TRANSMISSION OF THERMAL IMAGE DATA USING PLUSE CODE MODULATION*

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ABSTRACT

This paper presents a method for synchronous conversion of infra -red image data to a Pulse-Code Modulation (PCM) bit stream for recording on instrumentation tape recorders. The PCM data recording method provides an improvement over analog FM recording in signal to noise ratio, horizontal resolution, and speed of data formatting. The methodology was applied to the design of a PCM encoder for an AGA model 680 Thermovision camera. The extension of the design to other devices is discussed. Considerations for the display of real-time and reduced speed data display on conventional television monitors are presented.

INTRODUCTION

A technique for conversion of infra-red image data to digital Pulse-Code Modulation (PCM) serial data is presented. In the past, infra-red camera data has been recorded on either video tape recorders or analog instrumentation tape recorders via multiple channels. There are limitations associated with each of these methods of recording. Video tape recording is only suitable for qualitative data analysis through visual inspection. The accuracy of this analysis is limited by the signal to noise ratio of video recording equipment, 35 to 40 db.

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Instrumentation tape recorders with multiple channels have been used for quantitiative data analysis such as; calculations of field-of-view, area, centroid, total flux, and temporal averaging. These recorders have signal to noise ratios, of 50 db for limited bandwidth FM. However, separate recorder channels have been utilized to record the vertical trigger pulse and the horizontal trigger pulse, with multiple channels used to record the video output at separate gain levels. By overlapping the sensitivity on several recorder channels the dynamic range of the camera is adequately covered. The horizontal resolution of the analysed data is limited to approximately 100 pixels by the 80 KHz response of the instrumentation recorder.

Quantitative analyses of large volumes of image data require pre-editing of the raw data followed by computer processing. Pre-editing is done to limit the volume of data which will subsequently be processed. Analog tape recorders have long start and stop times, therefore irrelevant images are recorded both before and after the data frames of interest. The multiple channels used to record the video output of the camera have varying image to noise ratios, with some channels being saturated and some with the image lost in the noise of the tape recorder. Selection of the channel to process and the time interval of interest can best be accomplished by pre-editing of the raw data through visual inspection on a display.

Formatting of the data for the computer places constraints upon the usability of this analog recording technique. The real-time data rate of cameras, while limited by instrumentation recorders to 160 Kilo-samples per second, is still too fast for sustained formatting by computers. To accomodate the slower computer rate the speed of the recorders has been reduced by a factor of four. Careful calibration and speed control of the recorders is required because the data is still in analog form and the computer is unable to differentiate between tape speed errors and changes in data parameters.

Real-time digital recording of the camera data would reduce the formatting problems. PCM is a form of digital recording which allows packing densities in excess of 30 kilobits per inch on instrumentation tape recorders with bit error rates of less than one per million. Given a tape speed of 120 inches per second, digital data can be recorded at rates greater than four megabits per second. The attributes of PCM recording suggest an alternate more efficient method of recording infra-red image data for quantitative data analysis.

DESIGN DEVELOPMENT

The integrity of the data obtained by the PCM method should be equal to or better than that obtained by multiple channel analog recording if this method is to provide a viable alternative. Therefore, previously established analog data parameters were used as the criteria for evaluation of the PCM design.

The specific circuits used in the PCM encoder are determined by the camera specifications, consideration of tape recorder limitations and adherence to IRIG (Inter-Range Instrumentation Group) P C M recommendations. The maximum bit densities of instrumentation tape recorders is approximately 30,000 bits per inch which translates to 2MHz at tape speeds of 120 inches per second. This frequency establishes the upper limit of the sample rate and sample resolution of the PCM encoder. These two variables are also a function of the pixel rate and dynamic range of the camera used to acquire the data.

The design of the PCM encoder described in this paper was based upon the AGA 680 Thermovision camera. This camera provides three output signals. Two signals are trigger pulses to indicate the start of both the vertical and horizontal scan periods. The remaining output is a video signal which indicates the instantaneous value of the radiation falling on the detector. The vertical field rate is 16 hertz. the horizontal line rate is 1600 hertz. The optical instantaneous field-of-view defines the horizontal resolution to be greater than 200 pixels per line. The dynamic range of the video signal is approximately 10,000 to 1 (80 db).

The PCM data frame length is equal to one horizontal scan. This characteristic allows synchronization of a set number of PCM data samples with the horizontal trigger of the camera, creating a spatially-stable horizontal sample rate. The sample rate of 128 pixels per horizontal scan of the camera was chosen through iterative calculations. These calculations were compared to the equivalent data parameters of the analog recording method as well as the tape recorder limits. The sample rate of 204.8 kilo-samples per second was calculated as the product of the number of samples per line, 128, multiplied by the horizontal scan rate of 1600 lines per second. The maximum frequency is generated if alternate pixels are black and white resulting in a PCM data bandwidth of 102.4 KHz. This PCM bandwidth has 25% more spatial resolution than the 80 KHz analog method.

For accurate data analysis, the sample resolution should closely approximate the dynamic range of the camera. The maximum sample resolution is limited by the maximum frequency response of the tape recorder and the previously chosen sample rate. Resolutions of 12 to 14 bits satisfy the above requirements, however, 12 bits was chosen because of the availability of analog to digital converters that operate at the chosen sample rate. This resolution provides a signal to noise ratio of 4096 to 1 (72 db). The comparable analog method limits the signal to noise ratio of the processed channel to 50 db. The bit rate of 2.547 megabits per second is the product of the sample rate and the resolution. By utilizing non-return to zero level encoding the highest frequency the tape recorder must record will be 1.228 MHz.

Industry available PCM bit sychronizer and frame sychronizer equipment provide the interface to the computer used for data formatting and the display hardware used for pre-editing. The computer interface should be a parallel device capable of handling twelve bit words, to provide maximum speed data formatting.

The PCM image data was converted to EIA RS-170 NTSC television format to maintain compatibility with computer displays. This conversion allows pre-editing to be done on a computer monitor rather than specialized X, Y, Z oscilloscopes. This choice allows for the use of low cost readily available equipment which can be used for the insertion of time codes and other alpha numeric data, split screen presentations, multiple point distribution and hard copies of displayed information. The equipment used to convert the PCM data to television format was configured to allow for real-time or reduced speed data transfer.

GENERAL CIRCUIT DESCRIPTION

PCM Encoder

The system timing is generated by two phase-lock loop circuits. The first is locked to the 128-th multiple of the camera horizontal sync pulse. The output of this circuit is the word-clock of the encoder. The word-clock controls the sample rate of the analog-to-digital converter. It also is the input to the second phase-lock loop circiut which locks to the 12-th multiple of each word. This circuit generates the bit-clock of the PCM serial data stream.

An index counter is incremented by the camera horizontal trigger and reset by the camera vertical trigger. Two levels of digital multiplexing connect the data to the parallel to serial shift register.

The first level of multiplexing time shares the PCM frame sync pattern generator with the horizontal line index counter.

Video data from the camera is passed through a two-pole low pass filter to provide some anti-alaising protection and then a track and hold amplifier. The analog to digital (A/D) converter digitizes the video at the pixel rate determined by the word-clock generator. The digital output is passed through the forbidden code detector and on to the second level of multiplexing.

The forbidden code circuit tests each A/D sample for the condition of all “1’s” or all “0’s” and if either condition exists then the least significant bit of the sample is inverted. By doing this, a level transition will occur at least once every PCM word easing bit synchronizer lock-up problems and eliminating the low frequency component from the PCM data stream.

The second level of multiplexing time shares the sync pattern and line index with the pixel data output from the forbidden code generator. This results in three of the 128 A/D samples being discarded for every horizontal line and the 24 bit frame sync pattern and horizontal line index count inserted in their place.

The parallel to serial shift register is loaded at the word-clock rate and shifted out at the bit-clock rate producing a non-return to zero level (NRZL) bit stream for recording on instrumentation tape.

The result is a PCM frame consisting of 1536 bits. The frame is organized into a 24 bit sync word followed by a 12 bit horizontal line index count and 125 data words each 12 bits long.

The field of infra-red image data can be reconstructed from the PCM data by stacking the horizontal pixel information in columns of an array and adding a row to the array for each horizontal line index count until the count returns to zero.

Television Scan-Converter

The outputs of the frame synchronizer provide the inputs to the scan-converter. The frame sync pulse will coincide with the occurance of the PCM frame sync pattern. The word sync pulse will occur as a data word ready strobe to indicate when the 12 data lines contain a pixel of data.

These lines are input to the scan-converter. The frame sync pulse resets the horizontal address counter. The horizontal address counter increments one count for every word sync. The horizontal count is decoded to identify the vertical index word. The index word is loaded as the vertical address counter. The address counters are used to control the write location of a random access memory orgainzed in a square array 128 x 128 x 8 bits deep. Only the eight most significant bits are displayed as this gives 256 grey levels, more than the eye can resolve on a television monitor.

Another set of horizontal and vertical address counters are controlled by an NTSC TV sync generator. These counters control the read address of the memory. The read/write control logic eliminate the possiblity of simultaneous demand for the same memory cell.

The digital pixel information is stored and read from its spatially corresponding memory location. If at any time the flow of input data is halted, the memory will retain the last field of image data until power is removed. The memory data is read into a latching digital to analog converter where a voltage is generated representing the intensity of the infra-red energy falling on the detector of the camera. The RS 170 composite sync information is added and cable drivers are provided for distribution or processing of this video signal.

CONCLUSIONS

The methodology outlined in the design development can readily be adapted to other cameras. Sample rate and sample resolution are the two parameters that must be manipulated to most fully utilize the tape recorder capabilities and closely match the specifications of the particular camera.

For the AGA-680 Thermovision camera, the PCM recording method improves the accuracy of the data analysis by increasing the spatial resolution, increasing the signal to noise ratio, and reducing the time required for computer formatting.

The scan-conversion to television format reduces the costs associated with display and editing of the camera data by providing compatibility with existing data processing hardware.