DESIGN OF HIGH RESOLUTION DIGITAL CAMERAS FOR PRE-PRESS APPLICATIONS

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Abstract

This paper describes a family of 6.3 Megapixel digital cameras. The technology, features, and professional photography applications of these cameras will be presented. The family includes three different models, the Kodak Professional DCS 460 digital camera, the Kodak Professional EOS-DCS1 digital camera, and the Kodak Professional DCS 465 digital camera back. The DCS 460 and EOS-DCS 1 cameras utilize Nikon N90s and Canon EOS1n professional 35 mm camera bodies, respectively. The DCS 465 camera back can be used with numerous medium and large format camera systems.

The cameras are designed for portability and photographic versatility. The internal battery allows an average of 150 exposures per charge, and the battery can be recharged in as little as one hour. The PCMCIA interface is compatible with Type III-ATA removable disk drives. The integral SCSI interface allows quick connection and image download to a host computer. Voice annotation is provided for image documentation purposes. The DCS 460 and EOS-DCS 1 cameras are built on familiar professional 35 mm film camera bodies, and are compatible with the entire suite of lenses and other accessories offered by Nikon and Canon. The DCS 465 camera back incorporates a universal mounting system, developed by Eastman Kodak Company, which has been adopted by Hasselblad, Mamiya, Sinar, Toyo, and others.

The imaging technology used in the cameras allows for single exposure color image capture. The "single-shot" color capability, using 6.3 million pixels, provides a system that has tremendous versatility in a variety of photographic situations. The cameras can be used as a direct replacement for film in applications, such as commercial and catalog photography, when immediate access to the image in digital form is desired. All three cameras use the *Kodak Digital Science* ™ KAF-6300 Image Sensor. This device has been optimized for producing still images.

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The Family of Cameras

Kodak has responded to the needs of demanding professional photographers with introduction of the three different models of 6.3 megapixel digital cameras. This choice of models caters to the diverse needs that professional photographers place on their photographic system. Most often, the photographer already has a considerable investment in cameras, lenses, lighting equipment, and accessories. Since the digital camera is just another tool in their image capture toolbox, it must fit into this environment without disrupting their working style. Each of the models described here offer features that allow almost seamless integration into an existing photographic environment.

The DCS 460 camera, shown in Figure 1, is based upon the Nikon N90s SLR camera body. This system is compatible with all Nikon lenses and accessories. Due to the large 18.4 mm x 27.6 mm photosensitive area of the CCD imager, the lens magnification effect is only 1.3X. This allows the photographer to work with a wide range of photographic scenes from wide angle to telephoto. Additionally this large CCD area allows all metering modes in the camera body to function properly.

Figure 1. Professional DCS 460 Digital Camera

The EOS•DCS 1 camera, shown in Figure 2, is based upon the Canon EOS1n SLR camera body. This system is compatible with all Canon lenses and accessories. Like the Nikon system, the large CCD allows photographic versatility and compatibility with all metering modes in the Canon body.

Figure 2. Professional EOS•DCS 1 Digital Camera

The DCS 465 camera back, shown in Figure 3, is a camera back that attaches to a variety of 120 and 4x5 professional cameras. The DCS 465 camera back is compatible with the following host cameras:

Hasselblad 500, 503
Mamiya RB67, RZ67
Sinar P, X, and E 4x5 View Cameras
Sinar DCS 465 Digital Camera System
Toyo 4x5 View Camera
Cambo 4x5 View Camera
Arca Swiss 6x9cm View Camera

The DCS 465 camera back has a Kodak developed universal mount system that has been accepted by a large number of camera manufacturers. This allows the photographer more system versatility because the DCS 465 camera back can be moved easily from location shooting on a 120 camera to 4x5 work in the studio. The DCS 465 camera back has interfaces for electrical and mechanical release cameras that further enhances versatility.

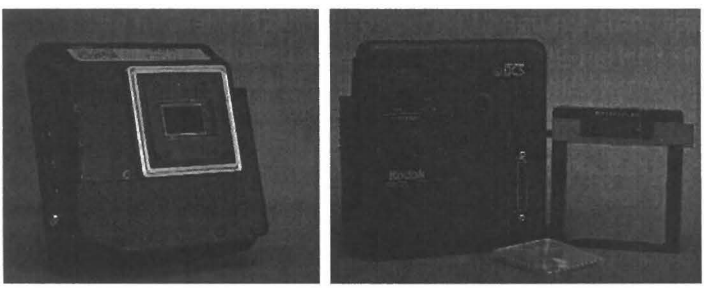


Figure 3. DCS 465 Digital Camera Back

Common Features

Each camera described above incorporates the Kodak KAF-6300 image sensor with 2048 x 3072 pixel resolution. "Single shot" color as well as monochrome systems are available. The color system uses the Bayer color filter array[1](CFA) pattern on the CCD, which when fully interpolated, provides an 18 megabyte output file size. One important design feature of this imager is integral anti-blooming protection using lateral overflow drains. Anti-blooming protection is very important to a portable camera system where the lighting outdoors is sometimes difficult to control.

The monochrome systems are also compatible with the KODAK Color Filter Wheel Accessory, shown in Figure 4. Although it requires three separate red, green, and blue exposures, this produces superior image structure and color quality.

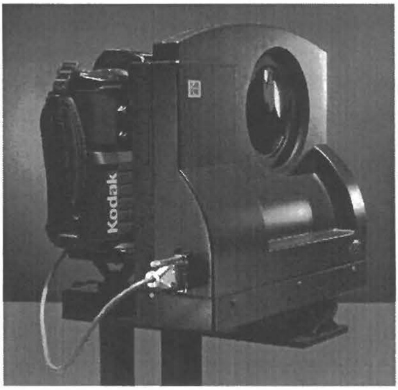


Figure 4. Kodak Color Filter Wheel Accessory

All cameras are powered by an internal nickel metal hydride battery pack that can be recharged in one hour. This battery provides for an average of 150 exposures between charges. This feature gives the photographer freedom to go shooting on location or simply to work in the studio without cables restricting movement. The system is compatible with PCMCIA Type III-ATA removable disk drives, or ATA compatible flash memory cards. A single 340 MB card can store up to 52 images. The built in SCSI interface allows using the camera as a PCMCIA card reader. The system formats the PCMCIA card as a DOS file system. This provides simple access to the images on the card if inserted into a Macintosh or Windows compatible computer. An audio annotation feature is provided, and the sound files are recorded on the disk with the images. Time and date stamps are used to track which images and sound files are related. Multiple sound files for a single image are supported.

From a photographic perspective the system offers impressive performance. The exposure index is rated at ISO 80, which is a familiar speed to photographers who shoot ISO 50 to 100 color reversal film. The CCD data is sampled at 12 bits per pixel to provide the necessary bit depth for recording scenes up to 8 stops (2.40 density) in dynamic range with a density resolution of 0.028 worst case. The upper 7 stops can be recorded with density resolution of 0.01 worst case. Figure 5 shows the actual dynamic range of the EOS•DCS 1 camera (the DCS 460 and DCS 465 cameras have similar responses). This plot is digital output code values vs. relative log exposure, generated by photographing a Kodak 21 step gray scale target. This curve demonstrates the system's ability to capture up to 8 stops of information from the scene. This dynamic range far exceeds commercial CMYK printing, which can only reproduce 4 to 5 stops.[2]

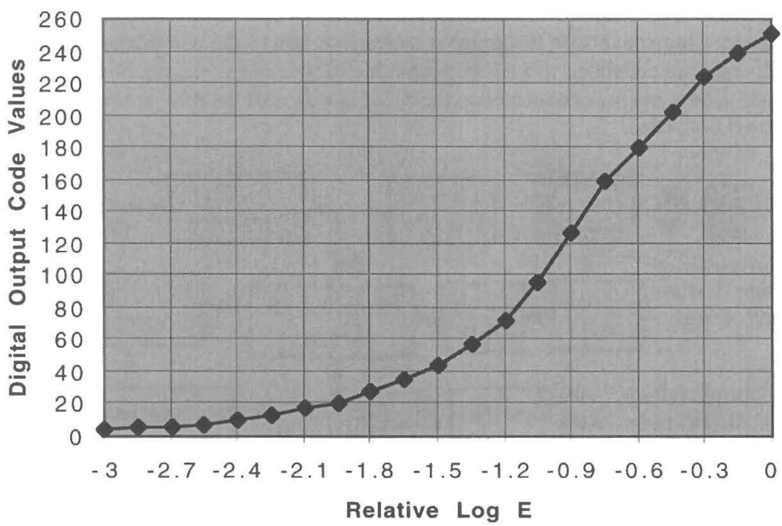


Figure 5. Digital Output Code Values vs. Relative Log E

The user can capture 2 images within 1.8 seconds into the internal 16 MB buffer memory. Additional images can be captured after one image is written to the disk, which averages 8 seconds later.

Applications

Applications for high resolution digital photography are usually driven by savings of time and money. Digital photography provides immediate image access, speeds up the imaging workflow, and eliminates the cost and time delay of scanning film. The primary application for this class of digital camera is commercial photography. Within commercial photography, the applications cover catalog imaging, advertising, and other pre-press imaging. Industrial photography is also a major application area, as well as government and scientific. Since this camera family is portable, and provides high resolution single shot color images, it can directly replace film in many applications.

Digital Camera Architecture

A block diagram of the camera system is shown in Figure 6. The scene is focused though the camera lens onto the CCD imager. The host camera controls the lens aperture and shutter speed. The output of the image sensor is amplified and digitized using a linear 12 bit analog-to-digital (A/D) conversion circuit controlled by a 4 MHz pixel rate clock. The 12 bit/pixel output of the A/D is processed by a proprietary algorithm to reduce the bit depth to 8 bits/pixel. Image dynamic range is not affected by this process and visible image quality is also maintained. This is done to effectively double the number of images stored per disk, increase the number of images during burst mode, reduce the disk write time, and reduce the SCSI download time. The result is a dramatic increase in system performance. After conversion the image is stored in a 16 MB DRAM memory. The DRAM images are converted to a TIFF compatible format and stored on the PCMCIA card. Finally, the camera is connected to the SCSI interface of the host computer, and the images are downloaded.

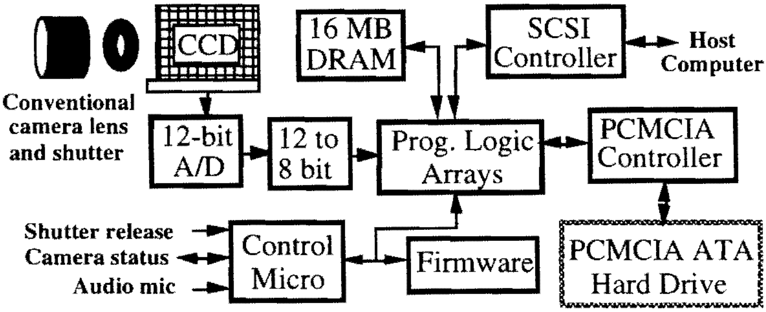


Figure 6. Camera Block Diagram

In all cameras, image processing is done entirely in the digital domain, rather than using analog circuits, to minimize noise and allow sophisticated image processing algorithms to be employed. Limited image processing is done in camera firmware before the image is stored. The more complex algorithms, such as CFA interpolation, are implemented in the host computer as the image is downloaded. This enables the camera to use sophisticated image processing algorithms that can easily be upgraded in the field and customized for special customer applications.

CCD Sensor Technology

The image sensor used in the system employs a "full frame" architecture,[3] where the scene is imaged directly onto the vertical CCD shift registers. The key difference is the number of photosites in the vertical CCD. The vertical register is an array of 9 micron square photocapacitors, shown in Figure 7. Because all of the cameras include mechanical shutters that block the light during image readout, a separate storage register is not needed. The sensor is fabricated using a proprietary "true two-phase" NMOS process with one electrode per phase. This is achieved by using implanted barrier regions under the two polysilicon electrodes, as shown in Figure 8.

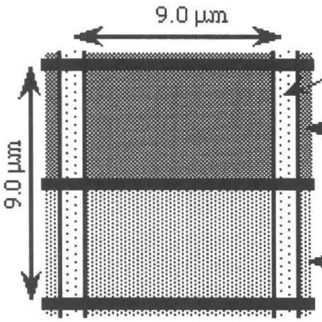


Figure 7. Pixel (from above)

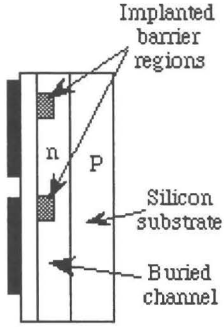
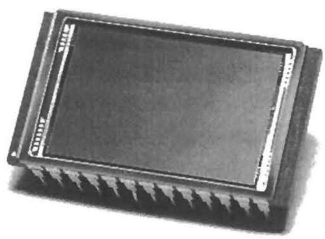


Figure 8. Vertical cross-section

The dynamic range is significantly enhanced by using accumulation mode integration and readout. To produce the accumulation mode, both vertical clocks are held negative during the entire integration period and the majority of the readout period. This holds the silicon/silicon dioxide interface in majority carrier accumulation and greatly reduces the dark current generation. A lateral overflow drain (LOD), shown in Figure 9, is used to prevent blooming. The LOD drains off charge in pixels with high illumination, before the charge capacity of the pixel is exceeded, as shown in Figure 10. This prevents the excess charge from spilling into neighboring pixels and causing visible artifacts. Key sensor performance specifications are listed in Table 1.

Table 1. Image Sensor Performance

Blooming Suppression: >1000
Optical fill factor: 70%
Saturation signal: 40,000 electrons
Output sensitivity: 10 uV/electron
Dark current: <10 pA/cm^2
Total sensor noise: 15 electrons RMS
Dynamic range: > 68 dB
No smear signal with mechanical shutter
No lag



KAF-6300 Image Sensor

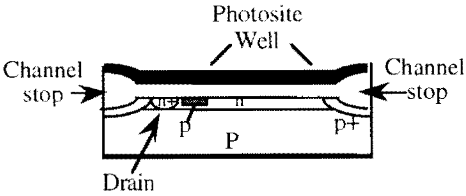


Figure 9. Horizontal cross-section

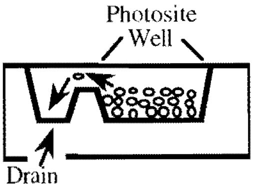


Figure 10. Anti-blooming protection

Because progressive (non-interlaced) readout is used, the color filter array can be designed for improved spatial sampling. The sensor uses the Bayer CFA pattern shown in Figure 11. The CFA is integrated onto the CCD using photolithographic techniques to pattern dye mordants. The Bayer CFA has 50% green pixels arranged in a checkerboard pattern, and alternating lines of red and blue pixels. This results in a diamond shaped Nyquist domain for green, and smaller rectangular shaped Nyquist domains for the red and blue, as shown in Figure 12. The human visual system is more sensitive to high spatial frequencies in luminance than in chrominance, and luminance is composed primarily of green light. Therefore, the Bayer CFA significantly improves the perceived sharpness of the digital image, since it provides the same Nyquist frequency for the horizontal and vertical spatial frequencies as a monochrome imager.

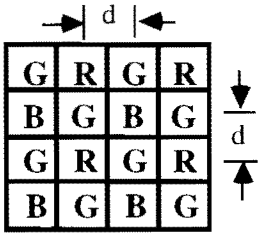


Figure 11. Bayer CFA pattern

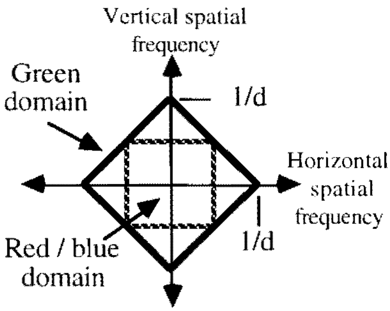


Figure 12. Nyquist domains

Digital Image Processing

The image processing that creates the final output image is performed in a Kodak developed "Plug-In" that runs under Adobe Photoshop software in the Macintosh environment and a Twain module that connects to numerous imaging applications under the Windows environment. The images can be processed directly from the camera through the SCSI port, or from the host computer file system if the PCMCIA card is mounted directly. Native "archive" files can also be downloaded from the camera to the host file system to be processed at a later time or just for archival storage. The native files provide the ability to re-process the images without loss of quality if the user has various output sizes or color aim requirements for the final image.

Figure 13 shows the block diagram of the image processing path. After the image file is accessed, the first step is to convert the 8 bits/pixel data back to 12 bits/pixel. This returns the image to linear space at the original captured dynamic range. Next the image is corrected for black balance and scaled for the user chosen white balance aim point. The software provides the user with the ability to "click" on a neutral area in the image to define the neutral, or they can select various default white balances.

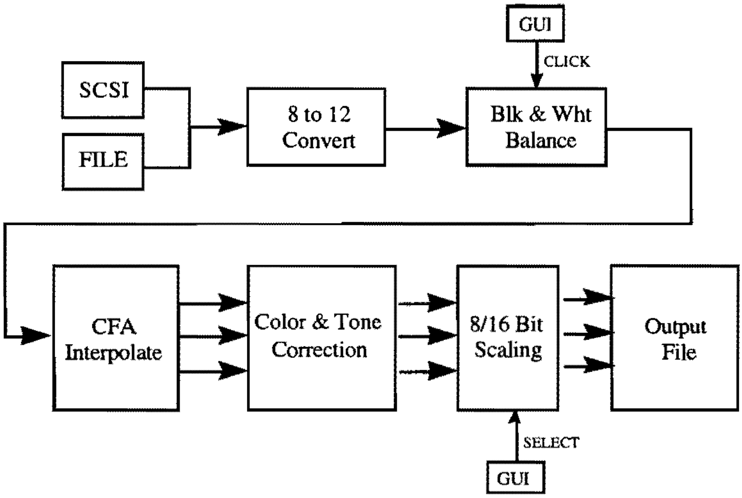


Figure 13. Image processing path

To produce a high quality color image, the pixels from the Bayer CFA must be interpolated to provide red, green, and blue sample values for each pixel, because each CCD photosite can capture only one of the three colors. The CFA interpolation used in digital cameras made by Kodak employs a gradient approach[4] to adaptively interpolate green values at the red and blue, or "missing green" photosites. Vertical and horizontal gradients are calculated in order to deduce whether the missing green pixel lies along a vertical or horizontal edge. For example, the horizontally adjacent green pixel values are averaged if the missing pixel is located along a vertically oriented edge. Once the missing green values are interpolated, the missing red and blue values are calculated by linearly interpolating the red to green and blue to green chrominance ratios.[5] This effectively provides high frequency luminance details to the sparsely sampled red and blue records.

Following CFA interpolation, a fast color correction matrix technique is used to provide improved color saturation. The red, green, and blue responsivities of any color CCD are always positive, and typically include some amount of color crosstalk. For example the blue photosites on a full frame CCD have some unwanted response to red and green light. This crosstalk is corrected by a matrix operating on the linear sensor signals.[6] The matrix also provides the desired negative responses needed to produce satisfactory color saturation. The tone scale correction uses curve shaping to produce a photographic film/paper "look" to the image. Finally, on the output the user can choose to acquire a standard 24 bit RGB image or a custom 48 bit RGB image. The 48 bit image is compatible with the Photoshop software"48 bit mode". In this mode the processing path scales the image from 12 bits/pixel up to 16 bits/pixel before entering Photoshop.

Figure 14 shows a modification to the standard image processing path by incorporating an ICC compatible color processing engine. Essentially, the color and tone correction section can be replaced by an equivalent ICC profile, allowing the camera image data to be converted to a reference color space. Additionally, an output profile can be specified that converts the reference image to the users desired output image format. As an example, the camera RGB image can be processed directly to a CMYK file and then printed directly on the profile specified printer. Interactive GUI based profile tuning tools for tone scale, global color, and selective color adjustments allow the user to tune the default profiles to better meet their needs.

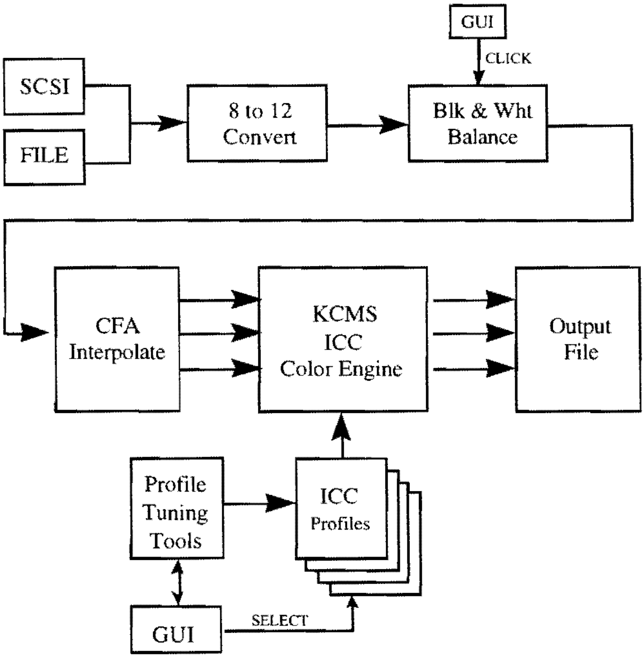


Figure 14. ICC image processing path

Conclusions

This paper has described a family of photographically versatile and high performance 6.3 megapixel digital cameras. They all use a Kodak developed full frame CCD imager with an integral Bayer CFA pattern. The camera architecture has been optimized for image quality, versatility, portability, and system compatibility. The image processing algorithms have employed the best image science Kodak has to offer. These cameras have proven in many applications that digital photography can provide the demanding professional with a new tool.

Acknowledgments

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