SSTV Image Processing

Image enhancement — a term we've grown accustomed to with today's computer processing of photographs from deep space. How about using some of those techniques to improve received SSTV pictures?

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In visual communications, transmission and display fidelity play a key role. Commercial television, for example, functions adequately only because defects due to quantization and/or transmission are hardly visible. Slow-scan television (SSTV) on the other hand functions in spite of problems of atmospheric noise, interference, multipath distortion and in many cases inadequate signal strength. The fact that SSTV is successful and growing in this less-than-ideal environment is a tribute to the many dedicated individuals using this mode of operation. Image quality, however, is becoming more important, particularly to those who have used this mode for more than a short time.

Interestingly enough, the field of image processing has the potential for improving the quality of SSTV pictures. With the advent of the digital scan converter for SSTV,[1] many of the techniques of image processing may be directly applied to the design of display systems, signal processors, and encoders for slow scan. Computer picture-processing techniques are relatively new, having been employed routinely in the space program only since 1964 when Ranger 7's moon pictures were processed by a computer to correct for image distortion in the on-board television camera. Such techniques are by no means limited to space applications, however, and have been successfully applied to the bio-medical, astronomical and radiographic fields.

What exactly is image processing? Simply stated it is the process of *encoding, restoring,* and/or *enhancing* images. (For the reader wishing a more detailed treatment of this subject than is presented here, reference is made to two special issues of the *Institute of Electrical and Electronics Engineers Journals*[2,3] which cover the subject in depth.)

Encoding is used primarily when converting a conventionally scanned image into another form for purposes of efficient transmission. Normally pictures are sent over a channel occupying a bandwidth greatly in excess of that actually required. This occurs because most pictures contain great amounts of redundancy — much of which is irrelevant to the viewer. (Prime examples of this are SSTV keyboard-generated pictures which require eight seconds of transmission time to supply only a few

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[1] References appear on page 16.

A slow-scan picture must be broken up into several brightness levels for digital processing. The more brightness levels there are, the more digital circuitry is required for the processing. With fewer brightness levels, objectional "contouring" takes place because of more abrupt changes in the gray-scale presentation. Noise dithering is one means of smoothing out the effects of contouring, as shown here. At the left is a 128 by 128 picture-element slow-scan picture with 16 brightness levels. At the right is the same picture except for the addition of pseudo-random noise.

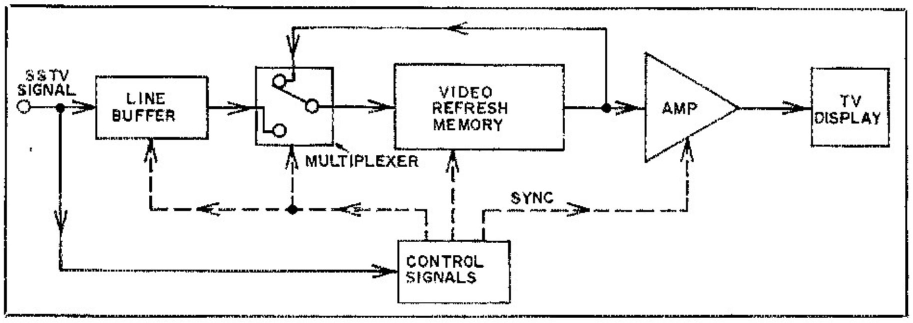

Fig. 1 — Generalized block diagram of a slow-scan to fast-scan converter. Control signals derived from the incoming slow-scan video are used for switching the multiplexer and entering the video into the main video refresh memory. A conventional television set is used for display purposes.

alpha-numeric characters of information.) However, because of the complex equipment needed there has been little encoding for purposes of efficient transmission, until recently. Integrated circuits have remedied the problem. Another application of encoding would be in reducing memory requirements in digital computer processors or in the refresh memory of a digital scan converter. Many different codes are used for images, and their efficiency (data-compression capability) varies from 6 bits per picture element to 0.5 bit per picture element. Typical of these are pulse-code modulation (PCM), run-length coding, differential PCM, delta modulation, and transform coding. Each has advantages and disadvantages under a given set of conditions.

Restoration of images is usually accomplished by reversing the effect of some degradation phenomenon known to have caused the distortion in the original process of forming the image. Examples of such distortion would be atmospheric effects, lens aberrations, and motion blur. The process of restoration is very complicated requiring detailed knowledge of the distortion and an accurate mathematical model. Most of these techniques are still in the very advanced development stage requiring large computers and memories.

Enhancement can generally be described as the manipulating of images to improve the apparent quality of the picture as seen by the viewer. These techniques include signal compression, pre-emphasis, noise averaging, and digital filtering. Commercial and scientific television systems use quite a few of these methods. In this connection, psychophysical aspects of vision perception must be carefully considered before a useful image display is designed since, after all, the ultimate receiver of the processed picture is the human.

It is the purpose of this article to discuss several of the above techniques as they have been applied to a prototype image processor developed especially for SSTV. The discussion will include a review of scan-converter operation, specialized image-processing techniques, and suggestions for future contributions in this area. Some circuit diagrams will be provided for advanced amateurs wishing to experiment with these concepts.

Scan Converters

The function of a slow- to fast-scan converter is to increase the scanning rate of a slow-scan signal so that it can be viewed on a conventional television display. As shown in Fig. 1, this is accomplished by employing a line buffer, video refresh memory, and a multiplexer, together with appropriate control signals. The scan conversion occurs in the line buffer which accepts an SSTV line at the normal rate and delivers it to the refresh memory. As each new line of slow scan is received it is inserted in the memory until eventually a complete image is stored. The video refresh memory has both slow- and fast-scan capability and can be read out at fast-scan rates directly to a regular television set. Although there are minor variations on this idea, depending on the device used for the video memory, this is roughly the concept of slow- to fast-scan conversion. Typical refresh memories utilize storage tubes, magnetic disks, CCD (charge-coupled display) registers, or a semiconductor memory. Of all of these, the semiconductor memory appears best-suited for use in a processor because of ease of access, excellent speed characteristics, and non-decaying information-retention capability. A digital scan converter such as described in a previous *QST* article[1] forms an ideal unit for an image processor. It is this device which will be used as the basis for much of the discussion to follow.

There are several image-processing techniques that can be used to improve the viewed image which is generated by the digital scan converter. We will restrict our discussion to three concepts that have been implemented on a digital scan converter and which are known to produce good results. They are pseudo-random dither circuits, video compression and expansion techniques, and picture-frame averaging. Many other techniques also exist for image processing and the field is wide open to experimentation by the advanced amateur. Later on in the article some suggestions will be made concerning possible future contributions by amateurs to this field.

Pseudo-Random Dither

In order to perform digital scan conversion it is necessary to digitally encode the intensity (brightness) of each point in the picture as a binary code. For good picture quality it has been established that at least 64 brightness levels (6 digital bits) per picture element (pixel) are necessary, since the eye is very sensitive to small brightness steps introduced by quantization. If less than 6 bits are used an objectionable phenomenon called contouring becomes apparent to the viewer.

Since a horizontal slow-scan line consists of 128 pixels and there are nominally 128 lines per picture, we find that a slow-scan picture consists of 16,384 pixels. And it is clear that at 6 bits per pixel, the total digital memory requires 98,304 bits. If less bits per pixel could be used and still retain good picture quality, a substantial savings could be made in the total number of bits.

In 1961 Roberts[4] discovered that adding noise to a video signal before it was quantized and subtracting the same noise after decoding produced a significant reduction in contouring. Subjective tests by Roberts indicated that good pictures could be obtained by using only 3 bits per pixel. It was also found that additional improvements could be obtained in the picture by compressing the brightness scale before adding the noise and performing the quantization. Video compression will be discussed later in the article.

Noise dithering appears to work because of the frequency-response characteristics of the eye. The eye can detect very small changes in intensity if there are large areas in the picture to compare. A large area of slowly changing intensity is fairly common and is transformed into contours by digital quantization. Contours are annoying and easily detected by visual inspection. However, if the quantization error is broken up and distributed as noise, a human will not notice it since there are no large areas to compare. Also the eye is less sensitive to high spatial frequencies generated by the pseudo-random noise.

One may take advantage of pseudo-random noise (dither) in digital scan conversion to reduce the number of bits per pixel required. The pseudo-random noise itself can be generated in a wide variety of ways using analog noise generators, shift registers, or counters. The subjective effect of using different noise generators can be significant and much research has been devoted to this problem in recent years.

A simple dither circuit that works fairly well is shown in Fig. 2A, with connections shown for use with the scan converter of reference.[1] The output of the 7402 at pin 13 is a square wave of 64 cycles per SSTV line, with a 180-degree phase reversal occurring at the end of each line. This has the effect of superimposing a very low-level checkerboard pattern on the analog SSTV signal before quantization. After quantization, all of the contours are effectively replaced by individual randomized pixels of varying brightness which appear more pleasing to the eye.

Shown at B in Fig. 2 is a high-speed dither circuit for subtracting an equal and opposite amount of dither from the fast-scan output after decoding. This serves to reduce the rms noise in the picture and smooth the picture even more. The photographs on page 13 show an actual slow-scan picture that has been improved by the addition of dither as discussed here.

Video Companding

One of the psychovisual aspects of human vision that can be effectively utilized in scan conversion is the apparent increased sensitivity of the eye to low brightness areas. Tests on the eye have indicated a logarithmic brightness sensitivity, rather than a linear one. Consequently, if the quantization errors could be shifted to the bright areas of the picture rather than the dark areas, subjective picture improvement should result. This can be accomplished if the brightness scale is made nonlinear so that most of the quantization levels occur in the dark areas, thus reducing the errors in the dark areas and increasing the errors in the bright ones. This process is called video compression and may be performed in the analog domain with a suitable nonlinear amplifier.

In order for the displayed picture to have the same gray scale as the original picture an expansion of the brightness scale should be performed after decoding. This may be done in several ways using analog devices. However, a particularly attractive method uses the expansion characteristics of certain phosphors found in commercial CRTs. Fig. 3 indicates a typical compression curve that one might utilize. Notice that the expansion curve would be the inverse of the compression curve, to compensate for the original brightness compression.

Frame Averaging

If a signal is sent repetitively in the presence of random noise with zero mean, the original signal can be recovered by averaging the combined signal and noise over several periods. The noise will tend to cancel out since it is uncorrelated, but the signal should remain and increase in strength. A memory is generally required to perform averaging of this type.

If we think of an SSTV picture as a signal that repeats itself every eight seconds it should be possible to perform frame averaging in much the same way

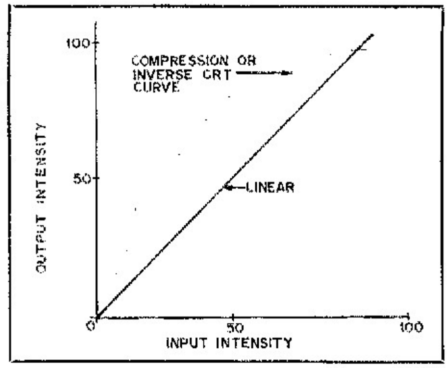

Fig. 3 — Compression curve for video companding. For best performance the inverse CRT characteristic should match the compression curve. This curve will depend to some extent on the settings of the brightness and contrast controls of the monitor.

as discussed above. A digital scan converter can be very simply modified to provide frame averaging capability over two frames. The circuitry required is shown in Fig. 4 and is for the most part self-explanatory. To give an indication of the performance of an SSTV frame-averaging circuit the following test was performed.

A standard SSTV signal was added to an analog noise generator to obtain a combined signal with a signal-to-noise ratio of about one to one. The resulting noisy signal was fed to the digital scan converter and averaged over two frames. The results are shown in Fig. 5. As may be seen, the frame-averaging capability can produce usable pictures under very poor conditions. Since it is normal procedure to transmit SSTV pictures two or three times, averaging should prove to be a practical technique. On-the-air experience indicates that oftentimes pictures can be "pulled through" by averaging when all else fails.

Suggestions for Further Work

As mentioned at the outset there are many areas of image processing that can be applied to SSTV processing. Several ideas, admittedly some of them "blue sky," are listed below.

Removal of electrical noise or multipath distortion from SSTV pictures by processing would be a great step forward. The low frequencies, 75 meters in particular, are extremely susceptible to this type of distortion. Perhaps it would be possible to model or measure the degradation phenomenon and remove it from the picture by reversing the process. Has anyone looked at this problem? Correlation techniques might also be considered.

Experimentation with different encoding schemes for slow scan might lead to greater reliability and/or narrower bandwidths. Digital encoding, possibly with the use of error-correcting codes, has the potential for extreme reliability

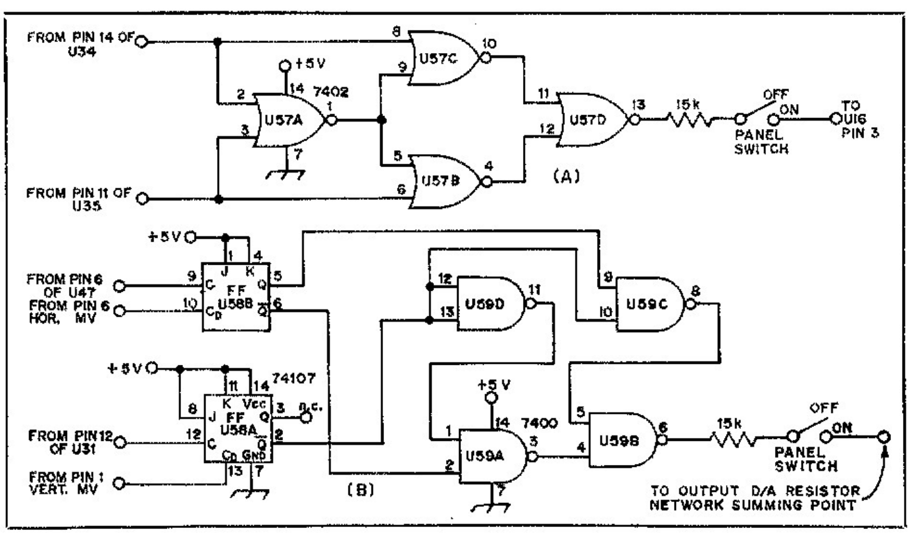

Fig. 2 — At A, schematic diagram of input dither circuit and at B, an output circuit for use with the WB9LVI scan converter. U57 supplies dither to the incoming slow scan and U59 subtracts a synchronized high-speed dither from the fast-scan video as discussed in the text. Vertical and horizontal multivibrator and summing resistor connections shown here are to be made to the circuit shown on page 36 of *QST* for May, 1976. Other connections are to related circuit diagrams in that issue.

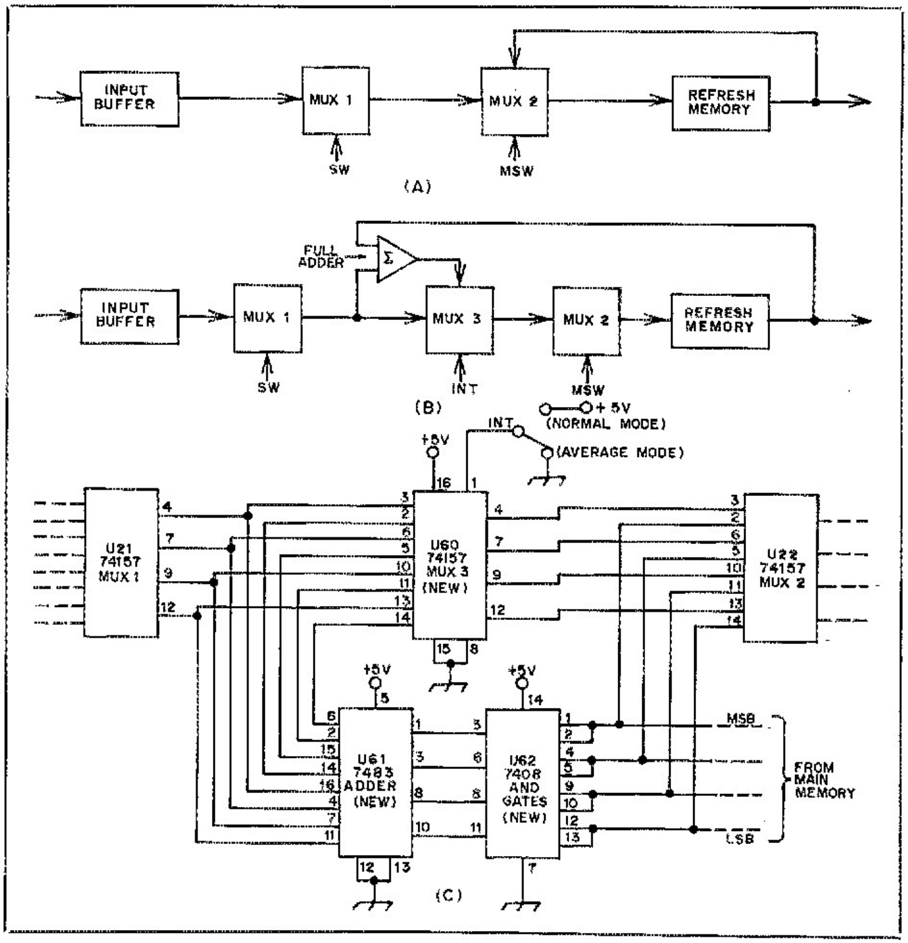

Fig. 4 — Block diagrams (A and B) and schematic diagram (C) of the frame-averaging addition to the WB9LVI scan converter. It requires three additional integrated circuits and provides true averaging of slow-scan pictures in real time. At A is shown the original circuit using two multiplexers, MUX 1 and MUX 2, to control the input video. At B is a modified diagram showing the addition of MUX 3 and a full adder. Shown at C are the actual circuit changes to the diagram originally published on pages 30 and 31, *QST* for May, 1975. U60, U61 and U62 are added.

and excellent performance in communications. Much work has already been done on encoders and perhaps some of it may be directly applicable.

Using conditional replenishment schemes or pseudo-random scanning, it may be possible to transmit pseudo-*motion* pictures over conventional SSTV channels. Strong considerations must be given to the effects of noise, QRM, and circuit complexity in proposing these systems. The experimenter should not be discouraged, however, as much work has already been done in transmitting true television over voice channels. As the cost of integrated circuits drops, many of these schemes may become more economical.

Color slow-scan television is already possible between two compatible amateurs. Many of the existing techniques have used photographic film to restore a full-color image from three separate SSTV frames, each photographed in a different primary color. It appears possible to develop a subcarrier color television signal, compatible with existing slow-scan standards, that could be used to drive a color slow- to fast-scan converter. The output could then be viewed immediately as it was received, directly on a color monitor. Also instead of transmitting the three primary colors one might consider sending only the short- and long-wavelength records, as in the Land experiments,[5] combining these records electronically to achieve nearly full color. This would reduce the bandwidth requirements considerably and still produce rich color pictures.

In conclusion, it may be said that there are numerous avenues of exploration in image processing awaiting the interested amateur — only a few of which were touched upon here. It is hoped that this article will act as a stimulus and perhaps cause some of you to take the gauntlet and get active in this field. If so, the author is satisfied and looks forward to hearing of your contribution.

The author wishes to thank the many amateurs who discussed the ideas contained in this article. As always, special thanks must go to my XYL, Gloria, for her constant inspiration in all of my work.

References

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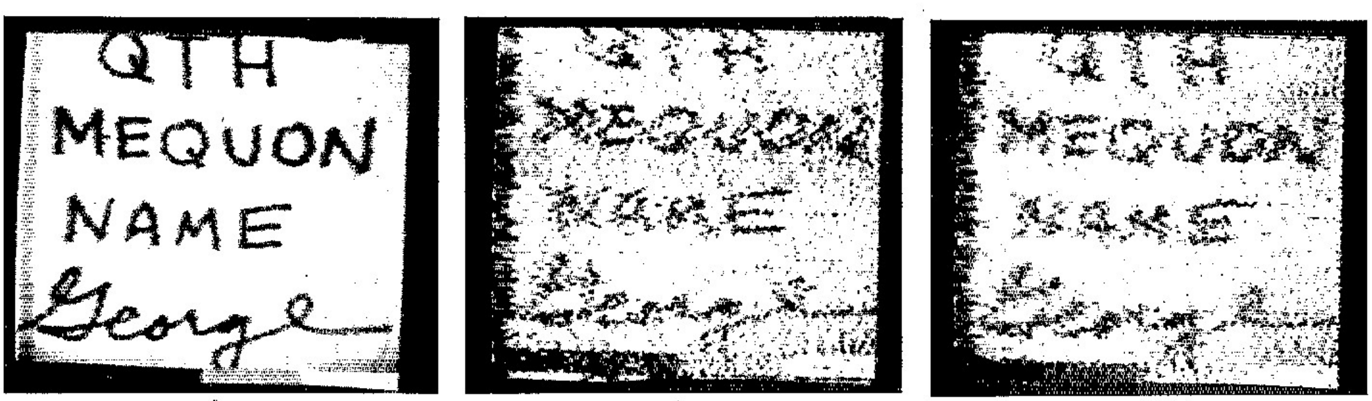

A B C

Fig. 5 — Example of frame averaging in the presence of severe noise. At A is the original with no noise. B is the first frame read into the scan converter memory and consists of the original SSTV signal plus random noise as described in the text. C is the result of averaging two successive, noisy frames.