HIGH-SPEED PHOTOGRAPHY USING TELEVISION TECHNIQUES

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ABSTRACT

There are many applications for High-speed photography, and most rely on film as the primary medium of data acquisition . One such application of interest to the military services is the study of stores separation from aircraft . This type of testing has traditionally used high-speed film to gather data, however, there are many disadvantages to using film, such as the high cost of raw film, as well as the high processing expense after it has been exposed . In addition, there is no way to review data from film until it has been processed, nor is there any way to preview in real-time other conditions such as lighting which may affect the outcome of a test event.

This paper discusses the characteristics of television systems with respect to motion picture systems, the challenges of recording and transmitting pictures, as well as the nature of what the first and eventual desired systems might be.

KEY WORDS

High-Speed Imaging, High-Speed Video, Instrumentation Video

INTRODUCTION

There are many uses for what are called "high-speed" visual imaging systems, particularly in the research and development and test and evaluation of military systems. "High-speed" is a relative term, and there are a wide variety of requirements for systems that fall under this category, although the underlying concept is the same for all of them; the more pictures that are recorded per second, the smaller the interval of time that can be looked at to analyze relative motion and also the higher the probability of being able to see events of extremely short duration . Generally, "high-speed" can be thought of as anything greater than the average cinema quality film or television system, which produce 24 or 30 frames per second respectively. Currently there are many high-speed systems in use, most of which utilize film techniques, operating at speeds which can be well into the thousands of images per second.

FILM SYSTEMS

When a motion picture film is made, each picture or frame is shot through the camera mechanism onto the film, which is held motionless by sprockets. The camera shutter opens, exposes the film, and then shuts so the film can be advanced to the next frame. Each picture is an individual photograph, with the exposure time limiting how fast the film may be advanced. With some shutters, it is possible to expose the film while it is in motion, but the film's exposure time still limits how fast the film may be advanced. Film's 'speed' refers to the film's sensitivity to light, and since a 'faster' or more sensitive film may effectively be advanced through the camera faster, improvements in film technology over the years have allowed the frame rates to grow quite large.

Film, however, must be developed, which is time consuming, expensive, and the chemicals used are environmentally unfriendly. After film processing, data reduction is accomplished by simply looking at each frame during an event and making manual quantitative measurements of displacement from frame to frame or by using some sort of semi-automatic process which usually involves a computer and digital camera which digitizes each projected frame of film at a rate many times slower than it may have been exposed in real-time. A human operator must then move cursors to designate edges on the images displayed on the computer, so that the computer can track them in order to get quantitative results. This is a very tedious process.

VIDEO SYSTEMS

The first television systems used tube pickups in the camera, utilizing a scanning beam to scan the area where the image was focused by a lens; scanning from left to right and top to bottom. Television systems now typically use solid-state charge-coupled device [CCD] sensors, which are analog in the way they report the presence of light over their surface, but digital in the way they produce and transfer those points, in a manner similar to a pulse-amplitude modulation [PAM] system. Typically, a shutter is used to expose the sensitive area of the pickup all at once in order to prevent smearing of objects that are in motion. The shutter, which may be electrical or electromechanical, is also fed back a signal from the camera to determine 'dwell' -- the amount of time the shutter stays open -- to control the maximum amount of light hitting the pickup.

Regardless of which type of sensor is used, the information is put into a composite format which is then scanned onto a monitor for viewing. The composite waveform contains all of the necessary information such as synchronizing and blanking signals that is required in addition to the actual picture information to display the video on a monitor. The number of left to right scanning sequences used for each picture determines the number of horizontal lines, or the vertical resolution of the system. [1] The horizontal resolution is a function of the system bandwidth since it is analog or continuous in nature, as opposed to the vertical "line" which is made of a countable number of dots. For a tube-pickup, horizontal resolution also depends on the size and shape of the scanning beam in the camera which is used. CCD type sensors have a fixed vertical resolution which depends on the scanning system used, but horizontal resolution depends on the number of picture elements or "pixels" on each line. Resolution can be lower than the number of pixels used because of frequency limitations and crosstalk in the system, but can often appear to be nearly as good as the number of pixels provided.

The resolution of a video system thus depends on both the resolution of the sensor and the format of the subsequently encoded video information. The National Television System Committee (NTSC) system, which evolved in the late 1940's in the case of the monochrome standard, and 1953 for color, is limited to 4.2 MHz of video bandwidth, which works out to a horizontal resolution of roughly 640 pixels. The vertical resolution is about 480 lines, and is a function of the scan rate chosen in the NTSC specification. (Although there are 525 lines specified in the specification, only approximately 480 have active video.)

There are other composite analog formats, such as PAL (Phase Alternation Line), which is a 625 line 50 Hz interlaced system, [2] and SECAM (Sequentiel Couleur Avec Memoire), a French system which is also a 625 line 50 Hz interlaced system -- (different from PAL in the way that color information is handled). Both of these systems boast actual resolutions of about 768 by 576 in their most popular forms.

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[1] An NTSC picture consists of 30 pictures, or frames, per second each consisting of 525 lines. Since a vertical sweep rate of 30 would be easily perceptible to the eye, each frame is transmitted as two fields containing 262.5 lines apiece. These fields are then "interlaced" and the net result is that the vertical rate is double what it would be if all of the lines were sent in progressive order from top to bottom. (i.e. 60 Hz)

[2] PAL is used throughout the world, and depending on exactly where, can have a video channel bandwidth of 4.2, 5.0, 5.5 or 6.0 MHz.

In addition to these composite formats, there are a number of component formats which allow separate signals for the luminance or basic picture information, chrominance (color signals) and sometimes the synchronizing signals . The primary advantage to this is that, due to the capabilities of video recording equipment, the quality of the recorded signals is improved immensely by separating the Y (luminance) and C (chrominance) signals. [3] One of the highest quality of these is the SMPTE High Definition Production standard, which has 1125 lines and a 60 Hz field rate (2:1 interlaced) and a resolution of 1920 by 1035 . This is mainly used for video production due to the immense 30 MHz bandwidth required.

DIGITAL VIDEO SYSTEMS

Digital component video and digital composite video were developed as alternate methods of storing and transmitting video digitally to preserve as much quality as possible. In addition, the multi-media explosion has caused the need for the fusion of video into computer graphics displays.

Dealing with video digitally is straightforward in concept, though more difficult in the real-world due to the tremendous amount of digital data required to represent even NTSC quality video. Basically, in the case of monochrome video, each pixel coming from the sensor is digitized and represented by usually 8 bit words . This results in a serial data stream of about 74 Million Bits per Second (MBPS) for a standard NTSC resolution of 640 by 480 at the NTSC 30 Hz frame rate! If a color sensor is used, (which often times is actually two or more sensors used together) each pixel would require 8 bits of luminance information, as well as 2 other 8 bit words to define the color space information, resulting in a serial data rate of approximately 221 MBPS.

There are many different formats for representing color or "color space," which is simply a mathematical representation for a set of colors . Most computer graphics and imaging systems use RGB color space, or Red, Green, Blue, which are three primary additive colors that when added together form a desired color . YUV color space is the basic color space used by NTSC, PAL, and SECAM and can be derived from RGB by a set of basic equations. The Y (intensity or luminance) information is the basic monochrome image, with the color information (U and V) added in such a way as to keep from interfering with a monochrome only monitor . Some of the other color spaces are YIQ, YDrDb, and YCrCb, and they differ from YUV in that the

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[3] The component S-VHS format is capable of recording the full resolution of an NTSC video signal, while a standard VHS recording loses about one-half of the resolution.

mathematical equations used to derive them from RGB color space are different . RGB is the basis for all of these difference signals, which are used because they are much more efficient than RGB.

Due to the amount of digital information required to represent color video, researchers have struggled to reduce the amount of data required to represent color space, and there are a variety of encoding formats to do this . One of the most popular digital component formats is 4:2:2 YCrCb format, which reduces the number of bits required to represent one pixel to 16 . Essentially, for every two Y samples, there is one Cr and Cb value. Each value is typically 8 bits and, during display, pixels with no Cr and Cb data are interpolated from the previous and next pixels which do . This still results in a serial data rate of 147 MBPS . In addition, there is at least one proprietary system which uses a software algorithm to encode luminance and color information together into 8 bits per pixel, but since it requires processing to do this, its use for high-speed video probably would be limited in real-time scenarios.

RECORDING HIGH-SPEED VIDEO

Analog Tape Recorders

Certainly technology has changed remarkably since the NTSC format was defined almost fifty years ago, and there are a number of ways an analog signal can be optimized for a specific purpose . For instance, the scan rate can be readily increased in order to either add fidelity to the resolution by scanning more lines per image, or increase the number of images scanned per second . Though there are of course finite limits to the performance of such a system, by far the limiting factor is recording it with all of its increased capabilities intact . Analog recorders are capable of recording wide bandwidth signals, but they use read/write heads that rotate at an angle to the tape's forward direction in order to increase the effective writing speed on the tape . As a result of this construction the recorder must switch from one head to another or blend the signal from one head to another in a controlled crossfade . Video recorders do this during the vertical blanking interval in order to hide the small amount of image jitter and color tint change which results from the tolerances of the different head alignments. This of course means that an analog recorder must be designed or optimized for a particular video signal format, and any custom format used for high-speed video would likely be expensive and add significantly to system development in an era when the use of non-developmental items is encouraged for military systems.

Analog recorders also have another disadvantage to offset their high-speed capabilities, and that is the nature of the recording process . Any errors due to noise or distortion can never be compensated for downstream, with the result that an identical copy cannot be made. The loss in quality of even second generation copies is significant.

Digital Recording

Digital recording can be accomplished using many different techniques which all have advantages and disadvantages . Digital data can be stored using some variation of electronic memory, or some sort of magnetic media such as tape or hard disks . Digital data can also be stored using laser light with optical or magneto-optical systems .

Because digital video produces such a large quantity of data that must be stored in real-time, usually a combination of these techniques must be used if very high-speed video is to be recorded. Generally, only electronic memory devices are capable of storing real-time video data, and almost all recorders utilize some sort of buffer to store data until it can be transferred to a more permanent medium . Even though memory prices are dropping, while the amount of data that can be stored in solid-state memory increases, buffering data is generally not feasible for more than a short time -- especially for high speed systems . Currently, most if not all digital recorders are limited to sustained serial data rates of less than 50 MBPS . However, the use of special techniques such as data multiplexing is making the use of digital recorders more feasible by allowing higher effective storage rates.

HIGH-SPEED VIDEO SYSTEMS

Because of the high resolution capabilities of film, plus its relatively easy, and proven implementation in high-speed systems, it is hard to justify using television techniques in such systems. However, television systems offer some considerable advantages such as their ability to be electronically stored without any chemical processing, which is expensive in terms of time and resources, and has the added disadvantage of creating environmentally damaging waste . Television systems offer the capability of being instantly viewed, allowing instant access to data or to preview such things as lighting conditions or camera alignment before an expensive test is performed . The output from video systems can also be transmitted electronically, which can be an advantage in some instances.

A high-speed video system is currently under development which will be taking advantage of some of the capabilities that a video imaging system can offer, and will overcome some significant disadvantages of the film medium . The Airborne Separation Video System (ASVS) is a tri-service project to develop an airborne system for use in aircraft stores separation testing . Currently, as many as 15 film cameras are mounted on test aircraft to record store separation data for military aircraft. The ASVS will be capable of recording data from as many as 16 digital cameras on board during flight at frame rates of up to 400 frames per second . The storage capability will allow on-board recording of at least 1000 frames per camera, and will also feature a sub-system which will telemeter the video data to the ground at a reduced rate so that test conductors can preview conditions before a test event, or take a quick look at test data resulting from a store release before proceeding to another test event. The data stored on the aircraft will then be downloaded and ready for data reduction immediately after the aircraft lands, which will also improve the flight-testing process.

The video telemetry system will utilize an existing IRIG Standard 210 compatible video compression system operating at either 5 or 10 MBPS to transmit the video images, though not at their full resolution or rate . This "near-real-time" capability will operate in two modes. First, the video compression system can simply compress and transmit as many frames as possible while throwing away all intervening images coming from the cameras, which will allow approximately 15 - 30 images per second, depending on picture complexity . Or, the ASVS system controller can send each and every image to the video compression system at whatever rate compression can be achieved so that every stored image is transmitted to the ground . This will take approximately a minute or so for each 1000 image record from each camera on the aircraft.

Unfortunately, system development is in the contracts award phase, and the exact capabilities and details of the system are not releasable until that is completed, which is expected sometime during the summer of 1995 . Details of the final system configuration will be presented at ITC-95 if contract award goes as planned.

CONCLUSION

Though there are some significant technical difficulties that remain to be overcome, the use of television techniques in high-speed imaging systems offer some very significant advantages when compared to traditional systems . The use of digital video techniques, which are becoming ever more prolific, can result in systems which allow data reduction to occur with greater speed and ease with the use of computers . It is anticipated that many more such systems will be developed in the near future.

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