Digital, Still-Optimized Architecture for Electronic Photography

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Introduction

This paper describes an architecture for electronic camera systems targeted at low cost computer imaging applications. These applications primarily use images to convey information rather than to create consumer or professional photographs. The architecture includes a custom image sensor optimized for still images, in-camera compression optimized for data from single-chip color sensors, and image storage using nonvolatile solid-state memory. Extensive signal processing is performed in the host computer, as the image is downloaded from the camera. The cost, image quality, and ease-of-use advantages of this digital software driven architecture are described. The architecture enables low cost color cameras to be developed to meet a variety of customer needs.

Background

Early electronic photography systems, such as those based on the still video floppy (SVF), used analog video capture and TV display driven formats.[1] These systems were initially targeted at the home consumer photography market, as a replacement for conventional film-based cameras. More recently, digital cameras, using miniature hard drives or removable IC memory cards, have been developed for professionals. These cameras are used in certain photojournalism and desktop publishing applications when there is a need for immediate access to images in digital form. One example is the Kodak professional DCS 200c digital camera, which uses a standard Nikon film camera body, and a custom image sensor with 1.6 million pixels.[2] Because of the high resolution sensor and the use of digital image processing and storage, the image quality from the DCS 200c camera far exceeds that available from SVF cameras, although it is still below that provided by 35 mm film systems. However, the current high cost of megapixel-based cameras prevents their widespread use as computer image input devices.

The Kodak photo CD system is a cost-effective method of inputting photographic quality images into desktop computers.[3] The format of the Kodak photo CD master disc preserves the high resolution and dynamic range of the film image, by creating a "digital negative" with 2048 rows and 3072 columns of data per image. The images are stored on a write-once disc that can be viewed on a home television set, or accessed by a computer using a CD-ROM drive. For some electronic imaging applications, only low resolution images are necessary. Recently, Kodak photo CD portfolio discs and authoring software have been introduced. This format allows 512 x 768 pixel BASE resolution images to be stored along with audio and branching instructions. Over 700 images can be stored per disc, so that the cost of archival storage is only pennies per image.

System Architecture

Figure 1 shows a block diagram of the complete digital electronic photography system. The electronic camera, shown in Fig. 2, captures and stores up to 32 images in Flash EPROM memory ICs. The images are downloaded via a standard serial interface to the host computer. Either an Apple MacIntosh or PC compatible desktop or portable computer may be used. The camera data is processed as it is downloaded to the computer. The software-based image processing both reduces the cost of the camera and allows more elaborate algorithms to be used. The host computer allows the images to be viewed, manipulated, and transmitted. Unlike video-based cameras, no new hardware is required for these features. Images are archived using a Kodak CD writer and portfolio CD discs. The disks can then be played on nearly all computers featuring a CD-ROM drive. Hardcopy prints are created using a thermal dye sublimation printer.

A serial interface connection is presently the most convenient method of transferring images between an electronic camera and a computer. Floppy disk-based cameras typically require a special video frame grabber board in the computer. Memory card-based cameras require a special reader, because few existing desktop computers have slots that accept memory cards. The serial interface data ~~rate~~ depends on the host. Rates of over 800 kbits/s can be supported on some computers, while lower rates are used on others. The camera image file includes low resolution "thumbnail" images[4] that are downloaded first. The user can quickly preview all of the thumbnails, and decide which images to download from the camera.

Camera Architecture

A simplified block diagram of the digital camera architecture is shown in Fig. 3. The scene is imaged by a fixed focal length camera lens, through an optical prefilter, and onto the color CCD. The image is digitized using a single A-to-D

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converter, which nonlinearly quantizes the CCD output signal. The DSP preprocesses the color filter array (CFA) image data into a luminance (green) and two color difference ($R-G_{int}$ and $B-G_{int}$) channels. The preprocessing also increases the immunity to decompression artifacts.[5] The DSP then performs a proprietary ADPCM compression algorithm, to reduce the stored image size. The camera includes a medium resolution mode having 256 x 384 pixels, and a full resolution mode having 512 x 768 pixels. This is a valuable feature, because the Flash EPROM memory storage is the most expensive camera subsystem. Because the camera storage uses a few small ICs, instead of magnetic disks or removable cards, the size and weight is minimized and the form factor constraints are reduced.

The DSP that implements the preprocessing and compression for the two resolution modes is controlled by firmware that can be uploaded from the host computer. The host computer software includes three components: an application program, an image processing module (IPM), and an I/O driver. The application provides the interface to allow users to display, store, and edit images, or to remotely trigger the camera for "tethered" applications. The IPM provides camera image processing functions. The I/O driver provides two-way communications with the camera. Both the camera firmware and host software can be modified to add improved algorithms or enhanced features without hardware changes.

Still-Optimized Image Sensor

A custom image sensor has been developed for the camera. The sensor, shown in Fig. 4, has 512 lines and 768 pixels per line, to match the BASE resolution of the photo CD format. It uses a full-frame architecture, where the scene is imaged directly onto the vertical CCD registers. Because the camera has a mechanical shutter, a separate storage register is not needed. The sensor is fabricated using a two-phase NMOS process with one electrode per phase. This is achieved by using implanted barrier regions under the polysilicon electrodes.[6] The dynamic range is significantly enhanced by using accumulation mode integration and readout.[7] A lateral overflow drain is used for blooming control, and the sensor has no lag or smear.

The sensor has square pixels and progressive scan (noninterlaced) readout to match computer displays and printers. The aspect ratio is 3:2, the same as 35 mm film. Images with 480 x 640 pixels can be provided by storing only the center elements of the array. Because progressive scan readout is used, there is no temporal displacement between adjacent lines. With interlaced readout, some misregistration caused by motion is possible between the two fields. Progressive scan readout also allows the color filter array to be designed for improved vertical spatial sampling. The sensor includes a CFA layer[8] with the checkerboard color pattern[9] shown in Fig. 4. Each photosite is sensitive to only one of the three colors.

Image Processing Module

The key IPM functions are shown in Fig. 5. The CFA interpolation creates red, green, and blue (RGB) values for all of the photosites. People have much higher acuity for luminance, which is composed primarily of green, than chrominance. Therefore, more photosites are used to determine the green luminance signal than to determine the color difference signals. The CFA interpolation adaptively interpolates the highly sampled green record, which also provides high frequency luminance details to the sparsely sampled red and blue records.[10]

The color correction uses fast color matrixing techniques to provide improved color saturation.[11] The red, green, and blue sensitivities of a color CCD have responses that are always positive, and typically include some amount of color crosstalk. For example, the blue photosites may have unwanted response to red light. This crosstalk is removed by a matrix operating on the linear sensor signals. The edge sharpening is implemented using adaptive FIR filters. The vertical and horizontal high-frequency "details" are extracted from the green channel before matrixing, processed, and added back to the red, green, and blue signals.[12] This makes the picture look subjectively "sharper".

Summary

This paper has described a computer-based still camera architecture that offers image quality superior to NTSC video-based still cameras. The digital computer provides capabilities for storing, manipulating, transmitting, and viewing digital pictures. By designing the image sensor specifically for still applications, it is possible to provide both higher image quality and a universal image format. The quality is further improved by digitally processing the image.

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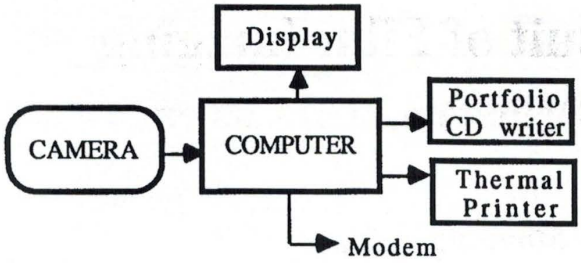

Figure 1. Digital Electronic Photography System

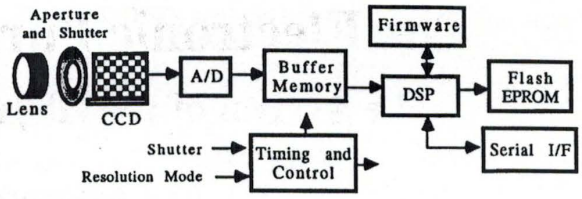

Figure 3. Digital Camera Architecture

Figure 2. Digital Electronic Still Camera

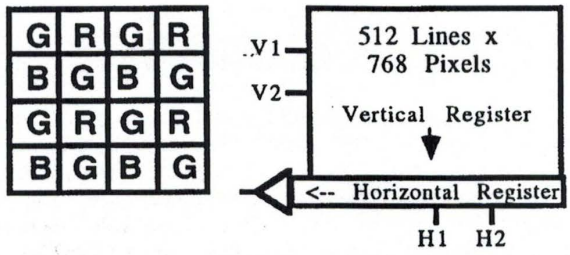

Figure 4. Still Optimized Image Sensor

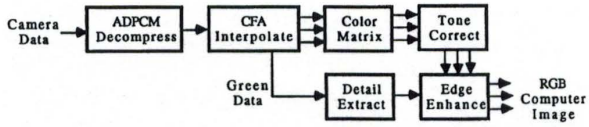

Figure 5. Imaging Processing Module Functions