Restoration and Enhancement of Earth Images from a Low Cost Sampled Video System

by

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1. INTRODUCTION

The WEBERSAT microsat has been in a 800 Km polar orbit of Earth since January of 1990^[1]. During this time an on board, low cost, color CCD camera has-logged several dozen video images of Earth and heavens. Each new image has presented a unique challenge in restoration and image enhancement.

Imaging from space is not a new story, with several space qualified systems proven to be highly reliable. The distinctiveness of the WEBERSAT imaging system is that it is not an expensive space qualified subsystem; rather, it is composed completely of slightly modified off-the-shelf commercial components as one would find from a consumer video store. Today's cost for such equipment is well under one thousand dollars.

2. WEBERSAT

The Center for AeroSpace Technology (CAST) at Weber State University in Ogden, Utah in partnership with The Amateur Satellite Community of North America (AMSAT/NA) designed, constructed and continue to operate WEBERSAT on a daily basis.

2.1. The Center for AeroSpace Technology (CAST)

Weber State University is a 4 year teaching Institution with outstanding Bachelor Degree programs in Engineering Technology. The main purpose of Weber's involvement in space related projects is to give students the opportunity to gain work experience in real world situations on quality projects. Each instrumentation module of

WEBERSAT, including the imaging sub-system, was conceived, designed, constructed, integrated and tested by student senior project groups supervised by an experienced professional from the teaching faculty or industry. The Center for AeroSpace Technology (CAST) at Weber State University is the administering agency for these projects. CAST is a designated Utah State Center of Excellence and as so receives partial funding from state and university sources; however, the vast majority of projects are funded strictly by donation and volunteer effort.

2.2. AMSAT

As a specialized group of amateur radio operators, the Amateur Satellite Community (AMSAT) has been active in designing, building and operating satellites from the early 60's. The North American branch of this group (AMSAT/NA) designed and constructed the communications, computer, and power management systems for 4 micro-sats. AMSAT/NA also designed the basic space frames which were constructed at Weber State University. AMSAT international is currently designing and con-

structing 'Phase 3d', a 1500 lb communications satellite with complete attitude control and station keeping. Several key components of this 'maxi' satellite will be furnish by CAST. The partnership between Weber State University and AMSAT has shown to be notably beneficial to both organizations.

2.3. Instrumentation

WEBERSAT measures 9" by 9" by 12" (see FIGURE 1). As described in other papers, it is designed to spin about its longer axis by using a combination of solar torques and geomagnetic forces^[2]. The top 3 inches comprise the 'penthouse' where five CAST experiments are housed. These include: flux gate magnetometer, inferred and optical spectrometer, horizon sensor, particle impact detector, and the CCD color imaging system^[3].

The color camera started life as a Cannon CI-10 commercial unit but under went the following modifications: the original case was discarded, the electrolytic capacitors were replaced with solid tantalum, after calibration the variable components were measured and replaced by fixed

FIGURE 1 - WEBERSAT SATELLITE

value components, the circuits were conformally coated, the mechanical iris was cleaned and relubricated with a high vacuum lubricant. Electrical signals were taken from the 3.58 MHz color oscillator and tripled to create a phase locked 10.7 MHz sampling clock for digitization of the video signal.

2.4. Communications and Control

On command from the ground station and receipt of parameters acquired from on board sensors, the video camera system digitizes one field of video at 8 bit resolution and stores the resulting 645 by 240 pixel values (0-255) into computer RAM (151

K bytes per image). Several images can be accumulated in this fashion until they are downloaded to the ground station using amateur radio 'packet' communication.

3. SAMPLED NTSC COMPOSITE VIDEO

The video signal from the camera is composite NTSC video (the national television standard for the U.S.A.). This is the same as output by any camcorder or VCR^[4].

3.1. Video Wave Form

FIGURE 2 shows a typical horizontal scan line of composite video. This signal is band limited to be below 4.5 MHz and can therefore be sampled at frequencies above 9 MHz^[5]. Using a sampling rate of 10.7 MHz each line is 645 samples in length. The first 10 samples are the end of the horizontal sync pulse or back porch as it is referred to in the literature. Next comes 10 to 13 cycles of 3.58 MHz which constitutes the color burst used to decode the color part of the image. Between samples 50 - 60 there is a horizontal plateau in

the signal which represents the dark level or the amplitude of the darkest or black parts of the image. The white level would be approximately 240 in an 8 bit system.

Samples 60 through 610 contain the black and white (luminance) and the color (chroma) information superimposed in amplitude. These signals can be separated by frequency filtering techniques. The luminance is lower in frequency than the chrominance.

3.2. Advantages

The advantage of using NTSC composite video is that even though there are as many as 12 different signals required to convey a color image, all of the signals are multiplexed together and are contained in one serial data signal which can be digitized with one A to D converter and stored as a sequence of binary values. The down link telemetry is also a serial stream of data.

3.3. Disadvantages

The disadvantage of combining

FIGURE 2 - NTSC VIDEO WAVEFORM

these image component in this manner is the frequency response of the image components are greatly reduced resulting in poor spatial resolution (loss of fine detail) in the reconstructed image. This can be verified by comparing even the best quality video image (NTSC standard) with a photographic image. Even photos of marginal quality have orders of magnitude better spatial resolution than an NTSC video image.

4. BLACK AND WHITE RESTORATION

To restore an image that has been coded as an NTSC waveform, a software package must accomplish the same functions as a black and white television monitor. Raw video images can be displayed on a computer screen but yield very poor pictures. IMAGE 1 show a raw video image of the Somali coast line taken from WEBERSAT. (Note: In all images South is to the left) For reference a terrestrial image is included (see IMAGE 2). This is a raw video image of a clock tower taken by the WEBERSAT imaging subsystem during final testing and integration. Note the poor contrast and definition.

The block diagram of a black and white monitor was followed as the software flow chart and architecture (see FIGURE 3). Software routines for each block were written in FORTRAN and later translated into Think 'C' to run on a Macintosh II ci computer.

4.1. Level Shifting

Referring back to the waveform in FIGURE 2, the first task is to identify the black and white levels of the waveform. The average level between samples 50 and 60 is used as a temporary black level. A temporary value of 240 is used as the white level. Temporary because these may be replaced by an enhanced value during contrast stretching.

4.2. Contrast Stretching

A common technique in the field of image processing to improve image quality is to use histogram mapping with stretches the contrast so that the darkest and lightest parts of the image are mapped into near black and near white respectively^[6]. The intermediate values are mapped as to give the greatest variation

IMAGE 1 - RAW IMAGE OF SOMALI COAST WITHOUT PROCESSING

IMAGE 2 - RAW IMAGE OF CLOCK WITHOUT PROCESSING

FIGURE 3 - Black and White Block Diagram

between adjacent pixel intensities while still preserving the relative ordering of intensity values (see FIGURE 4). The eye identifies detail more as a local change of intensity over small spatial areas rather than over the entire image. In this algorithm the dark level is determined to be the higher of either the black level as per section 4.1 or the value where 5% of the luminance data is below the black level. The white level is determined in similar manner being the lower of 240 or the level where 5% of the luminance values are above the white level. The re-

sulting black level is subtracted from each video luminance value. The result is an image with greater contrast and definition.

4.3. Synchronization

The raw image data is down loaded in packets and combined to form a 645 by 240, 8 bit integer array. This array represents one of the two required fields of a standard video image. The second field can be down loaded at a sacrifice of longer down load times; but at present, the

FIGURE 4 - HISTOGRAPHIC MAPPING

first field is duplicated to form an approximation of the second field with some loss in vertical resolution. With the image in array form there is no need to detect vertical or horizontal sync pulses.

One related problem that does need to be addressed is a sampling artifact that creates a half-pixel shift in time between adjacent horizontal scan lines. For compatibility with black and white television, NTSC standards requires the color phase of each scan line to alternate in phase. This not a problem for standard video monitors because they synchronize the start of each horizontal scan with the horizontal sync pulse. In

WEBERSAT the color sync was tripled and used for the sampling clock. This translates into sampling in phase with the color reference oscillator at 120° intervals. The result of sampling a signal that alternates 180° with a 120° sampling rate is a phase shift of 60° in every other line (see FIGURE 5). This half sample delay between the true start of a line and the sampling clock results in a serration of vertical lines (see IMAGE 3). This was remedied by filtering every other line with a phase group delay filter of 60° implemented in the frequency domain.

FIGURE 5
Two Adjacent Lines of Color Burst Showing Half Pixel Shift
(Should be 180° out of phase)

IMAGE 3 - SERRATED VERTICAL LINES DUE TO HALF PIXEL SHIFT

4.4. Graphic Enhancement

Although the camera optics were adjusted on the ground to focus at near infinity, there appears to be a small amount of circular

blurring in the images. Assuming star images to be close to point sources, an inverse convolution sliding mask function was derived and successfully employed to sharpen the images^[6].

4.5. Low Pass Filter

Removal of the color sub carrier requires low pass filtering with a cut off frequency near 3.0 MHz. A simple three point sliding average filter was used in this algorithm with reasonable success^[5].

4.6. Results

Fifty or so good images of the Earth have been acquired from WEBERSAT over the last 2 years. Using the techniques described above, image quality bordering the limits of commercial television have been achieved. The spatial resolution is approximately three pixels which translates into one mile on the ground (see IMAGE 4, IMAGE 5 and others at the end of this article). The resolution is limited by the band width properties of the NTSC video format.

5. COLOR RESTORATION

Color restoration is patterned after the block diagram of a color video monitor as per FIGURE 6. The basic philosophy

is to first create a luminance image (black and white part of the image) then to add color. For this reason several blocks are similar to corresponding blocks in the black and white algorithm.

Unfortunately it is difficult to incorporate color images into a journal article. These images are available both in DOS and Macintosh formats on several bulletin boards. CAST can also provide copies of these image in software or hardcopy format at reasonable cost.

5.1. Chroma Signal

The chrominance or color part of the NTSC waveform is superimposed on the luminance signal^[4]. To insure separability from the luminance, the chroma is first combined with a color subcarrier frequency of 3.58 MHz. using balanced modulation. The resulting double side band signal has spectral components ranging from 3.58 ± 0.5 MHz and can be separated from the luminance by spectral filtering. This algorithm uses an FFT and a Blackman high pass window to recover the chroma signal which is demodulated to restore the

IMAGE 4 - Processed Clock Image

IMAGE 5 - Processed Somali Image

FIGURE 6 - Color Block Diagram

FIGURE 7 - COLOR PHASES

color signals

5.2. Chroma Sync

Demodulation of the chroma signal requires a balanced demodulator which multiplies the chroma signal with three 3.58 MHz signals which have the phase relationships shown in FIGURE 7. A sample of the original signal is transmitted as a burst of 10 to 15 cycles at

the beginning of each horizontal line. Since the sampling rate is exactly three times the 3.58 MHz signal, only the phase needs to be determined. This is accomplished by comparing adjacent samples during the color burst.

The phase is computed by:

$$\text{phiy} = \cos(2\pi/3)$$

$$\text{phix} = \sin(2\pi/3)$$

$$y = \text{phiy} * (\text{value2} - \text{value1})$$

$$x = \text{phix} * (\text{value2} + \text{value1})$$

$$\text{phase} = \text{atan2}(y, x)$$

5.3. Color Matrix

The color image is a combination of luminance, red, blue and green mixed in the right proportions^[4] for the white to look white.

$$\begin{aligned} \text{WHITE} = \\ 1.14 \text{ RED} + 0.7 \text{ GREEN} \\ + 2.04 \text{ BLUE} \end{aligned}$$

The color matrix mixes these components as per the NTSC standard but can adjust for variations in the color

temperature of the camera.

Over the last two years the color temperature of the WEBERSAT camera has drifted towards the red end of the spectrum. This is possibly due to degradation of the optics from atomic oxygen and/or radiation. The average temperature of the spacecraft has been about zero degrees C, about 10° colder than the working specifications of the camera. This in itself could explain the red shift. The technique presently used is to adjust the color temperature subjectively to give proper whites where appropriate (cloud formations and such).

5.4. Color Palette

Color computer monitors can generally display 2 to the 48th different colors, but only 256 of these at one time on the screen. If an evenly distributed palette of 256 colors is used to display an image, color quantization is observed due to the large steps between allowable colors. Many colors, such as bright reds, are never found in earth images. A better way of selecting palette colors is to choose the 256 best colors for a particular image. In this algorithm an iterative

search is incorporated that selects 256 colors uniformly spaced over the image colors. Using this optimal palette reduces the color quantization to below human perception in most cases studied.

5.5. Results

Color in earth images yield additional information which helps identification. It has been noted that in many images the land and the sea have almost the same brightness values; therefore, it is difficult to distinguish coast lines. This is due in part to the sun synchronous noon/midnight orbit of WEBERSAT. When the camera is pointed toward the earth ($\pm 20^\circ$ from the magnetic equator) there are few shadows to add contrast. The sun is directly over head. The addition of color definitely improves the quality of the image and helps distinguishes land from water etc.

6. WHERE TO GO FROM HERE

Presently each image has to be enhanced using techniques as de-

termined by the individual image content. We are working on more automated ways of processing images that will yield good result on all images.

It has been noted on several horizon shots there has been stars in the image field (see following images). On analysis the amplitude of the stars image is at least as high as the sunlit earth. This has lead us to believe that star pattern imaging with a commercial grade CCD camera is possible. The outcome might be an ultra low cost star tracker. Currently we are taking images of star fields to explore this possibility.

7. CONCLUSION

Imaging the earth from space with a low cost video camera has been interesting and educational. The results based on resolution and color quality are on par with commercial NTSC television. These good result were only obtained after years of effort by several individuals. The results validate the use of small inexpensive CCD cameras in a space environment. Since the ultimate resolution has been shown to be limited by

IMAGE 6 - AMAZON RIVER

IMAGE 7 - NILE RIVER

IMAGE 8 - PHILIPPINES

IMAGE 9 - HORIZON WITH STARS

IMAGE 10 - SOMALI

the NTSC composite video format, resolution can be improved in future missions if the image components are stored and downloaded as separate data files rather than multiplexing them into one band limited NTSC waveform.

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