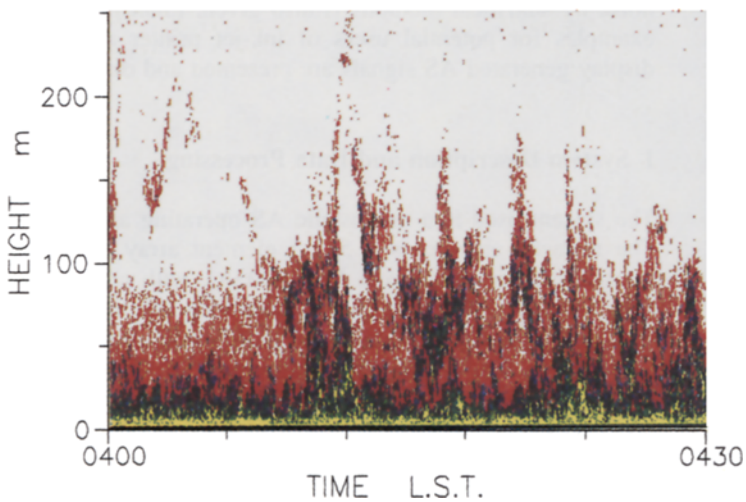

Fig. 1. High-frequency AS echo record displayed by an ink-jet printer. This was observed in Athens during the 1st of November 1990 experiment between 0400 to 0430 LST

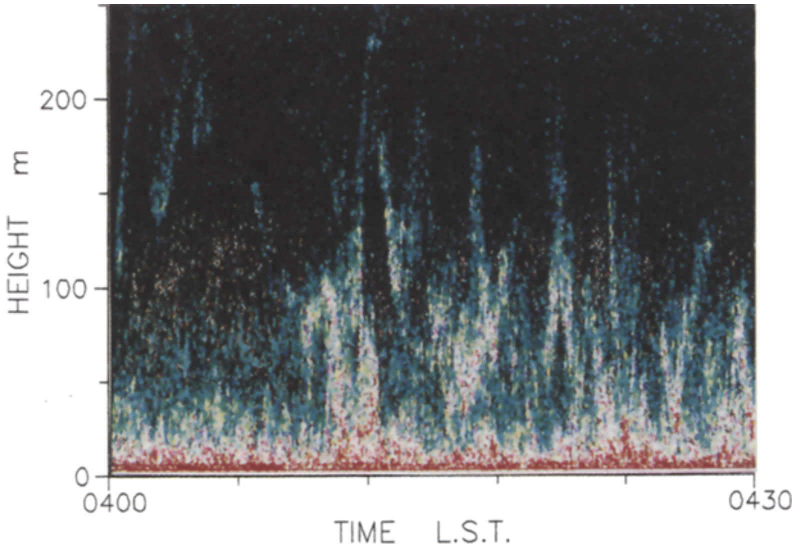

Fig. 2. As in Fig. 1 but displayed by color VGA monitor

higher intensity areas can be distinguished by their white or red color. The 16 colors used correspond to a dynamic range of 48 dB.

The echoes were again displayed up to 250 m using 480 pixels, i.e. a spatial resolution of 0.5 m per pixel, with a time resolution of 640 pulses per screen. The display used was an Acer 7015 VGA monitor with a maximum resolution of 800 (horizontally) by 600 (vertically) and an active display area of 245 mm by 180 mm.

Figure 2 is a photograph of the color VGA monitor display of the same data as in Fig. 1. Both time and space resolution of the VGA record are better than the ink-jet ones, allowing for a more detailed examination of the echoes. The VGA method, however, is less usable, since lengthy records can only be shown on the screen when low spatial resolution is used.

3 Concluding Remarks

The digital color display systems have made the use of facsimile recorders obsolete because they are characterized by:

- Higher time and space resolution,
- Variable effective range,
- Easy management and reproduction of recorded data,
- Easy modification of the operating parameters of the AS,
- Better dynamic range.

These advantages are very important, especially for the recently developed high-resolution AS. The relatively low cost of the computerized digital instrumentation makes the use of these techniques feasible for all users.

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