1000 FPS, 24 Bit
High Resolution Color Motion Analyzer

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ABSTRACT

Eastman Kodak Company Motion Analysis System Division has invested many years in developing technology used in our new 24 bit color accurate digital motion analyzer. This paper will describe the method for producing accurate 24 bit color at 1000 fps. Additionally, applications will be discussed using new tools embbeded in our motion analyzer.

Motion analyzers are used to capture images from high speed electronic cameras. These images are stored at high speed in the motion analyzer. After the images are captured [stored], frame-by-frame, they are reviewed in slow motion on the motion analyzer's display. Quantitative measurements (i.e., displacements, velocities, areas) are made by users. For some users, seeing just the images in slow motion gives enough seminal understanding. A high speed event could be virtual anything that moves faster than the eye can perceive. Industrial imaging of high speed subjects can provide the understanding for improving quality, trouble-shooting a problem, increase-ing capacity, reducing set-up time, and advancing research. It is apparent why companies throughout the world are using motion analyzers to remain competitive.

The first of our new generation of analyzers is called the KODAK EKTAPRO Motion Analyzer, Model 1000HRC. It consists of an Imager and a Processor. The Imager has an electronically shutterable 512 x 384 CCD sensor is used as the imaging element that runs at 1000 full fps and provides excellent detail of objects. The electronic shutter operates up to 50us or 1/20,000 sec exposure. This Imager digitizes the image data and transmits the information on high speed serial links to the Processor. The Processor provides all the storage, communication and control function necessary for "seeing what you could not see with the human eye." Playback of images on the Processor is extremely easy providing full control for viewing images in Color.

One of the distinctive capabilities in this new high-speed motion analysis system is the high color quality that is achieved at 1000 frames per second [fps]. These digital color images are displayed as 24 bit RGB pictures producing up to 16.7 million colors. These color images can be accessed in a standard TIFF formats that is fully compatible with 3rd party motion analysis, image processing or desktop publishing software packages. Digital images can be archived on a magneto optical drive that accepts low cost removable 1.2 GByte cartridges. This media provides a method of moving archived images to various computer platforms used for analysis.

The KODAK EKTAPRO Motion Analyzer, Model 1000HRC simplifies the entire range of analysis task with its complete set of tools. Images can be analyzed using the Processor or the data an be sent by one of many communication interfaces to a host computer. A remote computer can receive images and control the Motion Analyzer through SCSI, GPIB, RS422 or RS232 interfaces.

This paper will describe the method for producing accurate 24 bit color at 1000 fps. The paper will also describe new tools provided in this motion analyzer and how these tools may be used to further advance the scientific art of motion analysis.

BACKGROUND

The first motion analyzers were an outgrowth of magnetic recording technology in the early 1960's. The first generation motion analyzers became commercially available in the 1970's. These systems were limited by the era's technology, and could capture only 120 full frames per second (ffps). The second generation motion analyzer was introduced in 1979 and could capture 200 fps. In 1980, Kodak introduced a third generation motion analyzer. This motion analyzer was a revolutionary high-speed video system called the SP2000 Motion Analysis System This system recorded a monochrome images at a frame rate of 2000 fps or 12,000 partial frames per second (pfps) onto half-inch instrumentation tape. Although the frame rate was unsurpassed for many years, the handling of images on magnetic tape was cumbersome. The 4th generation analyzers introduced solid state memory as a recording media. Kodak introduced in 1990 the EktaPro EM Motion Analyzer that storeed digital images in Dynamic Random Access Memory (DRAM). Manipulating images with DRAM technology allows unique image capturiong techniques, improved image quality and continuous image recording.

The 5th generation motion analyzer distinguishing features are higher resolution, faster frame rates and improved image quality for color or monochrome images. There are two motion analyzers that qualify as 5th generation machines. They are the KODAK EKTAPRO Motion Analyzer, Model 4540 that records at 4500 to 40,500 fps and the KODAK EKTAPRO Motion Analyzer, Model 1000 HRC that has 4x resolution and superb color image quality. This paper will discuss only the advances in technology for the color motion analyzer.

INTRODUCTION

A new product family is being introduced by Eastman Kodak's Motion Analysis Systems Division in San Diego. This product family will offer better resolution, faster frame rate and improved image quality for both color and monochrome images. The first of this product family is the KODAK EKATPRO Motion Analyzer, Model 1000HRC. This motion analyzer has set a new level of image quality for our industry, as well as increased resolution. This analyzer is feature rich with simple to use yet sophisticated tools. This analyzer provides images in a digital format that is compatible with most 3rd party multi-media software. Some of the more recent product family members include a monochrome version of the HRC and a 16 mm Hi-G film camera replacement called the Record Only (RO). The RO will store images in memory contained in the camera. It will use the same sensor as the HRC and will have non-volatile storage. These cameras are part of a new generation of motion analyzers from Eastman Kodak, MASD.

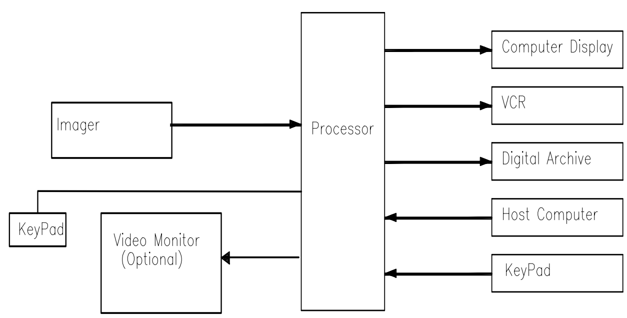


Figure 1 HRC System Block Diagram

The KODAK EKTAPRO Motion Analyzer, Model 1000 HRC records color images at 1000 fps . This motion analyzer accepts one monochrome or color imager. The HRC analyzer has full frame capture rates of 250, 500 and 1000 fps. Playback rates are variable both forwards and reverse at rates from 0 to 1000 fps. The motion analyzer can store appoximately 5,456 frames. The motion analyzer is configured and controlled through a back-lit Liquid Crystal Display (LCD) keypad or any one of its standard interfaces [SCSI, GPIB, RS422 or RS232]. The main display uses a 24 bit RGB computer monitor. Video taping to either NTSC or PAL is a standard interface. The images are annotated with data on the outside border. This data includes frame rate, replay rate, frame number, an identification number for the current recording, motion analyzer's operational status, elapsed time, exposure setting, input signal status, graphical representation of a user's analog or digital inputs and other special messages. Shown in Figure 1 is the system block diagram.

Imager Technical Description

The Imager has an electronic shutter on 512 x 384 CCD sensor. Operating at 1000 fps thesensor provides excellent subject detail. The electronic shutter operates at either 50us or 1/20,000 sec exposure. The Imager supports a monochrome or color sensor. The color sensor has a Color Filter Array (CFA) deposited on its surface. This CFA sensor coupled with a custom color co-processor produces accurate 24-bit color. The color processing will be discussed later in this paper.

Within the Imager body is all the signal processing electronics for the CCD. This Imager digitizes the image data and transmits the information on high speed serial links to the Processor. Shown in Figure 2 is a simplified block diagram of the Imager. The CCD sensor will be discussed later.

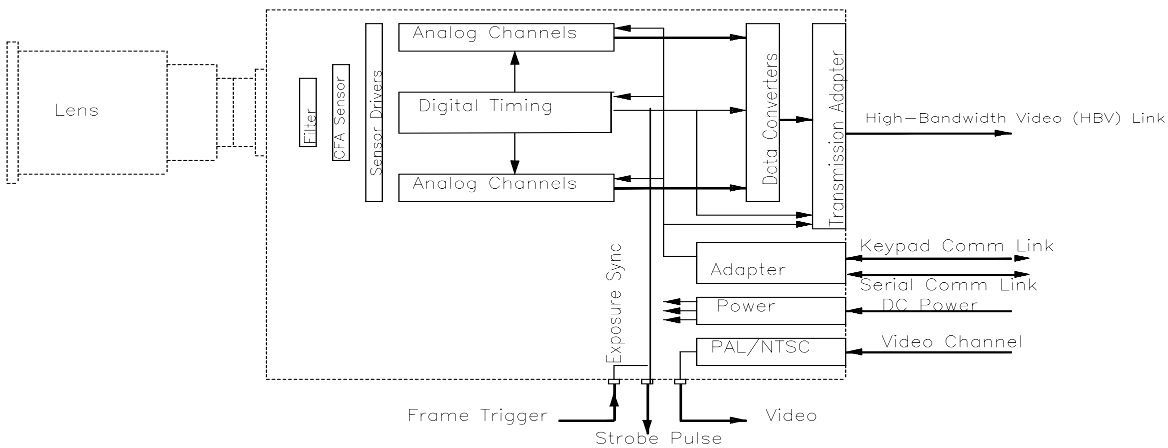


Figure 2 HRC Imager Block Diagram

Sensor Driver

The Sensor driver assembly provides the sensor bias voltages, and translates the pixel-level timing generated on the Imager controller into the precise timing and voltage drive signals necessary to drive video signals from the sensor.

Signal Processors & Data Conversion

The signal processors are responsible for conditioning the sensor signals for digital conversion. Analog control and setup of these functions are programmable, and controlled via a serial communication scheme. The sensor is followed by a pre-amp. The pre-amp amplifies the signal off the sensor to a level sufficient for processing. The next block is Gain & Offset. The Gain & Offset is to amplify the signal and remove unwanted noise. The next block is a Sample & Hold that retains an averaged sample of the video. This video is then digitized by an A/D converter. After the A/D is the Channel Formatter block that converts and buffers the digital signals for transmission to the Processor. This channel architecture is replicated for all of the outputs on the sensor.

Data Transmitters & Imager Controller

Sensor channels are combined into a very high bandwidth, serial communication port for transmission to the processor. The Imager controller is responsible for both high-level command interpretation and the generation of pixel-level timing signals needed by all other Imager assemblies.

Power Conversion

All special voltages necessary for the Imager is derived from a single-voltage DC source. The Power Conversion Assembly contains all necessary conversion circuitry and filtering.

CCD Technical Description

CCD Sensor

The video format used by the EktaPro HRC motion analyzer and the RO camera is based on a 512 x 384 Kodak CCD sensor. The video format breaks the single wideband video channel into many parallel channels, each of moderate bandwidths. This approach simplifies the signal processing functions compared to handling one very complex channel. The pixel is a photodiode. The charge on the photodiode is transferred to a shielded vertical CCD register. The charge is then transferred, line-by-line, to a horizontal register. The horizontal registers are then read as a block through a parallel channel. Each block must be balanced and maintained at precise black/white reference levels to produce it's outstanding image uniformity.

This sensor has anti-blooming structure designed to handle large amounts of light overload. This anti-blooming works so well that the sensor can look directly into flood lamps and still capture the surrounding scene. This sensor also has an electronic shutter that can operate at a 50 usec exposure per frame. The shutter can be position at any point within the frame. This provides a method to synchronize the frame to subject at a precise time interval.

To produce color, the sensor has a proprietary Color Filter Array [CFA]. This CFA will filter light into red, green and blue wavelengths for certain pixels. The filtered pixels are later interpolated into a full 24 bit color space. The color interpolation is done in a Kodak custom color co-processor designed for this array. This color processing will be covered in later sections.

The sensor has excellent sensitivity. In the Imager, the ASA speed is 480 for color and 2100 for monochrome. The sensor's spectral response is between 400nm to 1000nm.

Color Filter Array

A Color Filter Array (CFA) on the sensor produces full-frame, accurate-color images. Kodak was granted a U.S. Patent for this CFA called a Bayer pattern. It is designed for progressive scan sensors. The array is composed of a kernel of 4 pixels. The filters are deposited during fabrication of the sensor. Two corner pixels are green while the opposite corners are blue and red. A custom IC was designed to calculate in real-time 24-bit color [RGB] by reading the Bayer pattern and interpolating the two missing color pixels. Three color values per pixel must be calculated, red-green (rmg), green (g), and blue-green (bmg). All of the green pixels, rmg and bmg must be calculated. At the red pixels, bmg must be calculated. At the blue pixels, rmg must be calculated. Color difference values are obtained from either horizontal, vertical or bilinear interpolation of the color difference values at the chroma pixels. An array is as follows:

line 1	B1	G1	B2	G2	B3
line 2	G4	R1	G5	R2	G6
line 3	B4	G7	B5	G8	B6
line 4	G10	R3	G11	R4	G12
line 5	B7	G12	B8	G13	B9

At a horizontal edge: missing green pixel (g') = 1/2(G5+G6) [1]

At a vertical edge: missing green pixel (g') = 1/2(G2+G8) [2]

Both edges or no edges: missing green pixel (g') = 1/4(G5+G6+G2+G8) [3]

Using the missing green pixel (g'), the rmg and bmg values are calculated as follows for a red line:

line 1	B1-g'	G1	B2-g'	G2	B3-g'
line 2	G4	R1-g'	G5	R2-g'	G6
line 3	B4-g'	G7	B5-g'	G8	B6-g'
line 4	G10	R3-g'	G11	R4-g'	G12
line 5	B7-g'	G12	B8-g'	G13	B9-g'

examples:

calculated by horizontal interpolation rmg @ G5 green pixel = 1/2 [(R1-g') + (R2-g')] [4]
calculated by vertical interpolation bmg @ G5 green pixel = 1/2 [(B2-g') + (B5-g')] [5]
calculated by bilinear interpolation rmg @ B5 blue pixel = 1/4 [(R1-g') + (R3-g')+ (R2-g') + (R4-g')] [6]
calculated by bilinear interpolation bmg @ R2 red pixel = 1/4 [(B2-g') + (B5-g')+ (B3-g') + (B6-g')] [7]

Prior to these calculations, the pixels must have all offsets removed and be white balanced to achieve proper neutral tones. Other signal processing is done on the pixels after interpolation. Edges are enhanced to bring out fine detail by extracting the high frequency terms from the green field. These high frequency terms are scaled to ignore large edges. The pixels are next passed through a color correction & space conversion matrix for the RED, GREEN and BLUE colors. These colors should correspond to the SMPTE XA/11 standard referenced in the CCIR, 709.

Sensitivity

The photometric sensitivity for the Color Imager at 1000 fps [no shutter] is 480 ASA and 2100 ASA for the Monochrome Imager. These numbers are with an IR Blocking filter at 670 nm. The lighting source was xenon. This ASA calculation is not straight forward due to the differences in spectral response, radiometric for the sensor visa versa the photometric response for film. Film's spectral response beyond the fog level (30% above background noise) is between 300 nm to 700 nm. The sensor's spectral response is between 400nm to 1000nm. Figure 3 shows the spectral sensitivity curves for each type of sensor.

Figure 3 Color and Monochrome Sensor Spectral Sensitivity

The Monochrome Imager sensitivity is high enough to take pictures at 1000 fps in normal room lighting. This high sensitivity is due to several factors. First, the CCD was designed specifically for high speed applications by Eastman Kodak Company. It has a 16 micron pixel that provides a large well for collecting charge. Also, this sensor has highly efficient structures for transferring charge at minimum electronic noise levels. Second, the signal processing electronics can amplify the CCD signals with very little additive noise. In fact, at low gain levels, the SNR is limited by the quantizer. This means the noise of the channel at these gain levels is actually less than that of the sensor. The Signal-to-Noise Ratio (SNR) is defined as:

$$\text{SNR (db)} = 20 \log_{10} [S_{\text{electrons, full well}} / N_{\text{electrons, noise}}]$$

$S_{\text{electrons, full well}}$: is the signal charge in electron's rms stored in the fully saturated well.

$N_{\text{electron noise}}$: is the standard deviation of noise in electron rms.

The sensor has approximately 66 rms noise electrons with a full well of 100,000 rms signal electrons or a SNR of 63.6 db. The dynamic range for the sensor is about 1024 to 1.

Anti-Blooming

The Imager can accept light overload levels of many times that of full white, localizing the peak to only the saturated pixels. The sensor has specifically been designed to operate at high speeds with anti-blooming control. This is unique for high speed sensors. This anti-blooming works so well that the Imager can look directly into flood lamps that saturate a portion of the image and still capture the surrounding scene. Most CCDs and video tubes will bloom the entire image resulting in no information content for the scene. Capturing an unpredictable [explosion] event at high speed will often result in loss images due to a bright light washing out the scene. Most often, these images are the most critical ones since the cause of the unpredictable event, an explosion, can only be found in the images. This is why anti-blooming for high speed video imaging is so critical.

Frame Rates & Shutter

The frame rates for the Imager are 250, 500 & 1000 Frames/Second. These frame rates should provide a wide enough temporal range for most high speed applications. Temporal rate alone is not sufficient in stopping high velocity objects. An electronic shutter is essential for providing the stopping power. The shutter is disabled at 1/frame rate to allow the exposure period to be equal to the framing period. Periods of 50 uS, 100 uS, 1mS, 2 mS & 4 mS are the shutter rates.

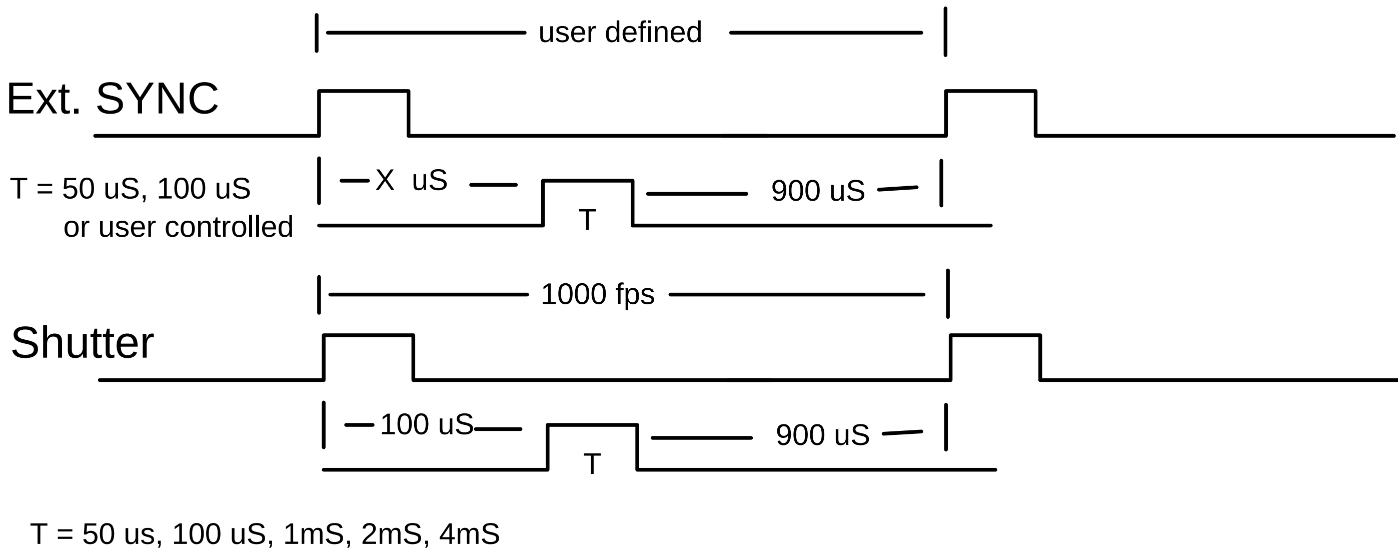


Figure 4 Shutter Timing

Resolution

The geometry of the Imager defines 512 active pixels horizontally by 384 active pixels vertically. The Imaging area is 8.7 mm (H) by 6.5 mm (V). The Imager lens format is "C"-mount. The theoretical limiting resolution is 31.3 lp/mm. Figure 5 shows the CTF curve monochrome sensor. Figure 6 shows a monochrome image of a chart taken at 1000 fps that gives the resolution in TV lines. Spacial modulation can be seen near the 512 x 384 resolution of the sensor. Figure 7 shows the CTF curve (lens not subtracted out) of a monchrome sensor and a color sensor operated in a monochrome mode. This show a reduction in the spatial resolution 25%. This spatial reduction is expected with any sensor using a CFA to produce color images. Figure 8 shows the green channel for the color sensor plotted next to that of the monochrome sensor. As would be expected, the green channel is limited in spatial response due to the CFA kernal configuration and size.

PROCESSOR TECHNICAL DESCRIPTION

The Processor provides all the image storage, communication, color processing, display and control functions for the motion analyzer.

The system architecture of a motion analyzer has many demands placed upon its performance. The architecture has to process the image data at a rate that will capture the event under analysis. The architecture must also be versatile and easy to operate. Above all, the analysis functions of the system must meet the evolving needs of the user. The VME System Controller has the power to meet these needs.

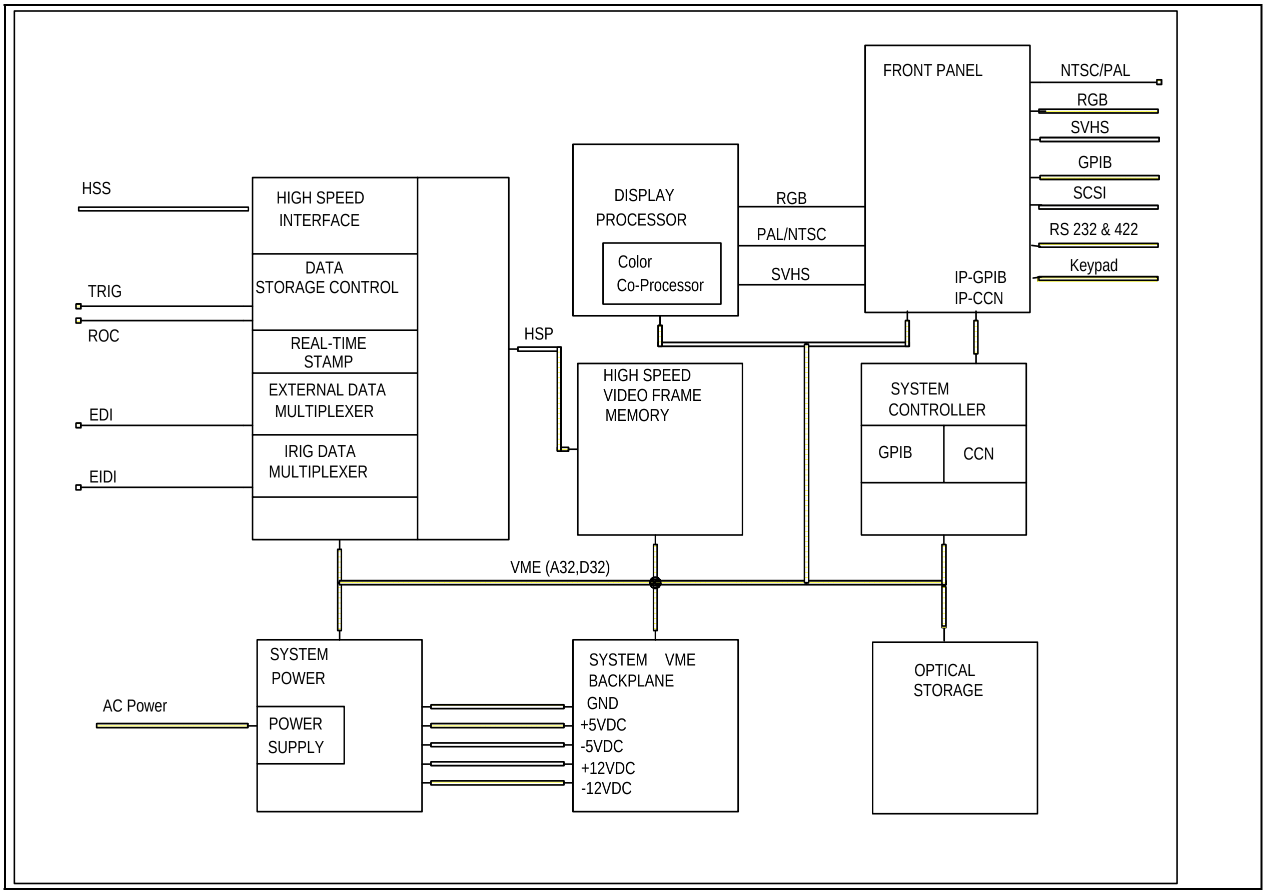
The Processor's architecture meets the need for storing image data at high rates. There are two types of image storage within the Processor, DRAM and an optical disc drive. DRAM storage is used to capture images at the record rate. Optical storage is used to save digital images for future analysis or transport to a different platform [i.e. PC, MAC].

Versatility requires the Processor to have a variety of communication interfaces. SCSI is provided for fast transfer of images. GPIB is provided for interfacing to other instrumentation. RS-422 is provided for long distance communication and RS-232 for short distance communication. These interfaces all have the capability of controlling the Processor and transferring images.

The quality of color processing and display of images from the Processor should meet the user's need for higher resolution. The Reticle, Grid and archiving images on optical storage will helps the user to analyze the images. Shown below is a block diagram of the Processor. Each block will be briefly described.

System Controller

The System Controller is a high performance VME single board computer using the 68040 processor. It provides the SCSI, GPIB, RS422 and RS232 communication interfaces.



Display Processor

The Display processor extracts data from the image storage system over the VME bus during LIVE, RECORD and PLAY states. Video signal generation and distribution are performed by the Display processor. The Color Co-Processor is a FPGA. It is for reconstruction of color images from a progressive scan CCD with a color filter array pattern. This co-processor interpolates a CFA image to 24-bit RGB image at 30 fps. The same processing on a 66MHz 486 DX2 PC compiled for Win32 takes 2 seconds per image!

Data Storage Controller

External Data Storage is managed by the Data Storage Controller. The two signals that effect the storage of images, ROC and TRIGGER, are processed by the Data Storage Controller. The Data Storage Controller performs the trigger positioning function required in triggered record mode. It also performs the ROC function by selectively enabling the storage of frames transmitted by the Imager.

High Speed Video (HSV) Frame Memory

The Image Storage Sub-System (ISS) is designed to record high speed digital video data that can be randomly accessed by the Processor bus. The incoming video data is stored into DRAM. The DRAM buffer is designed as a circular buffer of n frames. The value of n will be programmable to support the multiple record sessions feature. The maximum capacity of the DRAM buffer is 5454 frames. The memory sub-system has an interface to the system on the 32 bit VME interface.

Front Panel

The Front Panel Assembly provides the transition from external to internal interfaces.

System BackPlane

The system Backplane is a standard 6U VME motherboard.

System Power Conditioner

This subsystem transforms 115/220 VAC to various voltages required by the Processor and the Imager. Appropriate EMI filtering is incorporated to ensure compliance with regulatory standards.

VME Bus

Communication and data transfer over the System Backplanel conform to VME standards. Thirty-two bit data transfers are supported, with data bandwidths approaching 40 MB/s.

Interconnecting Cable System

Interconnecting cables to the Imager allow Imager-Processor distances from 20 feet to 50 feet. This interface could be modified to extend from 100 meters to 1 kilometer. Interconnection of a Processor and an Imager requires a single 1/2 inch cable. This single interconnection provides all data, video and power transmission needed for the Imager/ Processor system.

Optical Storage

DRAM memory is a very effective storage medium for high speed operation. However, it is volatile in that the images are not permanent. Power removed from the DRAMs will cause all image data to be lost. Storing to video tape is effective for presentations. However, if analysis of digital data or uploading the original test is required, an optical drive can be a very good storage medium. The EktaPro HRC has an optional magneto-optical drive. The drive has a removable cartridge that allows 1.2 GByte storage (appox. 6000 frames). After capturing an event, the session or parts of a session can be downloaded to the optical drive. Later, this same session can be reloaded into the Processor for analysis. The cartridge can be removed and placed into a PC, Mac or some other workstation. Images can be analyzed on these workstations as well. The image data is stored in the most compact form as "raw pixel data." Otherwise, the file size would be 3x larger.

HRC Embbeded Tools

Color Balance & Uniformity

The user may alter the image color balance by selecting between pre-defined color temperatures or defining an area within an image as a white patch. The best choice depends on the color temperature of the source of illumination. Color balance selections are provided to correct color balance for 5600 degree sources, such as Daylight and Xenon Flash tubes, 4500 degree sources, such as metal-halogen illuminators, 3200 degree sources such as Tungsten Incandescent lamps or under the users own lighting conditions.

Making sure that the image is uniform when exposed to a white or black flat field will help to produce high quality images. The user has the option to rebalance the Imager to produce a uniform field. Normally, this is not required, however, the capability is still accessible through the keypad. This process is similar to White Balance on a camcorder. A uniform white area needs to be imaged. The Processor changes the red, green & blue gains until the selected area is white. The Black Level process is similar except the lens is capped during this process. This process is expected to be required only when the user wants to do it and is not a regular part of ordinary product use.

Exposure Modes
The User has control of exposing and capturing image frames in several ways, dependent on a user application requirements. Selections of various Exposure Modes are made at the keypad. When the ROC is selected at the keypad, the image capture is continuous but image storage is qualified by the user's signal input to the ROC connector. Externally synchronized mode is also selected from the keypad. It allows the user to stimulate frame capture at any rate, or periodically, up to the maximum capability of the Imager. Externally synchronized image exposures occur when the user inputs a signal at the SYNC connector on the Imager body. When a single pulse is detected, the sensor is exposed for the selected exposure period. Following this, the image is transferred to the processor. Subsequent image capture will await the next pulse.

The advantage of these exposure modes are to image only what is nessecary and to synchronize the Imager to an application. It also allows the precise synchronization of multiple Imagers when more than one system is used.

Computer Control
Control of the system by a host computer is allowed in all configurations through the standard interfaces. Simultaneous control over more than one interface is not allowed. Each of the external control interfaces (RS-232C, RS-422, GPIB, SCSI) has a command set that has the same functions as found on the keypad. This means that these interfaces provide the user with a command set that can do everything the keypad can do, plus more. These external interfaces allow the downloading of RGB data, the downloading of a subset area of the video, the ability to "goto" a specific frame number within a session, the ability to move the Reticle or Grid to a specific coordinate and to receive motion analyzer status information.

The SCSI interface is a single ended 8 bit bus that has no termination. The image transfer rate on the optional optical disk is approximately 2.5 images/second. Although the SCSI bus can operate up to 4 MB/s, the magneto-optical drive transfer rate limits the down/up loading of images. The file formats on the SCSI cartridges are MS-DOS. A session is stored as a directory. Under the directory that has the name of the session will be individual files. These files have the name of the frame number including minus numbered frames.

Multi-Event Recording
The Processor memory can be broken into smaller record sessions. Through the Keypad, the user can specify how many recording sessions desired. Each session will be the same length. Therefore, if the Processor had 5000 frames and the user specified 5 record sessions, each session would last for 1000 frames. All of the record modes may be used in this configuration.

The advantage of this multi-event recording is that idependant recordings can be made without having to archive the images. It allows for fast comparision of multiple test. It allows for very long record times when used with a Trigger signal. The Processor can be put into an automatic rearm mode. Therefore, after a Trigger signal is recieved and the memory has filled, it will rearm itself for another recording. This contiues untill the last session is filled.

Display Modes
Two display modes are selectable from the keypad, a single-frame display mode and a multi-frame display mode. The RGB display operates at 640x480 pixel resolution. Graphical and "Data-Frame" information is displayed with 16-colors, with a 512x384 24 bit accurate-color window for video images. Multiple Image frames are displayed in a 4x4 array, within the video window occupied by the single frame described above. The user can step frame-by-frame with thumb-nail images wrapping from top to bottom.

There are three simultaneously supported video display interfaces. The RGB output is on standard VGA connector. The RGB port provides the maximum resolution and image stability. The NTSC/PAL output is on a coax connector. This base-band video signal is provided to allow the user to setup the Imager while composing the scene and to provide VCR archival data storage capability. The SVHS output is on a standard S-VHS connector. Separate luminance and chrominance signals permit the high quality archival data storage capability possible with S-VHS VCR's.

External Data

There are optional interfaces for IRIG-B timing data and user data. The IRIG-B interfaces accepts a FM carrier to sync the internal timecode. The user data is through the Kodak MCDL interface. This MCDL provides the user with two analog inputs and 6 digital inputs. The maximum external data recording rate is 10 samples per frame. The MCDL data during playback of images is displayed on a x-y graph below the image area. The two channels are in differant colors. The entire sample is displayed with the current frmae indicated by a marker on the plot.

The advantage of this display is the instant correlation of user data to image data. An example would be a a tranducer measuring pressure on a container under destructive testing. When the container begins to destruct, the visual change in the container can be observed along with it’s pressure. There is no guessing on what actually happen!

Grid

Users will often only analyze an image by observing what is moving within the scene. Our analyzer has X-Y reticles for measuring a displacement. However, laying a grid on top of the image would provide more visual data for referance. Therefore, we have provided the user with both a retanguliar and circuliar grid. This grid is not part of the image but an overlay. The grid can be calibrated from the Keypad and display. Calibration requires a setup of the user defined points within a live image. This setup is accomplished by identifying two points, XY1 and XY2, with the distance between these two points being the fundamental unit. This unit will have meaning to the user only and is valid only in the image plane in which the calibration was made. The origin of the grid is controlled by the user.

The advantage of the grid to a user is that the entire image has a referance plane. Judgements on relationships between objects in the scene are easily made with the grid.

Auto Save

Sometimes it takes a lot of patience to capture an fault in a process. Hours may acculmilate before a defect occurs requiring constant recording. The table below shows the amount of storage require to capture every image for 1 hour and how long it takes to play these images.

Activity	Quanity
1000 FPS Recorded for One Hour	3.6 Million Frames
Playing the Recording at 30 FPS	33.33 hours

Searching through 3.6 million frames to find a few frames that show the defect occuring can be very monotonous. A better approach is to record only what you need, archive and rearm for the next occurance. The user can configure the Processor to automatically save sessions on either the VCR, the SCSI or both VCR & SCSI. Therefore, a tranducer is set up to detect the problem under observation. The signal from the trasducer is used as a trigger for the Processor. When the Processor is triggered, it enters a Stop state. The last session will be saved on the selected device. After downloading the recorded frames the system rearms itself for the next session. When a VCR is used to record the images, there is a VCR interface that will command a proffessional recorder.

The advantage of AutoSave for a User is time. It provides a way to extend record time over long periods. It also saves time in finding the images that are important since these are the only ones saved.

Applications & Tools

An application that is very demanding for image analysis is the automotiive crash tests. An example of an image sequence is shown in Figure 7. This sled is on a rail. It is propelled from stand still to 30 MPH by a hydraulic piston. On the sled are replicas of human anatomies called hybrid dummies. These dummies are accelerated in the sled in the reverse direction. Since the dummies are facing in the opposite direction of movement, the motion simulates a deceleration experience in a crash. The sled does not sustain any crash damage in this process, but the dummies receive the full G force of a crash. The test engineers need to measure the displacements of objects in relationship to the crash dummies. Much of this emperical test data will eventually lead to wireframe models that can predit the displacement. In addition to the sled test the car manufactures must perform actual headon crashes called Barrier Test. Barrier tests are very expensive and you want to work out the geometry of the test before a car is committed. Sled tests are often repeated many times before the full scale crash. At the start of acceleration a signal called Time Zero marks the beginning of the test. This signal can be used as a Trigger to the motion analyzer. Once the user starts the motion analyzer recording, the test can begin. As the sled is fired from standstill to full acceleration, the Time Zero signal will trigger the motion analyzer. Frames before the trigger and those after the trigger are saved in memory. In this application, the test normally captures about 300 significant frames. Record-Trigger is ideal for this application.

An application that takes advantage of the resolution, electronic shutter and framing rate is the design of a golf club. The club/ball interface is critical for gaining additional yards, hitting true and having a move forgiving swing. The impact of the golf ball when it is struck be a driver is dramatic. The ball is deformed into an half moon. The club head velocity can exceed 185 MPH during impact. Being able to see the dyamics of the ball covering fold, the grip the groves on the ball, the flex of the shaft and the angle of attack as the ball leaves the club are all important in designing them. The motion blur is tremidious since the field of view is centered on the club/ball impact. A very fast shutter is required to stop this blur. The sensitivity of the camera is also important due to the depth of field. A short depth of field will induce blur as the ball moves away. The higher the resolution, the more sensititive the cameras will be to a given field of view and velocity of the ball. The higher the resolution the more detail and finer edge tracking. The 1000 fps will provide enough sampling that that the ball can be accurately tracked for yaw-pitch and spin. One of the major advantages on the KODAK EKTAPRO Motion Analyzer, Model 1000HRC are the tools provided for real-time playback of images. One of the tools is the calibrated grid. The user can set up a calibrated grid. This grid appears as a series of lines overlaying the scene. The grid type is selected by the users as either rectangular or circular. The origin and scale of the grid are controlled by the user. This allows quick-look estimates of motion while reviewing the images. This Grid is not saved with the images but the calibration value is saved for later reconstruction of this Grid overlay. By using the circuliar grid (calibrated) a fast measurement can be made on the club's angle of attack. Shown below in Figure 8 is the impact of the club face with the golf ball and the circuliar grid overlayed. The HRC is well suitted in this application.

Another tool is the graphical plot of user data (two analog data channels vs. time). This data comes through our MCDL interface at 10 samples per frame with two analog inputs and 6 digital inputs. The horizontal axis of the graph represents the entire session. There are no scales on the horizontal or vertical axis. The range of the vertical axis is the analog channel that has the largest range. The graph is not meant to be a precise measurement tool, but it gives a "birds-eye" view of what has happen during playback of each image. Correlation of external signals used as event markers to the images is very powerful for analysis.

There are several tools for adjusting the image color. The user may alter the image color balance by selecting between pre-defined values or defining an area within an image to use as a white patch. This allows the users to make any adjustments for better color differentiation. This is important in some applications such as automotive testing. There are additional tools for adjusting the color hue. The Imager has anti-blooming on the sensor. This keeps the image from being "washed out" when viewing directly into a bright lamp or light source. This is a very important feature for high speed video. However, in adjusting your scene illumination level it may not be clear when you are saturated in the image. We have provided a tool that clearly identifies in the image which areas are saturated or well under exposed. How it works is very straight forward. By selecting this function from the keypad, the color is turned off except for areas that are saturated or under-exposed. These areas are assigned the color red for over-exposed and blue for under-exposed. The user can then adjust in real-time the lens setting and lighting that gives the very best exposure for an area of interest. After the adjustment, the color is turned back on. The user can convert the color images into a monochrome output by turning the color off through the Keypad. This would allow the user to view the image for slight gray scale changes. These are just a few of the powerful tools in the KODAK EKTAPRO Motion Analyzer, Model 1000HRC. These tools will further advance the scientific art of motion analysis.

CONCLUSION

The EktaPro motion analyzer, model 1000HRC is the first of a new generation of high speed motion analyzers from Eastman Kodak Company. This motion analyzer image quality, color accuracy at high speed and the compatibility of images with 3rd party software will increase the spectrum of new applications for this motion analysis. The Kodak EktaPro motion analyzer, model 1000HRC was specifically designed to take full advantage of Kodak's color technology to produce the highest quality high speed video images in our industry.

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