

A Low-Cost Megapixel Digital Camera Using High-Performance In-Camera Image Processing

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Abstract

Digital cameras are becoming more powerful and affordable with each product generation. This paper describes a new generation digital camera that optimizes image quality and ease of use. Excellent image quality is obtained by employing a megapixel CCD sensor and advanced image processing algorithms. A 1.8" color LCD and a new graphical user interface (GUI) guide the user through the operation of the camera.

The camera has a 2X zoom lens, real image optical viewfinder, and a "camera like" industrial design. A host of "traditional" camera features are supported, including self-timer, five flash modes, macro mode, and exposure compensation. These features are augmented by digital camera features including preview (live viewfinder), instant image review, in-camera finished files (Exif/JPEG and FlashPix image formats) and video output.

Significant digital signal processing power is required to implement the image processing algorithms and the GUI. A 60 MHz RISC processor with an on-board 16-bit DSP coprocessor provides all of the camera image and display processing functions. The image processing functions include color filter array interpolation, white balance, color and tone correction, edge enhancement, thumbnail image generation, JPEG image compression, and file formatting.

Overview

Market Description

The digital camera market is growing at a rate of over 30% per year. A stream of products that deliver more features and better images at decreasing prices is fueling this growth.

Digital cameras were once used mainly by business users (e.g., real estate and insurance) and technologically adventurous "power users". Ease of use was not as large of an issue with this class of user. Large businesses wrote custom software tailored to their workflow and provided training on the use of the cameras. The camera was viewed as another business tool that improved efficiency and customer satisfaction. The technology driven user is very familiar with computers and related peripherals. Digital cameras were just another challenge.

Consumer interest in digital photography began with the Casio QV-10. This was the first camera to combine a digital camera and a color LCD, but at quarter VGA resolution the image quality was not acceptable for most applications. As is usual in electronic products, rapid improvements have since followed. The Kodak Digital Science DC210 zoom camera is a good example of latest in consumer oriented digital cameras.

Design Goals

Three major design goals were chosen for the Kodak DC210: the camera must capture excellent images, it must be easy and fun to use, and finally the camera needed to be affordable.

Excellent images were defined as photo realistic 5 x 7 sized prints. The technical details of how this goal was accomplished will be covered later in the paper.

If the Kodak DC210 was to be a success it must be easy to use by consumers. This problem was attacked in two main ways.

First the DC210 was designed to be very "camera" like. Meaning the design team wanted the user of a traditional film camera to feel comfortable with the DC210. This included the way the DC210 looks holds and operates. To accomplish this goal the DC210 has many of the standard film camera features (2X zoom, real image optical viewfinder, 5 flash modes, macro, self-timer, and exposure compensation) along with a "camera" like industrial design.

The second area of ease of use centered on the "digital" features. The DC210 needed to provide features that a film camera could not and it needed to do this in a way that was easy and fun for the user. User interaction, electronic view-finder and image review are provided using a 1.8" TFT color LCD. A menu-driven user interface that uses colorful screens and icons along with large stylish text to engage the user is provided. The user interacts with the interface using large buttons, with strong physical to function correlation, surrounding the LCD. Once the images are captured they may be reviewed and shared using either the color LCD or video out.

The last design goal was to deliver the DC210 for a price of $899. The Kodak Digital Science DC120 zoom camera became the first mega pixel camera for less then $1000 when it was announced in March of 1997. Therefore, this goal shows the aggressive price curve that this product segment is on.

Camera Features

The Kodak DC210 zoom camera, shown in Figure 1, provides a full set of features to the customer. The scene is framed using the zooming real image optical viewfinder. The color LCD can be used as a electronic viewfinder and is automatically used for framing when using the macro feature. The image is captured using an all-optical glass 2X zoom lens and a high-resolution CCD. The CCD is a 1/3 inch, square pixel, interlaced scan type. A RGB Bayer color filter array[1] is used on the CCD. Proprietary image processing algorithms are used to provide maximum image quality from the system. Low light photography is made possible by the on-board quenching strobe. The user can select automatic, fill, red eye reduction, and off modes of the strobe. For difficult lighting conditions the user can adjust the exposure by ±2 stops using the exposure compensation screen. All the image processing is done in the camera. The user can tradeoff between image quality and the number of images that can be stored by adjusting both resolution and compression rate. Two levels of resolution, full (1152 x 864) or VGA (640 x 480), and three levels of compression are provided. The user also may select between two output file formats (EXIF (.jpg) or FlashPix).

Figure 1. Kodak Digital Science DC210 zoom camera.

Once the images are captured they can be used in a number of ways. They can be viewed on either the color LCD or on a TV using the video out (NTSC or PAL) of the camera. They can also be transferred to a personal computer via the serial interface, IrDA 1.0 or PCMCIA card reader. Software is provided for WIN95, NT4.0, and MAC OS, and since the files are of standard formats, they can be used without special software.

Camera Architecture

Architectural decisions have a large impact on schedule, development cost and final product unit manufacturing cost (UMC). A low UMC was desired, but due to an aggressive schedule large scale integration was not possible. Schedule drove the selection of off the shelf parts and the cost goal drove the decision to fully implement the image processing in firmware. Product differentiation was delivered by moving newly available technologies (Hitachi SH-DSP, Sharp LZ23H3V CCD) into the finished product in a timely fashion.

Optics

The trend in traditional cameras is leaning strongly towards zoom lenses. Digital cameras users have the option of post capture zooming and cropping but the operation results in lower image quality. Therefore a 2X zoom lens was selected. Most current digital cameras have relatively long focal length (45 mm, 35mm film equivalent) lenses. Consumers and the real estate market both prefer to have a wider-angle option. Therefore the lens was designed with a relatively short focal length position of 29 mm (35 mm film equivalent).

Focal Length	4.4 mm to 8.8 mm
Equivalent 35 mm focal length	29 mm to 58 mm
F number	F4.0 to F4.7
Focus Range	
Wide angle	0.5 meters to infinity
Telephoto	1.0 meters to infinity
Construction	8 elements in 8 groups
	Optical quality glass

Color LCD

A major feature of digital cameras is the color LCD. Customer testing had shown that the dynamic range (contrast ratio), brightness, and color saturation delivered by TFT displays made them preferable to other technologies. Customers also preferred larger displays (2.5 inch vs 1.8 inch). The design team traded off these inputs with the other contradicting requests of small size, low cost, and better battery life. The final compromise was to use a 1.8" TFT display.

Technology	TFT
Size	1.8" Diagonal
Resolution	279 (H) x 220 (V) pixels
Color Filter Array	RGB Checker

Hardware Architecture

The hardware block diagram is shown in Figure 2.

A Hitachi SH-DSP running at 59 MHz is used as the main processor of the camera. The design team has extensive experience with Hitachi processors having used SH-1s and SH-2s in previous cameras. The SH-DSP combines a SH-2 16-bit RISC processor with an on board 16-bit DSP. It also has 48KB of internal ROM and 8KB of internal RAM. Internal memory can be accessed in a single CPU cycle and the DSP is designed to work especially well with internal memory. Therefore, ROM is used to hold the image processing code.

An 8-bit microcontroller handles most of the "camera" type functions. It provides the interface to the user inputs (buttons) and is used to control the zoom motor drive, shutter drive, strobe, black and white LCD, real-time clock, and power supply. The main criteria used in the selection of this component are code reuse from previous programs, number of I/Os, cost, and the availability of a pin compatible One-Time Programmable version.

KODAK DC210 Zoom Camera

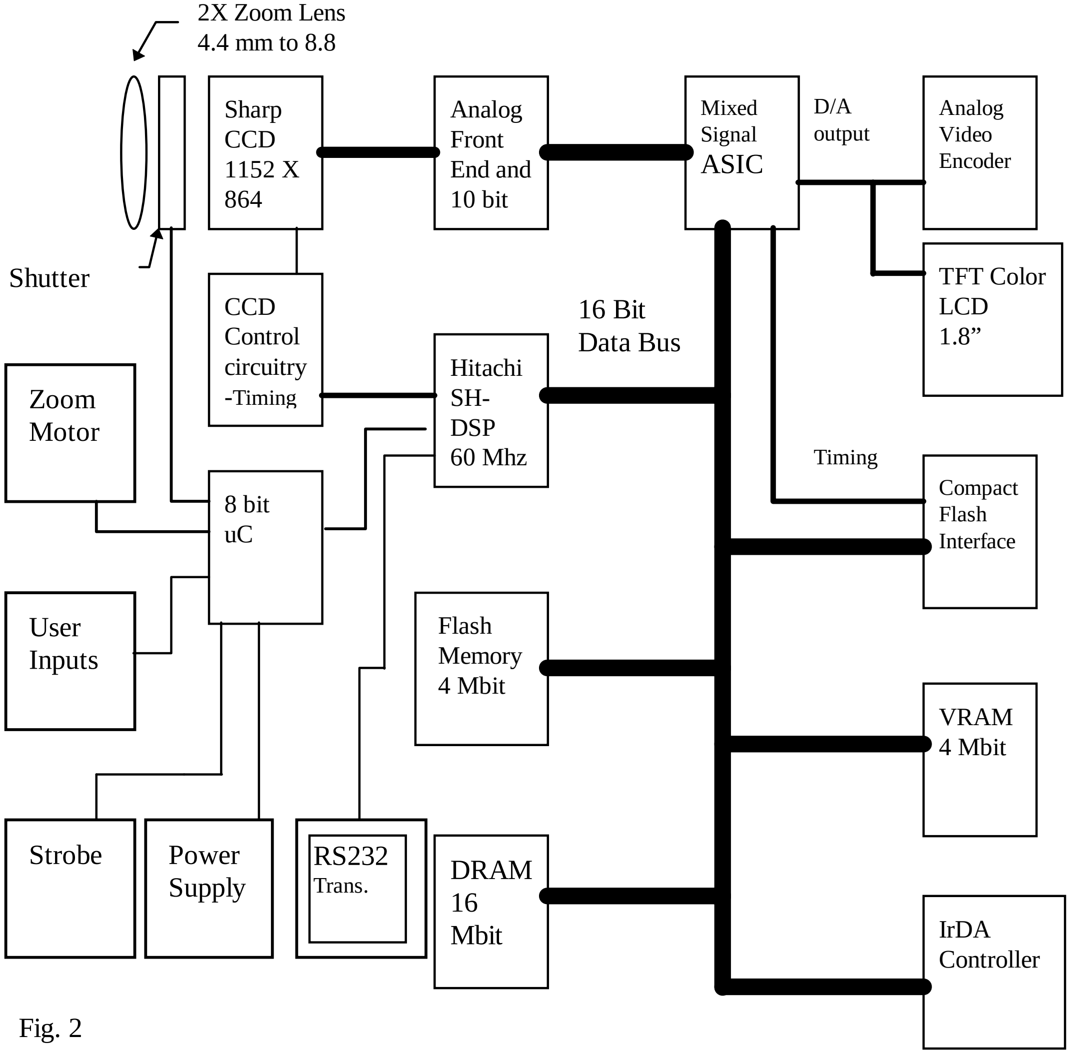

Fig. 2

Program code is stored in Flash memory. This allows easy upgradeability during development and the option of customer upgrades. Image processing code resides in ROM but can be "patched" from Flash based code. To keep costs to a minimum the DC210 uses 4 Mbits (256K x 16) of Flash.

DRAM is used for code execution and image buffering. At start up the program code is copied from the Flash memory into the DRAM. The version of SH-DSP that is being used does not have any cache. Therefore, the performance achieved by executing code directly from the Flash memory would be unacceptable. To keep system cost down, a minimum of DRAM was used (1M X 16). This is enough for program code, stack, buffers, and 1 CFA of data. A complete interpolated image file (3MB) will not fit because of ramifications that will be discussed later.

Data for the color LCD or video is stored in VRAM (256K x 16). This approach was taken over storing the data in DRAM and using DMA because it had a much smaller impact on bandwidth. The VRAM can hold several color LCD size images. This allows one image to be displayed while a second image is being written into memory.

A mixed signal ASIC implements a number of features. Four D/A converters are used to generate the analog signals required for the color LCD (analog RGB) and analog video encoder (Y, CR, CB, and f_{sc}). A look up table is used to convert the 10-bit linear CCD data to 8-bit nonlinear data. Live viewfinder image processing is accelerated by the use of hardware filtering and sub sampling. Control signals for the compact flash interface, CCD and color LCD are also generated by the ASIC.

An off the shelf IrDA controller and transceiver are used to implement the IrDA 1.0 interface. Two main considerations drove the design team to this selection. The first was how to obtain the protocol layers for IrDA 1.0. The supplier of the controller provided source code for the IrDA 1.0 protocol stack. The code was written for the SH family and required minimal changes. Along with the source code the supplier provided a testing environment that verified not only the protocols but also the physical layer. The second consideration was schedule. The ASIC vendor that had been selected was in the process of developing an IrDA macro but would not have proven silicon in time.

Data Path

A good way to understand the operation of the camera is to follow the image data. A typical image capture can be simplified like this. First, upon the users request the image data is read from the CCD. Timing generation along with vertical and horizontal drive signals are generated by a chip set that the CCD vendor supplies. The analog CCD data is converted to 10-bit digital data by an integrated CDS (correlated double sampling), 10-bit A/D IC. The 10-bit linear data is compressed into nonlinear 8-bit data by the mixed signal ASIC. The 8-bit data is packed into 16-bit words and is DMA'ed into DRAM. At this point the CFA data is processed by the SH-DSP into the final image, JPEG is compressed and stored into the compact flash memory card. There is not enough DRAM to hold the fully interpolated image. Therefore, the interpolation to image processing to JPEG to storage on the compact flash chain is done on block subsets of the data.

Stored images are displayed on the color LCD using the following flow. The thumbnail image is read from the card, processed, and displayed. This can be done very quickly and allows the user to quickly get to the image they are looking for. After the thumbnail is displayed, a higher resolution image is generated in the following manner. A subblock of image data is read from the compact flash card decompressed, processed, subsampled, and written to VRAM. This loop continues until the whole image has been processed. At that time, the new data is displayed on the color LCD.

Image Processing

All image processing for the DC210 is implemented in the camera (finished files). The resulting image files may be used with a wide variety of imaging applications. If the user has a PCMCIA card reader they can use the image files without any camera specific software.

Providing in-camera finished files greatly increased the MIPS requirements. Kodak uses proprietary algorithms in their image processing, some of which are computer intensive. Previous cameras had deferred this task to the customer's personal computer but to increase the ease of use of the camera it was decided finished files were a requirement. For cost reasons it was decided that all the image processing would be done in firmware. The SH-DSP provided the performance that was needed.

To take advantage of the SH-DSP to minimize the image processing time it was necessary for almost all of the image processing code to be written in assembly language. The code also needed to be executed from the internal ROM. This required the image processing firmware to be completed early in the development cycle.

Hitachi provided the JPEG library.

The following operations are performed during the image processing (not in order)

1. White Balance Correction
2. Thumbnail Generation
3. Quick View Image Generation
4. Defect Concealment
5. Interpolation
6. Edge Enhancement
7. Color Correction
8. Size Reduction (for VGA output image)
9. Color Space Conversion (RGB to YCC)
10. JPEG Compression

Two output file formats are supported in the camera. EXIF 1.0 is essentially a JIFF file with TIFF tag information. This file format can be read by a wide variety of JPG readers. The TIFF tag information includes a variety of image capture parameters that could be used by down stream devices to provide better output images.

The second file format is FlashPix. The DC210 is the first camera to implement this new file format. The FlashPix implementation that existed at the beginning of the camera development was targeted for the PC. Therefore, it required lots of code and working space. The firmware team developed a full reader writer implementation that fits within the tight resource limitations of an embedded system.

Conclusion

This paper describes a new digital camera targeted at the consumer market. The camera is more of an evolutionary product than a revolutionary one, but it provides an excellent example of the current digital camera market. The camera provides excellent image quality and has increased ease of use at a lower price point than was possible only 6 months before. It is this kind of evolutionary improvement that will continue to drive the growth of digital photography.

Acknowledgments

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References

1. B.E. Bayer, "Color Imaging Array", U.S. Patent 3,971,065 (1976).