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The Naval Research Laboratory's Map Data Formatting Facility is developing a seamless, compressed, digital database of the world called the Compressed Aeronautical Chart (CAC). The CAC consists of scanned, aeronautical chart images. The CAC's primary purpose is to support Navy and Marine Corps aircraft mission planning and digital moving map systems. However, other users on various platforms have expressed interest in using the CAC. Therefore, the CAC must be capable of adapting to the graphics capabilities of other platforms.

The CAC uses a set of custom color palettes that consists of 240 distinct colors. Each pixel from the precompressed data at full color (24-bit) indexes to its closest color palette entry as decided by Euclidean distance. Custom color palettes tend to maintain color integrity between the CAC and the original data.

Since graphics capabilities vary from platform to platform, the ability to reduce and remap a color palette is a useful tool. This paper describes the technique chosen to remap the CAC color palettes to the desired, reduced set of colors. An enhancement technique that uses a contrast stretch algorithm is also described. The enhancement is achieved by first calculating a given palette's luminance (Y) values. Then a ratio of the contrast stretch luminance to the original luminance is derived for each color in a given color palette.

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Color Palette Reduction and Enhancement Techniques

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Abstract

The Naval Research Laboratory's Map Data Formatting Facility is developing a seamless, compressed, digital database of the world called the Compressed Aeronautical Chart (CAC). The CAC consists of scanned, aeronautical chart images. The CAC's primary purpose is to support Navy and Marine Corps aircraft mission planning and digital moving map systems. However, other users on various platforms have expressed interest in using the CAC. Therefore, the CAC must be capable of adapting to the graphics capabilities of other platforms.[1]

The CAC uses a set of custom color palettes that consists of 240 distinct colors. Each pixel from the precompressed data at full color (24-bit) indexes to its closest color palette entry as decided by its Euclidean distance. Custom color palettes tend to maintain color integrity between the CAC and the original data.

Since graphics capabilities vary from platform to platform, the ability to reduce and remap a color palette is a useful tool. This paper describes the technique chosen to remap the CAC color palettes to the desired, reduced set of colors. An enhancement technique that uses a contrast stretch algorithm is also described. The enhancement is achieved by first calculating a given palette's luminance (Y) values. Then, a ratio of the contrast stretch luminance to the original luminance value is derived for each color in a given color palette.

Introduction

The CAC database is a library of compressed Defense Mapping Agency (DMA) Arc Digitized Raster Graphics (ADRG) images. CAC is available on CDROM as a standard DMA product. ADRG is compressed to the CAC in order to meet specifications of the digital moving map systems on-board the F/A-18 and AV8B aircraft. However, the CAC has also been used by the National Security Agency, Federal Emergency Management Agency and other mission planning and geographic information systems.

In order to increase its usage, the graphics requirement of the CAC needs to be flexible. This issue was first addressed with the Army's requirement for a 4-bit (16 color) compressed map database. Work began to develop a method of displaying the CAC in 4-bit color without having to recompress the source data. A simple method of remapping the CAC palette colors to an algebraically-defined palette in RGB space was chosen. This method allows the user to define a number of shades of red, green, and blue to find the total number of algebraic palette colors to be built. The overhead in this method of color reduction is a remapping array. The remapping array reindexes the original color palette entry in the CAC data to the new index in the algebraically-defined palette. Unfortunately, color degradation becomes very apparent when the reduced palette reaches about half its original size. Specifically, when the reduced palette becomes small (i.e., under 128 colors), significant color shifts appear. However, algebraic remapping is a viable method of creating a reduced color set for displaying CAC data on 8-bit color systems that reserve more than 16 colors. Algebraic remapping preserves much of the color information in the CAC data when the reduced palette is at least half the size of the original CAC palette. The CAC color palette consists of 240 colors, leaving only 16 colors available to the graphic display.

An enhancement technique was developed to help compensate for color shifts that tend to blend similar colors. A contrast stretch algorithm (CSA) was used. The CSA maps all palette colors that are within 10% of pure black (RGB=0,0,0) to pure black and 10% of pure white (RGB=255,255,255) to pure white. National Television Standards Committee (NTSC) luminance values are calculated for a palette's colors. The CSA is then applied to the luminance values. A ratio of the CSA luminance values to the original luminance values is calculated. The square root of this ratio is used to scale the palette colors, resulting in a brighter (i.e., higher contrast) image. The function of the square root is to create greater contrast at low ratios as compared to lower contrast at higher ratios which tends to better separate low intensity colors.

Color Palette Reduction

The initial thrust of color palette reduction was to produce an acceptable product for the Army by reducing the CAC palettes from 240 to 16 colors. An outgrowth from this effort was to algebraically remap a reduced set of colors to adapt to 8-bit color systems requiring a large number of reserved slots in a user-loadable palette.

The authors have developed a method of creating an algebraic palette, based upon shades of red, green, and blue (RGB). The algebraic palette consists of the centroid values of sub-rectangles formed in RGB space. For example, a palette based on four red shades, four green shades, and eight blue shades produces 128 colors (4×4×8 color vectors). Eight bits of color in CAC provide 256 shades. In this example, sub-rectangles in RGB space are formed by dividing the red and green vectors by four (256/4 = 64) and the blue vector by eight (256/8 = 32). This vectoring process produces sub-rectangles of (64×64×32 shades) where the centroid value for each sub-rectangle becomes an entry in the algebraic color palette.

For example, a Sun Sparc Server 300 with 8-bit color graphics, reserves, by default, 24 slots in a palette. Therefore, the user-loadable palette cannot exceed 232 entries. Since the CAC palettes may have as many as 240 entries,

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the CAC must be remapped to a smaller color palette to be displayed on this system. With the algebraic remap, the number of palette colors is user-selectable. For example, the user might choose to divide the RGB cube into six levels each of red, green, and blue. In other words, divide each color vector (red, green, and blue) into six equal increments, each of which consists of 42 shades (256/6 = 42). The centroid of each cube (42×42×42 shades) is defined as the algebraic color palette entry, resulting in an algebraically-defined palette of 216 colors (6×6×6 color vectors). A remap array is then created to map each of the CAC's original 240 palette colors to the reduced 216 color palette via Euclidean distance calculations. Thus, when the CAC data is displayed, a pixel's color value of 237 may, for example, be mapped to 215 in the remap array (see Figure 1). The RGB value in the algebraic palette at entry 216 is, in turn, displayed for that pixel on the screen.

#	R	G	B
1	0	0	0
2	8	22	12
3	30	15	45
4	48	29	20
.	.	.	.
.	.	.	.
.	.	,	.
237	235	218	188
238	216	223	226
239	226	205	245
240	255	255	255

Original 240 entry
CAC Color Palette

#	R	G	B
1	21	21	21
2	63	21	21
3	21	63	21
4	21	21	63
.	.	.	.
.	.	.	.
.	.	.	.
213	189	231	231
214	231	189	231
215	231	231	189
216	231	231	231

Algebraic 216 entry
Color Palette

#	remap
1	1
2	1
3	4
4	2
.	.
.	.
.	.
237	215
238	216
239	214
240	216

Remap Array

Figure 1. Palette Remapping based on RGB Euclidean Distances

Color Palette Enhancement

While the CAC custom color palettes are designed to maintain the original source data color, some loss does occur. This loss results during color compression from 24-bit to 8-bit color.[2] Enhancement of the color palette is a quick and simple means of altering the appearance of the displayed image without modifying the CAC data itself. Enhancing the CAC palette brightens the image, and restors some of the color loss. One negative side effect of enhancing an image in this way is the possiblity of enhancing the noise. The least possible amount of noise would best serve the needs of a pilot using the CAC with an on-board moving map display system. Threrefore, this enhancement technique may not be appropriate for use in the cockpit. However, the enhancement is useful for creating brighter images for mission planning and hardcopy output.

The enhancement technique described here uses the CSA. First, the NTSC luminance value (Y) of each palette color is calculated, based on equation (1).[3]

$$Y = 0.30R + 0.59G + 0.11B \qquad (1)$$

The resultant luminance values are sorted by increasing intensity. Thresholds are set to 10% to map the corresponding luminance values to either pure black or pure white. The step size is found by dividing 256 (i.e., the number of shades in 8-bit color) by the luminance values that are not within the thresholds.

A "stretched" luminance array is then calculated based upon the step size. Ratios are calculated between the original luminance over the "stretched" luminance values. Each palette color (RGB) is then scaled based upon the square root of its original/stretched luminance ratio. The square root of the ratio is used to increase separation between palette colors with small ratios and decrease separation at high ratios (see Figure 2).

```
    Comment: Calculate luminance values and determine high and
low thresholds.
Do  i = 1, 240
    Original_Luminance (i) = 0.3R(i) + 0.59G(i) + 0.11B(i)
    If (Original_Luminance (i) < (.10 x 255)) then
      Number_of_Threshold_Low=Number_of_Threshold_Low+1
       Original_Luminance (i) = 0
    Endif
    If (Original_Luminance (i) > (255 -(.10 x 255))) then
      Number_of_Threshold_Hi = Number_of_Threshold_Hi + 1
       Original_Luminance (i) = 0
    Endif
Enddo
Sort Original_Luminance (240)        ! Sort in ascending order
NewMax = 240 - Number_Of_Threshold_Hi
NewMin = Number_of_Threshold_Low
StepSize = 256.0 / (NewMax - NewMin)
StepValue = 0.0

Comment: Calculate CSA luminance values.
Do i = NewMin, NewMax
  Stretched_Luminance (i) = StepValue
  StepValue = StepValue + StepSize
Enddo
```

```
Comment: Calculate ratio between original and CSA luminance
values, apply square root of ratio to palette colors.
Do i = 1, 240
   Ratio(i) = Float(Stretched_Luminance(i)/Original_Luminance(i))
   Scaling_Factor(i) = SQRT (Ratio (i))
   Stretched_R (i) = Scaling_Factor(i) x R(i)
   Stretched_G (i) = Scaling_Factor(i) x G(i)
   Stretched_B (i) = Scaling_Factor(i) x B(i)
Enddo
```

Figure 2. Pseudo-code for CSA Color Palette Enhancement

Conclusions

Algebraic remapping is a simple method of reducing the color set of the CAC from a pre-defined color palette to an algebraically-defined color palette. While the algebraic remap has its limitations, it does serve as a useful display tool for systems that cannot display 240 colors, significantly increasing the potential user base of the CAC by providing greater color flexibility. The remapping technique tends to introduce noise to the CAC since similar colors in the original color palette may be remapped to dissimilar algebraic color palette values. As the size of the algebraically-defined color palette becomes smaller, the potential for noise is reduced because larger sub-rectangles in RGB space are used for remapping. However, the potential for significant color shifts becomes greater due to the larger sub-rectangles. The enhancement technique generates greater contrast in the CAC. This technique may be applied to either the original or algebraically-defined color palette. The appearance of noise due to the enhancement technique is not as significant as expected since the square root of the calculated ratio is applied to the palette colors. The "stretch" of a higher luminance color, then, is reduced as compared to the "stretch" of a lower luminance color. The enhancement technique is especially useful for better perception of details, such as roads and lettering.

The most significant attribute of these techniques is that both are applied only to the original CAC color palette. There is no manipulation of the original data itself, except to remap the CAC color indices. Therefore, these techniques are fast to implement and can be applied during display of the CAC data.

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Interpolation of Color Data

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Introduction

Recently there has been an increased activity focused on solving the problems associated with the transmission and display of high quality color image/video signals. The objective is to generate an image or video signal whose quality is as high as possible at the output of a given system. Of specific concern in this research are the characterization and calibration of color output devices, for example printers or electronic displays. In order to make accurate judgments about the images produced, such devices must be calibrated. To do this, a relationship needs to be defined between a set of measured CIE $L^*a^*b^*$ values and a set of control values for the output device. Impacting the solution of this problem are: the model of the output device and its limitations, the type and location of the measurement data, the variability in the data, the interpolation and extrapolation methods used, the variability in the output device under normal operating conditions, and the perceptibility of the errors.

One way to characterize a color output device is with a three-dimensional look-up table. The look-up table maps the set of CIE $L^*a^*b^*$ values $\{t_i\}$ to a set of control values $\{c_i\}$ of the output device. The control values $\{c_i\}$ are proportional to the concentration of the inks. The look-up table could be built directly, unfortunately this would require an excessive number of measurements. For a 32x32x32 table 32768 measurements would be required. An alternate approach for creating the look-up table is to make measurements on a coarser grid and then interpolate the values for a finer grid in the CIE $L^*a^*b^*$ space. The problem can be posed in the following manner. Let $\{(c_1, c_2, c_3)_i\}$ be the three-dimensional set of control values which map onto the set of CIE $L^*a^*b^*$ values $\{(t_1, t_2, t_3)_i\}$ such that